Menthol Use for Performance in Hot Environments

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*Abstract*

Menthol is a compound of plant origin and has recently been used to aid exercise performance in hot, humid environments. Menthol creates a sensation of coolness when applied to the skin or mucosal surfaces stimulating the cold receptors. In these environments fatigue is known to be accelerated and feelings of being hot are one of the main contributors to the early onset of fatigue. However, current research indicates that non-thermal perceptual cooling interventions could alter behaviour in the heat by reducing thermal perception. This would allow the athlete to feel cooler when exercising at the same work rate in the heat. Menthol has been investigated as an internal and external intervention. Greater benefits have currently been found for internal interventions than external methods. Future research should focus on the mechanisms, dosage and timing of both internal and external interventions and the role menthol could play within speed or strength.

*Keywords*

Menthol; Cooling Interventions; Fatigue; Perception; Heat stress

*Introduction: What is the problem?*

Menthol (C10H20O) is a naturally occurring compound of plant origin, frequency used an additive in many products, for example toothpastes and mouth rinses. When menthol is applied to the skin or mucosal surfaces it exerts a cooling sensation due to the stimulation of cold receptors TRPM8, similar to the action of spraying cold water on the face (1). The sensation of coolness has been attributed to the stimulation of cold thermoreceptors as early as 1886, by Golscheider (2, 3). Menthol could potentially be an intervention to alleviate symptoms of heat stress and improve exercise performance in a hot climate (4).

Heat stress has been proven to be detrimental to exercise due to the acceleration in fatigue. Many sporting events are scheduled in hot and humid environments with ambient temperatures of > 30 °C (5). Bongers et al., suggested once core temperature exceeds 40 °C exercise induced fatigue may lead to the development of heat related illnesses (6). Events such as Ironman world championship, Tour de France cycling race, Marathon Des Sables are held annually in hot humid environments, with future events such as FIFA world cup and Tokyo 2020 being held in similar conditions.

Practical strategies to cool the body can alleviate heat stress, and decrease core temperature, therefore reducing the risk of heat illness and lead to an improvement in exercise performance (7). The physiological responses to exercise in the heat have been well documented (8, 9). The cause for impaired exercise in the heat is multi-factorial combining physiological and psychological mechanisms (9). Research has found fatigue levels to be accelerated due to heightened feeling of discomfort with perceptions of feeling hot and uncomfortable, a main contributor for the early onset of fatigue (10). Recent articles suggest a combination of cardiovascular, thermoregulatory central nervous system and psychophysiological adjustments are largely responsible for heat mediated fatigue (5).

*Interventions to combat heat stress*

There are various types of interventions to help offset thermal discomfort in a hot environment. These can be broken down into physiological or non- thermal, perceptual cooling interventions and then down further to internal or external interventions. Internal interventions are consumed by the athlete, whereas external affect the athlete from outside of the body. Many interventions can be used both pre, mid and post exercise to cool athletes.

Physiological cooling interventions aim to diminish the thermoregulatory and cardiovascular strain, by reducing body temperature, heart rate and oxygen consumption during exercise (7) therefore offsetting thermal discomfort. Reduction in core body temperature may inhibit blood lactate accumulation therefore leading to increases in lactate threshold, resulting in improved exercise performance.

These cooling strategies were originally proposed to be a direct result of a lower core body temperature, however recent research has demonstrated that the perception of thermal sensation and comfort is also an important contributor to self-selected exercise intensity and performance (11, 12). Yet whilst changes in thermoregulatory behaviour during exercise in the heat have been more closely associated with thermal cooling, there is significant evidence that non-thermal cooling methods can also facilitate behavioural modification (12).

*Physiological cooling interventions to combat heat stress*

Thermal interventions such as whole body cold water immersion, part body cold water immersion, ice jackets and ice slurries are designed to lower the thermal state of the body shown by reductions in core and/ or skin temperature (6). Thermal interventions include both internal and external interventions. Whole body cold water immersion is an external cooling intervention as it acts on the skin, whereas ice slurries and cold beverages aim to reduce core temperature to create heat storage, class as an internal intervention.

External cooling interventions include whole or part body water immersion and ice jackets, these techniques aim to reduce body temperature via core temperature and / or skin temperature (6). External techniques are commonly used pre or post exercise, to either reduce temperature prior to exercise or as a mode of recovery (7). Combinations of cold water immersion and application of an ice jacket have been shown to improve time trial performance by 4 % in highly trained cyclists, however ice jackets alone have found little benefit (11, 13). These methods have been found to be time consuming and impractical for use in some sporting events (7).

Internal cooling interventions include ice slurries or cold beverages. These are typically used pre or mid exercise and are found to reduce core body temperature and discomfort when consumed (7, 14, 15). Ice slurries (14 g·kg-1) have been described as highly practical and have been shown to lower core body temperature by 0.66 ± 0.4 °C and subsequently increase running time to exhaustion (16, 17). However, in large quantities ice slurries have been found difficult to consume during exercise.

*Perceptual cooling interventions to combat heat stress*

Non- thermal perceptual cooling interventions such as menthol can be used to alter behaviour in the heat without necessarily causing thermoregulatory or cardiovascular changes. Instead of cooling the body, menthol works to improve perception of exercise and temperature (4). The perception of temperature has been studied using thermal comfort and sensation scales since the 1960’s (18), where an increase in thermal comfort or sensation is associated with a high core body temperature. Typical pre-cooling interventions cannot reduce thermal perceptions without a decrease in thermal state (core body temperature), however menthol allows the separation of perception and thermal state (18). Menthol can be applied to the skin (external intervention) in the form of a gel or spray, or the oral cavity (internal intervention) as a mouth- rinse or beverage. It has been stated (19) that the density of cold sensitive afferents in a particular body segments may influence the degree of cooling sensation felt. Menthol has been combined with ethanol and soaked into a garment to be worn (20). Ethanol is an alcohol that vaporises quicker than water or sweat and has the potential to increase the rate of evaporative heat loss from the skin, it was suggested that combined with menthol would improve evaporative cooling and thermal perceptions (20).

*External Menthol interventions to combat heat stress*

Menthol has been applied as an external perceptual intervention as a gel, spray or applied onto soaked garments. Menthol was applied as a gel (0.5g, 100cm2) (12) to the face during a cycling time to exhaustion at an RPE clamp of 16. The impact of the menthol gel, decreased thermal sensation and comfort and subsequently increased the total work completed and improved exercise duration. However, the exercise was clamped at an RPE of 16, meaning work rate and metabolic heat production varied allowing for speculation on where the changes occurred from. Menthol has also been applied as a spray (10, 21, 22) (106 ml, 0.05 % vs 100 ml, 0.05 % vs 100 ml, 0.02 %). The menthol was applied onto a cycling jersey or running top. In 2011, Barwood et al., found the application of menthol initiated improvements in thermal comfort and thermal sensation but did not improve performance in a 40 km time trial on the bike (0.05 %). In 2014, menthol was sprayed onto running top during a fixed load 5 km time trial, despite no change in performance times, thermal sensation did decrease giving the perception of being cooler (0.05 %), these improvements happened without any changes in rectal or skin temperature. In 2015, no change in performance was seen in 16.1 km time trial, but a decrease in thermal sensation was seen (0.02 %). These studies suggest that despite, no changes in performance times, a 0.02 % and a 0.05 % menthol spray can alter perception of temperature during exercise.

*Internal Menthol Interventions to combat heat stress*

Menthol applied as a mouth rinse (0.01 %, 0.64 mM) has demonstrated to decrease thermal sensation scores, RPE and therefore, improve performance in a time to exhaustion by 9 %. This was replicated in a 5 km performance with a 3 % improvement and a 3 km performance by 3.5 % when combined with facial water spray (4, 5, 11). The dosing for all three studies followed the same protocol, 25 ml every 10 minutes swilled for 5-10 seconds in the mouth then spat out (4).

Menthol has also been used in aromatized beverages and ice slurries as an perceptual internal intervention (1, 23, 24). Protocols used 190 ml at 0.05 % - 0.03 %. However, no performance effects were seen during time trial performance when drinks were room temperature (1), however when drinks were cold a 3 minute performance difference was seen (9 %). When combined into a Menthol aromatised ice slurry, performance time decreased by 5 minutes when performing five intervals of 4 km cycling followed by 1 km of running. (1, 23). From these studies, the most significant results were seen with ice slurry combined with menthol and cold water combined with menthol.

*Newest Developments in research on Internal and External Menthol Cooling Interventions*

In the last year significant findings have been made in both internal and external menthol cooling interventions.

Work completed by Flood et al., (2017) looked to develop and build upon the work of key papers (4, 11, 25). Using 8 male amateur cyclists ($\dot{V}$O2max 55.4 ml·kg·min-1, 1-5 hours training per week) the paper tested menthol mouth rinse vs a placebo rinse (4). Participants completed a fixed RPE protocol with an isokinetic sprint pre and post. Findings showed a significant decrease in sprint ability pre to post the fixed RPE protocol with the menthol mouth rinse. There was also a significant increase in power output with menthol during the fixed RPE protocol alluding to a change in pacing strategy with an increase in exercise duration equating to a ~7 % improvement. There was also a significant decrease in thermal sensation which echoes research by Mündel and Jones (4) and Stevens (11). This paper showed participants perceiving 16 RPE as a greater power output in comparison to placebo measure. When rinsing with L (-) menthol a higher work rate was voluntarily adopted (25). Capacity for generating peak power after the fixed RPE protocol was diminished, indicating participants worked harder and would have accumulated greater levels of peripheral fatigue. The reduced thermal sensation at the beginning of the trial may explain the increase in power output observed in the first few minutes of the protocol. No changes in rectal or skin temperature were seen throughout the trials, there was also no change in initial power output selected at the beginning of each trial. This is in line with past research where initial power output in self-paced exercise is set via a feed forward mechanism based on expectation of exercise.

Riera et al investigated cold water cooling (24), combined with mid-cooling using a menthol aromatised ice slurry (7 ml·kg-1, 0.03 %). Participants cycled for 10 minute at ventilatory threshold followed by a 30 km performance time trial, participants were allowed menthol ice slurry every 7.5 km of the 30 km time trial. No change was found in thermal sensation or thermal comfort despite mid-cooling with the slurry. A lower RPE was seen in the later part of the trial but this did not affect the outcome of performance. These findings suggest RPE rather than thermal sensation is a preliminary factor involved with improved pacing strategy and performance in a hot climate.

Recent research into external menthol by Gillis et al (20), looked at whether donning a garment saturated in menthol and ethanol can improve evaporative cooling and thermal perception vs a water spray and control condition during low intensity exercise and rest in warm, humid conditions. Many cooling interventions are difficult to implement in sporting or working scenarios such as cold water immersion so the soaked garment provided a practical solution. The garment was soaked with menthol and ethanol and contained 16.8 mg of menthol (0.2 % of 80 ml), this equated to 1.6 mg 100 cm2 spread over the upper body. The exercise was sufficient to provide a light to moderate thermoregulatory and cardiovascular challenge to test the hypothesis. There was a large heat storage response observed by menthol ethanol garment, which was mediated by a reduction in skin blood flow and possibly the withdrawal of sudomotor function (26). Mean skin temperature on the back and chest were found to be lowered which was coupled with an inverse relationship between skin and deep body temperature. Lowered thermal perception was seen throughout the entire test but no change in RPE was seen. The menthol and ethanol solutions enhanced evaporative cooling compared to the control conditions, the cooler sensations and heat storage response are both likely caused by the menthol in the solution. Ethanol also has the potential to increase the rate of evaporative heat loss from the skin, future research might look to assess the efficacy of an ethanol only solution.

Table 1: Recent Developments in Internal and External Menthol Interventions

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Author (year) | Menthol Intervention | Exercise protocol | Performance | Perceptual measurements |
| Flood et al., (2017) | Mouth rinse (0.05 %) | Fixed RPE Protocol, Isokinetic Sprints pre and post | ~7 % ↑ exercise duration↑ Pacing strategy↓ Peak power | ↓ TS, ↓ TC  |
| Riera et al., (2016 | Pre-cooling cold water, Mid-cooling Menthol Ice Slurry (0.03 %) | 10 minute at VT, 30 km TT | ↔ 30 km TT | ↔ TS, TC, ↓ RPE |
| Gillis et al., 2016 | Menthol (0.2 %), Ethanol Garment  | Low Intensity stepping | ↑ Heat storage response, | ↓ TS, ↔ RPE |

Note VT: ventilatory threshold, TS: Thermal Sensation, TC: Thermal Comfort, TT: Time Trial

*Mechanisms behind the use of Menthol*

The central governor model is critical to both physiological and psychological pathways, it has been developed to regulate both afferent and efferent physiological mechanisms to avoid the development of bodily hard. When force or work rate is self- selected, an anticipatory mechanism adjusts the work rate to ensure catastrophic failure of thermoregulation does not occur (27).

Theory has suggested that the brain is a master regulator and maintains homeostasis by eliciting effector responses in reaction to exercise induced fatigue based on afferent signals. The idea of sensation playing a major role in the mechanisms behind cooling in endurance performance are still relatively unexplained. It is feasible that thermal receptors in the oral cavity provide a more potent target for non-thermal cooling than more sparsely innervated regions of the body. Greater magnitude of afferent feedback from oral cavity could logically be prioritised by a central regulator (25).

*Mechanisms of Internal Menthol Interventions*

Internal menthol interventions evoke pleasant and refreshing sensations of airflow and nasal patency, altering the thermal comfort and sensation (4). The mucosal membranes of the oral cavity are one of the most densely innervated parts of the body in terms of peripheral receptors and are especially sensitive to menthol (1, 24). Eccles 1994 stated that Menthol acts on the thermoreceptors on the oral muscosal surfaces. It is feasible that the oral cavity provides a more potent target for perceptual cooling than areas more sparsely innervated. Mündel and Jones (4) also saw a reduced effort in breathing resulting in hyperventilation. . The drive to breathe can be inhibited by the stimulation of upper airway cold receptors; as menthol sensitises these receptors it is hypothesised that menthol could have the same effect as cool nasal airflow. Although menthol application orally has been found not to increase tidal volume runners have been found to voluntarily increase ventilation (4, 11, 19). The menthol induced cold sensation is thought to primarily rely on the sensation of the TRPM8 voltage gated ion channel present on A and C sensory nerve fibres (25, 28). TRPM8 is a voltage gated channel protein which allows the entry of calcium ions on sensing change in temperature. Centrally these neurons synapse with interneurons relaying information to the thalamus and then to the cortex where the subject’s interpretation of the stimulus occurs leading to perception. It is plausible that menthol elicits an afferent cue capable of subsequent integration into a central regulator that resets exercise intensity (25).

*Mechanisms of External Menthol Interventions*

When menthol is applied to the skin of heat stressed individuals (gel, spray or soaked garment) it causes a cool sensation, menthol activates the cold receptor TRPM8 which in acts to lower the perception of thermal sensation when in contact with a cold stimulus (5). It has been speculated that different body regions are more sensitive to menthol due to the greater density of cold sensitive afferents, this is particularly important to external cooling interventions (5, 20). Menthol when applied externally induces a heat storage effect, similar to a cold defence response heightening the activity of warm receptors improving heat storage. This heat storage response evokes vasoconstriction in a similar manner to cold challenge by reducing cutaneous blood flow and heat loss coupled with the possible withdrawal of sudomotor responses (20, 26).

*Practical Recommendations and Safety Considerations*

Current papers discussed in this review, provide recommendations on dosages and timings both as an internal and external perceptual intervention. However, these haven’t been tested in competitive events. Athletes wishing to experiment with menthol as a cooling intervention should exercise caution and only experiment under careful supervision and with informed knowledge of dosages and the effects of menthol on the body (19).

Menthol has the ability to mask true feelings of the perception of heat causing a false sense of lowered thermal perception. This may cause the athlete to push themselves beyond normal thermoregulatory limits and subsequently develop heat related illnesses (25, 29).There is a potential danger of thermal mis-regulation as the application of such techniques close to the onset of hyperthermia should be avoided to allow perception of symptoms associated with high levels of heat stress. The perception of temperature has been suggested to be a protective mechanism to preserve against exertional heat illness and hyperthermia (18)

Menthol as a perceptual external intervention has been shown to improve perception of exercise and temperature and elicit a heat storage effect but is not yet shown to consistently translate into a measureable effect on performance. Menthol as an external cooling intervention has shown to cause irritation to some participants (20, 26). Menthol as a perceptual internal intervention has been shown to reduce perception of exercise and temperature improving performance, however these results should be interpreted with caution when applying to competitive situations.

*Future Directions*

There are many paths for future developments in menthol work could go; developing a higher level of understanding of the mechanisms; optimal dosage and timing of interventions; the effect on ‘elite’ athletes and the effects of menthol interventions on speed or strength.

Future developments in this field of research should look to further understand the mechanisms that alter the perception of exercise and temperature once menthol is applied via as mouth rinse. Understanding the brain regions which are activated with menthol application may help us to understand the mechanisms fully. Research should aim to find an optimal dosage and timing to menthol consumption during competitive situations. More research is needed on different dosages of mouth rinse and timings as a pre, mid or post-cooling intervention. Menthol interventions may affect each individual differently due to inter-individual differences in thermal perception and heat tolerance. Further research is needed to look at the effects in an ‘elite’ population. This population will have a higher fitness level and the potential of being heat acclimated. It is already known that heat acclimation provides a barrier to heat stress, would this then alter the effects menthol creates as an intervention. Future research could look to assess a menthol intervention within sporting situations with high intensity exercise bouts focusing on speed or strength as opposed to endurance exercise. Many traditional cooling interventions have been found to be beneficial between repetitions of exercise or as a half time intervention, could menthol be a more practical solution, and have a practical application in this setting.

*Conclusion: What does this mean in terms of performance in the heat?*

The combination of past research and new developments focus on menthol as a cooling aid, creating a cooling sensation when applied either internally or externally. Research suggests greater beneficial effect with internal methods (mouth rinse, menthol ice slurry, cold beverage) than external methods (sprays, gels) with no known side effects. Internal interventions have been shown to successfully help alleviate symptoms of heat stress, improving the perception of exercise and temperature and subsequently improving endurance performance. Athletes wanting to use menthol as a cooling aid, must do so under careful supervision and with informed knowledge. Overall, the topic of menthol is a current topic of scientific interest and more research is needed to prove whether it could be beneficial for competitive situations and activities including speed or strength elements as well as endurance exercise.

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