# A SCOPING REVIEW OF THE EXERCISE PERFORMANCE AND THERMOREGULATORY RESPONSE TO MENTHOL COOLING STRATEGY IN HOT AND HUMID ENVIRONMENT


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By

**SITI NURHUSNA ‘AQILAH BINTI HAZMAN**

Dissertation submitted in partial fulfillment

of the requirements for the degree

of Bachelor of Health Science (Exercise and Sport Science)

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# CERTIFICATE

This is to certify that the dissertation entitled A SCOPING REVIEW OF THE EXERCISE PERFORMANCE AND THERMOREGULATORY RESPONSE TO MENTHOL COOLING STRATEGY IN HOT AND HUMID ENVIRONMENT is the bona fide record of research work done by Ms SITI NURHUSNA 'AQILAH BINTI HAZMAN during the period from March 2020 to June 2021 under my supervision. I have read this dissertation and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation to be submitted in partial fulfilment for the degree of Bachelor of Health Science (Exercise and Sports Science).

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## DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated and duly acknowledged. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at Universiti Sains Malaysia or other institutions. I grant Universiti Sains Malaysia the right to use the dissertation for teaching, research, and promotional purposes.

……..:………………………

(SITI NURHUSNA ‘AQILAH BINTI HAZMAN)

Date: 21.06.2021

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# ABSTRAK

## KAJIAN SKOP MENGENAI PRESTASI SUKAN DAN TINDAK BALAS PENGAWALATURAN SUHU TERHADAP MENTOL SEBAGAI STRATEGI PENYEJUKAN DALAM SUASANA PANAS DAN LEMBAB.

**Latar Belakang/Tujuan:** Strategi penyejukan badan telah dikaji sejak beberapa tahun lalu dan telah terbukti memberi manfaat kepada para atlet dalam suasana panas dan lembab. Mentol telah terbukti sebagai strategi penyejukan untuk meningkatkan prestasi sukan. Kajian skop ini bertujuan untuk menganalisis penemuan lepas mengenai strategi penyejukan mentol ketika dalam keadaan persekitaran panas terhadap prestasi sukan, suhu teras badan dan kulit dan tindak balas degupan jantung.

**Kaedah:** Kajian-kajian yang diambil adalah dari PubMed, ResearchGate, ProQuest, Scopus, ScienceDirect, SpringerLink dan hanya diterbitkan bermula 2015 hingga 2021.

**Keputusan:** Tiga belas penerbitan disertakan dan dianalisis. Antara kajian tersebut, tujuh (53.8%) artikel yang dikaji adalah strategi berkumur dengan mentol, dua (15.4%) artikel yang berkaitan pengambilan mentol, dan satu (7.7%) artikel berkaitan kombinasi semburan mentol, sapuan mentol ke kulit, rendaman pakaian dalam mentol, dan rendaman badan dalam mentol. Bukti yang ada menunjukkan bahawa strategi penyejukan mentol memberikan manfaat kepada prestasi sukan melalui berkumur mentol, pengambilan dan rendaman mentol semasa bersenam dalam keadaan tekanan termal. Walau bagaimanapun, strategi penyejukan mentol tidak dapat mengurangkan suhu teras badan dan kulit dan tiada perubahan kepada tindak balas degupan jantung.

**Kesimpulan:** Bukti yang ada menunjukkan bahawa strategi penyejukan mentol semasa sukan ketika panas dan lembap dapat meningkatkan prestasi sukan dan memerlukan penyelidikan lebih lanjut.

## ABSTRACT

## A SCOPING REVIEW OF THE EXERCISE PERFORMANCE AND THERMOREGULATORY RESPONSE TO MENTHOL COOLING STRATEGY IN HOT AND HUMID ENVIRONMENT

**Background/Aim:** Cooling strategy had been studied since many years ago and had been proven to be beneficial for athletes. Menthol has been documented as a cooling strategy to enhance exercise performance during hot and humid environment. This scoping review aims to synthesis the previous findings on menthol cooling strategy in thermally stress condition to exercise performance, body core and skin temperature and heart rate responses.

**Method:** The literatures were obtained from PubMed, ResearchGate, ProQuest, Scopus, ScienceDirect, and SpringerLink ranging from year 2015 until 2021.

**Results:** Thirteen publications were included and reviewed. Among the studies, seven (53.8%) articles investigated on menthol rinse/swill, two (15.4%) articles studied on menthol ingestion, and one (7.7%) article investigated combination of menthol spray, menthol skin application, garment soaked with menthol and menthol body immersion. Available evidence suggested that menthol cooling strategy confers benefits to exercise performance by menthol mouth rinse, ingestion, and menthol immersion during exercise in thermally stressed condition. However, menthol cooling strategy did not attenuate changes in core and skin temperature and heart rate responses.

**Conclusion:** Available evidence suggests that menthol cooling strategy during exercise in a hot and humid environment could improve exercise performance and warrants further investigation.

# CHAPTER 1: INTRODUCTION

## 1.1 Background of Study

Thermally stressed environments can lead to physiological and psychological disruption that contributes to the risk of heat-related illness and injury *(*Douzi, Dugué, Vinches et al., 2019*).* Likewise, Malaysia has annual temperatures of 27-35$^{o}$C and 70%-90% relative humidity (Che Jusoh, Stannard & Mündel, 2016; Wijayanto, Wakabayashi, Lee et al., 2011). As competitions and training programmes are scheduled throughout the year, Ramadan fasting may present a challenge for Muslim athletes. Some studies also mention that fasting compromises high-intensity endurance performance in athletes (Che Muhamed et al., 2013; Chennaoui 2009; Meckel et al., 2008). Therefore, it is advisable to minimise the risk of heat-related illness with cooling interventions so that exercise performance will not be compromised.

To date, various cooling methods such as pre-cooling and post-cooling, that are either external (direct application to the body) or internal (ingestion) applied have been used. Cooling techniques include cooling vest, cold water immersion, ice slurry ingestion, menthol cooling, cold water spray, and cooling packs. Most compelling evidence showed cooling intervention attenuates the exercise-induced increase in core temperature and accelerates recovery following intense exercise (Bongers, Hopman & Eijsvogels, 2017).

Menthol application, one of the cooling methods that revealed an ergogenic benefit to improve exercise performance in the hot and humid environment, is believed to convey a sensation of coolness, freshness and inhibits the perception of warmth (Stevens & Best, 2017). Several studies have begun to examine menthol mouth rinse among well-trained athletes as an internal cooling intervention, and menthol mouth rinse was associated with improved exercise performance in the heat.

A recent review was done by Jeffries and Waldron (2019) in which they studied the effect of menthol on exercise performance and thermal sensation. They used 11 studies and found most of the studies had shown great improvement in exercise performance upon menthol application. They also noted lower thermal sensation across all the studies, and concluded that menthol reduces perceptual measures of thermal sensation. What's different in our review is that we only include recent studies from 2015 until 2021, and the measures includes core temperature, skin temperature and heart rate responses to menthol.

Considering the current evidence, this review aimed to investigate whether the application of menthol mouth rinse intervention during exercise would confer exercise performance improvement in a hot and humid environment and attenuate thermoregulatory responses among recreational athletes. Findings from this review will benefit local (Malaysians) as a strategy to attenuate heat-related illness during training or competition in conditions of Malaysian climate.

### 1.2 Problem Statement and Study Rationale

This review was to investigate the effectiveness of menthol mouth rinse strategy in reducing thermoregulatory strain in an environmental condition similar to the hot-humid Malaysian climate. Therefore, the menthol strategy is proposed to reduce thermoregulatory and physiological strain for people who are exercising in the heat thermal stress conditions, thus minimising health risk such as hyperthermia. Nowadays, people are getting more aware of importance of physical fitness and many marathon events are getting held throughout the year which caught the attention of many. Thus, this review study offers important insights into the effectiveness of menthol intervention for recreational athletes while exercising in the Malaysian climate to minimise heat-related illness and improve exercise performance.

## 1.3 Research Questions

1. Does menthol cooling strategy improve exercise performance in a hot-humid environment?
2. Does menthol cooling strategy induce thermoregulatory and cardiovascular responses by reducing core and skin temperature and heart rate during exercise in a hot-humid environment?

## 1.4 Objectives

### 1.4.1 General Objective

1. To determine the effect of menthol cooling strategy on exercise performance and thermoregulatory responses in a hot-humid environment.

### 1.4.2 Specific Objectives

1. To determine exercise performance between menthol cooling strategy trial and control trial in a hot-humid environment.
2. To determine core body temperature response between menthol cooling strategy trial and control during exercise in a hot-humid environment.
3. To determine mean skin temperature between menthol cooling strategy trial and control trial during exercise in a hot-humid environment.
4. To determine heart rate response between menthol cooling strategy trial and control during exercise in a hot-humid environment.

## 1.5 Significance of the study

The most important effect of cooling strategies is to reduce thermoregulatory and physiological strain in the athletes who are exercising in heat thermal stress conditions and thus minimising health risks such as hyperthermia. However, some of the strategies like cold water immersion or cooling vests are impractical during an actual sporting event. Thus, the menthol cooling strategy in this review offers a more practical, inexpensive, and affordable method for exercising in a hot-humid environment. This review also provides new insights into menthol cooling strategy recommendation or guidelines for active persons or athletes to continue exercise in a hot-humid environment to help with safety and ensure optimal performance.

# CHAPTER 2: LITERATURE REVIEW

## 2.1 Thermoregulatory Responses during Exercise in a Hot Humid Environment

Thermoregulation is a mechanism by which the body maintains the body temperature by tightly controlled self-regulation, regardless of the temperature of their surroundings. Temperature regulation is a type of homeostasis, which is a process that body's biological systems use to preserve a stable internal state to survive. Human has a normal core, or an internal temperature of around 37°C. When the heat loss required for heat balance is exceeded by metabolic heat production such as in compensable heat stress, thermoregulation is dependent on behavioural adjustments in metabolic heat production, which is proportional to exercise work rate (Nybo and Nielsen, 2001).

Lim et al. (2008) mentioned that the core temperature ($T_c$) is the temperature of the abdominal, thoracic, and cranial cavities, whilst shell temperature ($T_s$) refers to the temperature of the skin, subcutaneous tissue, and muscles. The mammalian core temperature ($T_c$) is regulated by the brain in the hypothalamus to maintain a constant core temperature; therefore, it is not changed according to the environment. Skin temperature ($T_s$), on the other hand, is easily influenced by the external environment. During prolonged exercise, heat stress may occur which causes an increase in skin blood flow. This will increase skin temperature and increase heat dissipation. Metabolic heat production can increase by 10- to 20- fold during exercise, but less than 30% of the heat is used for energy. The rest of the 70% metabolic heat will be transported to the peripheral compartments of the body so that the energy can be dissipated. Heat stress will occur when that body's heat-dissipating mechanisms are unable to cope with the metabolic heat production (Lim et al., 2008).

Strenuous exercise may increase body temperature when exercise is performed in thermally stressed conditions, such as in a hot and humid environment. For different individuals, thermal environmental preference may vary with physiological, behavioural, and cultural choice. Malaysia has an average daily temperature ranging from 21°C to 32°C (Department of Information, Malaysia (2016)). Department of Standards Malaysia (DOSM) recommends an indoor temperature of 23°C to 26°C, therefore, temperature above this value can be considered hot and may be uncomfortable for most people. An extremely hot environment may overwhelm body's coping mechanism, causing heat stress. The DOSM also mentioned that the comfortable relative humidity ranges from 60 to 70%. Humidity above this may cause increased thermoregulatory strain and discomfort to athletes.  It has been shown that prolonged exercise performed under a constant high ambient temperature may lead to a significant increase in core body temperature, which then affects sports performance due to the acceleration of fatigue (Nybo & Nielsen, 2001). Intense exercise can produce metabolic heat that increases body temperature by 1ºC every 5-7 min which creates thermal strain to the body (Burton & Lauber, 2018). The gradient for heat exchange between the skin and the environment is lowered, thus causing a decrease in evaporative heat loss. It was proposed that a critically high core temperature (~39ºC) caused fatigue during exercise (Butts et al., 2017; Webster *et* al., 2005; Smith et al., 2018) and was associated with cellular damage (Cheung, 2008). Skin blood flow and sweating continue to increase until heat balance between heat dissipation and heat generation is equal, thus body core temperature is maintained in the normal range (Stevens et al., 2017). However, during exercise, this can lead to an exacerbated competition between the skin and the muscle for the contribution of the cardiac output with reduced blood flow, either to reduce muscle blood flow limiting the duration and intensity of exercise or with reduced cutaneous blood flow potentially causing hyperthermia over time (Burton & Lauber, 2018; Hohenauer et al., 2018; Otani et al., 2017; Tyler et al., 2013).

Thermoregulatory responses are the most crucial mechanisms in the body during exercise to prevent heat stress to the body. During exercise, it is typical for core body temperature to increase since only about 20% of the energy produced by the body is used for muscle contraction, whereas the remaining 80% becomes heat energy, causing an increase in muscle temperature (Takeda & Okazaki, 2018). Another study has also mentioned that exercise produces heat that is either dissipated from the body or accumulated in the tissues (Mora-Rodriguez, 2011). Depending on the intensity, body core temperatures may increase by 1 to 2°C during the first 15 to 20 minutes of cycling in temperate climates (Nybo and Nielsen, 2001). Therefore, an elevation in body core temperature has been hypothesised to contribute to performance disturbance. Monitoring core temperature during exercise is also mainly for athletes' safety to prevent heat-related injury.

The thermoregulatory strain has been known to increase in the heat with increasing humidity. This is due to a reduction in the environment's evaporation capacity, which hinders heat from dissipating to the environment. This causes sweating efficiency to decline, leading to an increase in skin temperature during exercising in a humid environment. High skin temperature will then increase the skin blood flow and therefore gives greater circulatory strain. This observation is supported by Che Muhamed et al. (2016) in which their study found non-acclimatised, well-trained male runners had a higher thermoregulatory and circulatory strain following a prolonged steady-state exercise in an environment of 30°C with increasing relative humidity. It was also noted that the athletes had reduced capacity for incremental exercise to exhaustion in higher humidity (61% and 71%) in comparison with the driest humidity (23%) (Che Muhamed et al., 2016).

## 2.2 Cooling Strategies during Exercise in Thermal Stress

Cooling intervention before, during, and after exercise has been discussed in many literatures with different techniques and methods. A variety of techniques used for cooling includes cooling vest, cold water immersion, ice slurry ingestion, menthol cooling, cold water spray, and cooling packs. Some studies mentioned the advantages of cooling intervention in terms of enhancing athletes' performance during exercise, especially during long continuous exercises which requires an athlete to endure a strenuous exercise for a long period, for example, in a marathon or cycling events (Flood et al, 2017; Gavel 2021; Jeffries et al, 2018; Kenny et al, 2011; Mundel & Jones, 2010; Nakamura et al, 2020; Riera et al, 2014; Stevens *et al*, 2016; Tyler et al, 2011 & Webborn et al, 2005). As mentioned before, long strenuous exercise tends to challenge the regulatory maintenance of the body's core temperature causing exercise-induced heat stress, which over time will reduce athletes' performance.

Therefore, pre-cooling, per-cooling, and post-cooling are proposed as interventions to reduce heat stress for better performance in sports. Pre-cooling is a technique where cooling interventions were done before the exercise began. The purpose of pre-cooling is to provide a larger heat storage capacity to prolong time-to-exhaustion in athletes. Bongers et al. (2017) reviewed numerous papers on the different techniques of pre-cooling and found that mixed-method cooling was the most effective to improve exercise performance. They also suggested that vigorous cooling of large body areas is the most effective. This finding is also supported by Wegmann et al. (2012) in their review of 18 literatures on pre-cooling. Though they found that pre-cooling with ice vests were less significant in reducing heat stress, but with regards to feasibility, cold drinks, cooling packs, and cooling vests might be the best practice. However, the downside to this method is that if pre-cooling were overly done, it might affect performance, since it causes the muscles to be colder, thus reducing exercise performance (Wegmann et al., 2012).

Per-cooling, also known as mid-cooling, which is cooling during exercise, has been of greater interest to many researchers nowadays. It is thought to benefit the athletes more than pre-cooling since the thermal stress generated during exercise is much higher than during warming up or rest. Per-cooling had also shown great improvements in exercise performance, with ice vest cooling as the most effective technique (Barwood et al, 2015; Bongers et al., 2017; Mundel et al., 2007; Mundel & Jones, 2010; Stevens et al., 2016 & Tyler & Sunderland, 2011). However, ice vest cooling may not be as practical since it requires the participants to wear the vest, which will add extra weight to the athletes. Menthol cooling has been of interest lately since it is a non-thermal cooling, and it can be easily infused in drinks, mouth rinse or facial spray. Stevens et al. (2016), found menthol mouth rinse as mid-cooling efficiently improves exercise performance compared to ice-slurry ingestion. Mouth rinse is highly practical since it is lightweight and can be carried during half or full marathon to be gargled intermittently.

Post-cooling is the intervention at which cooling was done immediately after exercise to reduce skin and core temperature for rapid recovery. It was found that post-cooling intervention administered immediately after exercise reduces muscle soreness after 24 hours and 96 hours of recovery. The most effective technique known for post-cooling was cold-water immersion (Bongers et al., 2017). Barwood et al. (2009) mentioned that cold water immersion might be impractical for sports when the interval breaks in between the events were short. They proposed that the most effective post-cooling intervention was body fanning.

Performing exercise in such a hot and humid environment may impair exercise capacity thus cooling strategy is essential to attenuate the detrimental increase in body temperature and induce alteration in physiological variables.

### 2.3 Effects of Menthol Cooling Strategy on Exercise Performance in a Hot Environment

Menthol's popularity is on the rise recently as it is used as a cooling agent to help increase exercise performance in hot and humid environments. It is a compound that can be made synthetically or extracted from plants that contain mint oil, a substance that gives a cooling sensation when applied to the skin or mucosal surface by stimulating the cold receptors (Flood, 2018). The cold receptor is known as the Transient Receptor Potential Cation Channel Subfamily M (melastatin) Member 8 (TRPM8). Menthol are added in various products such as candy, chewing gum,  toothpaste, common cold medications, vapour-rubs, cigarettes, aromatherapy medications, and mouth wash (Gavel, 2021). In reviewing the literature, menthol has been proven as ergogenic for enhancing exercise performance either internally or externally (Stevens & Best, 2017; Stevens et al., 2017). Researchers have attempted to evaluate the effect of menthol mouth rinse or ingestion in increasing the drive to breathe on exercise performance (Eccles, 2003), elevating ventilation (Meamarbashi & Rajabi, 2013), attenuating thirst, and triggering the sensations of coolness and freshness (Best et al., 2018).

Stevens et al. (2016) performed a study by instructing the participants to swill or rinsing the mouth with 25 mL of L-menthol solution during a self-paced 5 km run. They had found that mid-exercise menthol mouth rinse intervention has improved endurance running performance in the heat. They concluded that significant running performance improvement and a reduction in core temperature was due to a change in the sensation of oropharyngeal temperature and wetness from menthol mouth rinse  (Stevens et al., 2016). Similarly, 25 ml menthol solution mouth rinse for 1.5-min  before exercise increased exercise duration by 7% in the heat during self-regulated fixed cycling compared to placebo mouth rinse (Flood et al., 2017). A recent study by Hermand et al. (2020) uses menthol application on the skin by soaking the participants’ shirts in four different solutions which are water, cold water, menthol at ambient temperature, and menthol at cold temperature. It was discovered that the use of low-temperature menthol on the skin enhanced 10-km running performance and lowered thermal sensation in a hot and humid environment. The use of menthol as a non-thermal cooling to lower thermal sensation had been shown to reduce perceived effort, resulting in altered pacing strategy, elevated power output and extended exercise time in the heat at a fixed RPE (Flood et al., 2017). This suggests that menthol can override thermal homeostasis and may be able to improve performance by increasing time to exhaustion (Flood et al., 2017).

For professional runners, cyclist and sportsmen, it is well-known that performing in a hot and humid environment is inevitable. Therefore, good thermoregulatory responses are crucial in preventing thermal stress and impaired sports performance. Apart from that, importance of cooling intervention should be acknowledged, as it facilitates the body to cope with the hot and humid environment by adjusting the thermal sensation appropriately for increased comfort.

# CHAPTER 3: METHODOLOGY

## 3.1 Data Sources

The previous related studies were obtained from PubMed, ResearchGate, ProQuest, Scopus, ScienceDirect, and SpringerLink databases. Peer-reviewed articles obtained from databases were published in English language journals from January 2015 until January 2021. For additional information, no attempts were made to contact the authors. All the searches were made to be comparable with other databases.

## 3.2 Study Selection

The search was conducted based on the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines (*Figure 1*). The following keywords were used during the search: (Menthol) AND (Exercise Performance) AND (Hot-Humid Environment). Screening was done for studies that used menthol as intervention, exercise performance, core and skin temperature, and heart rate responses as outcome measures. The studies selected for this review were controlled trials and laboratory studies on humans. The interventions comprised: (1) menthol with placebo-controlled, and (2) menthol in combination with an exercise programme and hot humid environment. Exercise performance was described as: (1) Exercise to exhaustion, and (2) Time trial performance.

The inclusion criteria were: (1) any articles testing menthol intervention on exercise protocols; (2) any articles that included core, skin temperature, and heart rate responses as outcome measures; (3) any articles testing on male and/or female, well-trained athletes, or physically active human participants; and (4) any articles testing in a hot-humid laboratory controlled-environment.

Articles were excluded if: (1) studies that had not undergone full peer-review; (2) any articles testing on non-human participants; and (3) any articles published in languages other than English.

### 3.3 Data Extraction

The articles were reviewed based on titles and abstracts using criteria specified to determine whether full texts were required for further analysis. Each full-text manuscript was selected systematically according to the study: (1) objective/s, (2) characteristics of the study (study design, participants, ages, and sample size), (3) contents of intervention (intervention types, length of intervention) (4) targeted outcome/s, and (5) main findings. Due to the nature of this scoping review, the outcomes extracted from those studies were not combined, reanalysed, or changed from those studies.

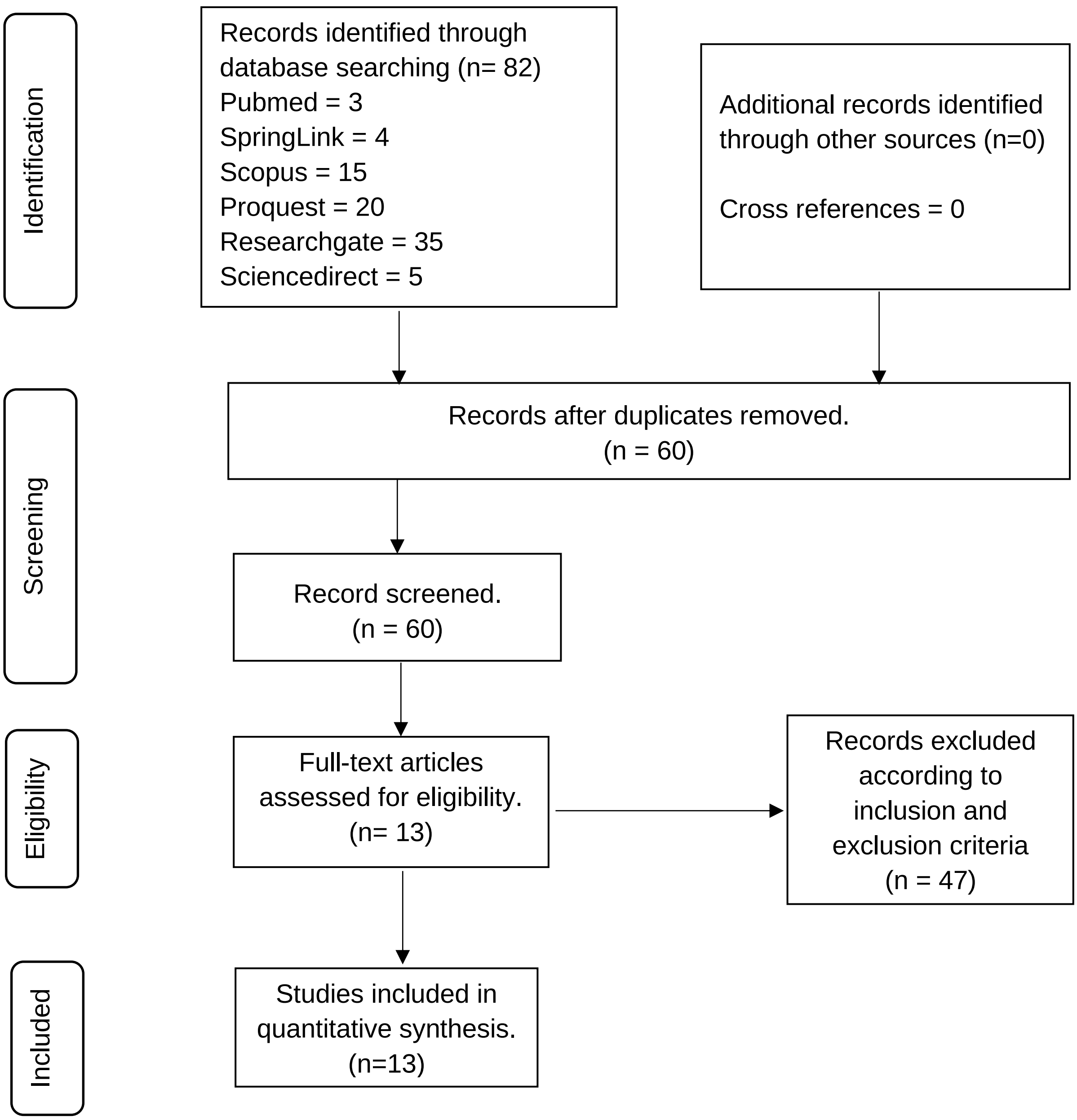


**Figure 1:** PRISMA flow for study selection

# CHAPTER 4: RESULTS

## 4.1 Articles Retrieved

The initial search from the database identified 82 potential articles. After screening for inclusion and exclusion criteria, 13 published articles were included in the review. Pertinent data extracted from each article are presented in *Table 1*.

## 4.2 Article Characteristics

All 13 articles were published between year 2015 and 2021. Specifically, articles were published in 2015 (n=2), 2016 (n=3), 2017 (n=2), 2018 (n=2), 2019 (n=1), 2020 (n=1), and 2021 (n=2). There was a total sample of 139 participants (119 males, 20 females) across all articles consisting of various population. *Figure 2* shows the distribution of study participants among the 13 articles that have been reviewed. Five articles mentioned their participants were physically active (38.5%), four articles used trained athletes (30.8%), two studies used runners (15.4%) and two studies used cyclists (15.4%).

Among the studies, seven (53.8%) articles reported on the investigation of menthol rinse/swill as an intervention, while two (15.4%) articles used menthol ingestion, one (7.7%) article investigated menthol spray, one (7.7%) in menthol skin application, one (7.7%) investigated garment soaked with menthol and one (7.7%) in menthol body immersion, respectively.

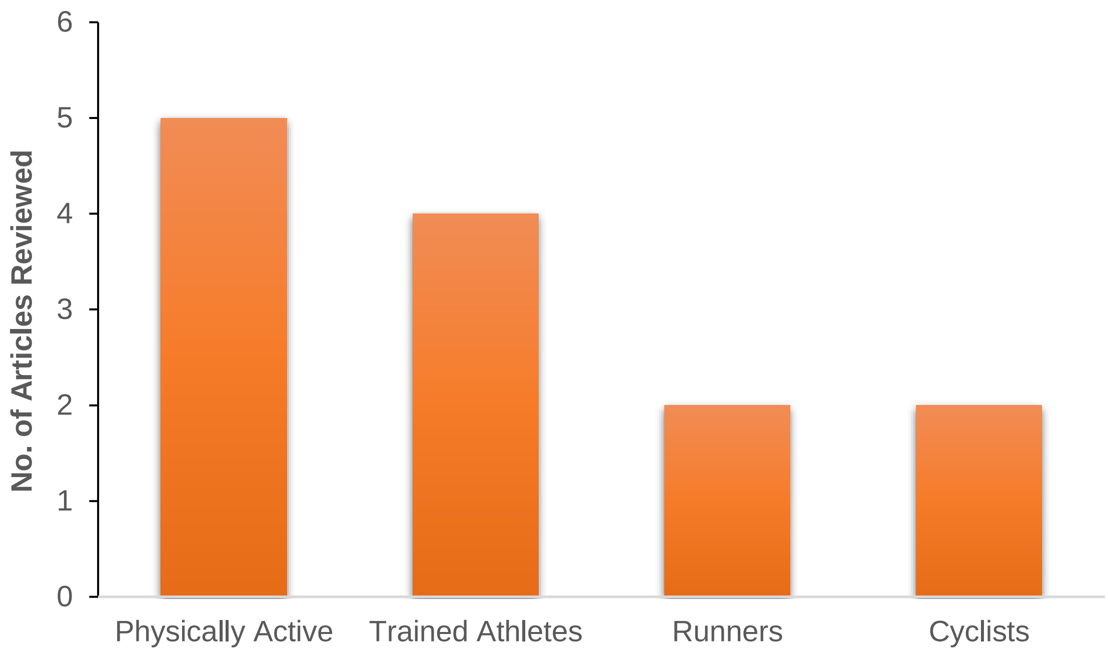


**Figure 2:** Distribution of Studies Participants

### 4.3 Exercise and Intervention Protocols

*Figure 3* shows the different methods of exercise protocol. Eight (61.5%) articles contained studies that used cycling protocol, three (23%) articles were using running protocol, one (7.7%) used adapted high and low-intensity exercise protocol, and one (7.7%) used a combination of cycling and running protocol. Most of the articles (n=7, 53.8%) investigated the effect of menthol on time trial, whereas a minority of the articles investigated time-to-exhaustion (n=2, 15.3%) performance.

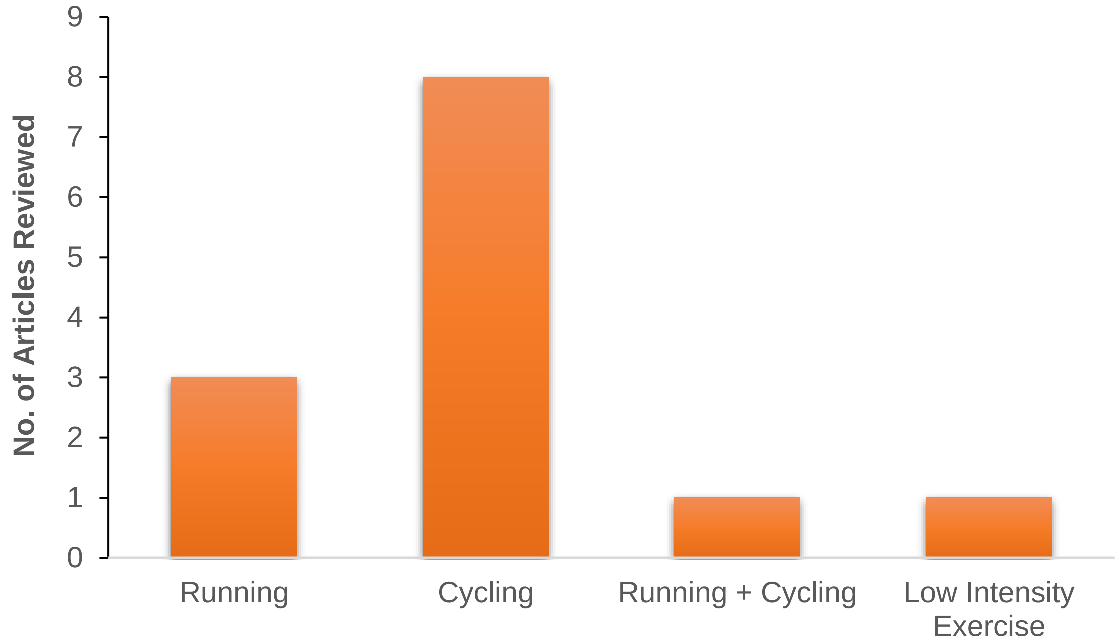


**Figure 3:** Distribution of Test Protocols

Referring to *Figure 4*, most of the reviewed articles applied menthol prior to exercise and during exercise (53.8%). Five other studies used menthol during exercise (38.5%) whilst only one study used menthol before exercise, during exercise and after exercise (7.7%).

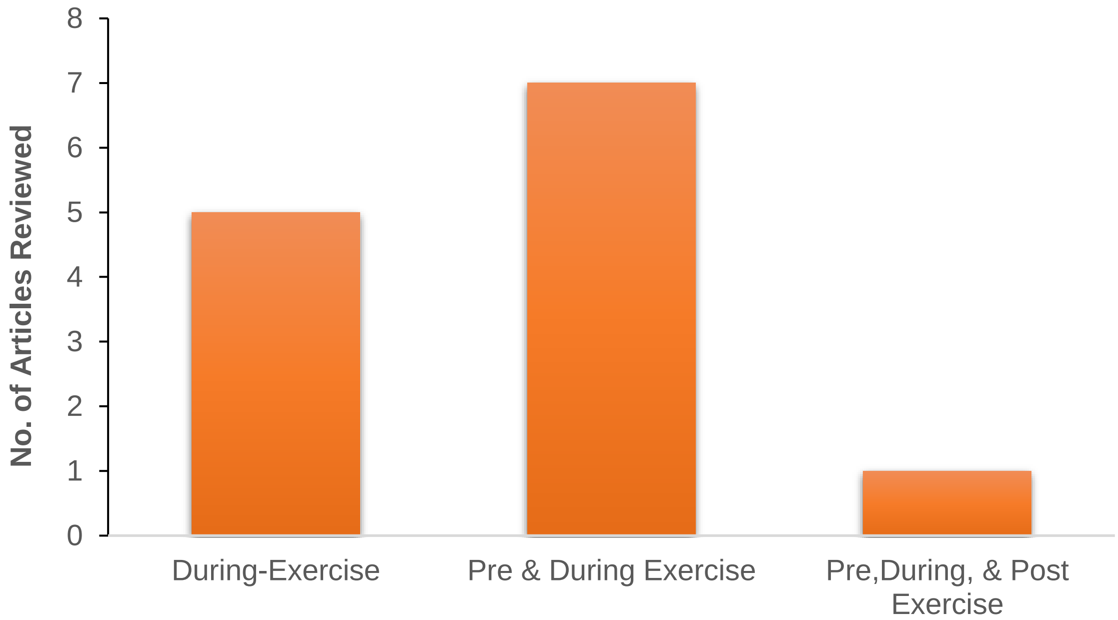


**Figure 4:** Distribution of Menthol Cooling Intervention Timing

## 4.4 Synthesis of Result

### 4.4.1 Menthol Intervention on Exercise Performance

Swilling with 0.01% of menthol mouth rinse had shown exercise performance improvement in hot and humid environment (Flood et al., 2017; Gavel et al., 2021; Jeffries et al., 2018; and Stevens et al., 2016). An equal concentration of menthol mouth rinse when combined with cold water spray during mid-cooling also increases performance in 5-km running time trial compared to pre-cooling with cold water immersion and ice slurry ingestion (Stevens et al., 2017). A 4% menthol application on skin also showed enhanced exercise performance during 10-km time to exhaustion (TTE) in a hot climate (Hermand et al., 2020). The 20-minute time trial (TT) cycling performance was also improved by using 0.1% menthol in cold water body immersion (Rinaldi et al., 2018). Ingestion of 0.025% of cold menthol beverage as pre-cooling and mid-cooling improved 4.5 km cycling and 1.5 km running time trials (Trong et al., 2015). However, 0.025% menthol ingestion as pre-cooling did not improve exercise performance (Riera et al., 2016). A 0.20% L-menthol in 3% surfactants plus water did not improve exercise performance when used as a facial spray in 16.1km running time trials (Barwood et al., 2015). Gibson et al., (2019) and Parton et al., (2021) also uses 0.01% menthol mouth rinse, but their findings showed no difference in exercise performance.

#### 4.4.2 Menthol Intervention on Thermoregulatory and Heart Rate Responses

Most of the articles noted the constant rise of core temperature during exercise in trials using menthol and control. Among 13 articles reviewed, only Barwood et al. (2015) and Gillis et al. (2016) found lower skin temperature following menthol application. Both studies used topical menthol application in which Barwood et al. (2015) used facial menthol and water spray while Gillis et al. (2016) used jersey soaked with menthol and ethanol. Other articles had noted there were no significant changes in skin and core temperature (Flood et al., 2017; Gavel et al., 2021; Gibson et al., 2019; Hermand et al., 2020; Jeffries et al., 2018; Parton et al., 2021; Riera et al., 2016; Rinaldi et al., 2018; Stevens et al., 2016; Stevens et al., 2017; Trong et al., 2015).

Gillis et al., (2016) observed the overall mean heart rate remained at 76.9 beats per minute but increased significantly during exercise due to increased demand and return to normal during the resting period. The mean heart rate remained the same for both menthol intervention and control trials, therefore no significant difference was found in both trials. Based on the reviewed, most of the articles found no difference in heart rate response between menthol and control trials (Flood et al., 2017; Gavel et al., 2021; Gibson et al., 2019; Hermand et al., 2020; Jeffries et al., 2018; Parton et al., 2021; Riera et al., 2016; Rinaldi et al., 2018; Stevens et al., 2016; Stevens et al., 2017; Trong et al., 2015).

**Table 1:** Data extracted from each article included for review (N=13)

| Articles | Study Participants | Study Design | Test Protocol | Menthol Concentration | Intervention | Key Exercise Performance Finding | Key Thermoregulatory Responses Finding |
|---|---|---|---|---|---|---|---|
| Barwood et al., 2015. | 8 males<br><br>Physically active | Acute Double-blind Crossover | 16.1 km cycling time trial<br><br>34°C and 70% RH environment | 0.20% menthol in water spray | Menthol spray at 10-km cycling time trial. | No difference in time trial performance between trials | No difference in core temperature between trials.<br><br>Skin temperature response was significantly lower after spraying.<br><br>Heart rate difference was not recorded. |
| Flood et al., 2017. | 8 males<br><br>Physically active | Randomised crossover<br><br>Single-blind | 1. Isokinetic sprint<br>2. Fixed-RPE cycling protocol<br><br>35.0 ± 0.8°C, 47.8 ± 2.3% RH. | 25 mL of 0.01% menthol mouth rinse | Menthol mouth rise before fixed-RPE trials and at 10-min interval. | Exercise performance significantly improved in menthol mouth rinse trial. | Lower thermal sensation for menthol mouth rinse trials.<br><br>No difference in core and skin temperature<br><br>No significant difference in heart rate. |
| Gavel et al., 2021. | 9 females<br><br>Physically active | Randomised crossover | 30-km individual time trial<br><br>30 ± 0.6°C, 70 ± 1% RH environment | 25 mL of 0.01% menthol mouth rinse | First menthol mouth rinse before the start of cycling, followed by menthol mouth rinsing are at every 5km intervals of the 30-km cycle. | Trial time was reduced in menthol mouth rinse compared to placebo. Power output was also higher in menthol compared to placebo. | No significant difference in thermoregulatory responses and heart rate responses |

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| Gibson et al., 2019. | 14 males<br><br>Trained team sports players | Randomised crossover | Cycling intermittent sprint protocol (CISP)<br>40°C and 50% RH environment. | 25 mL of 0.01% menthol mouth rinse | Menthol mouth rinse at rest and at every 10-min interval during the 40-min CISP. | No significant improvement in exercise performance | No main effect in rectal, skin temperatures and heart rate. |
| Gillis et al., 2016. | 6 healthy males<br><br>Physically active | Within-participant repeated measures | Low intensity exercises<br><br>30°C and 70% RH environment. | Jersey soaked with 0.2% menthol + 20% ethanol | Participants wore jersey soaked in menthol/ethanol, water or control during 60-minutes of low-intensity exercises. | Exercise performance was not recorded, but menthol/ethanol caused a significantly higher heat storage response. | Rectal temperature was significantly lower in menthol/ethanol compared to water and control.<br><br>Skin temperature was lower in menthol/ethanol.<br><br>No significant difference in heart rate response. |
| Hermand et al., 2020. | 13 males<br><br>Trained athletes | Randomised crossover | 10 km running<br><br>29.0 ± 1.3 °C and 59.0 ± 13.6% RH environment. | 4% cold topical menthol solution | A shirt soaked every 2-km either in a cold (~6°C) + 4% menthol solution or warm (~28°C) solution. | Running performance was improved in jersey soaked with cold menthol, warm menthol and cold water compared to control. | Thermal sensation was lower in menthol and cold water.<br><br>No significant difference in body and skin temperature and heart rate. |
| Jeffries et al., 2018. | 10 males<br><br>Endurance trained athletes | Randomised crossover | Cycling time to exhaustion<br><br>35 ± 0.2°C and 40 ± 0.5% RH environment. | 25 mL of 0.01% menthol mouth rinse | Intervention using placebo-flavoured mouth rinse, ice slurry or menthol mouth rinse at 85% of participants' baseline TTE. | Exercise time was extended in menthol mouth rinse and ice ingestion compared to control. | No significant difference in body, skin temperature and heart rate responses. |

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| Parton et al., 2021. | 11 males and 11 females<br><br>Physically active | Randomised crossover Double-blinded | Cycling at RPE 16 until exhaustion<br><br>34.9 ± 0.5°C, 40.6 ± 2.2% RH environment. | 25 mL of 0.01% menthol mouth rinse | Menthol mouth rinse at 30-s before trial and at 10-min intervals of cycling at a power output to represent RPE of 16. | No significant changes in exercise performance when using menthol mouth rinse compared to control. | Thermal sensation was lowered in menthol in both sexes during exercise.<br><br>No difference in core temperature and heart rate in both conditions and sexes. |
| Riera et al., 2016. | 9 males<br><br>Trained cyclists and triathletes | Randomised crossover | 30-km cycling time trials<br><br>30.7 ± 0.8°C, 78 ± 0.03% RH environment | Ingestion of 0.025% menthol in ice slush | Ice slush or menthol at 0, 7.5, 15, 22.5 and 30-km time-trial | No significant different in time trial performance. | No significant differences in mean core temperature and heart rate responses |
| Rinaldi et al., 2018. | 8 males<br><br>Elite road cyclists | Randomised crossover | 20-min cycling time trials<br><br>29.1 ± 1.5°C, 62 ± 4% RH environment | Immersion with 0.1% menthol in cold water | Cycled for 20-min interspersed with a 10-min immersion in either cold water (control) or cold menthol water. | Power output was significantly increased following immersion in cold menthol water compared to control trial | No significant differences in mean rectal and skin temperature in both trials. |
| Stevens et al., 2016. | 11 males<br><br>Moderately trained | Randomised crossover | 5-km running time trial<br><br>33°C and 46% RH environment. | 25 mL of 0.01% menthol mouth rinse | Pre-cooling with ice slurry ingestion<br><br>Mid-cooling with menthol mouth rinses every 1-km during the 5-km run. | Running performance was significantly improved with menthol mouth rinse mid-cooling | No significant differences in, rectal, skin temperature and heart rate response |

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| Stevens et al., 2017. | 11 males<br><br>Trained runners | Randomised crossover | 5-km running time trials<br><br>32.5 ± 0.1°C, 46.8 ± 7.9% RH environment | 25 mL of 0.01% menthol mouth rinse | Pre-cooling with cold-water immersion and ice slurry ingestion<br><br>Mid-cooling with menthol mouth rinse and facial water sprays every 1-km. | Time trial performance was improved following mid-cooling using menthol and facial water spray | No significant differences in rectal, skin and heart rate responses during mid-cooling with menthol and facial water spray compared to pre-cooling and control. |
| Trong et al., 2015. | 10 males<br><br>Trained athletes | Randomised crossover | 20-km cycling and 7.5-km running time trials divided into five segments of 4-km cycling and 1.5-km per segment.<br><br>32.5±1.2°C; 57%±0.05% RH outdoor environment. | Ingestion of 0.025% menthol | Subjects randomly drank menthol beverages with different temperature (neutral, cold, ice slurry) during warm-up and every running segment. | Ice slurry/menthol increases both cycling and running performance significantly compared to other cold water/menthol and neutral water/menthol. | No significant difference in in core and skin temperature and heart rate responses |

# CHAPTER 5: DISCUSSION

Through this scoping review, 13 articles were systematically identified and there was sufficient evidence that menthol intervention improved exercise performance, especially mid-cooling strategy. On another note, menthol mouth rinse has also been shown to improve exercise performance compared to other menthol cooling strategies, and it was also the most used method among the 13 reviewed articles. Menthol is known to stimulate the thermoregulatory responses via central nervous system, and in this review, core and skin temperature are mainly described. Apart from that, cardiovascular responses from heart rate changes following menthol application were also described.

## 5.1 Effects of Menthol Cooling Strategy on Exercise Performance

This scoping review examined the effect of menthol cooling strategy on exercise performance in thermally stressed conditions. Eight out of 13 articles concluded that menthol intervention confers benefits to exercise performance. Five studies used 25 mL of 0.01% menthol mouth rinse (Flood et al., 2017; Gavel et al., 2021; Jeffries et al., 2018; Stevens et al., 2016 and Stevens et al., 2017), one study used 4% cold menthol solution by soaking the subjects' jersey (Hermand et al., 2020), one article used body immersion with 0.1% menthol in cold water (Rinaldi et al., 2018) and another article used 0.025% of cold menthol ingestion (Trong et al., 2015). The other five articles that found menthol does not significantly improve exercise performance used 0.01% menthol mouth rinse (Parton et al, 2021 & Gibson et al, 2019), facial spray with 0.20% of menthol in water (Barwood et al., 2015), cold 0.025% menthol ingestion (Riera et al., 2016) and soaking exercise garments with 0.2% menthol and 20% ethanol (Gillis et al., 2016).