Influence of Menthol Nasal Inhalation on Self-Paced Cycling Time-Trial Performance, Perceptual and Physiological Responses in Active Adult Males and Females

by

Tyson J. Mayer

Supervisor: Dr. Derek Kivi

Committee Members: Dr. Zachariah Henderson, Dr. Taryn Klarner, Dr. Kathryn Sinden

In partial fulfillment of the requirements

for the degree of Master of Science in Kinesiology

SCHOOL OF KINESIOLOGY

LAKEHEAD UNIVERSITY

THUNDER BAY, ONTARIO, CANADA

September 2026

Abstract

Menthol has been investigated as a perceptual ergogenic aid because it produces a cooling sensation without directly reducing core or skin temperature. However, nasal inhalation remains underexplored during self-paced endurance exercise, particularly in studies examining sex-based differences. This study examined the effects of repeated menthol nasal inhalation and sex on performance, perceptual, and physiological responses during self-paced cycling in physically active adults. Forty participants (20 males and 20 females) completed a pseudo-randomized, counterbalanced study consisting of a familiarization session and two experimental trials: menthol and control. During each trial, participants completed a 15-minute self-paced cycling time trial at an individualized resistance. Menthol vapour or air was administered nasally for 5 seconds at 0, 5, and 10 minutes. Performance outcomes included total distance and distance normalized to body mass. Perceptual outcomes included ratings of perceived exertion (RPE), thermal sensation (TS), and respiratory comfort (RC), while the physiological outcome was heart rate (HR). RPE, TS, RC, and HR were averaged across the 5-, 10-, and 15-minute time points. Performance and HR were analysed using 2 × 2 mixed-design ANOVAs, whereas RPE, TS, and RC were analysed using Wilcoxon signed-rank tests, with Mann–Whitney U tests used to compare condition-related changes between sexes. Participants covered a greater total distance during menthol than control, $F(1, 38) = 7.65$, $p = .009$, $\eta p^2 = .168$, and achieved a greater normalized distance, $F(1, 38) = 7.63$, $p = .009$, $\eta p^2 = .167$. Significant Condition × Sex interactions indicated larger performance improvements among females. Within the perceptual domain, RPE did not differ significantly between conditions ($p = .054$), whereas TS ($p = .029$) and RC ($p = .041$) were significantly lower during menthol, indicating cooler thermal sensations and less respiratory discomfort. Condition-related changes in TS ($p = .039$) and RC ($p = .024$)

differed significantly between sexes, with larger responses among females. Within the physiological domain, mean HR was significantly higher during menthol ($p = .016$), with no significant Condition × Sex interaction. These findings indicate that repeated menthol nasal inhalation influences performance, perceptual, and physiological responses during self-paced cycling, with sex contributing to the magnitude of selected performance and perceptual responses.

Acknowledgements

Completing this thesis has been a challenging and rewarding journey, and it would not have been possible without the support, guidance, and encouragement of many people along the way. I am incredibly grateful to everyone who contributed to this experience, both academically and personally.

I would like to express my sincere gratitude to my supervisor, Dr. Derek Kivi, for his guidance, support, and encouragement throughout the development and completion of this thesis. His feedback and expertise were instrumental in shaping the study, refining the methodology, and supporting me through the research and writing process. I would also like to thank my committee members, Dr. Zachariah Henderson, Dr. Taryn Klarner, and Dr. Kathryn Sinden, for their thoughtful feedback, valuable perspectives, and contributions to the development of this research.

I would also like to thank all participants who volunteered their time and effort, as this project would not have been possible without them.

A special thank you goes to my mother, Melodie Mayer, for her unwavering support throughout not only this process, but throughout my life. She has always been my number one fan, and her encouragement and support made this journey considerably easier. I am incredibly grateful for everything you have done for me. I love you, Mom.

Finally, I would like to thank my family, friends, and loved ones for their encouragement and continued support throughout my graduate studies. Special thanks go to McKayla Gaudreau, Lena Rollick, and Milena Ljubicic, though my gratitude extends to many others beyond those named here.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

ANOVA	Analysis of variance
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ATP	Adenosine triphosphate
CI	Confidence interval
COPD	Chronic obstructive pulmonary disease
CNS	Central nervous system
CP	Critical power
CSEP	Canadian Society for Exercise Physiology
GAQ	Get Active Questionnaire
HR	Heart rate
LT1	First lactate threshold
LT2	Second lactate threshold
RC	Respiratory comfort
REB	Research Ethics Board
RER	Respiratory exchange ratio
RPE	Rating of perceived exertion
SD	Standard deviation
SEM	Standard error of the mean
SPSS	Statistical Package for the Social Sciences
TS	Thermal sensation
TT	Time trial
TTE	Time to exhaustion
TRP	Transient receptor potential
TRPM8	Transient receptor potential melastatin 8
TRPV1	Transient receptor potential vanilloid 1
VO_2max	Maximal oxygen uptake
VT1	First ventilatory threshold
VT2	Second ventilatory threshold

Chapter One: Review of the Literature

Overview

Endurance performance is a key determinant of success in many athletic disciplines, particularly in sports such as cycling and distance running, which require sustained aerobic effort (Joyner & Coyle, 2008). Athletes commonly employ a variety of nutritional, physiological, and perceptual interventions to enhance endurance performance or delay the onset of fatigue (Frączek et al., 2016; Thein et al., 1995). Among the many interventions available to enhance endurance performance, ergogenic aids are popular because of their accessibility and potential to influence both physiological and perceptual outcomes (Beck et al., 2015).

Endurance performance is commonly assessed using performance-based protocols such as time-trial (TT) and time-to-exhaustion (TTE) tests, which reflect an individual's ability to sustain work over prolonged periods (Laursen et al., 2007). Although maximal oxygen uptake (VO_2max) is the gold standard measure of aerobic capacity, it does not fully capture endurance performance under ecologically valid, self-paced conditions (Bassett, 2000; Martin-Rincon & Calbet, 2020). Consequently, there has been increasing interest in interventions that target perceptual responses such as ratings of perceived exertion (RPE), thermal sensation (TS), and respiratory comfort (RC) (Marcora, 2008; Mauger, 2014; Pageaux, 2014).

Menthol has emerged as a perceptual ergogenic aid because activation of cold-sensitive channels produces a cooling sensation without reducing core or skin temperature. This perceptual effect may enhance endurance performance by delaying discomfort and improving exercise tolerance (Barwood et al., 2020; Pergolizzi et al., 2018). Despite these potential benefits, most menthol-exercise research has focused on oral (e.g., Flood et al., 2017; Gavel et al., 2021) and topical applications (e.g., Barwood et al., 2015; Kounalakis et al., 2010), with

limited investigation into nasal inhalation as a mode of delivery. Menthol nasal inhalation directly stimulates thermosensitive channels within the nasal cavity, providing a distinct route relative to oral or topical delivery (Pereira et al., 2013). Furthermore, limited research has systematically examined whether responses to menthol differ between males and females, despite evidence of sex-based differences in thermal perception and respiratory sensations during exercise (Cory et al., 2015; Parton et al., 2021; Schoech et al., 2021).

Accordingly, this literature review examines the physiological basis of aerobic exercise, methods used to assess endurance performance, sex-based considerations in endurance exercise research, and the emerging role of menthol as a perceptual ergogenic aid, with particular emphasis on nasal inhalation as an underexplored administration strategy.

Aerobic Exercise

Aerobic exercise involves sustained rhythmic activity supported primarily by oxidative metabolism, which provides the energy required for endurance activities such as running, cycling, and swimming (Patel et al., 2017; Riebe et al., 2018). During aerobic exercise, adenosine triphosphate (ATP) resynthesis is supported primarily through the oxidation of carbohydrates and fatty acids (Brooks & Mercier, 1994; Spriet, 2002). As exercise duration and intensity increase, maintaining oxygen delivery, substrate utilization, and thermoregulation becomes progressively more challenging, contributing to physiological and perceptual strain that may impair endurance performance (Patel et al., 2017). Aerobic capacity is commonly characterized using physiological markers such as maximal oxygen uptake (VO_2max), lactate threshold, ventilatory threshold, and critical power (Valenzuela et al., 2021). VO_2max represents the maximal ability to take up, transport, and use oxygen during intense exercise (Martin-Rincon

& Calbet, 2020). Lactate threshold reflects the exercise intensity at which lactate accumulation exceeds clearance and is strongly associated with endurance performance (Ghosh, 2004; Wackerhage et al., 2022). Although these physiological markers provide important insight into aerobic capacity, they do not fully account for performance during self-paced endurance exercise, where perceptual regulation and pacing behaviour also influence performance outcomes.

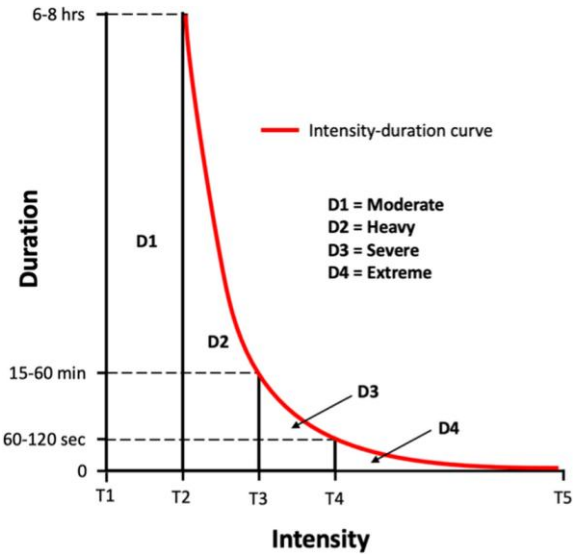
Ventilatory thresholds provide complementary information by identifying changes in ventilatory control associated with increasing metabolic stress during exercise (Anselmi et al., 2021). The first ventilatory threshold (VT1) reflects the initial sustained increase in ventilation relative to VO_2 associated with the buffering of accumulating hydrogen ions (Anselmi et al., 2021). The second ventilatory threshold (VT2) reflects a disproportionate increase in ventilation relative to oxygen consumption and carbon dioxide production during high-intensity exercise when rapid lactate accumulation occurs (Anselmi et al., 2021). Although ventilatory and lactate thresholds identify physiological intensity domains, they do not fully account for endurance performance during self-paced time-trial exercise, where perceptual regulation and pacing strategies play a prominent role (Anselmi et al., 2021). Critical power (CP) refers to the highest sustainable power output that can be maintained without continual increases in blood lactate or oxygen uptake (Poole et al., 2016). Critical power delineates the boundary between the heavy- and severe-intensity domains and represents an important indicator of sustainable aerobic performance capacity during prolonged exercise (Poole et al., 2016).

One framework commonly used to conceptualize endurance capacity is the duration-intensity domain model, which categorizes exercise intensity according to metabolic responses and key physiological thresholds, such as the first and second lactate thresholds (LT1 and LT2)

(Hofmann & Tschakert, 2017; see Figure 1). Four primary intensity domains are recognized: moderate, heavy, severe, and extreme (Hofmann & Tschakert, 2017; Korzeniewski & Rossiter, 2022). In the moderate-intensity domain, exercise occurs below LT1 or VT1, allowing oxygen uptake and blood lactate levels to stabilize quickly, enabling prolonged steady-state aerobic metabolism with minimal fatigue (Anselmi et al., 2021; Hofmann & Tschakert, 2017). The heavy-intensity domain lies between LT1 and LT2, where oxygen uptake reaches a delayed steady state and blood lactate rises to an elevated but stable concentration, with fatigue developing gradually (Hofmann & Tschakert, 2017). The severe-intensity domain occurs above LT2, where a steady state is unattainable, oxygen uptake continues to rise toward VO_2max, and fatigue develops rapidly because of progressive metabolite accumulation (Bassett, 2000). Finally, the extreme-intensity domain encompasses brief, all-out efforts performed at intensities above VO_2max, where fatigue occurs before maximal oxygen uptake can be achieved because of the overwhelming reliance on anaerobic energy systems (Helgerud et al., 2007).

Figure 1

Maximal Intensity-Duration Relationship



Note. Exercise-intensity domains are categorized relative to key physiological thresholds. Threshold 1 (T1) represents the first ventilatory threshold (VT1) or first lactate threshold (LT1). Threshold 2 (T2) represents the upper boundary of the heavy-intensity domain, commonly associated with the second lactate threshold (LT2) or critical power (CP). The severe domain occurs above T2, whereas the extreme domain comprises the highest-intensity efforts, during which fatigue develops before VO_2max can be attained. Adapted conceptually from Rosenblat et al. (2023).

Physiological Basis of Aerobic Exercise

Aerobic exercise places significant demands on the cardiovascular, respiratory, and thermoregulatory systems, which must be regulated to sustain prolonged activity (Bassett, 2000). The cardiovascular system delivers oxygenated blood to working muscles and facilitates the removal of metabolic waste products (Patel et al., 2017). The respiratory system facilitates gas exchange to meet the rising oxygen demand of aerobic metabolism (Korivi et al., 2025). During

sustained exercise, ventilation and pulmonary gas exchange increase in proportion to metabolic demand to preserve arterial oxygen saturation (Dominelli & Sheel, 2024).

The thermoregulatory system attempts to maintain homeostasis through mechanisms such as vasodilation and sweating to facilitate heat dissipation (Périard et al., 2021; Racinais et al., 2015; Tan & Knight, 2018). These competing circulatory demands become particularly pronounced in hot environments, where the distribution of blood flow between the skin and active musculature may be challenged (González-Alonso et al., 1999). Thermoregulatory strain influences thermal sensation (TS), a subjective perception reflecting the integration of core and skin thermal signals, thermoregulatory cardiovascular adjustments, and central processing mechanisms (González-Alonso et al., 2007; Montain & Coyle, 1992).

One consequence of sustained thermoregulatory strain during prolonged steady-state exercise is cardiovascular drift, defined as a progressive increase in heart rate accompanied by a reduction in stroke volume despite constant external workload (Wingo et al., 2005). Cardiovascular drift has been associated with reductions in maximal oxygen uptake over time, with decreases of approximately 15% observed during prolonged exercise (Wingo et al., 2005). As core temperature rises, physiological responses, including cardiovascular drift, elevated respiratory rates, and central fatigue, contribute to progressive declines in aerobic performance (Bassett, 2000; Périard et al., 2021; Racinais et al., 2015).

Fatigue during endurance exercise arises from the interaction of central and peripheral mechanisms (Tornero-Aguilera et al., 2022). Peripheral fatigue originates in skeletal muscle and is influenced by metabolic disturbances, including pH changes, substrate depletion, and ionic imbalances (Allen et al., 2008; Tornero-Aguilera et al., 2022). Central fatigue is commonly defined as a reduction in voluntary neural drive originating within the central nervous system

(CNS) and is influenced by factors such as cerebral temperature and perceived effort (Noakes, 2012; Tornero-Aguilera et al., 2022). In endurance tasks, volitional fatigue refers to the conscious decision to terminate exercise when perceived effort or discomfort becomes intolerable, reflecting central regulation rather than absolute physiological limitation (Pageaux & Lepers, 2016). Under conditions of high TS, these central mechanisms may play a greater role, as elevated brain temperature and discomfort reduce motor output (Taylor et al., 2016). As a result, thermally driven perceptual strain can impair pacing strategies and reduce endurance performance (Skorski & Abbiss, 2017). Collectively, these physiological and perceptual mechanisms contribute to the regulation of exercise tolerance and pacing behaviour during self-paced endurance performance.

Assessing Endurance Performance

Aerobic Performance Testing

Endurance performance is multifactorial and influenced by the interaction of physiological capacity, perceptual regulation, pacing behaviour, and environmental conditions, requiring testing protocols that accurately reflect the demands of sustained exercise performance. In exercise physiology research and competitive sport, performance testing is used to evaluate aerobic capacity, endurance, and the efficacy of performance-enhancing interventions (Puente-Maestu et al., 2016). Several laboratory-based and field-based protocols are used to assess aerobic endurance performance, each providing distinct physiological and performance-related information depending on the test objective (Löllgen & Leyk, 2018).

VO_2max is regarded as the gold standard of aerobic capacity and endurance potential; however, it does not directly reflect performance during self-paced endurance exercise (Bassett,

2000; Poole et al., 2008). A VO_2max test measures the maximum rate of oxygen consumption during an incremental exercise test until exhaustion (Beltz et al., 2016). VO_2max is commonly assessed using a graded exercise test performed on a treadmill or cycle ergometer (Beltz et al., 2016). A typical treadmill graded exercise protocol is based on the original Bruce protocol, which starts at 1.7 mph at a 10% incline, with an increase of 0.8 mph and a 2% incline increase every 3 minutes (Bruce et al., 1963). VO_2max may be estimated using predictive submaximal exercise tests or directly measured using metabolic carts during maximal graded exercise protocols that quantify oxygen consumption and carbon dioxide production (Santtila et al., 2013).

VO_2max is typically identified when oxygen consumption plateaus despite an increase in exercise intensity (Santtila et al., 2013). The benefits of VO_2max testing include the direct measurement of oxygen consumption and carbon dioxide production, allowing for the calculation of respiratory exchange ratio (RER) and the identification of ventilatory thresholds using standardized metabolic protocols (Beltz et al., 2016). However, VO_2max tests are psychologically demanding, require specialized equipment, and lack ecological validity because they exclude pacing strategy (Beltz et al., 2016). Consequently, performance-based protocols that incorporate self-paced exercise may provide greater ecological validity and sensitivity to perceptual interventions that influence pacing behaviour and exercise tolerance (Abbiss & Laursen, 2008; Marcora, 2008; Mauger et al., 2009). Accordingly, protocol selection is an important methodological consideration because different testing approaches may vary in their sensitivity to pacing behaviour, perceptual responses, exercise tolerance, and physiological determinants beyond VO_2max alone, including oxygen delivery, metabolic efficiency, and neuromuscular factors (Jacobs et al., 2011).

Performance Test Modalities

Given the limited sensitivity of VO_2max tests for detecting performance changes following interventions, performance-based exercise tests are frequently used in applied research (Fisher et al., 2017). Two common performance assessment approaches include time-to-exhaustion (TTE) and time-trial (TT) protocols. A TTE test involves participants exercising at a predetermined constant workload, often expressed relative to a percentage of VO_2max or peak power output, until volitional exhaustion is reached (Laursen et al., 2007). Volitional exhaustion is defined as the point at which the individual indicates an inability to continue exercising despite verbal encouragement (Weinstein et al., 2013). In contrast, TT protocols require participants either to complete a predetermined distance as quickly as possible or to maximize performance over a predetermined duration while self-pacing throughout the trial (Fisher et al., 2017). As TT protocols permit continuous self-regulation of exercise intensity, performance is influenced by the ongoing integration of physiological and perceptual feedback throughout the trial (Abbiss & Laursen, 2008).

In cycling TT research, performance is commonly expressed relative to body mass to facilitate comparison across participants of differing body sizes (Vos et al., 2025). Much of the existing endurance performance research has employed cycling protocols because they provide enhanced workload control and laboratory standardization (Beltz et al., 2016). Cycling also facilitates continuous measurement of physiological (e.g., heart rate) and perceptual responses without interruption, as demonstrated during laboratory cycling time trials where heart rate and pacing behaviour are recorded throughout the effort (Funnell et al., 2023). Additionally, the seated posture and fixed task constraints of cycling time trials improve within-subject reliability for detecting small condition-related changes in performance and perception, with lab protocols

demonstrating high consistency in repeated trials when standardized (Jusoh et al., 2015).

Although both TTE and TT protocols are commonly used to assess endurance performance, TT protocols are generally considered to possess greater ecological validity because they more closely replicate the self-paced nature of competitive endurance events and allow for continuous pacing adjustments in response to physiological and perceptual feedback (Abbiss & Laursen, 2008; Currell & Jeukendrup, 2008). Consequently, self-paced TT protocols may be particularly appropriate for investigating perceptual ergogenic aids such as menthol, which are proposed to influence exercise tolerance through alterations in perceived exertion, thermal sensation, and respiratory comfort (Abbiss & Laursen, 2008; Barwood et al., 2020; Marcora, 2008; Stevens & Best, 2017).

Strengths and Limitations of Endurance Performance Tests

Both TTE and TT protocols possess distinct methodological strengths and limitations that should be considered when selecting endurance performance assessments for exercise physiology research. TTE protocols are highly controlled and sensitive to physiological changes but lack ecological validity, as they do not incorporate pacing strategies (Currell & Jeukendrup, 2008). TTE protocols may be influenced by participant motivation and subjective termination criteria, potentially reducing test–retest reliability (Laursen & Jenkins, 2002). TT protocols allow participants to adjust intensity based on TS, RC, and RPE, closely reflecting endurance competition and enhancing ecological validity (Davies et al., 2016; Yu et al., 2024). Ecological validity refers to the extent to which a laboratory protocol reflects the pacing behaviours and perceptual demands characteristic of real-world endurance competition (Abbiss & Laursen, 2008; Araújo et al., 2007). Time-trial protocols have demonstrated strong reliability and validity

for assessing endurance performance, particularly when standardized procedures and familiarization sessions are implemented, supporting their use in intervention-based research (McGawley, 2017). Familiarization can improve the reliability of TT protocols by reducing learning effects and helping participants establish more consistent pacing strategies (Currell & Jeukendrup, 2008; Hibbert et al., 2017).

For perceptual interventions such as menthol, TT protocols are particularly relevant because alterations in perceived exertion, thermal sensation, and respiratory comfort may directly influence pacing behaviour, exercise tolerance, and subsequent performance outcomes during self-paced exercise (Marcora, 2008; Stevens & Best, 2017). Laboratory-based studies provide greater experimental control of the environment and measurement precision, whereas field-based studies offer greater ecological validity (Martin et al., 2025; Peserico & Machado, 2014). The selection of laboratory- or field-based testing environments is also an important methodological consideration, as environmental cues and external conditions may influence pacing behaviour and endurance performance outcomes (Martin et al., 2025). Laboratory settings may be useful for evaluating perceptual ergogenic aids because controlled environments improve internal validity and minimize external factors that may independently influence perceptual responses and pacing behaviour (Barwood et al., 2020; Currell & Jeukendrup, 2008).

A 15-minute self-paced TT may be particularly well suited for investigating perceptual ergogenic aids because it is reliable and long enough to elicit meaningful perceptual strain during exercise (Moss et al., 2021). Similar-duration self-paced cycling TT protocols have been used to examine pacing behaviour, perceived exertion, thermal sensation, and the effects of perceptual ergogenic aids on endurance performance (Funnell et al., 2023; Moss et al., 2021).

Sex-Based Considerations in Endurance Testing

Biological sex is commonly characterized by chromosomal, anatomical, hormonal, and physiological traits that typically differ between males and females (Delp et al., 2024; Torgrimson & Minson, 2005). In contrast, gender is a social construct that refers to socially defined roles and behaviours and is related to, but distinct from, biological sex (Torgrimson & Minson, 2005). Sex-based physiological differences may influence endurance exercise performance through variations in cardiopulmonary function, substrate metabolism, thermoregulation, and perceptual responses to exercise (Ansdell et al., 2020). Females generally exhibit lower absolute VO_2max values than males, largely because of sex-based differences in heart size, hemoglobin concentration, and stroke volume (Bassareo & Crisafulli, 2019). However, when VO_2max is normalized to body mass, these differences are reduced (Martins et al., 2023). Pulmonary limitations may be more pronounced in females, who typically have smaller lungs and narrower airways relative to their body size, potentially resulting in higher ventilatory effort during high-intensity exercise (LoMauro & Aliverti, 2018). Despite these physiological differences, sex-based differences in relative endurance performance may be reduced when training status, body composition, and performance scaling are appropriately considered (Cano et al., 2021).

Sex-based differences in substrate metabolism may also influence endurance regulation and fatigue development during prolonged exercise because of variations in hormonal regulation, muscle fibre composition, and enzymatic activity (Cano et al., 2021). Females rely more heavily on lipid oxidation and conserve glycogen stores more efficiently during submaximal endurance exercise (Cano et al., 2021). This reliance on lipid oxidation may be attributable to estrogen's influence on substrate utilization (Cano et al., 2021). In contrast, males rely more heavily on

carbohydrate metabolism and use greater glycogen stores during endurance exercise (Cano et al., 2021). This greater reliance on carbohydrate metabolism may reflect lower estrogen concentrations, greater muscle mass, a higher proportion of type II muscle fibres, and greater catecholamine responses (Lundsgaard & Kiens, 2014). Collectively, these physiological and metabolic differences may contribute to sex-based variation in endurance performance, fatigue development, and perceptual responses during exercise (Cano et al., 2021).

Menstrual Cycle Physiology

A eumenorrheic menstrual cycle typically ranges from 21 to 35 days and consists of follicular and luteal phases characterized by fluctuating concentrations of estrogen and progesterone (Carmichael et al., 2021; Fehring et al., 2006). These hormonal fluctuations may influence thermoregulatory and metabolic processes during exercise, with evidence demonstrating alterations in heat dissipation and core temperature regulation across menstrual cycle phases (Giersch et al., 2020; Pereira et al., 2020). However, associated perceptual responses, including ratings of perceived exertion and thermal discomfort, exhibit substantial inter-individual variability and do not consistently differ across menstrual cycle phases (McNulty et al., 2020; Pereira et al., 2020). Current evidence suggests that menstrual cycle phase exerts trivial-to-small effects on endurance performance, with substantial inter-individual variability and inconsistent findings reported across studies (McNulty et al., 2020; Meignié et al., 2021). Consistent with this, McLay et al. (2007) reported no significant differences in cycling time-trial performance across menstrual phases, and a large meta-analysis by McNulty et al. (2020) demonstrated that between-participant variability exceeds any phase-related differences in endurance performance. Furthermore, recent investigations report no significant differences in

ratings of perceived exertion or thermal perception across menstrual cycle phases during prolonged self-paced exercise (Christison et al., 2025; Rael et al., 2021). Collectively, these findings suggest that although menstrual cycle physiology may influence certain thermoregulatory and metabolic responses during exercise, its effects on endurance performance and perceptual responses during self-paced exercise appear to be relatively small and highly variable between individuals.

Menstrual Cycle Considerations and Methodological Approach

Given the limited and inconsistent effects of menstrual cycle phase on endurance performance and perceptual responses reported in the current literature, the present study did not experimentally control for menstrual cycle phase. Accurate menstrual cycle phase classification typically requires biochemical verification methods, which were not feasible within the logistical scope of the study. Self-reported menstrual cycle phase has been shown to be unreliable and may introduce greater misclassification error than benefit (Hamidovic et al., 2020). Additionally, restricting testing to specific cycle phases would reduce recruitment feasibility and limit external validity (McNulty et al., 2020). Importantly, competitive endurance events are not scheduled according to menstrual cycle phase; therefore, strict phase-based control may reduce the ecological validity of time-trial research (Elliott-Sale et al., 2021).

Hormonal contraceptive use (e.g., oral contraceptives, hormonal intrauterine devices [IUDs], or other systemic hormonal contraceptive methods) may alter endogenous hormonal profiles and thermoregulatory responses during exercise (Grucza et al., 1993). Hormonal contraceptive use is common within the studied age range and is associated with more stable circulating hormone concentrations compared with naturally cycling individuals (Elliott-Sale et

al., 2021). However, current evidence suggests that hormonal contraceptive use does not consistently produce meaningful differences in endurance time-trial performance or perceptual responses (Grucza et al., 1993). Participants were not excluded based on contraceptive use; instead, contraceptive status was documented and acknowledged as a potential source of inter-individual variability (Elliott-Sale et al., 2021). Consequently, menstrual cycle phase and hormonal contraceptive use were acknowledged as potential sources of inter-individual variability rather than experimentally controlled variables, consistent with current methodological recommendations for perceptual and performance-based endurance research (Elliott-Sale et al., 2021).

Performance Outcome Scaling

Time-trial performance is commonly quantified as the total distance covered (m), representing absolute cycling performance during a self-paced endurance task (Abbiss & Laursen, 2008). Absolute performance outcomes preserve ecological validity by reflecting the participant's actual cycling performance. However, because males generally possess greater body mass and lean muscle mass than females, absolute performance metrics may partly reflect differences in body size rather than physiological capacity alone (Ansdell et al., 2020; Bartolomei et al., 2021; Tanaka et al., 1993). To provide a body-mass-relative measure, endurance performance can also be expressed relative to body mass ($m \cdot kg^{-1}$), allowing absolute and size-relative outcomes to be considered together (Kappus et al., 2015; Santana et al., 2024). Reporting both absolute performance (m) and body-mass-normalized performance ($m \cdot kg^{-1}$) therefore provides complementary perspectives on performance across individuals of differing body sizes (Abbiss et al., 2016; Araújo et al., 2007).

Sex-Based Differences in Perceptual Responses

Beyond methodological considerations related to menstrual cycle variability, sex-based differences in perceptual responses during endurance exercise may further influence performance regulation and responses to perceptual interventions. Female participants have been shown to perceive thermal stress during exercise-induced hyperthermia as hotter, less comfortable, more unpleasant, and more stressful compared with males (Schoech et al., 2021). For example, Schoech et al. (2021) reported significant main effects of sex for thermal sensation ($F(1, 20) = 4.59$, $p < .05$), thermal comfort ($F(1, 20) = 4.78$, $p < .04$), and thermal pleasantness ($F(1, 20) = 4.79$, $p < .04$), with females consistently rating the same thermal environment as hotter and more uncomfortable than males. Females may also experience greater breathing discomfort at a given ventilation rate compared with males, potentially contributing to differences in respiratory perception during endurance exercise (Cory et al., 2015). Sex-based differences in perceived exertion have also been reported, with females potentially reporting higher RPE values than males at equivalent absolute workloads; however, findings become less consistent when exercise intensity is normalized relative to individual capacity (Garcin et al., 2005; Springer & Pincivero, 2009). Additionally, sex differences in cognitive and perceptual processes, including time perception during self-paced exercise, may further influence pacing behaviour and endurance performance outcomes (Hanson & Buckworth, 2016).

Both sexes have demonstrated lower thermal sensation following menthol administration; however, the time course and translation of that response into performance may differ by sex. Parton et al. (2021) reported that oral menthol lowered thermal sensation in males and females during fixed-RPE exercise in the heat, but the reduction was maintained for only part of the trial among females. Males significantly increased power output, whereas females did not. As

endurance performance is influenced by physiological capacity as well as perceptual and psychological regulation, examining sex-based differences in perceptual responses is central to understanding potential sex-related differences in response to menthol in the present study.

Protocol Selection for Sex-Based Differences

Accounting for sex-specific physiological and perceptual variables in experimental design can improve the validity, reliability, and generalizability of endurance performance research (White et al., 2021). Historically, endurance exercise research has predominantly been conducted using male participants, with female-specific physiological and hormonal considerations often underrepresented or insufficiently controlled within experimental designs (White et al., 2021). This reflects broader research practices in which sex has not consistently been treated as a critical biological variable, despite increasing recognition that its inclusion improves scientific rigour, reproducibility, and generalizability of exercise physiology findings (Maney et al., 2023).

Protocol selection may be particularly important when investigating sex-based differences in endurance exercise because physiological and perceptual responses may vary depending on whether exercise is externally controlled or self-paced. Self-paced TT protocols may be useful for identifying potential sex-related differences in pacing behaviour, thermal perception, respiratory comfort, and ratings of perceived exertion because self-paced exercise requires the continuous integration of physiological and perceptual feedback (Abbiss & Laursen, 2008; Marcora, 2008). Consequently, incorporating both male and female participants within ecologically valid self-paced exercise protocols may improve understanding of whether responses to perceptual ergogenic aids such as menthol differ between sexes.

Ergogenic Aids for Endurance Performance

Classifications of Ergogenic Aids

Ergogenic aids are widely used within athletic populations to enhance training adaptations, delay fatigue, and improve competitive performance, with approximately 50% of athletes reporting the use of at least one ergogenic aid (Frączek et al., 2016; Maughan, 1999; Thein et al., 1995; Vitale & Getzin, 2019). Within endurance sport, ergogenic aids may include substances, strategies, or devices intended to enhance performance through improvements in physiological capacity, perceptual regulation, thermoregulation, or pacing behaviour (Maughan et al., 2018; Peeling et al., 2018). Ergogenic aids are commonly classified as nutritional, pharmacological, physiological, mechanical, or perceptual/psychological interventions, each targeting distinct mechanisms associated with fatigue resistance and exercise performance (Maughan et al., 2018; Peeling et al., 2018).

Mechanistically, ergogenic aids may influence endurance performance through both peripheral physiological adaptations and central alterations in fatigue perception and exercise regulation (Wiącek & Karolkiewicz, 2023). Peripheral ergogenic mechanisms primarily influence physiological processes within skeletal muscle and cardiovascular systems that contribute to energy production and fatigue resistance during exercise (Jezek et al., 2022). For example, sodium bicarbonate functions as a buffering agent to delay the onset of metabolic acidosis, and creatine enhances muscle phosphocreatine storage to support intense energy demands (Hadzic et al., 2019). In contrast, central ergogenic mechanisms act through the central nervous system to alter fatigue perception, perceived exertion, motivation, and exercise tolerance during endurance exercise (Tornero-Aguilera et al., 2022). Caffeine functions as an adenosine receptor antagonist, reducing perceived exertion and improving alertness (Cappelletti et al.,

2014). Among these approaches, perceptual ergogenic aids have received increasing attention because they may enhance endurance performance through alterations in thermal perception, perceived exertion, respiratory comfort, and pacing behaviour without directly modifying physiological capacity.

Physiological Limitations Targeted by Ergogenic Aids

Endurance performance is limited by a combination of physiological and perceptual factors that contribute to fatigue development and reductions in exercise capacity during prolonged exercise (Marcora, 2008; Pageaux, 2014). Prolonged periods of elevated respiratory rates can lead to respiratory muscle fatigue, activating sympathetic vasoconstriction through the respiratory metaboreflex and contributing to performance decline (Johnson et al., 1996). Thermoregulatory strain is another key factor that can influence endurance performance during prolonged exercise (Nybo & Nielsen, 2001; Stevens et al., 2018). Nybo and Nielsen (2001) reported that elevations in brain temperature toward approximately 40°C were associated with reduced voluntary muscle activation. Elevated brain temperature and increased perceptual discomfort may interact to influence pacing decisions, exercise tolerance, and endurance performance by altering the athlete's perception of effort and willingness to sustain exercise intensity (Stevens et al., 2018). Among perceptual ergogenic aids, menthol has received increasing attention because of its thermosensory properties and potential influence during endurance exercise, although its application through nasal inhalation remains underexplored (Mauger, 2014).

Menthol as a Perceptual Ergogenic Aid

Menthol is a naturally occurring organic compound derived from plants of the *Mentha genus*, although it may also be produced synthetically (Kamatou et al., 2013). Menthol is widely used in consumer and pharmaceutical products, including topical analgesics, cough suppressants, lozenges, and cooling gels because of its characteristic cooling sensation and sensory effects (Kamatou et al., 2013). In exercise research, menthol is known for its perceived cooling properties, analgesic effects, and distinct odour (Kamatou et al., 2013; Pergolizzi et al., 2018). Several menthol stereoisomers exist; however, L-menthol is the most commonly used form in exercise research and produces the strongest cooling sensation (Jeffries & Waldron, 2019). Menthol has received increasing attention as a perceptual ergogenic aid, particularly in hot and humid environments, where it has been shown to reduce perceived exertion and thermal sensation while improving respiratory comfort during endurance exercise (Flood, 2018).

Regardless of the route of administration, menthol primarily exerts its perceptual effects through interactions with transient receptor potential melastatin 8 (TRPM8) and transient receptor potential vanilloid 1 (TRPV1) channels. Menthol activates TRPM8 channels in oral, nasal, and dermal tissues and can modulate TRPV1 activity, contributing to a subjective cooling sensation without necessarily reducing core or skin temperature (Barwood et al., 2020; Takaishi et al., 2015; Than et al., 2013; Yosipovitch et al., 1996). TRP channels are expressed in thermosensory neurons that innervate trigeminal nerve endings, particularly within the nasal cavity respiratory epithelium (Than et al., 2013). The nasal cavity contains a dense network of sensory afferents that project to cortical regions involved in thermosensation and perception (Than et al., 2013). The TRPM8 channel is a thermosensitive receptor that responds to cool temperatures or chemical stimuli, such as menthol (Yosipovitch et al., 1996).

During prolonged exercise, menthol may improve thermal sensation through modulation of thermosensory afferent feedback (Jang et al., 2015). Previous research has primarily examined airflow sensation and respiratory responses at rest, whereas only one study has investigated menthol inhalation during exercise in a clinical population. Schaeffer et al. (2025) examined continuous menthol inhalation during constant-load cycling exercise in adults with COPD. Menthol reduced dyspnea and enhanced perceived inspiratory airflow but did not improve exercise endurance time; the study did not assess self-paced performance. Accordingly, the effects of menthol nasal inhalation on self-paced endurance performance, perceptual responses, and physiological responses in healthy, physically active individuals remain largely unexplored.

Physiological Mechanisms of Menthol

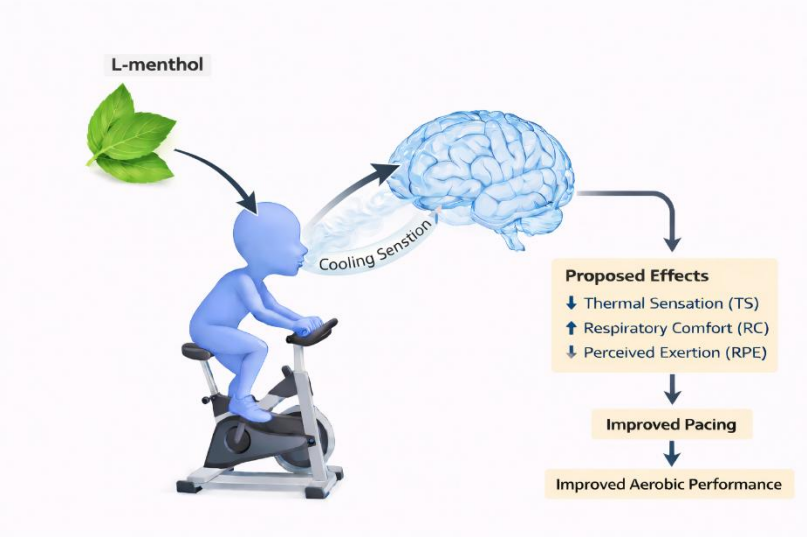
TRPM8 Channel Activation

TRPM8 is a non-selective thermosensory cation receptor channel expressed in peripheral nociceptor terminals (Lamberti et al., 2025). Trigeminal sensory afferent fibres expressing TRPM8 are abundant within the subepithelial layer of the nasal mucosa (Liu et al., 2015). TRPM8 is activated by cool temperatures (< 28°C) or chemical stimuli such as menthol (Iftinca & Altier, 2020; Lamberti et al., 2025). Upon activation, TRPM8 permits calcium and sodium influx, resulting in depolarization of trigeminal nerve endings located within the nasal epithelium (Iftinca & Altier, 2020; Liu et al., 2013). This depolarization generates action potentials that travel through the trigeminal nerve to the brainstem, with ascending projections to the thalamus and somatosensory cortex (Liu et al., 2013; Renner & Schreiber, 2012). These neural signals are integrated cortically and perceived as a cooling sensation despite no reduction in core or skin temperature (Peier et al., 2002).

The resulting cooling sensation has been associated with reduced TS, improved RC, and lower RPE, particularly in hot environments (Barwood et al., 2020; Stevens & Best, 2017). The magnitude of these perceptual responses may be concentration-dependent, as higher menthol concentrations have been shown to elicit greater alterations in thermal perception and thermoregulatory responses (Gillis et al., 2020). This proposed perceptual pathway is illustrated in Figure 2. Through these perceptual mechanisms, menthol may influence exercise tolerance by altering thermal sensation and perceived discomfort during endurance exercise (Jeffries & Waldron, 2019).

Figure 2

Proposed Perceptual Effects of Menthol During Exercise



Note. Proposed perceptual pathway of L-menthol, illustrating its effects on thermal sensation, perceived exertion, respiratory comfort, pacing, and aerobic performance. Adapted conceptually from Stevens and Best (2017) and Barwood et al. (2020).

TRPV1 Channel Involvement

The TRPV1 channel is sensitive to capsaicin, hot temperatures (>43°C), and acidic conditions (pH 4.0–6.5) (Shuba, 2021). TRPV1 contributes to thermosensory signalling and plays a key role in the perception of heat and thermal discomfort during intense exercise (Shuba, 2021). At high concentrations, menthol may activate TRPV1 channels (Takaishi et al., 2015). However, at the lower concentrations commonly used in exercise research, menthol inhibits TRPV1 activation induced by heat or capsaicin, the compound responsible for the characteristic burning sensation associated with chili peppers (Takaishi et al., 2015). Menthol-mediated inhibition of TRPV1 may reduce calcium influx into sensory neurons, potentially attenuating the perception of heat stress (Takaishi et al., 2015). As TRPV1 channels are involved in the transmission of nociceptive and heat-related sensory signals, menthol-mediated inhibition may attenuate the perception of thermal strain and discomfort during exercise (Takaishi et al., 2015; Zhang et al., 2023). Together with TRPM8 activation, inhibition of TRPV1 may contribute to the cooling sensation and reduction in thermal discomfort associated with menthol administration, potentially enhancing exercise tolerance during endurance exercise performed in thermally challenging environments (Li et al., 2022).

Menthol Administration Methods

Menthol can be delivered through several administration methods that differ in onset speed and duration of action. The most investigated menthol administration methods in exercise research include nasal inhalation, oral rinsing, and topical application (Stevens & Best, 2017). Nasal inhalation delivers menthol to the nasal and upper-airway mucosa, producing a rapid cooling sensation through activation of thermosensitive receptors (Eccles et al., 1988). This

method may be relevant to endurance exercise because it influences sensations of airflow and breathing discomfort (Nishino et al., 1997). Oral rinsing involves participants swishing a menthol solution within the oral cavity without swallowing, allowing stimulation of oral thermosensory receptors while minimizing ingestion (Gavel et al., 2021). Menthol mouth rinsing activates TRPM8 channels in the oral cavity and may simultaneously improve RC and overall comfort during exercise (Gavel et al., 2021). Topical application of menthol to the skin, typically the face, neck, or limbs, can stimulate peripheral receptors and potentially enhance whole-body thermal perception (Jeffries & Waldron, 2019). Menthol is incorporated into commercially available topical products marketed for musculoskeletal pain relief and menstrual discomfort, reflecting menthol's broader application in thermosensory modulation and perceived symptom relief (Kamatou et al., 2013; Pergolizzi et al., 2018). Although all three administration methods stimulate thermosensory pathways, they differ in the location, onset, and duration of receptor activation, which may influence their effectiveness during endurance exercise.

Previous investigations have demonstrated that menthol delivered via nasal inhalation produces an immediate perceptual cooling sensation and enhanced perception of nasal airflow, consistent with trigeminally mediated sensory effects rather than changes in physiological airflow (Lindemann et al., 2008). For oral rinsing, activation of oral TRPM8 receptors occurs rapidly, typically within seconds to a few minutes following administration (Stevens et al., 2016). The perceptual effects of menthol oral rinsing typically persist for 10–15 minutes following administration (Stevens & Best, 2017).

Compared with nasal inhalation and oral rinsing, topical application produces a slower onset of action because menthol must diffuse through the skin before reaching thermosensory receptors (Silva, 2020). Due to menthol's lipophilic properties, it may accumulate within dermal

tissues, prolonging perceptual and vasoactive effects during exercise (Craighead et al., 2016). Menthol application to the skin produces vasoactive effects within approximately 15 minutes that may persist for up to 1 hour (Craighead et al., 2016). Topical menthol may serve as a pre-exercise cooling strategy that continues to exert perceptual effects during exercise, thereby reducing perceived heat strain (Keringer et al., 2020).

Potential Risks and Safety Considerations of Menthol Use

Menthol's ability to alter thermal perception warrants consideration of potential safety implications during exercise. Unlike traditional cooling strategies that reduce core or skin temperature, menthol elicits a subjective cooling sensation by activating thermosensitive receptors without inducing physiological heat dissipation (Barwood et al., 2020; Kamatou et al., 2013). This dissociation between perceived and actual thermal strain may mask physiological stress during prolonged or high-intensity exercise (Barwood et al., 2020; Stevens et al., 2016). Reductions in thermal sensation may influence pacing decisions and perceptions of thermal strain, particularly in warm environments (Stevens et al., 2016). As thermal discomfort serves as an important protective feedback mechanism during exercise, attenuating this perceptual signal may increase the risk of excessive heat strain under certain environmental conditions (Nybo & Nielsen, 2001). Similar concerns have been reported in topical menthol studies, where delayed sweating onset and vasoconstriction may impair heat dissipation (Kounalakis et al., 2010).

However, repeated administration protocols using low menthol concentrations have not been associated with serious adverse outcomes in healthy participants during controlled laboratory exercise trials (Barwood et al., 2015; Jeffries et al., 2018; Stevens et al., 2016). These studies have included oral rinse solutions containing approximately 0.01% menthol and topical

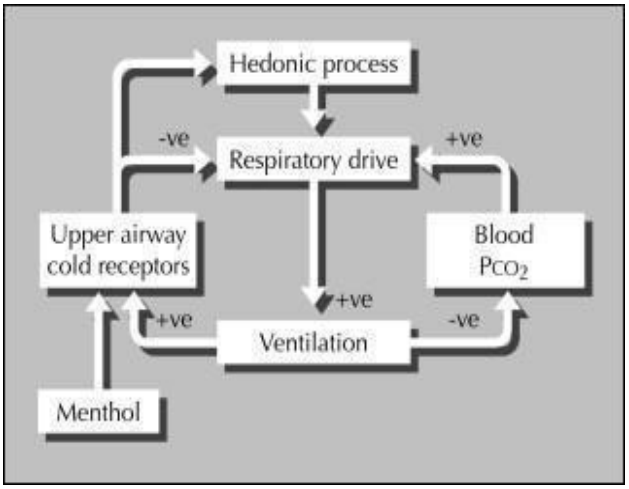
formulations containing 5–8% menthol, administered under controlled experimental conditions (Jeffries et al., 2018; Peel et al., 2023; Schlader et al., 2011; Stevens et al., 2016). Low to moderate menthol concentrations have generally been well tolerated in exercise studies, with mild sensory effects such as nasal or throat irritation reported (Jeffries & Waldron, 2019; Pergolizzi et al., 2018). These findings emphasize the importance of standardized administration protocols and appropriate safety precautions when menthol is used during exercise.

Relevance of Menthol to Endurance Exercise

Menthol may be particularly relevant during time-trial performance because pacing during TT protocols is strongly influenced by perceptual cues (De Camargo et al., 2022). During self-paced TTs, pacing behaviour is continuously regulated by perceptual cues such as perceived exertion, thermal sensation, and respiratory comfort (O'Malley et al., 2023). Through activation of TRPM8 channels, menthol shifts thermal sensation toward a cooler perceptual state and may improve respiratory comfort during exercise (Vogel et al., 2023). Collectively, these perceptual effects may influence exercise tolerance and pacing behaviour during self-paced endurance exercise (see Figure 3). Consequently, menthol may be particularly relevant when thermal strain or respiratory discomfort contributes to pacing behaviour during endurance exercise (Jeffries & Waldron, 2019; Stevens & Best, 2017).

Figure 3

Proposed Effects of Menthol on Ventilatory Drive



Note. Conceptual model illustrating proposed relationships among menthol stimulation of upper-airway cold receptors, respiratory drive, ventilation, and blood PCO_2. Adapted from Eccles (2003).

Effects of Menthol Administration on Endurance Performance

Oral Rinsing

Oral menthol rinsing involves swilling a menthol-containing solution in the mouth for approximately five seconds before expelling it (Mündel & Jones, 2010; Stevens et al., 2016). This method stimulates TRPM8 thermoreceptors within the oral cavity and oropharynx without ingestion (Gavel et al., 2024b). Mündel and Jones (2010) examined the effects of menthol mouth rinsing on time-to-exhaustion during cycling in hot conditions. The authors hypothesized that activation of thermosensitive receptors would enhance subjective comfort and extend exercise duration by attenuating the rise in thermal sensation. Nine non-acclimatised healthy male participants completed placebo-controlled trials in a heat chamber (34 ± 1°C; 27 ± 4% relative

humidity). The menthol rinse (25 mL; 0.01%) significantly increased exercise capacity and reduced cardiopulmonary ratings of perceived exertion compared with placebo.

Building upon these findings, Stevens et al. (2016) investigated repeated menthol rinsing during a self-paced 5-km running time trial in the heat (33°C; 46% relative humidity). Eleven moderately trained male runners completed trials with a control solution, ice slurry ingestion, and a 25 mL (0.01%) menthol rinse administered every two hundred meters. The menthol condition resulted in faster completion times, along with reduced thermal sensation and perceived exertion, indicating perceptual rather than physiological cooling effects. Jeffries et al. (2018) further examined menthol rinsing during time-to-exhaustion cycling in hot conditions (35°C). Ten male participants received a menthol rinse, ice slurry ingestion, or placebo at 85% of baseline exercise duration. The menthol rinse significantly increased exercise time compared with placebo, with no difference between menthol and ice slurry conditions. Core and skin temperatures remained unchanged; however, a large effect size was observed for thermal sensation, supporting a perceptual cooling mechanism (Jeffries et al., 2018).

Several studies have implemented repeated menthol administration throughout exercise to provide intermittent perceptual stimulation (Jeffries et al., 2018; Mündel & Jones, 2010; Stevens et al., 2016). Collectively, these studies suggest that oral menthol rinsing can improve endurance performance and perceptual responses such as perceived exertion and thermal discomfort, particularly in hot environments (Jeffries et al., 2018; Mündel & Jones, 2010; Roriz et al., 2024; Stevens et al., 2016; Trong et al., 2015). However, most of these investigations recruited exclusively or predominantly male participants, limiting the ability to draw conclusions regarding potential sex-based differences in response to menthol.

Topical Application

Topical menthol application involves the use of gels, sprays, or creams applied directly to the skin, which activate cutaneous thermoreceptors primarily via TRPM8 channels (Iftinca & Altier, 2020). Topical menthol has been associated with vasoconstriction, delayed onset of sweating, and analgesic effects (Barwood et al., 2020; Finch & Drummond, 2015; Kounalakis et al., 2010). When applied over large skin areas, TRPM8-mediated vasoconstriction may impair heat dissipation and increase rectal temperature, potentially compromising endurance performance in hot environments (Kounalakis et al., 2010; Nybo & Nielsen, 2001). Menthol exhibits well-documented analgesic properties resulting from its interaction with afferent nerves at the dermal-epidermal junction (Galeotti et al., 2002; Pergolizzi et al., 2018).

Peel et al. (2023) examined the effects of a 5% menthol topical cream applied 20 minutes prior to time-to-exhaustion cycling in the heat (35°C; 20% relative humidity). The study included 10 physically active participants (7 males and 3 females), who completed randomized crossover trials at 70% Wmax during a time-to-exhaustion test. No ergogenic effect on performance was observed; however, reductions in pain, perceived exertion, and thermal sensation were reported. Conversely, Schlader et al. (2011) studied twelve physically active males and demonstrated a 21% improvement in time-to-exhaustion following application of an 8% menthol gel to the face, despite no changes in core temperature or sweat rate. Reduced thermal sensation occurred without alterations in facial temperature, supporting menthol's perceptual mechanism of action.

Collectively, current evidence suggests that topical menthol can improve perceptual outcomes such as thermal sensation, pain, and perceived exertion; however, translation of these effects into reliable endurance performance improvements remains inconsistent (Jeffries &

Waldron, 2019; Stevens & Best, 2017). Like oral administration studies, topical menthol research has involved male-dominated samples, further limiting understanding of potential sex-specific responses.

Nasal Inhalation

In contrast to topical administration, nasal inhalation delivers menthol vapour directly to thermosensitive receptors within the nasal mucosa. This route has emerged as a promising method of administration for targeting perceptual mechanisms relevant to endurance performance rather than inducing physiological cooling (Liu et al., 2013). Nasal inhalation directly stimulates the high density of TRPM8 receptors located within the upper nasal cavity and respiratory tract, which are sensitive to chemical stimuli such as menthol (Iftinca & Altier, 2020). This dense distribution of thermosensitive receptors facilitates rapid trigeminal activation and cortical perception of cooling following menthol exposure (Riera et al., 2014). Activation of TRPM8 receptors via nasal exposure has been associated with enhanced airflow sensation and reduced respiratory discomfort through trigeminal afferent signalling pathways (Eccles et al., 1988; Naito et al., 1997).

Early investigations employed acute, single-dose menthol vapour exposures delivered intranasally, typically via crystalline menthol positioned near the nostrils or menthol-infused airflow. These studies demonstrated immediate improvements in perceived nasal patency and reductions in respiratory discomfort despite no measurable changes in airway resistance, supporting a trigeminally mediated perceptual mechanism rather than true physiological cooling (Eccles et al., 1988). However, these protocols were conducted at rest or under loaded-breathing conditions and did not assess endurance performance outcomes.

More recently, Schaeffer et al. (2025) examined continuous menthol inhalation during constant-load cycling exercise in 20 adults with COPD (12 males and 8 females). Menthol was delivered through the breathing circuit throughout exercise and reduced dyspnea while enhancing perceived inspiratory airflow, but it did not improve exercise endurance time. Although this study demonstrated the feasibility of menthol inhalation during exercise, it involved an older clinical population and did not examine repeated, discrete nasal exposures during self-paced performance. Further supporting the perceptual mechanism of menthol, nasal stimulation has been shown to improve breathlessness in clinical populations without altering pulmonary function (Kanezaki et al., 2023). However, the effects of repeated menthol nasal inhalation during self-paced endurance performance in physically active individuals remain largely unexplored. Furthermore, limited research has examined whether responses to menthol nasal inhalation differ between males and females, despite known sex-based differences in perceptual responses during endurance exercise.

Methodological Limitations and Research Gaps

Across menthol-exercise research, substantial methodological variability exists in administration protocols, including differences in delivery route, menthol concentration or quantity, timing of exposure, frequency of administration, and exercise modality. Studies have employed both laboratory- and field-based designs, each offering distinct advantages with respect to experimental control and ecological validity (Currell & Jeukendrup, 2008; Laursen et al., 2007). This heterogeneity complicates direct comparisons of findings and limits the ability to establish optimal menthol administration strategies for endurance exercise.

Menthol concentrations vary widely, ranging from low concentrations commonly used in

oral rinsing protocols (e.g., 0.01%) to higher concentrations applied topically (e.g., 5–8%). Administration protocols in exercise studies typically employ fixed concentrations or exposure durations rather than doses scaled to body mass or sex (Jeffries et al., 2018; Stevens et al., 2016). The timing of administration also differs across studies: some protocols employ a single pre-exercise exposure, whereas others implement repeated dosing throughout exercise to provide repeated perceptual stimulation (Flood et al., 2017; Jeffries et al., 2025).

Despite differences in the timing and frequency of menthol administration, no studies identified in the literature reviewed for the present thesis directly compared single versus repeated menthol exposure within the same exercise performance task. Evidence from repeated-dosing protocols suggests that intermittent re-stimulation may help maintain perceptual effects as sensory effects diminish after exposure (Best et al., 2021). Several studies employing repeated-dosing protocols have reported perceptual and performance benefits during prolonged exercise (Jeffries et al., 2018; Stevens et al., 2016).

Delivery route further contributes to variability in outcomes (Jeffries & Waldron, 2019; Stevens & Best, 2017). Oral rinsing has produced the most consistent ergogenic effects, including reductions in thermal sensation and perceived exertion. In contrast, topical application has yielded mixed findings, including potential impairment of thermoregulatory responses. Nasal inhalation remains underexplored in performance-based research. Existing nasal inhalation studies have focused primarily on perceptual outcomes, with limited investigation of endurance performance. Although oral rinsing has been shown to improve time-trial performance (Stevens & Best, 2017), both the oral and nasal cavities contain TRPM8 receptors that are sensitive to menthol stimulation. Nasal menthol exposure directly stimulates upper-airway thermoreceptors associated with breathing comfort and airflow sensation (Zhao et al., 2011). Furthermore,

repeated menthol nasal inhalation during a self-paced cycling time trial in healthy, physically active males and females remains unexamined in the literature reviewed for the present thesis.

Collectively, the considerable methodological heterogeneity across menthol studies underscores the need for standardized experimental protocols to improve replicability and strengthen conclusions regarding menthol's ergogenic potential. Inconsistencies in administration strategies limit the ability to identify the most effective delivery method and administration protocol. Controlled, systematic investigation of menthol nasal inhalation using standardized administration intervals and ecologically valid performance measures, such as self-paced time trials, is therefore warranted. Establishing consistent protocols can improve internal validity, facilitate cross-study comparison, and support investigation of the perceptual mechanisms through which menthol influences endurance performance. Such research may also improve understanding of potential sex-based differences in response to menthol nasal inhalation, an area that remains underexplored within the current literature.

Theoretical Framework

Psychobiological Model of Endurance Performance

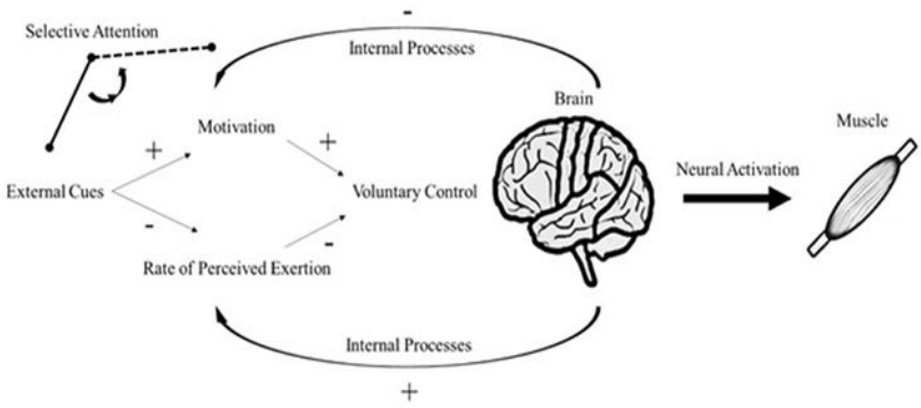
The Psychobiological Model of Endurance Performance provides a framework to explain menthol's potential impact on endurance performance tasks (Pageaux, 2014). Although multiple theoretical frameworks have been proposed to explain endurance performance regulation, including the Central Governor Model and the Integrative Model of Exercise Performance, the present study primarily focuses on the Psychobiological Model of Endurance Performance (Inzlicht et al., 2014; Tornero-Aguilera et al., 2022). The Psychobiological Model conceptualizes endurance performance as a function of cognitive regulation, perception of effort, and

motivational factors that determine exercise tolerance (Bigliassi, 2015; Marcora, 2008). These interacting components influence pacing strategies and task disengagement during prolonged exercise (see Figure 4). The Psychobiological Model of Endurance Performance is commonly applied to endurance exercise tasks involving a self-pacing strategy, suggesting that conscious regulation of pace is influenced by the perception of effort, motivation, knowledge of distance or time to be covered, and prior experience of exertion (Pageaux, 2014). Accordingly, endurance performance is regulated by physiological capacity as well as by how sensory information is perceived, interpreted, and integrated into pacing decisions (Pageaux, 2014). Executive function has also been identified as a key component of endurance performance regulation, influencing decision-making, effort allocation, and pacing strategies during prolonged exercise (Hyland-Monks et al., 2018).

Within this framework, interventions that modify sensory perception may indirectly influence these regulatory processes. The cooling sensation produced by menthol may influence endurance performance by redirecting attentional focus away from fatigue-related sensations and toward cooling-related sensory inputs (Bigliassi, 2015). Through this attentional shift, menthol may reduce the salience of fatigue-related signals, thereby influencing perception of effort, pacing behaviour, and exercise tolerance during prolonged exercise (Pageaux, 2014). Changes in perceived exertion, thermal sensation, and respiratory comfort may therefore represent important perceptual pathways through which menthol influences endurance performance within the psychobiological framework. Consequently, menthol nasal inhalation may represent a promising perceptual intervention for influencing pacing behaviour and endurance performance during self-paced exercise, particularly through its effects on perceived exertion, thermal sensation, and respiratory comfort (Tsutsumi et al., 2022).

Figure 4

Psychobiological Model of Endurance Performance



Note. Plus (+) symbols represent positive influences, and minus (-) symbols represent negative influences on endurance performance. Adapted from Bigliassi (2015).

Menthol's Impact on the Psychobiological Model of Endurance Performance

Building upon the Psychobiological Model of Endurance Performance, menthol may influence endurance performance through its effects on perceived effort, motivation, and exercise tolerance (Marcora, 2008; Pageaux, 2014). Menthol's cooling sensation may influence endurance performance by altering perceived effort and exercise tolerance (Flood, 2018). This aligns with evidence showing that perceptual interventions, such as menthol administration, can reduce RPE and alter exercise tolerance in hot environments (Flood, 2018; Stevens & Best, 2017). Activation of TRPM8 channels in the nasal mucosa produces a perceptual cooling effect without reducing core temperature (Eccles, 2000; Iftinca & Altier, 2020). This perceptual alteration may lower thermal sensation and influence the perceptual experience of effort during exercise (Barwood et al., 2015). Within the psychobiological model, perceived effort is an important determinant of exercise tolerance and decisions to sustain or reduce exercise intensity (Marcora, 2008).

These effects provide a rationale for menthol's role as a perceptual ergogenic aid by influencing variables central to the psychobiological model, even in the absence of direct physiological change (Flood, 2018; Stevens & Best, 2017). However, despite growing evidence supporting menthol's perceptual effects during exercise, important methodological and population-specific gaps remain within the current literature.

Research Problem

Menthol has been investigated as a potential ergogenic aid using several administration methods, including internal applications such as oral rinses and menthol-containing beverages, as well as external applications such as gels and sprays applied to the skin or clothing (Stevens & Best, 2017). However, research examining menthol nasal inhalation during exercise remains limited, with only one relevant exercise-based study identified in the literature reviewed for the present thesis: Schaeffer et al. (2025), who examined continuous menthol inhalation during constant-load cycling in adults with chronic obstructive pulmonary disease. Menthol interacts with the transient receptor potential melastatin 8 (TRPM8) receptors, which are expressed in the skin, oral cavity, and nasal mucosa (Vogel et al., 2023). Activation of TRPM8 receptors produces a cooling sensation that may reduce perceived exertion and thermal sensation and improve respiratory comfort through perceptual rather than physiological mechanisms (Kanezaki & Ebihara, 2017; Peel et al., 2023). TRPM8 activation generates afferent signalling to cortical regions involved in thermosensation, resulting in a perceived cooling effect without altering core or skin temperature (Gavel et al., 2024b; Liu et al., 2013). Previous research has shown that oral menthol administration can improve endurance performance and perceptual responses, while topical menthol has produced more mixed performance findings, with effects occurring primarily

through perceptual rather than direct physiological mechanisms (Barwood et al., 2015; Gavel et al., 2024b; Jeffries et al., 2018).

Female participants remain underrepresented in menthol-exercise research, as many investigations have exclusively or predominantly recruited male samples, with few studies including equal male and female cohorts (Barwood et al., 2020; Mündel & Jones, 2010; Stevens et al., 2016). Despite limited evidence regarding sex-based differences in menthol responses within athletic or recreational populations, few studies have been explicitly designed or adequately powered to determine whether responses to menthol differ between males and females (Barwood et al., 2020; Villegas-Serna et al., 2024). A recent systematic review and meta-analysis by Gavel et al. (2024a) examining menthol mouth rinsing during exercise included 10 studies (n = 153), of which 115 participants were male and 38 were female. Accordingly, the limited inclusion of female participants represents an important methodological gap in the current literature and restricts the generalizability of existing findings. To date, limited research has directly examined the effects of repeated menthol nasal inhalation on self-paced endurance time-trial performance, and no studies have concurrently evaluated potential sex-based differences in healthy, physically active adults. Therefore, further research is warranted to examine the effects of menthol nasal inhalation on performance, perceptual, and physiological responses while accounting for potential sex-based differences.

Purpose

The purpose of this study was to determine the effects of repeated menthol nasal inhalation and sex on performance, perceptual, and physiological responses during a self-paced cycling time trial in physically active adults.

Objectives

The objectives of this study were as follows:

1. To determine the effects of menthol nasal inhalation and sex on performance, as measured by total distance covered (m) and distance normalized to body mass ($m \cdot kg^{-1}$), during a self-paced cycling time trial.
2. To determine the effects of menthol nasal inhalation and sex on perceptual responses, including rating of perceived exertion, thermal sensation, and respiratory comfort, during a self-paced cycling time trial.
3. To determine the effects of menthol nasal inhalation and sex on the physiological response, as measured by heart rate, during a self-paced cycling time trial.

Hypotheses

1. It was hypothesized that menthol nasal inhalation would increase total distance covered and distance normalized to body mass, and that these condition-related improvements would be greater among females than males.

This hypothesis was based on evidence that females may experience greater thermal and respiratory perceptual strain during endurance exercise (Racinais et al., 2015; Sheel et al., 2004) and that menthol may attenuate perceptual strain that influences pacing regulation (Jeffries & Waldron, 2019; Stevens et al., 2016; Trong et al., 2015). Accordingly, reductions in perceptual strain may permit a greater self-selected work rate and produce a larger performance benefit among females.

2. It was hypothesized that menthol nasal inhalation would reduce RPE, produce cooler thermal sensations, and reduce respiratory discomfort. It was further hypothesized that condition-related changes in thermal sensation and respiratory comfort would be greater among females, whereas the change in RPE would not differ between sexes.

This hypothesis was based on evidence that menthol can reduce perceived exertion during endurance exercise (Jeffries & Waldron, 2019; Stevens et al., 2016), with no consistent evidence of sex-specific differences in RPE responses (McNulty et al., 2020). Menthol has also been shown to produce cooler thermal sensations (Jeffries & Waldron, 2019; Stevens et al., 2016), while females may experience greater sensations of warmth and thermal discomfort during endurance exercise (Giersch et al., 2020; Racinais et al., 2015), potentially resulting in a larger reduction in thermal sensation among females. In addition, females may experience greater breathing discomfort during endurance exercise (Cory et al., 2015; Sheel et al., 2004), while menthol has been shown to improve dyspnea and respiratory perception (Kanezaki & Ebihara, 2017; Kanezaki et al., 2023), potentially resulting in a larger improvement in respiratory comfort among females.

3. It was hypothesized that heart rate would be higher during the menthol condition than during the control condition, with no difference in the condition-related change between males and females.

This hypothesis was based on the possibility that menthol may indirectly increase heart rate through an increase in self-selected work rate during the time trial, as improvements in perceptual responses may facilitate greater exercise intensity (Jeffries & Waldron, 2019; Stevens et al., 2016).

Chapter Two: Methodology

Study Design

This study used a pseudo-randomized, counterbalanced design to examine the effects of menthol nasal inhalation on performance, perceptual, and physiological responses during a self-paced cycling time trial and whether these responses differed by sex. Following a familiarization session, each participant completed two experimental trials: a menthol nasal inhalation trial and a control trial, involving air inhalation via an identical apparatus. Experimental trials were separated by a minimum 48-hour washout period to minimize potential carryover effects (Jeffries & Waldron, 2019; Stevens & Best, 2017). Participants were assigned to trial order using a pseudo-randomized, counterbalanced allocation procedure to ensure balanced representation of males and females across each condition sequence. Allocation was concealed using sealed envelopes and revealed immediately prior to the participant's first experimental trial to reduce allocation bias. This design allowed each participant to serve as their own control, thereby reducing inter-individual variability and increasing statistical power (Mills et al., 2009). Condition (control, menthol) was treated as a within-subjects factor and Sex (male, female) as a between-subjects factor for the mixed-design ANOVA outcomes. For the ordinal perceptual outcomes, condition differences were evaluated using Wilcoxon signed-rank tests, and sex differences in condition-related changes were evaluated using Mann–Whitney *U* tests.

The study was conducted following approval from the Lakehead University Research Ethics Board (REB; file #1471820) and after all participants provided written informed consent. Participants were informed that they could stop participating at any time without penalty and could request withdrawal of their collected data for up to four weeks after completing their final

session, before the data were de-identified and combined with the study dataset (World Medical Association, 2013).

Participants

An a priori power analysis conducted using G*Power 3.1.9.7, with an estimated interaction effect size of $f = .239$, $\alpha = .05$, and 80% power, indicated a required total sample of 38 participants (Appendix A). Forty participants were recruited and completed the study, comprising 20 males and 20 females. Participants were physically active adults aged 18–35 years, with physical activity status determined by self-reported engagement in at least 150 minutes of moderate-intensity or 75 minutes of vigorous-intensity aerobic physical activity per week for a minimum of three months. This age range was selected to represent a healthy, physically active adult population while minimizing the influence of age-related physiological changes on endurance performance (Joyner, 1993; Stathokostas et al., 2004). Height and body mass were measured to characterize the sample but were not included as covariates in the inferential analyses. Males were descriptively taller (181.0 ± 5.8 vs. 167.3 ± 5.5 cm) and heavier (80.4 ± 7.8 vs. 68.6 ± 8.5 kg) than females.

Participants were equally distributed between condition orders: 20 completed the control condition first, and 20 completed the menthol condition first. Participant characteristics are presented in Table 1.

Table 1

Participant Characteristics by Sex

Characteristic	M (n = 20)	F (n = 20)	Total (N = 40)
Age (years)	25.3 ± 3.4	23.7 ± 3.9	24.5 ± 3.7
Height (cm)	181.0 ± 5.8	167.3 ± 5.5	174.1 ± 8.9
Body mass (kg)	80.4 ± 7.8	68.6 ± 8.5	74.5 ± 10.0
Individualized resistance (kg)	1.9 ± 0.2	1.5 ± 0.3	1.7 ± 0.3

Note. Values are presented as mean ± SD. Body mass represents the mean of the measurements recorded during the control and menthol experimental sessions. Condition-specific normalized-distance values were calculated using the body mass recorded during the corresponding experimental session. M = male; F = female.

Inclusion Criteria

No participants were excluded by the Get Active Questionnaire (GAQ; Canadian Society for Exercise Physiology, 2017) and were cleared for participation. Participants were 18–35 years of age and reported engaging in at least 150 minutes of moderate-intensity aerobic physical activity or 75 minutes of vigorous-intensity aerobic physical activity per week for a minimum of three months (Crosby et al., 2022). All participants self-reported being free of injuries or medical conditions that would limit exercise performance. No specific sport or training background was required.

Exclusion Criteria

Exclusion criteria included a known allergy or sensitivity to menthol; cardiovascular, neurological, or orthopedic conditions that could limit safe participation; anosmia or dysgeusia; use of medications or supplements known to influence cardiovascular or perceptual responses to exercise; current smoking; and pregnancy (Barwood et al., 2020; Sadaka et al., 2021; Vogel et al., 2023). No enrolled participants met any of these exclusion criteria.

Recruitment

Participants were recruited through posters placed throughout the Lakehead University campus, including the C.J. Sanders Fieldhouse and School of Kinesiology facilities, as well as through electronic distribution of recruitment materials (e.g., social media). Interested individuals were asked to contact the student researcher via email to receive additional information and to schedule testing sessions. Email addresses were obtained only through participant-initiated contact in response to recruitment materials.

Instrumentation

All exercise trials were performed on a mechanically braked cycle ergometer (Monark 894E), which has demonstrated strong reliability for laboratory cycling time-trial protocols (Currell & Jeukendrup, 2008; Paton & Hopkins, 2001).

Rating of perceived exertion was assessed using Borg's Original RPE Scale (see Figure H1 in Appendix H), which has demonstrated strong construct validity and reliability for quantifying perceived exercise intensity across a range of workloads (Borg, 1970, 1982; Cabral et al., 2020; Scherr et al., 2012). Thermal sensation was evaluated using the nine-point ASHRAE

thermal sensation scale (see Figure H2 in Appendix H), ranging from very cold (-4) to very hot (+4), with 0 representing neutral thermal sensation. The scale has demonstrated acceptable reliability and sensitivity for assessing perceptual thermal responses during exercise (Flood et al., 2017; Zhang et al., 2004; Zolfaghari & Maerefat, 2011). Respiratory comfort was assessed using the Modified Borg Dyspnea Scale (see Figure H3 in Appendix H), with lower dyspnea ratings indicating greater perceived respiratory comfort. This scale has demonstrated validity and reliability for quantifying perceived breathlessness during physical exertion (Borg, 1982).

Heart rate (HR) was recorded continuously using a Polar H10 chest-strap monitor (Polar Electro Oy, Kempele, Finland) secured over the sternum. The Polar H10 has demonstrated excellent criterion validity compared with electrocardiography and high test-retest reliability during rest and exercise conditions (Gillinov et al., 2017). HR data were recorded using Polar Flow software, with calculated heart rate values available at 1-second intervals for analysis (Haddad et al., 2024; Currell & Jeukendrup, 2008; Plews et al., 2017).

Procedures

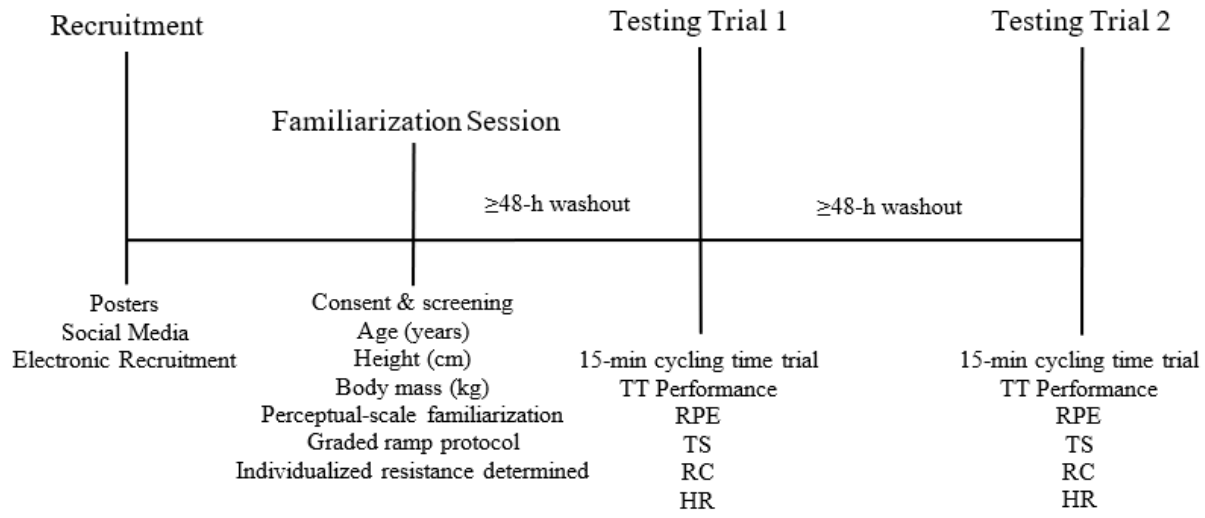
Design Overview

Participants were required to complete one familiarization session followed by two experimental sessions: control and menthol, completed in a pseudo-randomized, counterbalanced order. All sessions were conducted in room SB-1025 of the C.J. Sanders Fieldhouse and lasted approximately 45 minutes each, resulting in a total time commitment of approximately 2 hours and 15 minutes. A schematic overview of participant involvement across laboratory visits is presented in Figure 5. Each participant was tested at a consistent time of day (± 1 hour) to minimize circadian rhythm variation (Reilly, 1990). A sensory-matched placebo inhalation was

not included, given the difficulty of creating a true placebo that matches menthol's distinct sensory profile (Barwood et al., 2020). The control trial involved nasal inhalation at identical time points using an identical container that contained only air (Barwood et al., 2020).

Figure 5

Overview of Participant Involvement



Note. Overview of participant involvement across recruitment, familiarization, and the two experimental trials. The control and menthol conditions were completed in a pseudo-randomized, counterbalanced order with a minimum 48-hour washout period. RPE = rating of perceived exertion; TS = thermal sensation; RC = respiratory comfort; HR = heart rate.

Pre-Trial Procedures

Prior to the experimental sessions, participants were instructed to fast for two hours; refrain from strenuous physical activity and alcohol consumption for 24 hours; and avoid caffeine intake for 12 hours (Best et al., 2021; Gavel et al., 2024b; Mock et al., 2021). Participants were also instructed to avoid peppermint-containing products (such as gum or breath

mints) for two hours prior to testing to prevent residual menthol stimulation (Vogel et al., 2023). Body mass (kg) was measured at the beginning of each experimental trial under standardized conditions to account for day-to-day fluctuations and to support body-mass-normalized performance calculations (Armstrong et al., 2013). Participants were asked to report prior experience with menthol or nasal inhalants and recorded but were not included in the inferential analyses (Iftinca & Altier, 2020). They were also instructed to wear similar athletic clothing across sessions and maintain consistent hydration before each experimental session (Currell & Jeukendrup, 2008; Merrell et al., 2024).

Laboratory Conditions

All experimental sessions were conducted in the same laboratory, where a digital monitor displayed current, minimum, and maximum temperature and relative humidity. No external airflow was used during testing sessions. Across the data-collection period from June 4 to July 23, 2026, the monitor recorded temperatures ranging from 20.5°C to 30.8°C and relative humidity ranging from 31% to 77%. Testing sessions were not conducted when the displayed temperature exceeded 28°C. As session-specific conditions were not recorded, these values describe only the general laboratory environment and were not included in the statistical analyses.

Ergometer Setup

Prior to each trial, the ergometer was inspected to ensure consistent mechanical function (Paton & Hopkins, 2001). Seat height was adjusted so that the participant’s leg was nearly fully extended, with slight knee flexion, when the heel was placed on the pedal at its lowest point

(Holmes et al., 1994; see Figure 6). Participants were instructed to remain seated throughout the time trial (Paton & Hopkins, 2001). Upon arrival to the laboratory, participants completed the standardized pre–time-trial protocol consisting of 5 minutes of seated rest, a standardized warm-up, and baseline perceptual and physiological measurements collected in a 30-second window prior to the start of the time trial (see Figure 7).

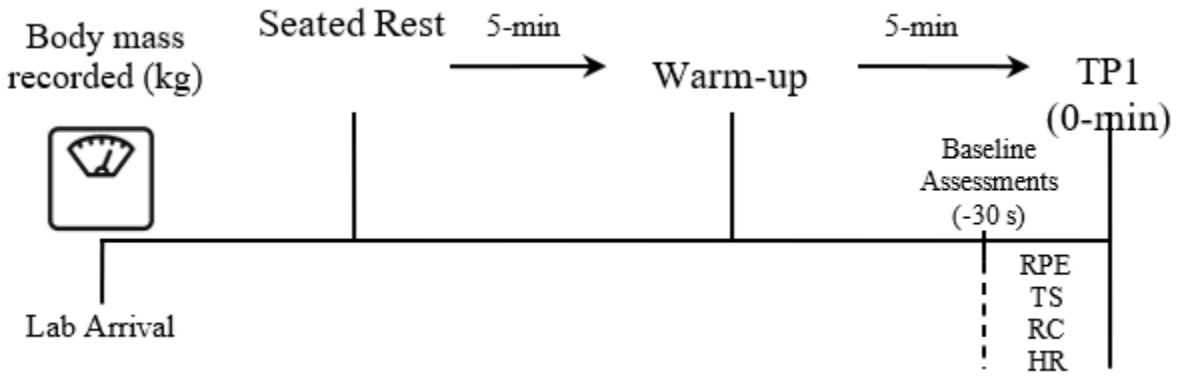
Figure 6

Cycle Ergometer Seat-Height Setup

Note. Representative cycle ergometer setup used during the familiarization and experimental sessions. Seat height was adjusted so that the participant's leg was nearly fully extended, with slight knee flexion, when the heel was positioned on the pedal at its lowest point.

Figure 7

Pre–Time-Trial Protocol



Note. Pre–time-trial protocol timeline. Participants completed 5 minutes of seated rest and a 5-minute standardized warm-up. Baseline perceptual measures and heart rate were collected during the 30 seconds immediately preceding the time trial (TP1, 0 minutes). RPE = rating of perceived exertion; TS = thermal sensation; RC = respiratory comfort; TP = time point.

Warm-Up Protocol

Participants completed the same standardized warm-up during the familiarization session and each experimental trial. The warm-up consisted of 5 minutes of cycling on a Monark 894E cycle ergometer (Monark, Varberg, Sweden) at a resistance of 1.5 kg and a cadence of 70 ± 5 rpm, corresponding to approximately 100 W at 70 rpm. The protocol was adapted from Barwood et al. (2015) to standardize physiological preparation, and cadence was visually monitored throughout.

Familiarization Session

Participants attended the familiarization session after reviewing and signing all required ethics forms. During this visit, demographic information, including age, height, and body mass, was collected, with height and body mass measured using a stadiometer (Tanita HR-200) and digital scale (Omron HBF-500), respectively.

The purpose of this session was to familiarize participants with the perceptual assessment scales (RPE, TS, RC) and to determine the individualized resistance to be used in subsequent experimental trials. Individualizing the workload reduced the likelihood that a fixed resistance would be disproportionately easy or difficult across participants (Currell & Jeukendrup, 2008; Laursen et al., 2007). To ensure consistent interpretation of the perceptual measures, participants received standardized verbal instructions describing the purpose, scale range, and verbal descriptors associated with each perceptual scale. Rating of perceived exertion (RPE; Borg's Original RPE Scale) was described as a measure of overall whole-body effort. Thermal sensation (TS; ASHRAE 9-point scale) was described as a measure of overall thermal perception. Respiratory comfort (RC; Modified Borg Dyspnea Scale) was described as a measure of breathing discomfort. Participants were provided with visual copies of each scale and completed brief practice ratings throughout the warm-up and familiarization trial to reinforce understanding. A standardized instruction script was used for all participants and is provided in Appendix H.

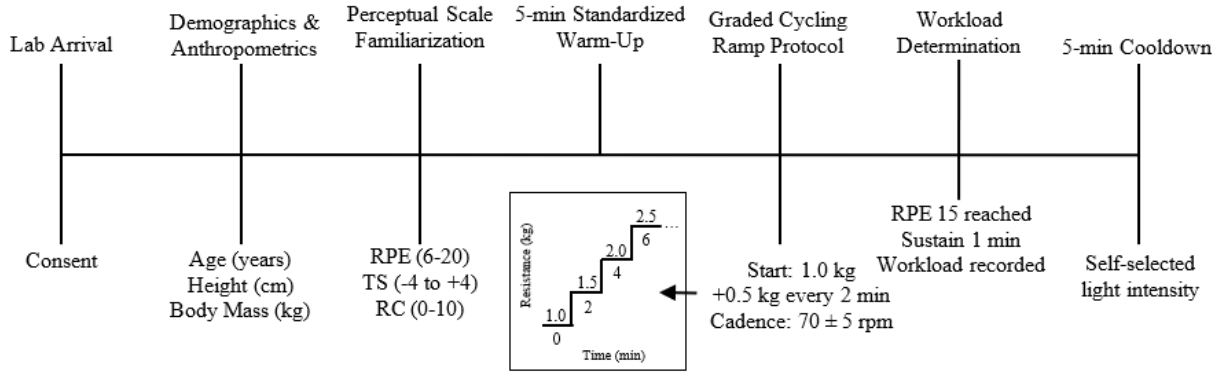
Participants completed the standardized warm-up described previously, followed by standardized instructions regarding perceptual assessments. A standardized study-specific graded cycling ramp protocol was then performed. Resistance began at 1.0 kg and increased by 0.5 kg every two minutes while participants maintained a cadence of 70 ± 5 rpm. The protocol continued until an RPE of 15 was reached and sustained for an additional minute (Bentley et al.,

2007; Borg, 1982). The resistance corresponding to RPE 15 was recorded and used as the fixed workload for both subsequent experimental trials. An RPE of 15 was selected to approximate a hard but sustainable intensity, representative of effort levels typically maintained during a 15-minute self-paced time trial (Gaskill et al., 2023). The graded cycling ramp protocol lasted 10–15 minutes, depending on the participant's fitness level and the workload at which an RPE of 15 was obtained. This protocol was a submaximal task and was not intended to induce volitional exhaustion. The familiarization session occurred on a separate day from the experimental trials to minimize residual fatigue and prevent it from influencing subsequent performance. The sequence of procedures performed during the familiarization session is illustrated in Figure 8.

The session concluded with a 5-minute self-paced cooldown at a light intensity (Riebe et al., 2018). No nasal inhalation was administered during the familiarization session. Participants completed practice perceptual ratings to reduce potential learning effects and standardize scale administration; however, these responses were not recorded or included in the statistical analyses. The familiarization session was separated from the first experimental trial by at least 48 hours to minimize residual fatigue effects (Jeffries & Waldron, 2019; Stevens & Best, 2017).

Figure 8

Familiarization Session Protocol



Note. Familiarization session timeline. Individualized resistance was determined using a graded cycling ramp beginning at 1.0 kg and increasing by 0.5 kg every 2 minutes at 70 ± 5 rpm until an RPE of 15 was reached and sustained for 1 minute. The corresponding resistance was used during both experimental trials. RPE = rating of perceived exertion; TS = thermal sensation; RC = respiratory comfort.

Experimental Trials

Each experimental visit began with the same warm-up protocol used during the familiarization session, followed by baseline perceptual assessments (Barwood et al., 2015; Malik et al., 1996). The individualized resistance determined during familiarization was used as a fixed workload for both experimental trials, during which participants completed a 15-minute self-paced cycling time trial (Bentley et al., 2007; Borg, 1982). Participants were permitted to freely adjust their cadence to maximize total distance covered; however, they were blinded to elapsed time, distance, and cadence, with the ergometer display covered throughout the time trial to prevent pacing based on external performance feedback (Paton & Hopkins, 2001).

Inhalant administration occurred at the onset of the time trial (0 minutes), and again at 5

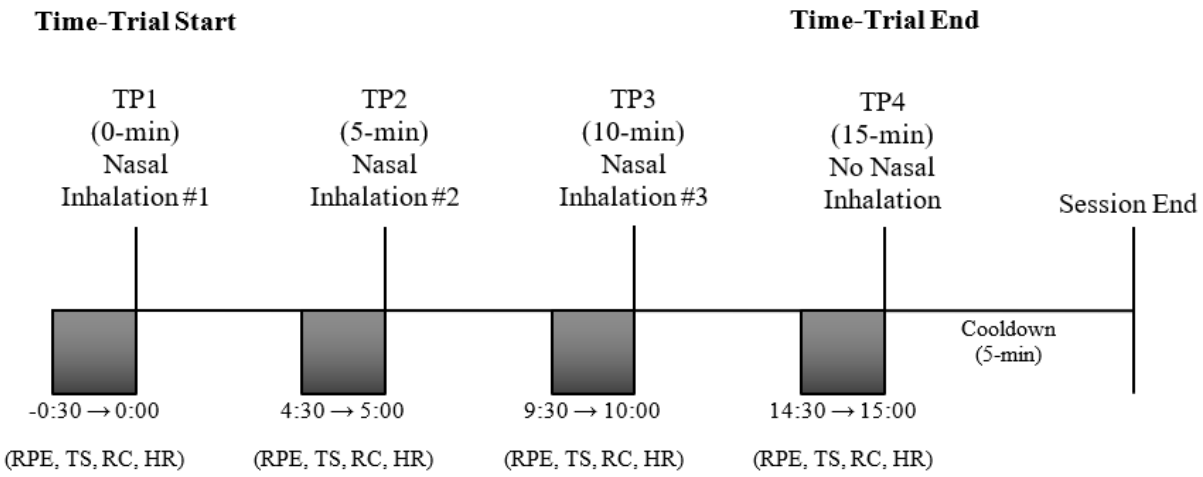
and 10 minutes during each trial. Perceptual measures (RPE, TS, RC) were assessed immediately prior to the inhalant administration at the onset of the time trial and during a 30-second assessment window occurring prior to the 5-, 10-, and 15-min time points (4:30–5:00, 9:30–10:00, and 14:30–15:00 minutes). Each perceptual scale was presented for approximately 10 seconds within this window, resulting in a total assessment duration of 30 seconds. Assessments were completed while participants continued cycling to minimize disruption to pacing. At each time point, visual copies of the perceptual scales (see Figures H1–H3 in Appendix H) were presented to participants, who verbally reported the numerical value corresponding to their current perception. The investigator recorded each response immediately. The sequence and timing of assessments and inhalant administration during the experimental time trial are illustrated in Figure 9.

Heart rate was continuously monitored using the Polar H10, which provided calculated heart rate values at 1-second intervals. Heart rate was summarized as the mean of the 30-second interval preceding each assessment time point (0, 5, 10, and 15 minutes). Nasal inhalation followed the assessments at 0, 5, and 10 minutes only. Perceptual variables (RPE, TS, and RC) were assessed before each inhalation so that responses were not influenced by the acute exposure.

Each trial concluded with a 5-minute self-paced cooldown at a self-selected “light” intensity (Riebe et al., 2018). Experimental trials were separated by a minimum 48-hour washout period to minimize potential carryover effects between conditions (Jeffries & Waldron, 2019; Stevens & Best, 2017).

Figure 9

Experimental Time-Trial Protocol



Note. Experimental time-trial protocol. Perceptual measures and heart rate were assessed during the 30 seconds preceding TP1–TP4. A 5-second nasal inhalation followed assessments at 0, 5, and 10 minutes; no inhalation occurred at 15 minutes. The trial concluded with a 5-minute self-paced cooldown. RPE = rating of perceived exertion; TS = thermal sensation; RC = respiratory comfort; TP = time point.

Inhalant Administration Procedures

During the menthol condition, participants were exposed to vapour generated from 5 g of L-menthol crystals for 5 seconds at three standardized time points (0, 5, and 10 minutes) during the 15-minute self-paced time trial (Eccles et al., 1988; Lindemann et al., 2008). L-menthol crystals (≥99% purity; Mentha arvensis-derived; commercially sourced) were used as the stimulus agent. Repeated, short-duration menthol exposures at fixed intervals have been employed in previous exercise studies, particularly in oral administration protocols lasting 10–20 minutes, to sustain perceptual cooling throughout prolonged efforts (Barwood et al., 2020;

Jeffries et al., 2018; Stevens & Best, 2017; Stevens et al., 2016). The selected administration time points (0, 5, and 10 minutes) were chosen to provide repeated, evenly spaced perceptual stimulation across the 15-minute time trial while minimizing disruption to pacing. Given that the perceptual effects of menthol may diminish during continued exercise (Roriz et al., 2024), intermittent re-administration every five minutes was selected to maintain perceptual stimulation throughout the time trial.

Menthol was administered using a refillable nasal inhaler device consisting of an amber glass vial fitted with a screw cap and nasal attachment to standardize vapour exposure while preventing visual identification of the contents (see Figure 10). The reservoir contained 5 g of L-menthol crystals and remained sealed between administrations to ensure consistent vapour availability and minimize unintended dissipation. During each administration, the researcher positioned the nasal attachment below but not touching the participant's nostrils to avoid direct contact with the nasal mucosa, which may independently influence trigeminal sensory responses (Hur et al., 2017; see Figure 11). Participants were instructed to breathe normally and to avoid deep or forceful inhalation during each 5-second exposure (Lindemann et al., 2008; Stevens & Best, 2017). These instructions were intended to reduce variability in inspiratory flow; however, inhaled volume and vapour concentration were not measured.

During the control condition, inhalation procedures were identical in timing and positioning; however, the inhaler device contained no menthol crystals. Separate inhaler devices were used for the menthol and control conditions to prevent residual odour contamination. To minimize cross-participant contamination risk, each inhaler device was stored in a sealed plastic bag between uses and the external surfaces were cleaned and disinfected between participants.

Figure 10

Inhalant Apparatus

Note. The inhalation apparatus used for menthol and control administration consisted of an amber glass vial fitted with a detachable nasal inhaler attachment.

Figure 11

Nasal Inhalant Apparatus Positioning

Note. Representative positioning of the nasal attachment during menthol and control administration. The attachment was positioned directly below, but did not contact, the participant's nostrils.

Data Processing

Time-trial distance was recorded as the total distance covered during each 15-minute self-paced cycling time trial. Distance normalized to body mass was calculated separately for each condition by dividing the total distance covered during that trial (m) by the body mass (kg), recorded during the corresponding experimental session, producing a value expressed as $m \cdot kg^{-1}$. For perceptual variables, ratings of perceived exertion, thermal sensation, and respiratory comfort were recorded at 0, 5, 10, and 15 minutes during each experimental trial. For statistical analysis, time-trial average values were calculated using the mean of the 5-, 10-, and 15-minute values. The 0-minute values were treated as baseline measurements and excluded from TT-average calculations and inferential analyses. Heart rate was continuously monitored and recorded at 1-second intervals. For each assessment time point (5, 10, and 15 minutes), the mean HR during the preceding 30 seconds was calculated. These three 30-second mean HR values were then averaged to produce a single time-trial average HR value for each experimental condition.

Variables and Outcome Measures

Independent Variables

The independent variables were nasal inhalation condition and sex, which were of equal interest in the present study. Condition consisted of control (air inhalation) and menthol (L-menthol inhalation) and was treated as a within-subjects factor. Sex (assigned at birth) was self-reported during screening, categorized as male or female for analysis, and treated as a between-subjects factor.

Dependent Variables

The dependent variables were organized into three domains of equal interest: performance, perceptual responses, and physiological responses.

Performance outcomes included total distance covered (m) during the 15-minute self-paced cycling time trial and distance normalized to body mass ($m \cdot kg^{-1}$) (Currell & Jeukendrup, 2008; Kappus et al., 2015; Paton & Hopkins, 2001; Santana et al., 2024). Perceptual outcomes included rating of perceived exertion (RPE), thermal sensation (TS), and respiratory comfort (RC). RPE was assessed using Borg's Original RPE Scale (Borg, 1982; Chen et al., 2002), TS using the nine-point ASHRAE thermal sensation scale (Schlader et al., 2011; Zolfaghari & Maerefat, 2011), and RC using the Modified Borg Dyspnea Scale, with lower scores indicating less respiratory discomfort (Mahler & Horowitz, 1994; Wilson & Jones, 1989). The physiological outcome was heart rate (HR), quantified as the 30-second mean immediately preceding each assessment time point. For RPE, TS, RC, and HR, a time-trial average was calculated as the mean of the 5-, 10-, and 15-minute values. The 0-minute values were treated as baseline measurements and excluded from time-trial average calculations and inferential analyses.

Statistical Analysis

All statistical analyses were conducted using IBM SPSS Statistics (Version 31; IBM Corp., Armonk, NY). Descriptive statistics were calculated for all variables of interest and reported as mean ± standard deviation, including participant characteristics and study outcomes.

The dependent variables were analysed according to their measurement characteristics within the three domains of performance, perceptual responses, and physiological responses.

Separate 2 × 2 mixed-design ANOVAs were conducted for total distance (m), distance normalized to body mass ($m \cdot kg^{-1}$), and time-trial average heart rate, with Condition (control, menthol) as the within-subjects factor and Sex (male, female) as the between-subjects factor. Time-trial average rating of perceived exertion, thermal sensation, and respiratory comfort were analysed using nonparametric procedures because these outcomes were derived from ordinal rating scales. Wilcoxon signed-rank tests were used to compare the control and menthol conditions across the full sample. To determine whether condition-related changes differed between males and females, Menthol − Control difference scores for RPE, thermal sensation, and respiratory comfort were compared between sexes using Mann–Whitney U tests.

Statistical significance was set at $\alpha = .05$ for all analyses. For the mixed-design ANOVAs, significant Condition × Sex interactions were followed by simple-effects comparisons. No family-wise adjustment was applied across the separate outcome analyses. Accordingly, results were interpreted within their respective performance, perceptual, and physiological domains, with consideration given to the number of statistical tests conducted. Effect sizes were reported as partial eta squared (ηp^2) for ANOVA effects, and mean differences were reported with 95% confidence intervals for follow-up comparisons. For the ANOVA outcomes, assumptions of normality were evaluated using Shapiro–Wilk tests and visual inspection of Q–Q plots of the condition difference scores, and homogeneity of variance was assessed using Levene's test. Potential outliers were identified using boxplots of the condition difference scores, with values falling more than 1.5 times the interquartile range below the first quartile or above the third quartile classified as potential outliers. Data were screened for missing values prior to analysis, and missing data were handled using listwise deletion.

Chapter Three: Results

Assumption Checks and Data Screening

Prior to inferential analysis, the dataset was screened for missing values, data-entry errors, outliers, and violations of the assumptions underlying the intended analyses. No missing values or out-of-range observations were identified; therefore, all 40 participants were retained for analysis. Condition difference scores for total distance, normalized distance, rating of perceived exertion (RPE), thermal sensation (TS), respiratory comfort (RC), and heart rate (HR) were available for all participants.

Outlier Screening

Potential outliers were assessed using boxplots of the condition difference scores. Values falling more than 1.5 times the interquartile range (IQR) below the first quartile or above the third quartile were classified as potential outliers, whereas values exceeding 3 times the IQR were classified as extreme outliers. Several observations met the 1.5-IQR criterion for potential outliers; however, no observations met the 3-IQR criterion for extreme outliers. All flagged observations were retained after confirming that they represented plausible individual responses and did not reflect data-entry or measurement errors (Aguinis et al., 2013).

Normality

Normality was assessed separately for males and females using Shapiro–Wilk tests and visual inspection of histograms and normal Q–Q plots for the continuous outcomes analysed using mixed-design ANOVA. Significant Shapiro–Wilk tests were observed for total distance among females, $W = .866$, $p = .010$, and HR among males, $W = .895$, $p = .033$. The remaining

continuous-outcome difference-score distributions did not significantly depart from normality ($p > .05$). Visual inspection of the corresponding histograms and Q–Q plots indicated that the departures were not sufficiently severe to preclude the intended ANOVAs. Given the absence of extreme outliers, the equal group sizes, and the relative robustness of the mixed-design ANOVA to modest violations of normality, these analyses were retained.

Homogeneity of Variance

Homogeneity of variance between males and females was assessed using Levene's tests for the continuous outcomes analysed using mixed-design ANOVA. Levene's tests conducted on the condition difference scores were nonsignificant for total distance, normalized distance, and HR, indicating that the variability in the condition effects was comparable between sexes. When homogeneity of variance was also examined separately for the control and menthol condition scores, the assumption was satisfied for all continuous outcomes except control-condition normalized distance, for which Levene's test was significant, $F(1, 38) = 5.30$, $p = .027$. The corresponding test for menthol condition normalized distance approached, but did not reach significance, $F(1, 38) = 3.87$, $p = .056$. Given the equal group sizes and homogeneous difference-score variance, the normalized-distance mixed-design ANOVA was retained and interpreted with appropriate caution. Overall, the screening procedures indicated that the continuous outcomes were suitable for the intended 2 × 2 mixed-design ANOVAs, while the ordinal perceptual outcomes were analysed using the intended nonparametric procedures. No participants were excluded from the analyses.

Performance Responses

Descriptive statistics for total and body-mass-normalized time-trial distance by condition and sex are presented in Table 2.

Table 2

Time-Trial Performance by Condition and Sex

Outcome	Group	Control	Menthol
Total distance (m)	Male	5786 ± 518	5802 ± 585
	Female	5094 ± 568	5246 ± 603
	All participants	5440 ± 641	5524 ± 650
Normalized distance ($m \cdot kg^{-1}$)	Male	72.4 ± 7.9	72.6 ± 8.4
	Female	75.3 ± 11.7	77.4 ± 11.7
	All participants	73.9 ± 10.0	75.0 ± 10.3

Note. Values are presented as mean ± standard deviation. Menthol and control refer to the experimental nasal inhalation conditions.

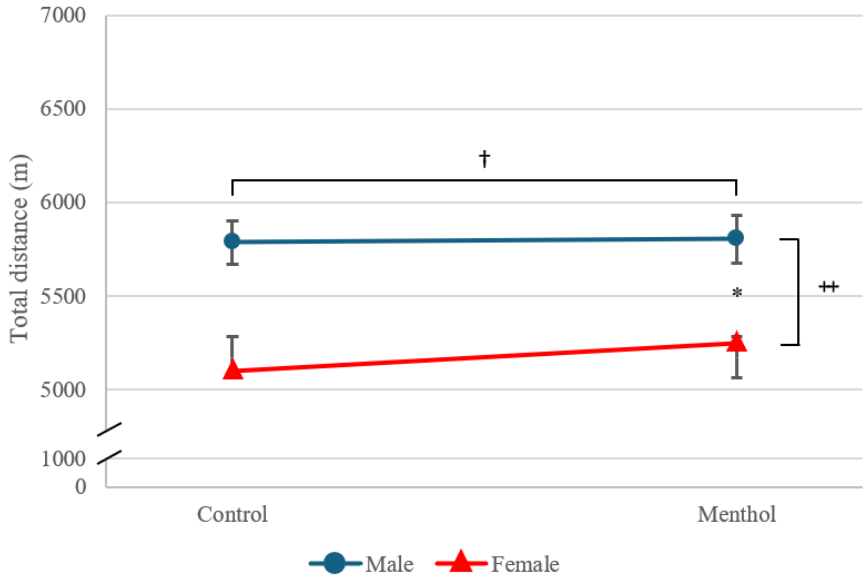
Total Time-Trial Distance

The Condition × Sex interaction for total distance was significant, $F(1, 38) = 5.02$, $p = .031$, $\eta p^2 = .117$ (Figure 12). Simple-effects comparisons showed that females covered significantly more distance during menthol than control, with a mean difference of 153 m ($p = .001$, 95% CI [65, 240]), whereas the 16-m difference between conditions among males was not significant ($p = .712$, 95% CI [−71, 104]). The main effect of Condition was also significant, $F(1, 38) = 7.65$, $p = .009$, $\eta p^2 = .168$, with participants covering an estimated 84 m more during

menthol, 95% CI [23, 146]. The main effect of Sex was significant, $F(1, 38) = 12.35$, $p = .001$, $\eta p^2 = .245$, with males covering a greater absolute distance than females when averaged across conditions.

Figure 12

Total Time-Trial Distance by Condition and Sex



Note. Values are mean ± SEM. † indicates a significant main effect of Condition, $p = .009$. ‡ indicates a significant main effect of Sex, $p = .001$. * indicates a significant Condition × Sex interaction, $p = .031$.

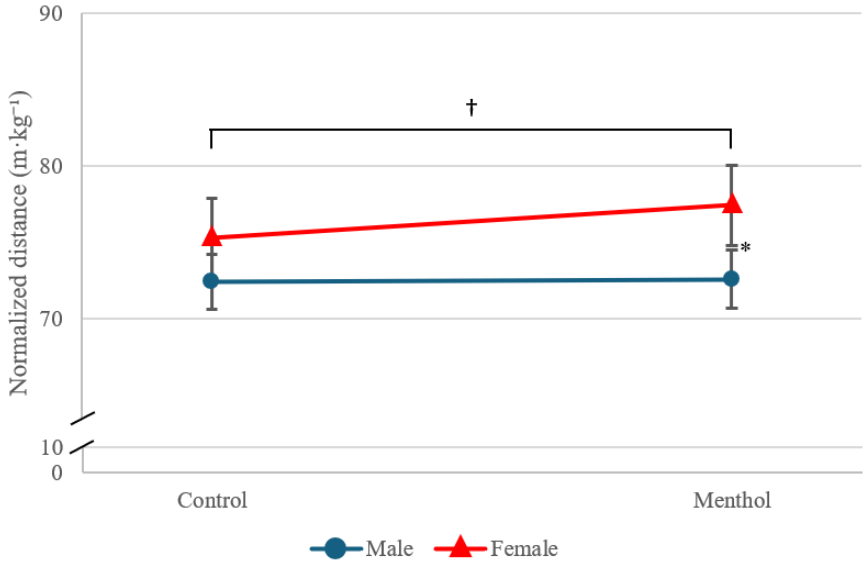
Normalized Time-Trial Performance

The Condition × Sex interaction for normalized distance was significant, $F(1, 38) = 5.47$, $p = .025$, $\eta p^2 = .126$ (Figure 13). Simple-effects comparisons showed that females achieved a significantly greater normalized distance during menthol than control, with a mean difference of 2.2 $m \cdot kg^{-1}$, $p < .001$, 95% CI [1.0, 3.4], whereas the 0.2 $m \cdot kg^{-1}$ difference among males was not

significant, $p = .767$, 95% CI [−1.0, 1.4]. The main effect of Condition was significant, $F(1, 38) = 7.63$, $p = .009$, $\eta_p^2 = .167$, with participants achieving an estimated 1.2 $m \cdot kg^{-1}$ greater normalized distance during menthol, 95% CI [0.3, 2.0]. The main effect of Sex was not significant, $F(1, 38) = 1.47$, $p = .233$, $\eta p^2 = .037$.

Figure 13

Normalized Time-Trial Distance by Condition and Sex



Note. Values are mean ± SEM. † indicates a significant main effect of Condition, $p = .009$. * indicates a significant Condition × Sex interaction, $p = .025$.

Perceptual Responses

Descriptive statistics for the perceptual and physiological outcomes by condition and sex are presented in Table 3.

Table 3

Perceptual and Physiological Responses by Condition and Sex (Mean ± SD)

Outcome	Group	Control	Menthol
RPE	Male	15.0 ± 0.9	14.8 ± 1.1
	Female	15.1 ± 0.9	14.9 ± 1.1
	All participants	15.1 ± 0.9	14.9 ± 1.1
TS	Male	2.2 ± 0.4	2.2 ± 1.0
	Female	2.5 ± 0.3	1.6 ± 1.0
	All participants	2.3 ± 0.4	1.9 ± 1.0
RC	Male	4.9 ± 1.1	4.9 ± 1.3
	Female	4.7 ± 1.0	4.2 ± 1.2
	All participants	4.8 ± 1.1	4.5 ± 1.3
HR (bpm)	Male	156.9 ± 3.8	158.2 ± 4.3
	Female	158.5 ± 4.7	159.2 ± 5.4
	All participants	157.7 ± 4.3	158.7 ± 4.8
HR (% predicted HRmax)	Male	82.5 ± 2.2	83.1 ± 2.4
	Female	82.8 ± 2.8	83.2 ± 3.0
	All participants	82.6 ± 2.5	83.2 ± 2.7

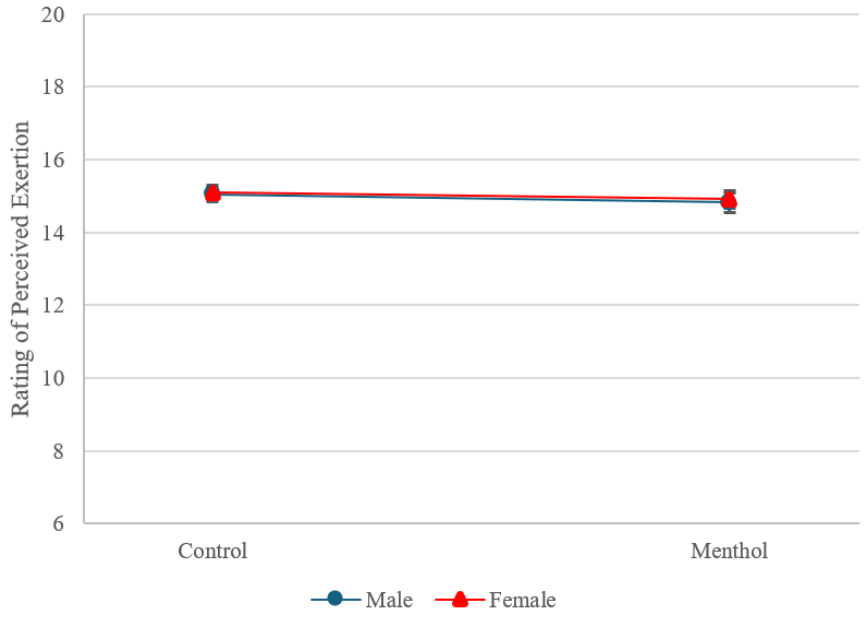
Note. RPE, TS, RC, and HR values represent time-trial averages calculated across the 5-, 10-, and 15-minute time points. Values are presented as mean ± SD. Lower TS scores indicate feeling cooler, whereas lower RC scores indicate less respiratory discomfort. Age-predicted maximal heart rate (HRmax) was estimated using the equation $208 - (0.7 \times \text{age})$ (Tanaka et al., 2001). RPE = rating of perceived exertion; TS = thermal sensation; RC = respiratory comfort; HR = heart rate.

Ratings of Perceived Exertion

A Wilcoxon signed-rank test indicated that time-trial average RPE did not differ significantly between the menthol and control conditions ($Z = -1.92$, $p = .054$; Figure 14). The condition-related change in RPE did not differ significantly between males and females based on the Mann–Whitney U test ($U = 196.5$, $Z = -0.10$, $p = .924$).

Figure 14

Ratings of Perceived Exertion by Condition and Sex



Note. Values are mean ± SEM.

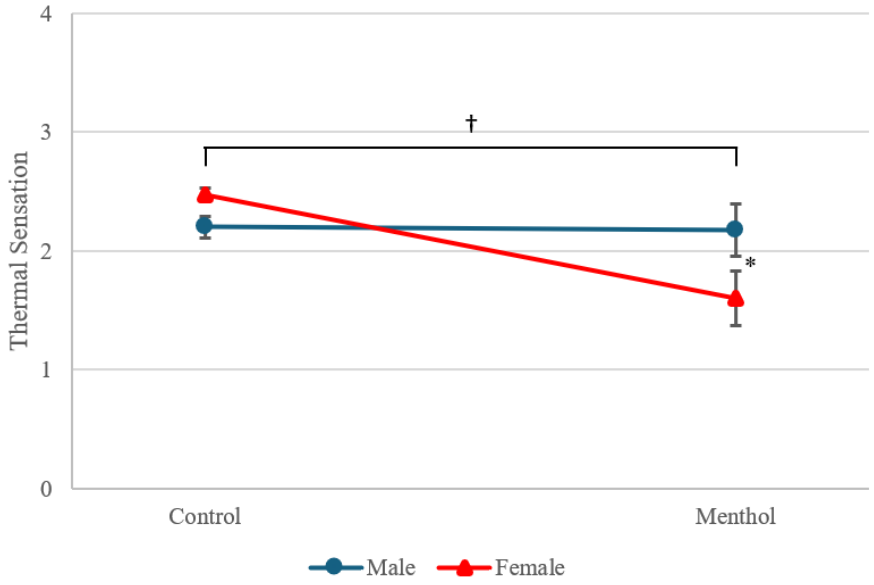
Thermal Sensation

A Wilcoxon signed-rank test indicated that time-trial average thermal sensation was significantly lower during the menthol condition than during the control condition ($Z = -2.19$, p

= .029; Figure 15). The condition-related change in thermal sensation also differed significantly between males and females based on the Mann–Whitney *U* test (*U* = 124.0, *Z* = −2.06, *p* = .039).

Figure 15

Thermal Sensation by Condition and Sex



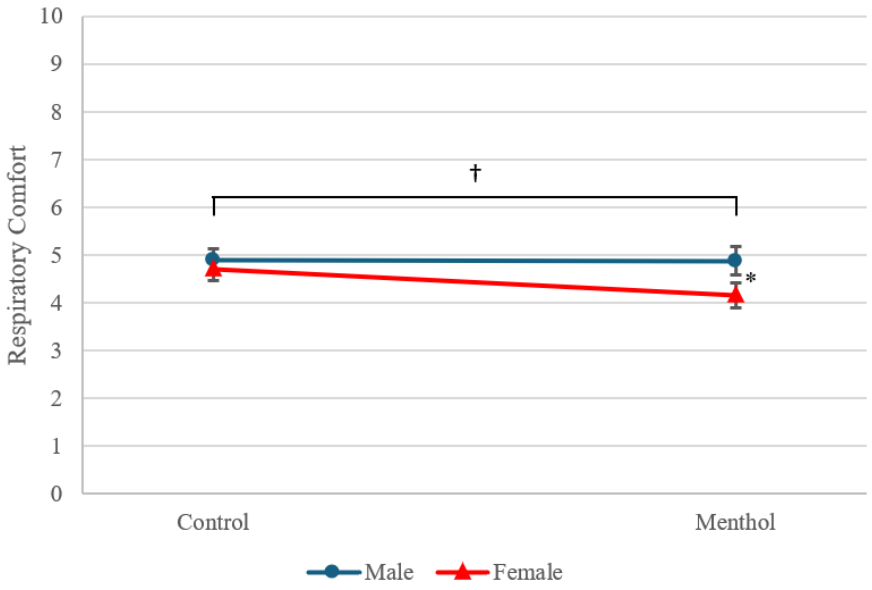
Note. Values are mean ± SEM. Lower scores indicate cooler thermal sensation. † indicates a significant difference between conditions, *p* = .029. * indicates that the condition-related change differed significantly between males and females, *p* = .039.

Respiratory Comfort

A Wilcoxon signed-rank test indicated that time-trial average respiratory comfort scores were significantly lower during the menthol condition than during the control condition, reflecting greater respiratory comfort (*Z* = −2.05, *p* = .041; Figure 16). The condition-related change in respiratory comfort also differed significantly between males and females based on the Mann–Whitney *U* test (*U* = 117.0, *Z* = −2.26, *p* = .024).

Figure 16

Respiratory Comfort by Condition and Sex



Note. Values are mean ± SEM. Lower scores indicate less respiratory discomfort and therefore greater respiratory comfort. † indicates a significant difference between conditions, $p = .041$. * indicates that the condition-related change differed significantly between males and females, $p = .024$.

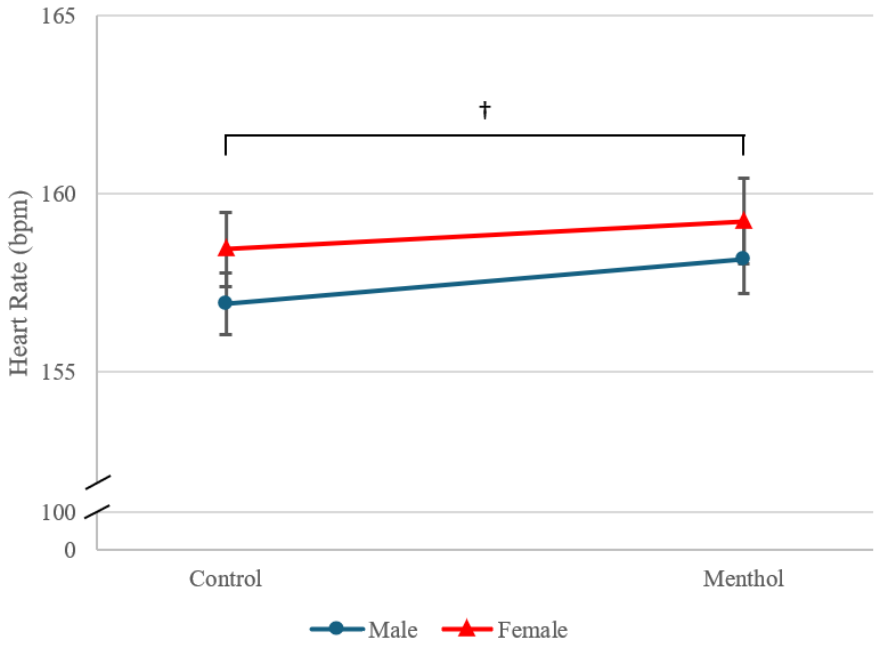
Physiological Responses

Heart Rate

The Condition × Sex interaction for heart rate was not significant, $F(1, 38) = 0.32$, $p = .576$, $\eta p^2 = .008$. The main effect of Condition was significant, $F(1, 38) = 6.39$, $p = .016$, $\eta p^2 = .144$, with heart rate averaging 1.0 bpm higher during menthol, 95% CI [0.20, 1.82] (Figure 17). The main effect of Sex was not significant, $F(1, 38) = 0.86$, $p = .359$, $\eta p^2 = .022$.

Figure 17

Heart Rate by Condition and Sex



Note. Values are mean ± SEM. † indicates a significant main effect of Condition, $p = .016$.

Chapter Four: Discussion

Overview and Main Findings

The purpose of this study was to determine the effects of menthol nasal inhalation and sex on performance, perceptual, and physiological responses during self-paced cycling. Menthol improved absolute and body-mass-normalized performance, lowered thermal sensation and respiratory discomfort, and increased mean heart rate, whereas RPE did not differ significantly between conditions. Performance improvements and changes in thermal sensation and respiratory comfort were larger among females, while RPE and heart rate responses did not differ by sex.

These findings are notable because females have been underrepresented in previous menthol-exercise research; a systematic review and meta-analysis of menthol mouth-rinsing studies included 153 participants, of whom only 38 were female, limiting previous conclusions regarding sex-based differences (Gavel et al., 2024a). By recruiting equal numbers of males and females and balancing condition order within each sex, the present study addressed an important limitation of the existing literature. The study was not designed to identify the biological mechanisms responsible for the observed sex-related differences, so the mechanisms underlying these findings remain uncertain.

Effects of Menthol Nasal Inhalation and Sex on Performance

Menthol nasal inhalation improved both absolute and body-mass-normalized time-trial performance, supporting the performance hypothesis. With trial duration and individualized resistance held constant between conditions, the greater distance covered suggests that participants selected a greater overall cycling work rate during the menthol trial.

Significant Condition × Sex interactions were observed for both performance outcomes, driven by improvements among females, with no significant condition differences among males, consistent with the hypothesized sex-related difference in the performance response. Their performance improvement occurred alongside larger changes in thermal sensation and respiratory comfort, whereas the heart rate response did not differ significantly by sex. This pattern is consistent with larger menthol-related changes in selected perceptual responses among females, although the present design cannot establish whether these changes caused the larger performance improvement.

These findings should be interpreted alongside previous meta-analytic evidence on menthol mouth rinsing rather than nasal inhalation. In a systematic review and meta-analysis of 10 menthol mouth-rinse studies, the overall effect on exercise performance and capacity was not statistically significant, although the authors suggested that endurance exercise may be more likely to benefit from menthol mouth rinsing (Gavel et al., 2024a). Much of the existing exercise literature has also been conducted in exclusively or predominantly male samples, particularly in studies examining oral and topical menthol administration (Jeffries & Waldron, 2019; Stevens & Best, 2017). Accordingly, the available evidence remains limited with respect to both administration route and sex-based responses.

Oral menthol administration has produced the most consistent performance benefits, whereas topical application has yielded mixed findings (Jeffries & Waldron, 2019; Stevens & Best, 2017). By comparison, nasal inhalation has remained underexplored, with previous studies focusing primarily on perceived nasal airflow and respiratory discomfort at rest or under respiratory loading, or on exercise responses in clinical populations such as adults with COPD, rather than self-paced endurance performance in healthy adults (Eccles et al., 1988; Lindemann

et al., 2008; Schaeffer et al., 2025; Zhao et al., 2011). The present study therefore extends this literature by examining repeated menthol nasal inhalation during self-paced cycling in a balanced sample of physically active males and females. As the previous meta-analysis concerned oral rinsing rather than nasal inhalation, the present findings provide route-specific evidence that repeated menthol nasal inhalation can improve self-paced cycling performance under the conditions tested.

Repeated administration was a defining feature of the present protocol. Menthol was administered at the onset of the time trial and again at 5 and 10 minutes, providing repeated exposure throughout the 15-minute trial. Menthol's perceptual effects may diminish within 10–15 minutes, and intermittent re-exposure has therefore been proposed as a strategy for sustaining perceptual stimulation during endurance exercise (Stevens et al., 2016; Stevens & Best, 2017). Repeated menthol administration has been used in endurance protocols lasting approximately 23–25 minutes; however, differences in administration route, concentration, timing, and exercise modality limit direct comparison across studies (Flood et al., 2017; Stevens et al., 2016). The present study did not directly measure the duration of the sensory response or compare repeated administration with a single pre-exercise exposure.

Participants covered approximately 84 m more during the menthol condition than during the control condition, representing an improvement of approximately 1.5% relative to the control condition mean. This improvement occurred without changes to the prescribed resistance or trial duration. Normalizing distance to body mass produced a similar condition effect, suggesting that the overall improvement was not simply attributable to differences in body size between participants.

The approximately 1.5% improvement in time-trial performance should not be projected proportionally to longer-duration or real-world events. Pacing decisions, substrate use, fatigue development, hydration, and environmental exposure change as exercise duration increases, and the duration of menthol's sensory effect may also become more important (Abbiss & Laursen, 2008; Stevens & Best, 2017). The present result therefore provides evidence of a performance benefit under the 15-minute protocol but does not indicate whether a similar relative benefit would persist during longer endurance exercise.

Effects of Menthol Nasal Inhalation and Sex on Perceptual Responses

Menthol nasal inhalation significantly lowered thermal sensation and respiratory comfort scores, indicating cooler thermal sensations and less respiratory discomfort, whereas the reduction in RPE did not reach statistical significance. Within the Psychobiological Model of Endurance Performance, perceived effort and discomfort contribute to pacing decisions and exercise tolerance (Marcora, 2008; Pageaux, 2014). Cooler thermal sensations and less respiratory discomfort may therefore reduce the sensory burden of exercise and alter how discomfort-related information is integrated into self-selected pacing (Marcora, 2008; Pageaux, 2014). This interpretation is also consistent with attentional-focus accounts, whereby the cooling and airflow sensations produced by menthol may redirect attention away from fatigue-related cues and reduce their prominence during exercise (Bigliassi, 2015). Together, the perceptual findings provide a plausible mechanism through which nasal menthol may have influenced self-selected performance during the time trial.

RPE was descriptively lower during the menthol condition, although the magnitude of the difference was small and did not reach statistical significance. RPE represents the conscious

sensation of effort and is considered an important determinant of pacing and exercise tolerance during self-paced endurance exercise (Marcora, 2008; Pageaux, 2014). Previous menthol research has reported reductions in perceived exertion, although the magnitude and consistency of these effects vary with administration route and exercise setting. Mündel and Jones (2010) reported lower perceived exertion during exercise in the heat following an oral menthol rinse, while Flood et al. (2017) found that oral L-menthol enabled a higher work rate and longer exercise tolerance at a fixed RPE. Stevens et al. (2016) likewise reported improved running performance alongside lower thermal sensation and perceived exertion with repeated menthol mouth rinsing. Menthol-related cooling sensations may reduce the prominence of discomfort-related sensory information or redirect attention away from fatigue-related cues (Barwood et al., 2020; Bigliassi, 2015). The descriptive reduction in RPE occurred alongside improved performance, and the condition-related change did not differ significantly between males and females.

Thermal sensation was also significantly lower during menthol exposure, indicating that participants felt cooler despite no intervention intended to reduce core or skin temperature. The lower thermal sensation during the menthol condition may be attributed to menthol-mediated activation of TRPM8 receptors, which produces a cooling sensation through afferent sensory signalling without necessarily changing core or skin temperature (Barwood et al., 2020; Iftinca & Altier, 2020; Kamatou et al., 2013; Stevens & Best, 2017). As thermal discomfort can influence pacing and exercise tolerance, the cooler sensation may have contributed to participants selecting a greater overall work rate during the menthol trial (Pageaux, 2014; Stevens et al., 2018).

Several factors may explain why females experienced larger changes in thermal sensation. Previous research indicates that females may perceive equivalent thermal

environments as hotter, less comfortable, or more unpleasant than males, although these differences vary according to environmental conditions, exercise intensity, body composition, and measurement method (Schoech et al., 2021). Sex-related differences in responses to menthol have also been reported. Parton et al. (2021) found that oral menthol lowered thermal sensation in both males and females during fixed-RPE exercise in the heat; however, the reduction was maintained for only part of the trial among females, while only males significantly increased power output. In the present study, the higher thermal sensation score in the control-condition among females provided greater potential for a reduction, and menthol-induced cooling may have changed the appraisal of thermal discomfort more strongly in that group. Differences in TRPM8-mediated sensory sensitivity or in attention to the cooling stimulus are also plausible, but these explanations remain provisional because skin temperature, core temperature, sweat rate, and sensory sensitivity were not measured.

The lower thermal sensation scores therefore likely reflect altered sensory appraisal rather than physiological cooling; direct temperature measurements would be required to distinguish these possibilities. Interpretation of the thermal sensation findings is also limited by the broad range of laboratory temperature and relative humidity observed across the data-collection period (20.5–30.8°C and 31–77%, respectively). As session-specific environmental conditions were not recorded, it is not possible to determine whether differences in laboratory conditions contributed to individual thermal sensation responses.

Respiratory comfort scores were also lower during menthol, indicating less breathing discomfort. Nasal menthol exposure can enhance the sensation of airflow and nasal patency through stimulation of trigeminal sensory pathways, even when nasal resistance and pulmonary function remain unchanged (Eccles et al., 1988; Lindemann et al., 2008; Zhao et al., 2011). The

improvement observed in the present study therefore likely reflects a perceptual change in breathing sensation rather than a direct improvement in airway mechanics. This sensory interpretation is consistent with evidence that menthol can improve perceived nasal patency or breathlessness without corresponding improvements in objective airway or pulmonary function (Lindemann et al., 2008; Schaeffer et al., 2025).

The condition-related change in respiratory comfort differed significantly between males and females, with a descriptively larger reduction in respiratory discomfort among females that may also have contributed to the performance interaction. Previous research indicates that females can experience greater exertional dyspnea under some matched-intensity conditions because of smaller airway dimensions, lower lung volumes, and a greater mechanical cost of breathing (Cory et al., 2015; LoMauro & Aliverti, 2018). However, this explanation was not supported by the control-condition scores in the present sample: females reported less, rather than more, respiratory discomfort than males (4.7 vs. 4.9). Therefore, the larger female response cannot be attributed to a higher initial level of respiratory discomfort. It may reflect differences in sensory responsiveness or another unmeasured factor, but ventilation, respiratory mechanics, pulmonary function, respiratory muscle work, and perceived airflow were not directly measured.

Effects of Menthol Nasal Inhalation and Sex on Physiological Responses

Mean heart rate was significantly higher during the menthol condition than during the control condition, supporting the physiological hypothesis. As participants also covered a greater distance during menthol while exercising against the same individualized resistance, the higher heart rate is consistent with participants selecting and sustaining a higher work rate. There was

no significant Condition × Sex interaction for heart rate, providing no evidence that the heart rate response differed between sexes.

This response should not be interpreted as evidence that menthol directly increased cardiovascular capacity. Menthol is primarily understood to influence exercise through sensory and perceptual pathways, particularly TRPM8-mediated cooling and enhanced airflow sensation, rather than through direct enhancement of cardiac function or aerobic metabolism (Barwood et al., 2020; Iftinca & Altier, 2020; Lindemann et al., 2008). The increase in heart rate more likely reflects a behavioural adjustment in pacing, as the cooler thermal sensation and reduced respiratory discomfort experienced during menthol may have supported a greater overall work rate, thereby increasing cardiovascular demand (Marcora, 2008; Pageaux, 2014). Despite the higher heart rate and greater distance achieved during menthol, RPE did not significantly increase, while thermal sensation and respiratory discomfort were lower. This pattern is consistent with menthol altering the perceptual experience of exercise during the higher self-selected work rate.

The heart rate increase averaged approximately 1 bpm, consistent with the greater distance covered during the menthol condition. Although heart rate was continuously monitored, with calculated HR values recorded at 1-second intervals, the inferential outcome was calculated from the 30-second windows preceding the 5-, 10-, and 15-minute assessments. The analysis therefore does not indicate whether the condition difference persisted throughout the trial or was concentrated within a particular pacing phase.

Practical Applications

The findings indicate that repeated menthol nasal inhalation can be a practical perceptual strategy for supporting short-duration, self-paced cycling performance. The intervention was brief, required minimal interruption to exercise, and was associated with greater distance covered, cooler thermal sensations, and less respiratory discomfort, while RPE was descriptively lower but did not differ significantly between conditions. Nasal administration may therefore be useful in settings where athletes seek a rapid sensory intervention without consuming fluid or applying menthol to large areas of skin. Although statistically significant, the average performance improvement was modest at approximately 1.5%, so its practical importance may depend on the performance context and the magnitude of change considered meaningful to the individual athlete.

The repeated dosing schedule used in the present study may be especially relevant for practical application. Menthol was administered for 5 seconds at the onset of the time trial and again at 5 and 10 minutes. As menthol's perceptual effects can diminish after exposure, repeated administration has been proposed as a strategy for maintaining sensory effects as discomfort increases during continuous endurance exercise (Stevens et al., 2016; Stevens & Best, 2017). Repeated administration has been used in prior endurance protocols, but those studies have differed in route, concentration, timing, environmental conditions, and exercise mode (Barwood et al., 2020; Jeffries et al., 2018). The existing literature has not directly compared a single exposure with repeated nasal inhalation under the same exercise conditions. The present schedule was effective under the conditions tested but should not be interpreted as evidence that repeated dosing is superior to a single exposure or other administration schedules.

Larger condition-related changes in performance, thermal sensation, and respiratory comfort were observed among female participants. These findings indicate that responses to menthol nasal inhalation vary by sex for selected performance and perceptual outcomes. Athletes and practitioners should therefore evaluate the intervention during training before using it in competition.

The findings were obtained during a 15-minute laboratory cycling time trial in physically active adults. Longer events involve different pacing, fatigue, hydration, and thermal demands and may require different exposure durations or administration schedules. The findings should therefore not be assumed to apply directly to longer-duration events, running, team sports, highly trained athletes, or competition outside controlled conditions. Accordingly, the practical value of menthol nasal inhalation should be evaluated within the specific demands and context of the intended sport or event.

The intervention should also be used cautiously in warm or hot environments. Previous research indicates that menthol can reduce perceived thermal strain without a corresponding reduction in core or skin temperature (Barwood et al., 2020; Stevens & Best, 2017). Physiological heat strain was not measured in the present study, so this dissociation cannot be confirmed here. Future applied work should pair menthol with direct temperature monitoring and established hydration, environmental-cooling, pacing, and heat-safety procedures rather than treating the cooling sensation as evidence of reduced physiological strain.

The present laboratory protocol standardized the reservoir mass, apparatus position below but not touching the nostrils, exposure duration, administration timing, and cleaning procedures. Future applied use should incorporate comparable standardization and hygienic delivery procedures. Excessive exposure should be avoided because menthol may cause nasal or throat

irritation (Jeffries & Waldron, 2019; Pergolizzi et al., 2018). The protocol used in the present study should therefore be viewed as an experimental approach rather than an established dosing recommendation.

Limitations

Several limitations should be considered when interpreting the findings of the present study. First, a sensory-matched placebo condition was not used. The control condition involved inhalation from an identical apparatus containing only air, but menthol produces a distinctive cooling sensation that participants could identify (Barwood et al., 2020). Consequently, participants may have been aware of the experimental condition, and expectancy or placebo effects may have contributed to the observed responses. Although the pseudo-randomized design and standardized procedures reduced between-participant variability, they could not eliminate the influence of treatment awareness.

The study measured average responses across the time trial rather than continuous pacing behaviour. Total distance provided a valid overall performance outcome, but cadence, power output, and distance were not recorded continuously throughout the trial. It is therefore unclear whether menthol influenced pacing consistently across the full 15 minutes or primarily altered the opening pace, mid-trial effort, or end-spurt. Continuous performance data would have provided a more detailed explanation of how participants achieved the greater distance observed during menthol.

In the present study, physiological measurements were limited to heart rate, and respiratory comfort was assessed using a perceptual scale rather than an objective measure of respiratory function. Core and skin temperature, oxygen consumption, ventilation, respiratory

mechanics, airway resistance, perceived nasal airflow, breathing frequency, and inspiratory resistance were not measured. Consequently, the study cannot confirm whether the reductions in thermal sensation and respiratory discomfort occurred independently of physiological changes or whether improved respiratory comfort reflected altered airflow sensation. Based on the established perceptual action of menthol (Barwood et al., 2020; Stevens & Best, 2017), these responses are interpreted as primarily sensory; however, direct physiological measurements would be required to verify these mechanisms.

Session-specific laboratory temperature and relative humidity were not recorded, and environmental conditions such as temperature, humidity, and airflow could not be experimentally controlled within the available laboratory setting. The monitor documented a broad range across the data collection period, and testing was withheld only when the displayed temperature exceeded 28°C; therefore, the degree to which each participant's control and menthol trials were environmentally matched cannot be verified. As ambient heat and humidity can influence thermal perception, cardiovascular strain, and endurance performance, unmeasured between-session variation may have contributed to the condition effects, particularly for thermal sensation (Périard et al., 2021).

The study also relied on perceptual scores averaged across the time trial using the 5-, 10-, and 15-minute measurements. Averaging provided a useful representation of the overall exercise experience but may have obscured meaningful changes across time. For example, menthol may have produced a stronger perceptual effect immediately after administration that weakened before the subsequent dose. A time-resolved analysis could provide more information about the onset and duration of the sensory response and whether these patterns differ by condition or sex, although changes across time were not examined in the present study.

Another limitation relates to blinding of performance information. Participants were blinded to elapsed time, distance, assessment timing, and inhalation timing, which reduced the influence of external feedback. However, withholding time and distance feedback may have reduced ecological validity because self-paced performance typically incorporates external pacing cues (Abbiss & Laursen, 2008; Currell & Jeukendrup, 2008).

Although participants attended a familiarization session, they did not complete the full 15-minute time trial during that visit. In recreationally active males, variability in a comparable 15-minute cycling time trial decreased across repeated trials, indicating that pacing reliability may improve with additional task exposure (Funnell et al., 2023). Residual learning or pacing adaptation may therefore have occurred between the two experimental trials. Counterbalancing condition order reduced systematic condition bias, but period and sequence effects were not formally examined.

Multiple inferential analyses were conducted across the performance, perceptual, and physiological outcomes, and no family-wise adjustment was applied across outcomes. The number of tests therefore increases the possibility of Type I error, and the findings should be interpreted with appropriate caution and confirmed in future studies. Accordingly, some of the statistically significant findings may represent false-positive results rather than true effects of menthol and should therefore be interpreted cautiously until replicated.

The sample consisted of physically active adults aged 18–35 years rather than trained or elite cyclists. Participants may have differed in cycling experience, pacing ability, fitness, and familiarity with high-intensity time-trial exercise. Although familiarization and individualized resistance were used to reduce these concerns, the findings may not generalize to highly trained endurance athletes with more established pacing strategies or to sedentary and clinical

populations. As such, the magnitude and consistency of the observed responses may differ in populations with greater cycling experience, higher fitness levels, or more established pacing strategies.

Menstrual-cycle phase and hormonal-contraceptive use were not experimentally controlled. This decision was consistent with evidence that phase-related effects on self-paced endurance performance and perceptual responses are small, inconsistent, and highly variable (McNulty et al., 2020). Strict phase verification would also have reduced feasibility and ecological validity (Elliott-Sale et al., 2021). Nevertheless, hormonal status may have contributed to variability in thermal perception, respiratory discomfort, or menthol responsiveness within the female group. The findings should therefore not be interpreted as indicating that all females respond similarly to menthol.

The inhaled menthol dose was not quantified. Although the reservoir contained 5 g of L-menthol crystals and exposure duration and apparatus position were standardized, vapour concentration, inspiratory flow, and inhaled volume were not measured. Accordingly, the 5-g reservoir mass should not be interpreted as the dose delivered to each participant, and between-participant variability in actual exposure may have influenced the results.

Prior menthol use was recorded on the screening form, but exposure frequency and sensory familiarity were not assessed using a standardized measure and were not included in the analyses. The study also did not assess perceived stimulus intensity, treatment expectancy, or participants' beliefs about condition allocation. These factors may have influenced perceptual and performance responses and should be assessed in future research.

Finally, the findings are specific to the 5-g menthol reservoir mass, exposure duration, administration schedule, exercise protocol, and environmental conditions used in the present

study. Menthol was administered for 5 seconds at 0, 5, and 10 minutes during a 15-minute cycling time trial. Different quantities, exposure durations, administration frequencies, exercise modes, or environmental temperatures may produce different outcomes. The present protocol should therefore not be assumed to represent the optimal or universally effective approach to menthol nasal inhalation.

Despite these limitations, the pseudo-randomized, counterbalanced design, standardized testing procedures, familiarization session, balanced male and female sample, and use of both absolute and normalized performance outcomes strengthen confidence in the observed within-participant effects. The findings provide a basis for further investigation of repeated menthol nasal inhalation while identifying several methodological areas that should be addressed in future research.

Future Directions

Future research should incorporate more detailed performance and physiological measurements to better identify the mechanisms underlying the observed effects. Continuous cadence, power output, speed, and heart rate should be recorded to determine how menthol influences pacing throughout a self-paced trial. Segment-by-segment data would clarify whether performance improvements result from a faster initial pace, a more consistent middle portion, a stronger end-spurt, or a general increase in work rate. Core and skin temperature should also be assessed to determine whether changes in thermal sensation occur independently of physiological cooling. These measures would help distinguish changes in pacing behaviour from changes in physiological strain and clarify whether menthol alters perceived thermal state without corresponding changes in body temperature (Barwood et al., 2020; Stevens & Best,

2017). Measurements of oxygen consumption, ventilation, breathing frequency, tidal volume, respiratory mechanics, and pulmonary function would help determine whether the respiratory comfort response is entirely perceptual or is accompanied by measurable physiological changes. Perceived nasal airflow could also be measured directly because enhanced airflow sensation is a proposed mechanism of nasal menthol exposure (Eccles et al., 1988; Lindemann et al., 2008).

Further investigation is needed to identify the optimal menthol administration protocol. Studies should compare reservoir masses, vapour concentrations, exposure durations, administration frequencies, timing strategies, and, where feasible, the delivered dose. Direct comparison of single and repeated exposures would help determine whether intermittent dosing is necessary to maintain perceptual effects and whether repeated exposure produces sensory desensitization (Iftinca & Altier, 2020; Yin et al., 2024). Comparisons among nasal inhalation, oral rinsing, and topical application would also clarify whether administration route influences the magnitude, duration, and type of response. Using equivalent exercise protocols and standardized sensory exposure across routes would help identify which approach is most appropriate for different performance contexts (Lindemann et al., 2008; Stevens & Best, 2017).

Participant-level factors that may influence responses to menthol also warrant further examination. Formal assessments of expectancy and blinding could determine which condition participants believed they received, their confidence in that judgment, their expectations regarding menthol, and the perceived intensity of the cooling sensation. Although creating a truly sensory-matched placebo is difficult (Barwood et al., 2020), alternative control conditions could help distinguish sensory effects from expectancy-related influences. Studies should also determine whether prior menthol use, cooling sensitivity, aerobic fitness, cycling experience, and baseline thermal or respiratory discomfort are associated with the magnitude and consistency of

perceptual and performance responses. These measures may help explain individual variability without assuming a uniform response across all athletes.

The generalizability of the present findings should be examined across training levels, exercise protocols, and environmental conditions. Studies involving trained cyclists and endurance athletes could determine whether responses differ from those of recreationally active adults, particularly because pacing expertise may influence the practical relevance of perceptual changes. Longer-duration time trials and other exercise modalities, including running and rowing, should also be examined. Given menthol's frequent use as a cooling intervention, future trials should compare temperate, warm, and hot environments while incorporating direct measures of physiological heat strain and appropriate safety monitoring (Barwood et al., 2020; Stevens & Best, 2017). Field-based research would further clarify whether the intervention remains effective when athletes receive normal performance feedback and are exposed to environmental variability.

The observed sex-related differences should be replicated, and the factors contributing to these responses should be investigated. Studies should continue to recruit balanced male and female samples and should collect information on menstrual-cycle characteristics and hormonal-contraceptive use. Where feasible and justified by the research question, hormonal status could be verified using appropriate biochemical methods (Elliott-Sale et al., 2021). However, future research should avoid treating females as a uniform group and should consider within-sex variability alongside comparisons between sexes. Measurements of baseline thermal perception, respiratory discomfort, pulmonary function, body composition, and sensory sensitivity may help determine why females demonstrated larger responses in selected outcomes.

Chapter Five: Conclusion

This study examined the effects of repeated menthol nasal inhalation and sex on performance, perceptual, and physiological responses during self-paced cycling in physically active adults. Menthol nasal inhalation significantly improved performance, as participants covered a greater total distance and achieved greater body-mass-normalized performance during the 15-minute time trial. Menthol also lowered thermal sensation and respiratory comfort scores, indicating cooler thermal sensations and less respiratory discomfort, while RPE was descriptively lower but did not differ significantly between conditions. Mean heart rate was higher during the menthol condition, consistent with participants sustaining a greater self-selected work rate alongside these perceptual changes.

Sex influenced selected performance and perceptual responses to menthol, with larger performance improvements and greater changes in thermal sensation and respiratory comfort among females, whereas RPE and heart rate responses did not differ by sex. The mechanisms underlying these sex-related differences remain uncertain. The combined performance, perceptual, and physiological findings are consistent with menthol acting primarily as a perceptual ergogenic aid that may support a greater self-selected work rate during exercise. The present study extends the menthol-exercise literature by examining repeated nasal inhalation during self-paced cycling in a sex-balanced sample.

Overall, repeated menthol nasal inhalation represents a promising perceptual strategy for supporting self-paced cycling performance, with sex influencing selected performance and perceptual responses. Further research is needed to establish its optimal administration protocol, mechanisms, safety, and applicability across populations and exercise settings.

References

Abbiss, C. R., & Laursen, P. B. (2008). Describing and understanding pacing strategies during athletic competition. *Sports Medicine*, *38*(3), 239-252. https://doi.org/10.2165/00007256-200838030-00004

Abbiss, C. R., Thompson, K. G., Lipski, M., Meyer, T., & Skorski, S. (2016). Difference in pacing between time- and distance-based time trials in trained cyclists. *International Journal of Sports Physiology and Performance*, *11*(8), 1018-1023. https://doi.org/10.1123/ijspp.2015-0613

Aguinis, H., Gottfredson, R. K., & Joo, H. (2013). Best-practice recommendations for defining, identifying, and handling outliers. Organizational Research Methods, 16(2), 270–301. https://doi.org/10.1177/1094428112470848

Allen, D. G., Lamb, G. D., & Westerblad, H. (2008). Skeletal muscle fatigue: cellular mechanisms. *Physiological Reviews*, *88*(1), 287-332. https://doi.org/10.1152/physrev.00015.2007

Ansdell, P., Thomas, K., Hicks, K. M., Hunter, S. K., Howatson, G., & Goodall, S. (2020). Physiological sex differences affect the integrative response to exercise: acute and chronic implications. *Experimental Physiology*, *105*(12), 2007-2021. https://doi.org/10.1113/ep088548

Anselmi, F., Cavigli, L., Pagliaro, A., Valente, S., Valentini, F., Cameli, M., Focardi, M., Mochi, N., Dendale, P., Hansen, D., Bonifazi, M., Halle, M., & D'Ascenzi, F. (2021). The importance of ventilatory thresholds to define aerobic exercise intensity in cardiac patients and healthy subjects. *Scandinavian Journal of Medicine and Science in Sports*, *31*(9), 1796-1808. https://doi.org/10.1111/sms.14007

Araújo, D., Davids, K., & Passos, P. (2007). Ecological validity, representative design, and correspondence between experimental task constraints and behavioral setting: comment on Rogers, Kadar, and Costall (2005). *Ecological Psychology*, *19*(1), 69-78. https://doi.org/10.1080/10407410709336951

Armstrong, L. E., Johnson, E. C., McKenzie, A. L., & Muñoz, C. X. (2013). Interpreting common hydration biomarkers on the basis of solute and water excretion. *European Journal of Clinical Nutrition*, *67*(3), 249-253. https://doi.org/10.1038/ejcn.2012.214

Bartolomei, S., Grillone, G., Di Michele, R., & Cortesi, M. (2021). A comparison between male and female athletes in relative strength and power performances. *Journal of Functional Morphology and Kinesiology*, *6*(1), 1-11. https://doi.org/10.3390/jfmk6010017

Barwood, M. J., Corbett, J., Thomas, K., & Twentyman, P. (2015). Relieving thermal discomfort: Effects of sprayed L-menthol on perception, performance, and time trial cycling in the heat. *Scandinavian Journal of Medicine and Science in Sports*, *25*(1), 211-218. https://doi.org/10.1111/sms.12395

Barwood, M. J., Gibson, O. R., Gillis, D. J., Jeffries, O., Morris, N. B., Pearce, J., Ross, M. L., Stevens, C., Rinaldi, K., Kounalakis, S. N., Riera, F., Mündel, T., Waldron, M., & Best, R. (2020). Menthol as an ergogenic aid for the Tokyo 2021 Olympic Games: An expert-led consensus statement using the modified Delphi method. *Sports Medicine*, *50*(10), 1709-1727. https://doi.org/10.1007/s40279-020-01313-9

Bassareo, P. P., & Crisafulli, A. (2019). Gender differences in hemodynamic regulation and cardiovascular adaptations to dynamic exercise. *Current Cardiology Reviews*, *16*(1), 65-72. https://doi.org/10.2174/1573403x15666190321141856

Bassett, D. R. (2000). Limiting factors for maximum oxygen uptake and determinants of

endurance performance. *Medicine & Science in Sports & Exercise, 32*(1), 70-84. https://doi.org/10.1097/00005768-200001000-00012

Beck, K., Thomson, J. S., Swift, R. J., & Von Hurst, P. R. (2015). Role of nutrition in performance enhancement and postexercise recovery. *Open Access Journal of Sports Medicine*, *2015*(6), 259-267. https://doi.org/10.2147/oajsm.s33605

Behrens, M., Gube, M., Chaabene, H., Prieske, O., Zenon, A., Broscheid, K., Schega, L., Husmann, F., & Weippert, M. (2022). Fatigue and human performance: An updated framework. *Sports Medicine*, *53*(1), 7-31. https://doi.org/10.1007/s40279-022-01748-2

Beltz, N. M., Gibson, A. L., Janot, J. M., Kravitz, L., Mermier, C. M., & Dalleck, L. C. (2016). Graded exercise testing protocols for the determination of VO_2max: Historical perspectives, progress, and future considerations. *Journal of Sports Medicine*, *2016*(1), 1-12. https://doi.org/10.1155/2016/3968393

Bentley, D. J., Newell, J., & Bishop, D. (2007). Incremental exercise test design and analysis. *Sports Medicine*, *37*(7), 575-586. https://doi.org/10.2165/00007256-200737070-00002

Best, R., Crosby, S., Berger, N., & McDonald, K. (2021). The effect of isolated and combined application of menthol and carbohydrate mouth rinses on 40 km time-trial performance, physiological and perceptual measures in the heat. *Nutrients*, *13*(12), 1-17. https://doi.org/10.3390/nu13124309

Bigliassi, M. (2015). Corollary discharges and fatigue-related symptoms: The role of attentional focus. *Frontiers in Psychology*, *6*(1002), 1-4. https://doi.org/10.3389/fpsyg.2015.01002

Borg, G. (1970). Perceived exertion as an indicator of somatic stress. *Journal of Rehabilitation Medicine*, *2*(2), 92-98. https://doi.org/10.2340/1650197719702239298

Borg, G. (1982). Psychophysical bases of perceived exertion. *Medicine and Science in Sports*

and Exercise, 14(5), 377-381. https://doi.org/10.1249/00005768-198205000-00012

Brooks, G. A., & Mercier, J. (1994). Balance of carbohydrate and lipid utilization during exercise: the "crossover" concept. *Journal of Applied Physiology*, *76*(6), 2253-2261. https://doi.org/10.1152/jappl.1994.76.6.2253

Bruce, R. A., Blackmon, J. R., Jones, J. W., & Strait, G. (1963). Exercise testing in adult normal subjects and cardiac patients. *Pediatrics*, *32*(1), 742-756. https://pubmed.ncbi.nlm.nih.gov/14070531/

Cabral, L. L., Nakamura, F. Y., Stefanello, J. M. F., Pessoa, L. C. V., Smirmaul, B. P. C., & Pereira, G. (2020). Initial validity and reliability of the Portuguese Borg Rating of Perceived Exertion 6–20 Scale. *Measurement in Physical Education and Exercise Science*, *24*(2), 103-114. https://doi.org/10.1080/1091367X.2019.1710709

Canadian Society for Exercise Physiology. (2017). *Get Active Questionnaire*. https://csep.ca/wp-content/uploads/2021/05/GETACTIVEQUESTIONNAIRE_ENG.pdf

Cano, A., Ventura, L., Martinez, G., Cugusi, L., Caria, M., Deriu, F., & Manca, A. (2021). Analysis of sex-based differences in energy substrate utilization during moderate-intensity aerobic exercise. *European Journal of Applied Physiology*, *122*(1), 29-70. https://doi.org/10.1007/s00421-021-04802-5

Cappelletti, S., Daria, P., Sani, G., & Aromatario, M. (2014). Caffeine: cognitive and physical performance enhancer or psychoactive drug? *Current Neuropharmacology*, *13*(1), 71-88. https://doi.org/10.2174/1570159x13666141210215655

Carmichael, M. A., Thomson, R. L., Moran, L. J., & Wycherley, T. P. (2021). The impact of menstrual cycle phase on athletes' performance: A narrative review. *International Journal of Environmental Research and Public Health, 18*(4), 1-22.

https://doi.org/10.3390/ijerph18041667

Chen, M. J., Fan, X., & Moe, S. T. (2002). Criterion-related validity of the Borg ratings of perceived exertion scale in healthy individuals: A meta-analysis. *Journal of Sports Sciences, 20*(11), 873–899. https://doi.org/10.1080/026404102320761787

Christison, K. S., Gurney, S. C., Williamson-Reisdorph, C. M., Covington, A. C., & Dumke, C. L. (2025). Menstrual cycle effects on thermoregulation while exercising in the heat. *Journal of Thermal Biology, 127*(2025), 1-8. https://doi.org/10.1016/j.jtherbio.2024.104036

Cory, J. M., Schaeffer, M. R., Wilkie, S. S., Ramsook, A. H., Puyat, J. H., Arbour, B., Basran, R., Lam, M., Les, C., MacDonald, B., Jensen, D., & Guenette, J. A. (2015). Sex differences in the intensity and qualitative dimensions of exertional dyspnea in physically active young adults. *Journal of Applied Physiology*, *119*(9), 998-1006. https://doi.org/10.1152/japplphysiol.00520.2015

Cowley, E. S., Olenick, A. A., McNulty, K. L., & Ross, E. Z. (2021). "Invisible Sportswomen": The sex data gap in sport and exercise science research. Women in Sport and Physical Activity Journal, 29(2), 146–151. https://doi.org/10.1123/wspaj.2021-0028

Craighead, D. H., McCartney, N. B., Tumlinson, J. H., & Alexander, L. M. (2016). Mechanisms and time course of menthol-induced cutaneous vasodilation. *Microvascular Research*, *45*(1), 43-47. https://doi.org/10.1016/j.mvr.2016.11.008

Crosby, S., Butcher, A., McDonald, K., Berger, N., Bekker, P., & Best, R. (2022). Menthol mouth rinsing maintains relative power production during three-minute maximal cycling performance in the heat compared with cold water and placebo rinsing. *International Journal of Environmental Research and Public Health, 19*(6), 1-19.

https://doi.org/10.3390/ijerph19063527

Currell, K., & Jeukendrup, A. E. (2008). Validity, reliability and sensitivity of measures of sporting performance. *Sports Medicine*, *38*(4), 297-316. https://doi.org/10.2165/00007256-200838040-00003

Davies, M. J., Clark, B., Welvaert, M., Skorski, S., Garvican-Lewis, L. A., Saunders, P., & Thompson, K. G. (2016). Effect of environmental and feedback interventions on pacing profiles in cycling: A meta-analysis. *Frontiers in Physiology*, *7*(1), 1-24. https://doi.org/10.3389/fphys.2016.00591

De Camargo, R., Vilaça, A., Mota, G. R., Elsangedy, H. M., Haile, L., & Sasaki, J. E. (2022). The influence of L-menthol on time trial running performance in recreational runners. *Research Quarterly for Exercise and Sport*, *94*(2), 510-518. https://doi.org/10.1080/02701367.2021.2014049

Delp, M., Chesbro, G. A., Pribble, B. A., Miller, R. M., Pereira, H. M., Black, C. D., & Larson, R. D. (2024). Higher rating of perceived exertion and lower perceived recovery following a graded exercise test during menses compared to non-bleeding days in untrained females. *Frontiers in Physiology, 14*(1), 1-10. https://doi.org/10.3389/fphys.2023.1297242

Dominelli, P. B., & Sheel, A. W. (2024). The pulmonary physiology of exercise. *Advances in Physiology Education, 48*(2), 238-251. https://doi.org/10.1152/advan.00067.2023

Eccles, R. (2000). Role of cold receptors and menthol in thirst, the drive to breathe and arousal. *Appetite*, *34*(1), 29-35. https://doi.org/10.1006/appe.1999.0291

Eccles, R. (2003). Menthol: Effects on nasal sensation of airflow and the drive to breathe. *Current Allergy and Asthma Reports*, *3*(3), 210-214. https://doi.org/10.1007/s11882-003-

0041-6

Eccles, R., Griffiths, D. H., Newton, C. G., & Tolley, N. S. (1988). The effects of menthol isomers on nasal sensation of airflow. *Clinical Otolaryngology*, *13*(1), 25-29. https://doi.org/10.1111/j.1365-2273.1988.tb00277.x

Elliott-Sale, K. J., Minahan, C. L., De Jonge, X. A. K. J., Ackerman, K. E., Sipilä, S., Constantini, N. W., Lebrun, C. M., & Hackney, A. C. (2021). Methodological considerations for studies in sport and exercise science with women as participants: A working guide for standards of practice for research on women. *Sports Medicine*, *51*(5), 843-861. https://doi.org/10.1007/s40279-021-01435-8

Fehring, R. J., Schneider, M., & Raviele, K. (2006). Variability in the phases of the menstrual cycle. *Journal of Obstetric, Gynecologic, and Neonatal Nursing, 35*(3), 376-384. https://doi.org/10.1111/j.1552-6909.2006.00051.x

Finch, P. M., & Drummond, P. D. (2015). Topical treatment in pain medicine: From ancient remedies to modern usage. *Pain Management*, *5*(5), 359-371. https://doi.org/10.2217/pmt.15.23

Fisher, J., Clark, T., Newman-Judd, K., Arnold, J., & Steele, J. (2017). Intra-subject variability of 5 km time-trial performance completed by competitively trained runners. *Journal of Human Kinetics*, *57*(1), 139-146. https://doi.org/10.1515/hukin-2017-0055

Flood, T. R. (2018). Menthol use for performance in hot environments. *Current Sports Medicine Reports*, *17*(4), 135-139. https://doi.org/10.1249/jsr.0000000000000474

Flood, T. R., Waldron, M., & Jeffries, O. (2017). Oral L-menthol reduces thermal sensation, increases work-rate and extends time to exhaustion, in the heat at a fixed rating of perceived exertion. *European Journal of Applied Physiology*, *117*(7), 1501-1512.

https://doi.org/10.1007/s00421-017-3645-6

Frączek, B., Warzecha, M., Tyrała, F., & Pięta, A. (2016). Prevalence of the use of effective ergogenic aids among professional athletes. *Roczniki Państwowego Zakładu Higieny, 67*(3), 271-278. https://pubmed.ncbi.nlm.nih.gov/27546324/

Funnell, M. P., Mears, S. A., & James, L. J. (2023). A self-paced 15-minute cycling time trial is a reliable performance measure in recreationally active individuals. *Journal of Sports Sciences*, *41*(17), 1581-1586. https://doi.org/10.1080/02640414.2023.2283993

Galeotti, N., Di Cesare Mannelli, L., Mazzanti, G., Bartolini, A., & Ghelardini, C. (2002). Menthol: a natural analgesic compound. *Neuroscience Letters*, *322*(3), 145-148. https://doi.org/10.1016/s0304-3940(01)02527-7

Garcin, M., Fleury, A., Mille-Hamard, L., & Billat, V. (2005). Sex-related differences in ratings of perceived exertion and estimated time limit. *International Journal of Sports Medicine, 26*(8), 675-681. https://doi.org/10.1055/s-2004-830440

Gaskill, S. E., Skinner, J. S., & Quindry, J. (2023). Ventilatory threshold related to VO_2 reserve, heart rate reserve, and rating of perceived exertion in a large, varied sample. *Medicine & Science in Sports & Exercise*, *55*(10), 1876-1885. https://doi.org/10.1249/mss.0000000000003220

Gavel, E. H., Barreto, G., Hawke, K. V., Stellingwerff, T., James, L. J., Saunders, B., & Logan-Sprenger, H. M. (2024a). How cool is that? The effects of menthol mouth rinsing on exercise capacity and performance: A systematic review and meta-analysis. *Sports Medicine - Open, 10*(18), 1-14. https://doi.org/10.1186/s40798-024-00679-8

Gavel, E. H., Hawke, K. V., Bentley, D. J., & Logan-Sprenger, H. M. (2021). Menthol mouth rinsing is more than just a mouth wash: Swilling of menthol to improve physiological

performance. *Frontiers in Nutrition*, *8*(1), 1-7. https://doi.org/10.3389/fnut.2021.691695

Gavel, E. H., Hawke, K. V., & Logan-Sprenger, H. M. (2024b). The effect of menthol mouth rinsing and fluid temperature on male cycling performance in thermoneutral conditions. *Nutrients*, *16*(7), 1-12. https://doi.org/10.3390/nu16071016

Ghosh, A. K. (2004). Anaerobic threshold: Its concept and role in endurance sport. *Malaysian Journal of Medical Sciences, 11*(1), 24-36. https://pmc.ncbi.nlm.nih.gov/articles/PMC3438148/

Giersch, G. E., Morrissey, M. C., Katch, R. K., Colburn, A. T., Sims, S. T., Stachenfeld, N. S., & Casa, D. J. (2020). Menstrual cycle and thermoregulation during exercise in the heat: A systematic review and meta-analysis. *Journal of Science and Medicine in Sport*, *23*(12), 1134-1140. https://doi.org/10.1016/j.jsams.2020.05.014

Gillinov, S., Etiwy, M., Wang, R., Blackburn, G., Phelan, D., Gillinov, A. M., Houghtaling, P., Javadikasgari, H., & Desai, M. Y. (2017). Variable accuracy of wearable heart rate monitors during aerobic exercise. *Medicine & Science in Sports & Exercise*, *49*(8), 1697-1703. https://doi.org/10.1249/mss.0000000000001284

Gillis, D. J., Capone, S., Nestor, K., & Snell, M. (2020). The influence of menthol dose on human temperature regulation and perception. *Journal of Thermal Biology, 92*(102659), 1-9. https://doi.org/10.1016/j.jtherbio.2020.102659

González-Alonso, J., Crandall, C. G., & Johnson, J. M. (2007). The cardiovascular challenge of exercising in the heat. *The Journal of Physiology*, *586*(1), 45-53. https://doi.org/10.1113/jphysiol.2007.142158

González-Alonso, J., Teller, C., Andersen, S. L., Jensen, F. B., Hyldig, T., & Nielsen, B. (1999). Influence of body temperature on the development of fatigue during prolonged exercise

in the heat. *Journal of Applied Physiology*, *86*(3), 1032-1039. https://doi.org/10.1152/jappl.1999.86.3.1032

Grucza, R., Pekkarinen, H., Titov, E.-K., Kononoff, A., & Hänninen, O. (1993). Influence of the menstrual cycle and oral contraceptives on thermoregulatory responses to exercise in young women. *European Journal of Applied Physiology and Occupational Physiology, 67*(3), 279–285. https://doi.org/10.1007/BF00864229

Haddad, T., Spence, A. L., Peiffer, J., Blain, G. M., Brisswalter, J., & Abbiss, C. R. (2024). The improvement in exercise performance during reduced muscle mass exercise is associated with an increase in femoral blood flow in older and younger endurance-trained athletes. *Journal of Sports Science & Medicine, 23*(1), 46-55. https://doi.org/10.52082/jssm.2024.46

Hadzic, M., Eckstein, M. L., & Schugardt, M. (2019). The impact of sodium bicarbonate on performance in response to exercise duration in athletes: A systematic review. *Journal of Sports Science and Medicine, 18*(2), 271-281. https://pmc.ncbi.nlm.nih.gov/articles/PMC6544001/

Hamidovic, A., Karapetyan, K., Serdarevic, F., Choi, S. H., Eisenlohr-Moul, T., & Pinna, G. (2020). Higher circulating cortisol in the follicular vs. luteal phase of the menstrual cycle: A meta-analysis. *Frontiers in Endocrinology, 11*(2020), 1-12. https://doi.org/10.3389/fendo.2020.00311

Hanson, N. J., & Buckworth, J. (2016). Sex differences in time perception during self-paced running. *International Journal of Exercise Science*, *9*(4), 514-523. https://doi.org/10.70252/xrjv6155

Helgerud, J., Høydal, K., Wang, E., Karlsen, T., Berg, P., Bjerkaas, M., Simonsen, T., Helgesen,

C., Hjorth, N., Bach, R., & Hoff, J. (2007). Aerobic high-intensity intervals improve VO_2max more than moderate training. *Medicine & Science in Sports & Exercise*, *39*(4), 665-671. https://doi.org/10.1249/mss.0b013e3180304570

Hibbert, A. W., Billaut, F., Varley, M. C., & Polman, R. C. J. (2017). Familiarization protocol influences reproducibility of 20-km cycling time-trial performance in novice participants. *Frontiers in Physiology*, *8*(488), 1-10. https://doi.org/10.3389/fphys.2017.00488

Hofmann, P., & Tschakert, G. (2017). Intensity- and duration-based options to regulate endurance training. *Frontiers in Physiology*, *8*(337), 1-9. https://doi.org/10.3389/fphys.2017.00337

Holmes, J. C., Pruitt, A. L., & Whalen, N. J. (1994). Lower extremity overuse in bicycling. *Clinics in Sports Medicine, 13*(1), 187–203. https://doi.org/10.1016/S0278-5919(20)30363-X

Hue, O., Chabert, C., Collado, A., & Hermand, E. (2019). Menthol as an adjuvant to help athletes cope with a tropical climate: Tracks from heat experiments with special focus on Guadeloupe investigations. *Frontiers in Physiology*, *10*(1360), 1-6. https://doi.org/10.3389/fphys.2019.01360

Hur, K., Zhao, K., Leopold, D., Wrobel, B., & Shen, J. (2017). Determinants and evaluation of nasal airflow perception. *Facial Plastic Surgery*, *33*(04), 372-377. https://doi.org/10.1055/s-0037-1603788

Hyland-Monks, R., Cronin, L., McNaughton, L., & Marchant, D. (2018). The role of executive function in the self-regulation of endurance performance: A critical review. *Progress in Brain Research*, *240*(19), 353-370. https://doi.org/10.1016/bs.pbr.2018.09.011

Iftinca, M., & Altier, C. (2020). The cool things to know about TRPM8! *Channels*, *14*(1), 413-

420. https://doi.org/10.1080/19336950.2020.1841419

Inzlicht, M., Schmeichel, B. J., & Macrae, C. N. (2014). Why self-control seems (but may not be) limited. *Trends in Cognitive Sciences*, *18*(3), 127-133. https://doi.org/10.1016/j.tics.2013.12.009

Jacobs, R. A., Rasmussen, P., Siebenmann, C., Díaz, V., Gassmann, M., Pesta, D., Gnaiger, E., Nordsborg, N. B., Robach, P., & Lundby, C. (2011). Determinants of time trial performance and maximal incremental exercise in highly trained endurance athletes. *Journal of Applied Physiology*, *111*(5), 1422-1430. https://doi.org/10.1152/japplphysiol.00625.2011

Jang, Y.-J., Kim, J.-H., & Lee, J.-Y. (2015). Effects of menthol on thermoregulatory responses after exercise-induced hyperthermia. *Extreme Physiology & Medicine, 4*(27), 1-2. https://doi.org/10.1186/2046-7648-4-S1-A6

Jeffries, O., Goldsmith, M., & Waldron, M. (2018). l-Menthol mouth rinse or ice slurry ingestion during the latter stages of exercise in the heat provide a novel stimulus to enhance performance despite elevation in mean body temperature. *European Journal of Applied Physiology*, *118*(11), 2435-2442. https://doi.org/10.1007/s00421-018-3970-4

Jeffries, O., Jibi, G., Clark, J., Barwood, M., & Waldron, M. (2025). Determination of the optimal dose and dosing strategy for effective l-menthol oral rinsing during exercise in hot environments. *European Journal of Applied Physiology*, *125*(3), 629-638. https://doi.org/10.1007/s00421-024-05609-w

Jeffries, O., & Waldron, M. (2019). The effects of menthol on exercise performance and thermal sensation: A meta-analysis. *Journal of Science and Medicine in Sport*, *22*(6), 707-715. https://doi.org/10.1016/j.jsams.2018.12.002

Jezek, F., Randall, E. B., Carlson, B. E., & Beard, D. A. (2022). Systems analysis of the mechanisms governing the cardiovascular response to changes in posture and in peripheral demand during exercise. *Journal of Molecular and Cellular Cardiology*, *163*(7), 33-55. https://doi.org/10.1016/j.yjmcc.2021.09.013

Johnson, B. D., Aaron, E. A., Babcock, M. A., & Dempsey, J. A. (1996). Respiratory muscle fatigue during exercise: Implications for performance. *Medicine & Science in Sports & Exercise*, *28*(9), 1129-1137. https://doi.org/10.1097/00005768-199609000-00008

Joyner, M. J. (1993). Physiological limiting factors and distance running: influence of gender and age on record performances. *Exercise and Sport Sciences Reviews*, *21*(1), 103-133. https://doi.org/10.1249/00003677-199301000-00004

Joyner, M. J., & Coyle, E. F. (2008). Endurance exercise performance: The physiology of champions. *The Journal of Physiology*, *586*(1), 35-44. https://doi.org/10.1113/jphysiol.2007.143834

Jusoh, M. R. C., Morton, R. H., Stannard, S. R., & Mündel, T. (2015). A reliable preloaded cycling time trial for use in conditions of significant thermal stress. *Scandinavian Journal of Medicine and Science in Sports*, *25*(1), 296-301. https://doi.org/10.1111/sms.12332

Kamatou, G. P., Vermaak, I., Viljoen, A. M., & Lawrence, B. M. (2013). Menthol: A simple monoterpene with remarkable biological properties. *Phytochemistry, 96*, 15-25. https://doi.org/10.1016/j.phytochem.2013.08.005

Kanezaki, M., & Ebihara, S. (2017). Effect of the cooling sensation induced by olfactory stimulation by L-menthol on dyspnoea: A pilot study. *European Respiratory Journal*, *49*(4), 1-4. https://doi.org/10.1183/13993003.01823-2016

Kanezaki, M., Terada, K., & Ebihara, S. (2023). Nasal stimulation with l-menthol ameliorates

breathlessness in patients with interstitial lung disease. *European Respiratory Journal, 61*(6), 1-4. https://doi.org/10.1183/13993003.02453-2022

Kappus, R. M., Ranadive, S. M., Yan, H., Lane-Cordova, A. D., Cook, M. D., Sun, P., Harvey, I. S., Wilund, K. R., Woods, J. A., & Fernhall, B. (2015). Sex differences in autonomic function following maximal exercise. *Biology of Sex Differences*, *6*(28), 1-8. https://doi.org/10.1186/s13293-015-0046-6

Keringer, P., Farkas, N., Gede, N., Hegyi, P., Rumbus, Z., Lohinai, Z., Solymar, M., Ruksakiet, K., Varga, G., & Garami, A. (2020). Menthol can be safely applied to improve thermal perception during physical exercise: A meta-analysis of randomized controlled trials. *Scientific Reports*, *10*(13636), 1-12. https://doi.org/10.1038/s41598-020-70499-9

Korivi, M., Ghanta, M. K., Nuthalapati, P., Natesh, N. S., Tang, J., & Bhaskar, L. (2025). Influence of exercise on oxygen consumption, pulmonary ventilation, and blood gas analyses in individuals with chronic diseases. *Life*, *15*(8), 1-27. https://doi.org/10.3390/life15081255

Korzeniewski, B., & Rossiter, H. B. (2022). Skeletal muscle biochemical origin of exercise intensity domains and their relation to whole-body VO2 kinetics. *Bioscience Reports*, *42*(8), 1-17. https://doi.org/10.1042/bsr20220798

Kounalakis, S. N., Botonis, P. G., Koskolou, M. D., & Geladas, N. D. (2010). The effect of menthol application to the skin on sweating rate response during exercise in swimmers and controls. *European Journal of Applied Physiology*, *109*(2), 183-189. https://doi.org/10.1007/s00421-009-1345-6

Lamberti, A., Aprile, S., Cabañero, D., Travagin, F., Butron, L., Fernández-Ballester, G., Tron, G. C., Fernández-Carvajal, A., Ferrer-Montiel, A., & Galli, U. (2025). An adamantane-

based ligand as a novel chemical tool for thermosensory TRPM8 channel therapeutic modulation. *The FEBS Journal*, 292(13), 3449-3476. https://doi.org/10.1111/febs.70065

Laursen, P. B., Francis, G. T., Abbiss, C. R., Newton, M. J., & Nosaka, K. (2007). Reliability of time-to-exhaustion versus time-trial running tests in runners. *Medicine & Science in Sports & Exercise*, *39*(8), 1374-1379. https://doi.org/10.1249/mss.0b013e31806010f5

Laursen, P. B., & Jenkins, D. G. (2002). The scientific basis for high-intensity interval training. *Sports Medicine*, *32*(1), 53-73. https://doi.org/10.2165/00007256-200232010-00003

Li, Z., Zhang, H., Wang, Y., Li, Y., Li, Q., & Zhang, L. (2022). The distinctive role of menthol in pain and analgesia: Mechanisms, practices, and advances. *Frontiers in Molecular Neuroscience*, *15*(1006908), 1-19. https://doi.org/10.3389/fnmol.2022.1006908

Lindemann, J., Tsakiropoulou, E., Scheithauer, M. O., Konstantinidis, I., & Wiesmiller, K. M. (2008). Impact of menthol inhalation on nasal mucosal temperature and nasal patency. *American Journal of Rhinology*, *22*(4), 402-405. https://doi.org/10.2500/ajr.2008.22.3194

Liu, B., Fan, L., Balakrishna, S., Sui, A., Morris, J. B., & Jordt, S. (2013). TRPM8 is the principal mediator of menthol-induced analgesia of acute and inflammatory pain. *Pain*, *154*(10), 2169-2177. https://doi.org/10.1016/j.pain.2013.06.043

Liu, S., Lu, H., Cheng, L., Chu, Y., Lee, F., Wu, C., & Wang, H. (2015). Identification of the cold receptor TRPM8 in the nasal mucosa. *American Journal of Rhinology and Allergy*, *29*(4), 112-116. https://doi.org/10.2500/ajra.2015.29.4202

Löllgen, H., & Leyk, D. (2018). Exercise testing in sports medicine. *Deutsches Ärzteblatt International,* 115(24), 409-416. https://doi.org/10.3238/arztebl.2018.0409

LoMauro, A., & Aliverti, A. (2018). Sex differences in respiratory function. *Breathe*, *14*(2), 131-140. https://doi.org/10.1183/20734735.000318

Lundsgaard, A., & Kiens, B. (2014). Gender differences in skeletal muscle substrate metabolism—molecular mechanisms and insulin sensitivity. *Frontiers in Endocrinology*, *5*(195), 1-16. https://doi.org/10.3389/fendo.2014.00195

Mahler, D. A., & Horowitz, M. B. (1994). Clinical evaluation of exertional dyspnea. *Clinics in Chest Medicine, 15*(2), 259–269. https://doi.org/10.1016/S0272-5231(21)01072-8

Malik, M., Bigger, J. T., Camm, A. J., Kleiger, R. E., Malliani, A., Moss, A. J., & Schwartz, P. J. (1996). Heart rate variability: Standards of measurement, physiological interpretation, and clinical use. *European Heart Journal*, *17*(3), 354-381. https://doi.org/10.1093/oxfordjournals.eurheartj.a014868

Maney, D. L., Karkazis, K., & Hagen, K. B. S. (2023). Considering sex as a variable at a research university: Knowledge, attitudes, and practices. *Journal of Women's Health*, *32*(8), 843-851. https://doi.org/10.1089/jwh.2022.0522

Marcora, S. M. (2008). Do we really need a central governor to explain brain regulation of exercise performance? *European Journal of Applied Physiology*, *104*(5), 929-931. https://doi.org/10.1007/s00421-008-0818-3

Martin, E., Seiwert, S., Fautrelle, L., Tisseyre, J., Gasq, D., Lemay, M., Amarantini, D., & Tallet, J. (2025). From lab to real life: Is there a link between lab-based and ecological assessment of Procedural Perceptual-Motor Learning tasks? *PLOS ONE*, *20*(4), 1-20. https://doi.org/10.1371/journal.pone.0319715

Martin-Rincon, M., & Calbet, J. A. L. (2020). Progress update and challenges on VO_2max testing and interpretation. *Frontiers in Physiology*, *11*(1070), 1-8. https://doi.org/10.3389/fphys.2020.01070

Martins, H. A., Barbosa, J. G., Seffrin, A., Vivan, L., Souza, V. R. D. A., De Lira, C. A. B.,

Weiss, K., Knechtle, B., & Andrade, M. S. (2023). Sex differences in maximal oxygen uptake adjusted for skeletal muscle mass in amateur endurance athletes: A cross-sectional study. *Healthcare*, *11*(10), 1-9. https://doi.org/10.3390/healthcare11101502

Mauger, L. (2014). Factors affecting the regulation of pacing: Current perspectives. *Open Access Journal of Sports Medicine*, *2014*(5), 209-214. https://doi.org/10.2147/oajsm.s38599

Mauger, A. R., Jones, A. M., & Williams, C. A. (2009). Influence of feedback and prior experience on pacing during a 4-km cycle time trial. *Medicine & Science in Sports & Exercise, 41*(2), 451–458. https://doi.org/10.1249/MSS.0b013e3181854957

Maughan, R. J. (1999). Nutritional ergogenic aids and exercise performance. *Nutrition Research Reviews*, *12*(2), 255-280. https://doi.org/10.1079/095442299108728956

Maughan, R. J., Burke, L. M., Dvorak, J., Larson-Meyer, D. E., Peeling, P., Phillips, S. M., Rawson, E. S., Walsh, N. P., Garthe, I., Geyer, H., Meeusen, R., Van Loon, L. J. C., Shirreffs, S. M., Spriet, L. L., Stuart, M., Vernec, A., Currell, K., Ali, V. M., Budgett, R. G., Ljungqvist, A., Mountjoy, M., Pitsiladis, Y. P., Soligard, T., Erdener, U., & Engebretsen, L. (2018). IOC consensus statement: Dietary supplements and the high-performance athlete. *British Journal of Sports Medicine*, *52*(7), 439-455. https://doi.org/10.1136/bjsports-2018-099027

McGawley, K. (2017). The reliability and validity of a four-minute running time-trial in assessing VO_2max and performance. *Frontiers in Physiology*, *8*(270), 1-9. https://doi.org/10.3389/fphys.2017.00270

McLay, R. T., Thomson, C. D., Williams, S. M., & Rehrer, N. J. (2007). Carbohydrate loading and female endurance athletes: Effect of menstrual-cycle phase. *International Journal of Sport Nutrition and Exercise Metabolism, 17*(2), 189-205.

https://doi.org/10.1123/ijsnem.17.2.189

McNulty, K. L., Elliott-Sale, K. J., Dolan, E., Swinton, P. A., Ansdell, P., Goodall, S., Thomas, K., & Hicks, K. M. (2020). The effects of menstrual cycle phase on exercise performance in eumenorrheic women: A systematic review and meta-analysis. *Sports Medicine, 50*(10), 1813-1827. https://doi.org/10.1007/s40279-020-01319-3

Meignié, A., Duclos, M., Carling, C., Orhant, E., Provost, P., Toussaint, J., & Antero, J. (2021). The effects of menstrual cycle phase on elite athlete performance: A critical and systematic review. *Frontiers in Physiology*, *12*(654585), 1-10. https://doi.org/10.3389/fphys.2021.654585

Merrell, L. H., Perkin, O. J., Bradshaw, L., Collier-Bain, H. D., Collins, A. J., Davies, S., Eddy, R., Hickman, J. A., Nicholas, A. P., Rees, D., Spellanzon, B., James, L. J., McKay, A. K., Smith, H. A., Turner, J. E., Koumanov, F., Maher, J., Thompson, D., Gonzalez, J. T., & Betts, J. A. (2024). Myths and methodologies: standardisation in human physiology research—Should we control the controllables? *International Journal of Sport Nutrition and Exercise Metabolism*, *34*(4), 242-250. https://doi.org/10.1123/ijsnem.2024-0091

Mills, E. J., Chan, A., Wu, P., Vail, A., Guyatt, G. H., & Altman, D. G. (2009). Design, analysis, and presentation of crossover trials. *Trials*, *10*(27), 1-6. https://doi.org/10.1186/1745-6215-10-27

Mock, M. G., Hirsch, K. R., Blue, M. N. M., Trexler, E. T., Roelofs, E. J., & Smith-Ryan, A. E. (2021). Post-exercise ingestion of low- or high-molecular-weight glucose polymer solution does not improve cycle performance in female athletes. *Journal of Strength and Conditioning Research*, *35*(1), 124-131. https://doi.org/10.1519/JSC.0000000000002560

Montain, S. J., & Coyle, E. F. (1992). Influence of graded dehydration on hyperthermia and

cardiovascular drift during exercise. *Journal of Applied Physiology*, *73*(4), 1340-1350. https://doi.org/10.1152/jappl.1992.73.4.1340

Moss, J. N., Trangmar, S. J., Mackenzie, R. W., & Tyler, C. J. (2021). The effects of pre- and per-cooling interventions used in isolation and combination on subsequent 15-minute time-trial cycling performance in the heat. *Journal of Science and Medicine in Sport*, *24*(8), 800-805. https://doi.org/10.1016/j.jsams.2021.04.006

Mündel, T., & Jones, D. A. (2010). The effects of swilling an l(−)-menthol solution during exercise in the heat. *European Journal of Applied Physiology*, *109*(1), 59-65. https://doi.org/10.1007/s00421-009-1180-9

Naito, K., Komori, M., Kondo, Y., Takeuchi, M., & Iwata, S. (1997). The effect of l-menthol stimulation of the major palatine nerve on subjective and objective nasal patency. *Auris Nasus Larynx*, *24*(2), 159-162. https://doi.org/10.1016/s0385-8146(96)00005-3

Nevill, A. M., Ramsbottom, R., & Williams, C. (1992). Scaling physiological measurements for individuals of different body size. *European Journal of Applied Physiology*, *65*(2), 110-117. https://doi.org/10.1007/bf00705066

Nishino, T., Tagaito, Y., & Sakurai, Y. (1997). Nasal inhalation of L-menthol reduces respiratory discomfort associated with loaded breathing. *American Journal of Respiratory and Critical Care Medicine*, *156*(1), 309-313. https://doi.org/10.1164/ajrccm.156.1.9609059

Noakes, T. D. (2012). Fatigue is a brain-derived emotion that regulates the exercise behavior to ensure the protection of whole body homeostasis. *Frontiers in Physiology*, *3*(82), 1-13. https://doi.org/10.3389/fphys.2012.00082

Nybo, L., & Nielsen, B. (2001). Hyperthermia and central fatigue during prolonged exercise in humans. *Journal of Applied Physiology*, *91*(3), 1055-1060.

https://doi.org/10.1152/jappl.2001.91.3.1055

O'Malley, C., Fullerton, C., & Mauger, A. (2023). Analysing experienced and inexperienced cyclists' attentional focus and self-regulatory strategies during varying intensities of fixed perceived effort cycling: A mixed method study. *Psychology of Sport and Exercise*, *70*(102544), 1-16. https://doi.org/10.1016/j.psychsport.2023.102544

Ose, B. M., Eisenhauer, J., Roepe, I., Herda, A. A., Vopat, B. G., & Vopat, L. M. (2025). Where are all the female participants in sports and exercise medicine research? A decade later. The American Journal of Sports Medicine, 53(8), 2022–2028. https://doi.org/10.1177/03635465241278350

Pageaux, B. (2014). The psychobiological model of endurance performance: An effort-based decision-making theory to explain self-paced endurance performance. *Sports Medicine*, *44*(9), 1319-1320. https://doi.org/10.1007/s40279-014-0198-2

Pageaux, B., & Lepers, R. (2016). Fatigue induced by physical and mental exertion increases perception of effort and impairs subsequent endurance performance. *Frontiers in Physiology*, *7*(587), 1-9. https://doi.org/10.3389/fphys.2016.00587

Parton, A. J., Waldron, M., Clifford, T., & Jeffries, O. (2021). Thermo-behavioural responses to orally applied l-menthol exhibit sex-specific differences during exercise in a hot environment. *Physiology & Behavior*, *229*(113250), 1–8. https://doi.org/10.1016/j.physbeh.2020.113250

Patel, H., Alkhawam, H., Madanieh, R., Shah, N., Kosmas, C. E., & Vittorio, T. J. (2017). Aerobic vs anaerobic exercise training effects on the cardiovascular system. *World Journal of Cardiology*, *9*(2), 134-138. https://doi.org/10.4330/wjc.v9.i2.134

Paton, C. D., & Hopkins, W. G. (2001). Tests of cycling performance. *Sports Medicine*, *31*(7),

489-496. https://doi.org/10.2165/00007256-200131070-00004

Peel, J., John, K., Page, J., Jeffries, O., Heffernan, S. M., Tallent, J., & Waldron, M. (2023). Topical application of isolated menthol and combined menthol-capsaicin creams: Exercise tolerance, thermal perception, pain, attentional focus and thermoregulation in the heat. *European Journal of Sport Science*, *23*(10), 2038-2048. https://doi.org/10.1080/17461391.2023.2211966

Peeling, P., Binnie, M. J., Goods, P. S., Sim, M., & Burke, L. M. (2018). Evidence-based supplements for the enhancement of athletic performance. *International Journal of Sport Nutrition and Exercise Metabolism*, *28*(2), 178-187. https://doi.org/10.1123/ijsnem.2017-0343

Peier, A. M., Moqrich, A., Hergarden, A. C., Reeve, A. J., Andersson, D. A., Story, G. M., Earley, T. J., Dragoni, I., McIntyre, P., Bevan, S., & Patapoutian, A. (2002). A TRP Channel that Senses Cold Stimuli and Menthol. *Cell*, *108*(5), 705-715. https://doi.org/10.1016/s0092-8674(02)00652-9

Pereira, E. J., Sim, L., Driver, H. S., Parker, C. M., & Fitzpatrick, M. F. (2013). The effect of inhaled menthol on upper airway resistance in humans: A randomized controlled crossover study. *Canadian Respiratory Journal*, *20*(1), 1-4. https://doi.org/10.1155/2013/383019

Pereira, H. M., Larson, R. D., & Bemben, D. A. (2020). Menstrual cycle effects on exercise-induced fatigability. *Frontiers in Physiology*, *11*(517), 1-12. https://doi.org/10.3389/fphys.2020.00517

Pergolizzi, J. V., Taylor, R., LeQuang, J., & Raffa, R. B. (2018). The role and mechanism of action of menthol in topical analgesic products. *Journal of Clinical Pharmacy and*

Therapeutics, *43*(3), 313-319. https://doi.org/10.1111/jcpt.12679

Périard, J. D., Eijsvogels, T. M. H., & Daanen, H. A. M. (2021). Exercise under heat stress: Thermoregulation, hydration, performance implications, and mitigation strategies. *Physiological Reviews*, *101*(4), 1873-1979. https://doi.org/10.1152/physrev.00038.2020

Peserico, C. S., & Machado, F. A. (2014). Comparison between time trial running performances performed on a track and on a treadmill. *Brazilian Journal of Kinanthropometry and Human Performance*, *16*(4), 456-464. https://doi.org/10.5007/1980-0037.2014v16n4p456

Plews, D. J., Scott, B., Altini, M., Wood, M., Kilding, A. E., & Laursen, P. B. (2017). Comparison of heart-rate-variability recording with smartphone photoplethysmography, Polar H7 chest strap, and electrocardiography. *International Journal of Sports Physiology and Performance*, *12*(10), 1324-1328. https://doi.org/10.1123/ijspp.2016-0668

Poole, D. C., Burnley, M., Vanhatalo, A., Rossiter, H. B., & Jones, A. M. (2016). Critical power. *Medicine & Science in Sports & Exercise*, *48*(11), 2320-2334. https://doi.org/10.1249/mss.0000000000000939

Poole, D. C., Wilkerson, D. P., & Jones, A. M. (2008). Validity of criteria for establishing maximal O_2 uptake during ramp exercise tests. *European Journal of Applied Physiology*, *102*(4), 403-410. https://doi.org/10.1007/s00421-007-0596-3

Puente-Maestu, L., Palange, P., Casaburi, R., Laveneziana, P., Maltais, F., Neder, J. A., O'Donnell, D. E., Onorati, P., Porszasz, J., Rabinovich, R., Rossiter, H. B., Singh, S., Troosters, T., & Ward, S. (2016). Use of exercise testing in the evaluation of interventional efficacy: An official ERS statement. *European Respiratory Journal*, *47*(2), 429-460. https://doi.org/10.1183/13993003.00745-2015

Racinais, S., Alonso, J. M., Coutts, A. J., Flouris, A. D., Girard, O., González-Alonso, J.,

Hausswirth, C., Jay, O., Lee, J. K. W., Mitchell, N., Nassis, G. P., Nybo, L., Pluim, B. M., Roelands, B., Sawka, M. N., Wingo, J., & Périard, J. D. (2015). Consensus recommendations on training and competing in the heat. *British Journal of Sports Medicine*, *49*(18), 1164-1173. https://doi.org/10.1136/bjsports-2015-094915

Rael, B., Alfaro-Magallanes, V., Romero-Parra, N., Castro, E., Cupeiro, R., De Jonge, X. J., Wehrwein, E., & Peinado, A. (2021). Menstrual cycle phases influence on cardiorespiratory response to exercise in endurance-trained females. *International Journal of Environmental Research and Public Health, 18*(3), 1-12. https://doi.org/10.3390/ijerph18030860

Reilly, T. (1990). Human circadian rhythms and exercise. *Critical Reviews in Biomedical Engineering*, *18*(3), 165-180. https://pubmed.ncbi.nlm.nih.gov/2286092/

Renner, B., & Schreiber, K. (2012). Olfactory and trigeminal interaction of menthol and nicotine in humans. *Experimental Brain Research*, *219*(1), 13-26. https://doi.org/10.1007/s00221-012-3063-2

Riebe, D., Ehrman, J. K., Liguori, G., & Magal, M. (2018). *ACSM's guidelines for exercise testing and prescription (10th ed.).* Wolters Kluwer.

Riera, F., Trong, T. T., Sinnapah, S., & Hue, O. (2014). Physical and perceptual cooling with beverages to increase cycle performance in a tropical climate. *PLOS ONE*, *9*(8), 1-7. https://doi.org/10.1371/journal.pone.0103718

Roriz, M., Brito, J., Teixeira, F. J., Spyrou, K., & Teixeira, V. H. (2024). The effect of menthol rinsing before intermittent exercise on physiological, physical, and thermo-behavioral responses of male football referees in hot and humid environment. *Frontiers in Sports and Active Living*, *6*(1334739), 1-12. https://doi.org/10.3389/fspor.2024.1334739

Rosenblat, M. A., Arnold, J., Nelson, H., Watt, J., & Seiler, S. (2023). The additional effect of training above the maximal metabolic steady state on VO_2peak, Wpeak, and time-trial performance in endurance-trained athletes: A systematic review, meta-analysis, and reality check. *Sports Medicine*, *54*(2), 429-446. https://doi.org/10.1007/s40279-023-01924-y

Sadaka, A. S., Faisal, A., Khalil, Y. M., Mourad, S. M., Zidan, M. H., Polkey, M. I., & Hopkinson, N. S. (2021). Reduced skeletal muscle endurance and ventilatory efficiency during exercise in adult smokers without airflow obstruction. *Journal of Applied Physiology*, *130*(4), 976-986. https://doi.org/10.1152/japplphysiol.00762.2020

Santana, E. J., Cauwenberghs, N., Celestin, B. E., Kuznetsova, T., Gardner, C., Arena, R., Kaminsky, L. A., Harber, M. P., Ashley, E., Christle, J. W., Myers, J., & Haddad, F. (2024). A generalized equation for predicting peak oxygen consumption during treadmill exercise testing: mitigating the bias from total body mass scaling. *Frontiers in Cardiovascular Medicine*, *11*(1393363), 1-13. https://doi.org/10.3389/fcvm.2024.1393363

Santtila, M., Häkkinen, K., Pihlainen, K., & Kyröläinen, H. (2013). Comparison between direct and predicted maximal oxygen uptake measurement during cycling. *Military Medicine*, *178*(2), 234-238. https://doi.org/10.7205/milmed-d-12-00276

Sarria, I., Ling, J., Zhu, M. X., & Gu, J. G. (2011). TRPM8 acute desensitization is mediated by calmodulin and requires PIP2: distinction from tachyphylaxis. *Journal of Neurophysiology*, *106*(6), 3056–3066. https://doi.org/10.1152/jn.00544.2011

Schaeffer, M. R., Vanden Bossche, L., Beckers, K., Verbeke, K., Janssens, W., Jensen, D., Arnold, J. I., Von Leupoldt, A., & Langer, D. (2025). Inhaled menthol for dyspnea relief

during cycle exercise in COPD: A randomized trial. *CHEST Journal, 168*(2), 390-401. https://doi.org/10.1016/j.chest.2025.03.002

Scherr, J., Wolfarth, B., Christle, J. W., Pressler, A., Wagenpfeil, S., & Halle, M. (2012). Associations between Borg's rating of perceived exertion and physiological measures of exercise intensity. *European Journal of Applied Physiology*, *113*(1), 147-155. https://doi.org/10.1007/s00421-012-2421-x

Schlader, Z. J., Simmons, S. E., Stannard, S. R., & Mündel, T. (2011). The independent roles of temperature and thermal perception in the control of human thermoregulatory behavior. *Physiology & Behavior*, *103*(2), 217-224. https://doi.org/10.1016/j.physbeh.2011.02.002

Schoech, L., Allie, K., Salvador, P., Martinez, M., & Rivas, E. (2021). Sex differences in thermal comfort, perception, feeling, stress and focus during exercise hyperthermia. *Perceptual and Motor Skills*, *128*(3), 969-987. https://doi.org/10.1177/00315125211002096

Sheel, A. W., Richards, J. C., Foster, G. E., & Guenette, J. A. (2004). Sex differences in respiratory exercise physiology. *Sports Medicine, 34*(9), 567–579. https://doi.org/10.2165/00007256-200434090-00002

Shuba, Y. M. (2021). Beyond neuronal heat sensing: Diversity of TRPV1 heat-capsaicin receptor-channel functions. *Frontiers in Cellular Neuroscience*, *14*(612480), 1-17. https://doi.org/10.3389/fncel.2020.612480

Silva, H. (2020). Current knowledge on the vascular effects of menthol. *Frontiers in Physiology*, *11*(298), 1-11. https://doi.org/10.3389/fphys.2020.00298

Skorski, S., & Abbiss, C. R. (2017). The manipulation of pace within endurance sport. *Frontiers in Physiology*, *8*(102), 1-8. https://doi.org/10.3389/fphys.2017.00102

Spriet, L. L. (2002). Regulation of skeletal muscle fat oxidation during exercise in humans.

Medicine & Science in Sports & Exercise, *34*(9), 1477-1484. https://doi.org/10.1097/00005768-200209000-00013

Springer, B. K., & Pincivero, D. M. (2009). Differences in ratings of perceived exertion between the sexes during single-joint and whole-body exercise. *Journal of Sports Sciences*, *28*(1), 75-82. https://doi.org/10.1080/02640410903390097

Stathokostas, L., Jacob-Johnson, S., Petrella, R. J., & Paterson, D. H. (2004). Longitudinal changes in aerobic power in older men and women. *Journal of Applied Physiology*, *97*(2), 781-789. https://doi.org/10.1152/japplphysiol.00447.2003

Stevens, C. J., & Best, R. (2017). Menthol: A fresh ergogenic aid for athletic performance. *Sports Medicine*, *47*(6), 1035-1042. https://doi.org/10.1007/s40279-016-0652-4

Stevens, C. J., Mauger, A. R., Hassmén, P., & Taylor, L. (2018). Endurance performance is influenced by perceptions of pain and temperature: Theory, applications, and safety considerations. *Sports Medicine*, *48*(3), 525-537. https://doi.org/10.1007/s40279-017-0852-6

Stevens, C. J., Thoseby, B., Sculley, D. V., Callister, R., Taylor, L., & Dascombe, B. J. (2016). Running performance and thermal sensation in the heat are improved with menthol mouth rinse but not ice slurry ingestion. *Scandinavian Journal of Medicine and Science in Sports*, *26*(10), 1209-1216. https://doi.org/10.1111/sms.12555

Takaishi, M., Uchida, K., Suzuki, Y., Matsui, H., Shimada, T., Fujita, F., & Tominaga, M. (2015). Reciprocal effects of capsaicin and menthol on thermosensation through regulated activities of TRPV1 and TRPM8. *The Journal of Physiological Sciences*, *66*(2), 143-155. https://doi.org/10.1007/s12576-015-0427-y

Tan, C. L., & Knight, Z. A. (2018). Regulation of body temperature by the nervous system.

Neuron, *98*(1), 31-48. https://doi.org/10.1016/j.neuron.2018.02.022

Tanaka, H., Bassett, D. R., Jr., Swensen, T. C., & Sampedro, R. M. (1993). Aerobic and anaerobic power characteristics of competitive cyclists in the United States Cycling Federation. *International Journal of Sports Medicine*, *14*(6), 334-338. https://doi.org/10.1055/s-2007-1021188

Tanaka, H., Monahan, K. D., & Seals, D. R. (2001). Age-predicted maximal heart rate revisited. *Journal of the American College of Cardiology*, *37*(1), 153–156. https://doi.org/10.1016/s0735-1097(00)01054-8

Taylor, J. L., Amann, M., Duchateau, J., Meeusen, R., & Rice, C. L. (2016). Neural contributions to muscle fatigue. *Medicine & Science in Sports & Exercise*, *48*(11), 2294-2306. https://doi.org/10.1249/mss.0000000000000923

Than, J. Y., Li, L., Hasan, R., & Zhang, X. (2013). Excitation and modulation of TRPA1, TRPV1, and TRPM8 channel-expressing sensory neurons by the pruritogen chloroquine. *Journal of Biological Chemistry*, *288*(18), 12818-12827. https://doi.org/10.1074/jbc.m113.450072

Thein, L. A., Thein, J. M., & Landry, G. L. (1995). Ergogenic aids. *Physical Therapy*, *75*(5), 426-439. https://doi.org/10.1093/ptj/75.5.426

Torgrimson, B. N., & Minson, C. T. (2005). Sex and gender: What is the difference? *Journal of Applied Physiology*, *99*(3), 785-787. https://doi.org/10.1152/japplphysiol.00376.2005

Tornero-Aguilera, J. F., Jiménez-Morcillo, J., Rubio-Zarapuz, A., & Clemente-Suárez, V. J. (2022). Central and peripheral fatigue in physical exercise explained: A narrative review. *International Journal of Environmental Research and Public Health*, *19(7), Article 3909.* https://doi.org/10.3390/ijerph19073909

Trong, T. T., Riera, F., Rinaldi, K., Briki, W., & Hue, O. (2015). Ingestion of a cold temperature/menthol beverage increases outdoor exercise performance in a hot, humid environment. *PLOS ONE, 10*(4), 1-8. https://doi.org/10.1371/journal.pone.0123815

Tsutsumi, Y., Momma, H., Ebihara, S., & Nagatomi, R. (2022). L-menthol administration facilitates breathing comfort during exhaustive endurance running and improves running capacity in well-trained runners: A randomized crossover study. *European Journal of Sport Science*, *23*(9), 1913-1921. https://doi.org/10.1080/17461391.2022.2115404

Valenzuela, P. L., Alejo, L. B., Montalvo-Pérez, A., Gil-Cabrera, J., Talavera, E., Lucía, A., & Barranco-Gil, D. (2021). Relationship between critical power and different lactate threshold markers in recreational cyclists. *Frontiers in Physiology*, *12*(676484), 1–8. https://doi.org/10.3389/fphys.2021.676484

Villegas-Serna, T., Wilson, L. J., & Curtis, C. (2024). Topical application of L-menthol—Physiological and genetic considerations to assist in developing female athlete research: A narrative review. *Journal of Thermal Biology, 119*(103758), 1–9. https://doi.org/10.1016/j.jtherbio.2023.103758

Vitale, K., & Getzin, A. (2019). Nutrition and supplement update for the endurance athlete: Review and recommendations. *Nutrients*, *11*(1289), 1–20. https://doi.org/10.3390/nu11061289

Vogel, R. M., Varone, N., Clark, C., Ramirez, K., Ross, M. L. R., Swann, C., & Stevens, C. J. (2023). A menthol-enhanced “cooling” energy gel does not influence laboratory time trial performance in trained runners. *Nutrients, 15*(15), 1-13. https://doi.org/10.3390/nu15153379

Vos, L., Vergeer, R. N., Goulding, R. P., Weide, G., De Koning, J. J., Jaspers, R. T., & Van Der

Zwaard, S. (2025). Predicting cycling performance before and after training: Insights from machine learning using small samples. *Applied Artificial Intelligence, 39*(2565167), 1–21. https://doi.org/10.1080/08839514.2025.2565167

Wackerhage, H., Gehlert, S., Schulz, H., Weber, S., Ring-Dimitriou, S., & Heine, O. (2022). Lactate thresholds and the simulation of human energy metabolism: Contributions by the Cologne Sports Medicine Group in the 1970s and 1980s. *Frontiers in Physiology*, *13*(899670), 1-13. https://doi.org/10.3389/fphys.2022.899670

Weinstein, A. A., Chin, L. M., Keyser, R. E., Kennedy, M., Nathan, S. D., Woolstenhulme, J. G., Connors, G., & Chan, L. (2013). Effect of aerobic exercise training on fatigue and physical activity in patients with pulmonary arterial hypertension. *Respiratory Medicine*, *107*(5), 778-784. https://doi.org/10.1016/j.rmed.2013.02.006

White, J., Tannenbaum, C., Klinge, I., Schiebinger, L., & Clayton, J. (2021). The integration of sex and gender considerations into biomedical research: Lessons from international funding agencies. *The Journal of Clinical Endocrinology & Metabolism*, *106*(10), 3034-3048. https://doi.org/10.1210/clinem/dgab434

Wiącek, J., & Karolkiewicz, J. (2023). Different approaches to ergogenic, pre-, and probiotic supplementation in sports with different metabolism characteristics: A mini review. *Nutrients*, *15*(6), 1-12. https://doi.org/10.3390/nu15061541

Willis, D. N., Liu, B., Ha, M. A., Jordt, S., & Morris, J. B. (2011). Menthol attenuates respiratory irritation responses to multiple cigarette smoke irritants. *The FASEB Journal*, *25*(12), 4434-4444. https://doi.org/10.1096/fj.11-188383

Wilson, R. C., & Jones, P. W. (1989). A comparison of the visual analogue scale and modified Borg scale for the measurement of dyspnoea during exercise. *Clinical Science, 76*(3),

277–282. https://doi.org/10.1042/cs0760277

Wingo, J. E., Lafrenz, A. J., Ganio, M. S., Edwards, G. L., & Cureton, K. J. (2005). Cardiovascular drift is related to reduced maximal oxygen uptake during heat stress. *Medicine & Science in Sports & Exercise*, *37*(2), 248-255. https://doi.org/10.1249/01.mss.0000152731.33450.95

World Medical Association. (2013). World Medical Association Declaration of Helsinki: Ethical principles for medical research involving human subjects. *JAMA*, *310*(20), 2191-2194. https://doi.org/10.1001/jama.2013.281053

Yin, Y., Park, C., Zhang, F., Fedor, J. G., Feng, S., Suo, Y., Im, W., & Lee, S. (2024). Mechanisms of sensory adaptation and inhibition of the cold and menthol receptor TRPM8. *Science Advances*, *10*(31), 1-16. https://doi.org/10.1126/sciadv.adp2211

Yosipovitch, G., Szolar, C., Hui, X. Y., & Maibach, H. (1996). Effect of topically applied menthol on thermal, pain and itch sensations and biophysical properties of the skin. *Archives of Dermatological Research*, *288*(5–6), 245–248. https://doi.org/10.1007/bf02530092

Yu, L., Chen, Z., Wu, W., Xu, X., Lv, Y., & Li, C. (2024). Effects of precooling on endurance exercise performance in the heat: A systematic review and meta-analysis of randomized controlled trials. *Nutrients*, *16*(23), 1-16. https://doi.org/10.3390/nu16234217

Zhang, H., Huizenga, C., Arens, E., & Wang, D. (2004). Thermal sensation and comfort in transient non-uniform thermal environments. *European Journal of Applied Physiology, 92*(6), 728–733. https://doi.org/10.1007/s00421-004-1137-y

Zhang, M., Ma, Y., Ye, X., Zhang, N., Pan, L., & Wang, B. (2023). TRP (transient receptor potential) ion channel family: structures, biological functions and therapeutic

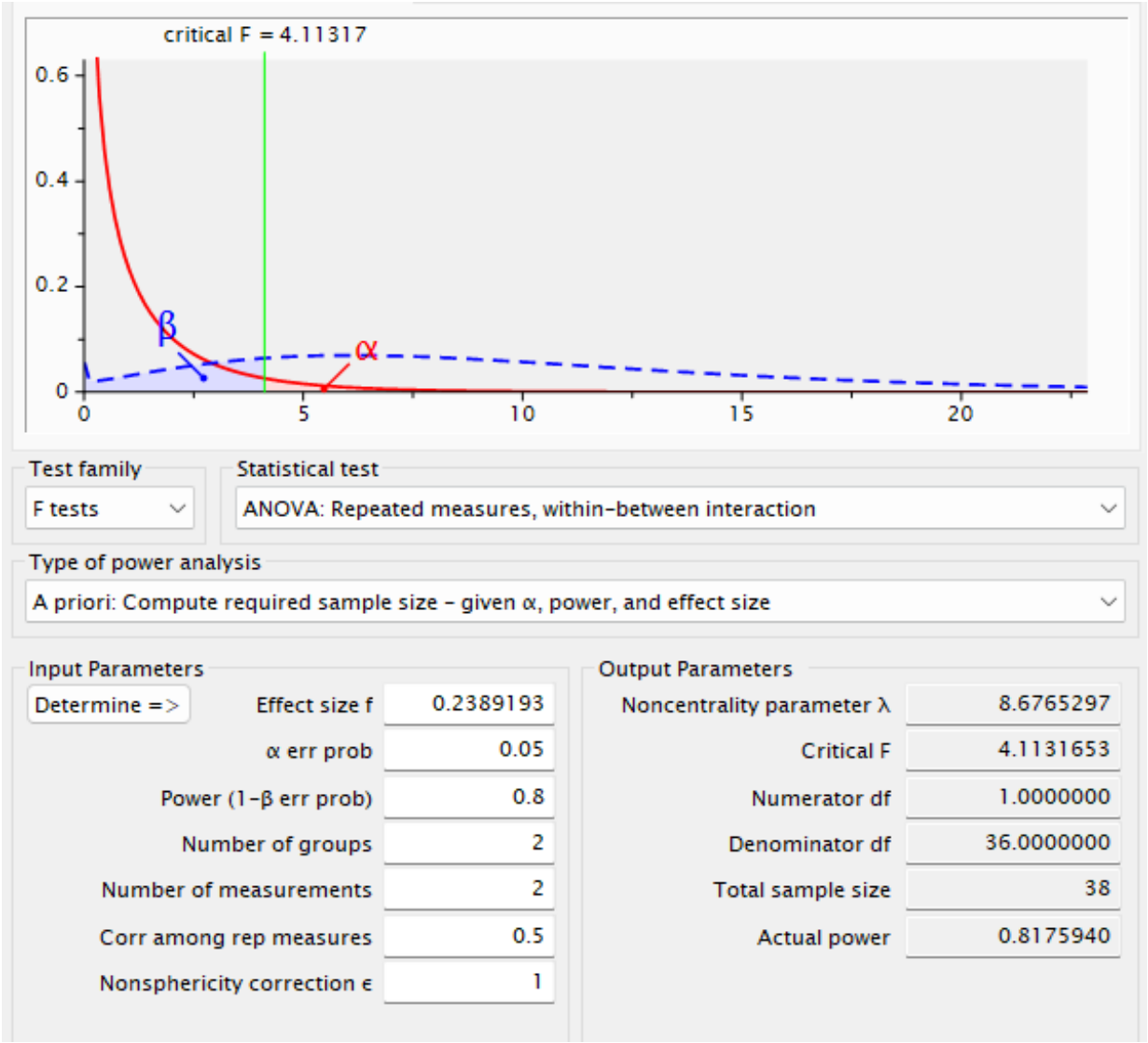
interventions for diseases. *Signal Transduction and Targeted Therapy*, *8*(261), 1–38. https://doi.org/10.1038/s41392-023-01464-x

Zhao, K., Blacker, K., Luo, Y., Bryant, B., & Jiang, J. (2011). Perceiving nasal patency through mucosal cooling rather than air temperature or nasal resistance. *PLOS ONE*, 6(10), 1-8. https://doi.org/10.1371/journal.pone.0024618

Zolfaghari, A., & Maerefat, M. (2011). A new predictive index for evaluating both thermal sensation and thermal response of the human body. *Building and Environment*, *46*(4), 855–862. https://doi.org/10.1016/j.buildenv.2010.10.011

Appendices

Appendix A: A Priori Power Analysis



Note. As no prior study had reported a Condition × Sex interaction effect for repeated menthol nasal inhalation during self-paced exercise in healthy adults, the interaction effect size was estimated from related oral-menthol research. Parton et al. (2021) reported $\eta p^2 = .054$ for a sex-specific response to orally applied L-menthol. This value was converted to Cohen's f ($f = .239$) and used as the approximate interaction effect for the a priori analysis in G*Power 3.1.9.7.

Appendix B: Recruitment Poster

Lakehead UNIVERSITY | School of Kinesiology

Physically Active Adults Needed

for Cycling Performance Study Using Menthol Inhalation

Are You Eligible to Participate?

Must be:

- Between the ages of 18 and 35
- Perform ≥150 minutes of moderate aerobic exercise per week or ≥75 minutes of vigorous exercise per week for the past three months
- Able to safely perform moderate-to-vigorous cycling exercise
- Free from any cardiovascular, respiratory, metabolic, or musculoskeletal conditions that could limit exercise participation

Your Commitment

3 laboratory visits totalling 2 hours and 15 minutes:

- One familiarization session (~45mins).
- Two cycling time-trial sessions, 15-minute time-trial (~45 mins each).

Participation Requirements

- Inhalation of menthol vapour during one trial.
- Provide rating of perceived exertion, thermal sensation and breathing comfort.
- Wear a chest-strap heart rate monitor.

Potential Benefits

While there are no direct personal benefits, participants may gain insight into their cycling performance and physiological responses to exercise. As well as contribute to research on strategies that may influence endurance performance.

Contact Information

Student Researcher:
Tyson Mayer
tjmayer@lakeheadu.ca
+1 (807) 633-4214

This study has been approved by the Lakehead University Research Ethics Board

Appendix C: Participant Information Letter

Lakehead UNIVERSITY | Research Services

Information Letter

Dear Potential Participant,

Thank you for expressing an interest in the research study titled "Influence of Menthol Nasal Inhalation on Self-Paced Cycling Time-Trial Performance, Perceptual and Physiological Responses in Active Adult Males and Females."

The study is being conducted by Tyson Mayer, a graduate student in the Master of Science (MSc) program in the School of Kinesiology at Lakehead University. This research project will be conducted under the supervision of Dr. Derek Kivi, Associate Professor in the School of Kinesiology.

Purpose

The purpose of this study is to investigate the effects of menthol nasal inhalation on cycling time-trial performance and perceptual responses during exercise in active adult males and females.

Menthol is a naturally occurring compound which is commonly used in consumer products due to its cooling sensation and potential to improve breathing comfort. This study will examine whether menthol inhalation influences cycling performance, perceived exertion, thermal sensation, and respiratory comfort during a laboratory cycling time-trial.

What is Requested as a Participant?

You are being asked to voluntarily participate in this study because you are a physically active adult between the ages of 18 and 35 years.

To be eligible to participate in this study, you must:

- Engage in regular aerobic exercise.
- Be able to perform moderate-to-vigorous cycling exercise safely.
- Be either male or female, which was assigned at birth.
- Complete the Get Active Questionnaire (GAQ), confirming that participation in exercise is safe.

Individuals with cardiovascular, respiratory, metabolic, or musculoskeletal conditions that could limit participation in safe exercise will not be eligible.

What Will Participation Involve?

If you agree to participate in this study, you will be asked to attend three laboratory sessions at the C.J. Sanders Fieldhouse (SB-1025) at Lakehead University. Each session will last approximately 45 minutes for a total of 2 hours and 15 minutes.

During the **familiarization session**, you will:

- Complete a standardized warm-up on the cycle ergometer.
- Perform a graded ramp cycling protocol in which resistance gradually increases until a rating of perceived exertion (RPE) of fifteen is reached.
- Become familiar with the perceptual rating scales that will be used during the experimental trials.
- Have the cycling resistance for the experimental trials been determined from your performance during the ramp protocol.

During the **experimental sessions**, you will:

- Complete a standardized warm-up on the cycle ergometer.
- Perform a 15-minute self-paced cycling time trial on a cycle ergometer and inhale menthol vapour nasally during one of the trials.
- Provide ratings of perceived exertion, thermal sensation, and respiratory comfort during exercise.
- Wear a Polar H10 heart rate chest-strap monitor to continuously measure heart rate.

Nasal inhalation will occur for 5 seconds at 0, 5, and 10 minutes during the cycling time trial. Perceptual ratings will be collected at 0, 5, 10, and 15 minutes during the time trial. A cooldown will be completed following the exercise test.

What Risks Come with Participating in This Study?

Participation in this study involves moderate-to-vigorous exercise, which carries inherent risks such as:

- Fatigue.
- Shortness of breath.
- Dizziness.
- Muscle soreness.

To minimize risks:

- Participants will complete the Get Active Questionnaire (GAQ) before participation.
- A standardized warm-up will be performed before testing.
- The researcher will supervise all exercise testing.

Menthol nasal inhalation may produce mild sensations, such as cooling or tingling, in the nasal passages, but it is generally considered safe at the amount used in this study. Two dedicated nasal inhalation apparatuses will be used: one for the menthol condition and one for the control condition. The apparatuses will be cleaned between participants and stored separately to help prevent cross-contamination. Participants may stop the test at any time if they feel discomfort.

If nasal discomfort or irritation lasts for more than 24 hours following a session, please contact the research team to determine appropriate next steps, which may include seeking medical attention if deemed necessary.

How Does Participating in This Study Benefit You?

You may not receive direct personal benefits from participation. However, you may gain insight into your cycling performance. Additionally, your participation will contribute to research examining the use of menthol inhalation during endurance exercise, including its potential effects on perceptual responses (such as perceived effort, thermal sensation, and breathing comfort) and overall performance.

What Are Your Rights as a Participant?

As a potential participant, you maintain the following rights throughout this study:

I. You are under no obligation to participate and may stop any laboratory/cycling session at any time without penalty.
II. Your decision to participate will not affect your academic, employment, or athletic status.
III. You will be given information relevant to your decision to continue participation during the study.
IV. You may request that your collected data be withdrawn from the study for up to four weeks after completing your final session. After this four-week period, your data may be de-identified and combined with other participant data, and it may no longer be possible to remove your individual data from the study dataset.

How to Receive a Copy of the Research Results

If you wish to receive a copy of your individual results and/or a summary of the overall results of the study, please indicate this on the consent form and provide an email address where the results can be sent.

Withdrawal of Data

You may request to withdraw your collected data from the study for up to four weeks after completing your final session. To withdraw your data, you may contact the research team using the contact information provided in this letter. After the four-week withdrawal period, your data may be de-identified and combined with other participant data, and it may no longer be possible to remove your individual data from the study dataset.

How Will Confidentiality Be Maintained?

All information collected during this study will remain confidential. Participants will be assigned a unique identification number, and no identifying information will be attached to the data. All electronic data will be stored on a password-protected computer, and hard-copy

documents will be securely stored at Lakehead University. Only the student researcher and research supervisor will have access to the data.

How Will the Results of the Study Be Published?

The results of this study may be presented to graduate students and faculty in the School of Kinesiology at Lakehead University and may also be submitted for publication in a peer-reviewed scientific journal or presented at a scientific conference.

Participants will not be identified in any publication or presentation.

Where Will Your Data Be Stored?

Upon completion of this study, the data will be stored at the School of Kinesiology at Lakehead University with Dr. Derek Kivi for a seven-year period. All electronic data will be securely stored on a password-protected computer, with hard copies of the consent forms, GAQs, and information/demographic forms locked in Dr. Derek Kivi's office. Only the student researcher and the research supervisor involved in this study may access the results.

Researcher Contact Information

If you have any questions and/or are interested in participating in this study, feel free to contact the student researcher, Tyson Mayer, using the contact information listed below. You may also contact the research supervisor, Dr. Derek Kivi.

Research Ethics Board Review and Approval

This study has been approved by the Lakehead University Research Ethics Board. If you have any questions regarding the ethics of this research, you would like to talk with someone other than the involved researchers, contact Sue Wright at the Lakehead University Research Ethics Board at 1(807)343-8283 or research@lakeheadu.ca

Your participation would be greatly appreciated. Thank you for your consideration.

Sincerely,
Tyson Mayer
Student Researcher
tjmayer@lakeheadu.ca

Dr. Derek Kivi
Research Supervisor
dkivi@lakeheadu.ca

Appendix D: Informed Consent Form

I Understand and Consent to the Following:

- ☐ I have read and understood the information contained in the Information Letter.
- ☐ I have responded truthfully to any screening measures, even if it limits my ability to participate in this study.
- ☐ I agree to participate.
- ☐ I understand that I may stop any laboratory/cycling session at any time without penalty.
- ☐ I understand that I may request to withdraw my collected data from the study for up to four weeks after completing my final session.
- ☐ I understand the risks and benefits of the study.
- ☐ The data will be securely stored at Lakehead University for a minimum of 7 years following completion of the research project.
- ☐ The research findings will be made available upon request.
- ☐ My information will remain confidential in any publications or presentations of the research findings.
- ☐ Any previous questions/concerns have been addressed

By consenting to participate, I have not waived any rights to legal recourse in the event of research-related harm.

Name (printed): _____

_____ _____
Signature of Participant Date (dd/mm/yyyy)

Would you like to receive a copy of your individual results and/or a summary of the overall results of the study?

☐ Individual results Email: _____
☐ Summary of results ☐ Neither

_____ _____
Signature of Student Researcher Date (dd/mm/yyyy)

_____ _____
Signature of Research Supervisor Date (dd/mm/yyyy)

Appendix E: Get Active Questionnaire (GAQ)

CSEP | SCPE
THE GOLD STANDARD IN EXERCISE SCIENCE AND PERSONAL TRAINING

Get Active Questionnaire

CANADIAN SOCIETY FOR EXERCISE PHYSIOLOGY –
PHYSICAL ACTIVITY TRAINING FOR HEALTH (CSEP-PATH®)

Physical activity improves your physical and mental health. Even small amounts of physical activity are good, and more is better.

For almost everyone, the benefits of physical activity far outweigh any risks. For some individuals, specific advice from a Qualified Exercise Professional (QEP – has post-secondary education in exercise sciences and an advanced certification in the area – see csep.ca/certifications) or health care provider is advisable. **This questionnaire is intended for all ages – to help move you along the path to becoming more physically active.**

☐ I am completing this questionnaire for myself.

☐ I am completing this questionnaire for my child/dependent as parent/guardian.

PREPARE TO BECOME MORE ACTIVE

The following questions will help to ensure that you have a safe physical activity experience. Please answer **YES** or **NO** to each question before you become more physically active. If you are unsure about any question, answer **YES**.

YES	NO	
		1 Have you experienced **ANY** of the following (A to F) **within the past six months**?
○	○	**A** A diagnosis of/treatment for heart disease or stroke, or pain/discomfort/pressure in your chest during activities of daily living or during physical activity?
○	○	**B** A diagnosis of/treatment for high blood pressure (BP), or a resting BP of 160/90 mmHg or higher?
○	○	**C** Dizziness or lightheadedness during physical activity?
○	○	**D** Shortness of breath at rest?
○	○	**E** Loss of consciousness/fainting for any reason?
○	○	**F** Concussion?
○	○	2 Do you currently have pain or swelling in any part of your body (such as from an injury, acute flare-up of arthritis, or back pain) that affects your ability to be physically active?
○	○	3 Has a health care provider told you that you should avoid or modify certain types of physical activity?
○	○	4 Do you have any other medical or physical condition (such as diabetes, cancer, osteoporosis, asthma, spinal cord injury) that may affect your ability to be physically active?

NO to all questions: go to Page 2 – ASSESS YOUR CURRENT PHYSICAL ACTIVITY

YES to any question: go to Reference Document – ADVICE ON WHAT TO DO IF YOU HAVE A YES RESPONSE

CSEP | SCPE
THE GOLD STANDARD IN EXERCISE SCIENCE AND PERSONAL TRAINING

Get Active Questionnaire

ASSESS YOUR CURRENT PHYSICAL ACTIVITY

Answer the following questions to assess how active you are now.

1 During a typical week, on how many days do you do moderate- to vigorous-intensity aerobic physical activity (such as brisk walking, cycling or jogging)? ☐ DAYS/WEEK

2 On days that you do at least moderate-intensity aerobic physical activity (e.g., brisk walking), for how many minutes do you do this activity? ☐ MINUTES/DAY

For adults, please multiply your average number of days/week by the average number of minutes/day: ☐ MINUTES/WEEK

Canadian 24-Hour Movement Guidelines recommend that adults accumulate at least 150 minutes of moderate- to vigorous-intensity physical activity per week. For children and youth, at least 60 minutes daily is recommended. Strengthening muscles and bones at least two times per week for adults, and three times per week for children and youth, is also recommended (see csep.ca/guidelines).

GENERAL ADVICE FOR BECOMING MORE ACTIVE

Increase your physical activity gradually so that you have a positive experience. Build physical activities that you enjoy into your day (e.g., take a walk with a friend, ride your bike to school or work) and reduce your sedentary behaviour (e.g., prolonged sitting).

If you want to do **vigorous-intensity physical activity** (i.e., physical activity at an intensity that makes it hard to carry on a conversation), and you do not meet minimum physical activity recommendations noted above, consult a Qualified Exercise Professional (QEP) beforehand. This can help ensure that your physical activity is safe and suitable for your circumstances.

Physical activity is also an important part of a healthy pregnancy.

Delay becoming more active if you are not feeling well because of a temporary illness.

DECLARATION

To the best of my knowledge, all of the information I have supplied on this questionnaire is correct.
If my health changes, I will complete this questionnaire again.

I answered NO to all questions on Page 1

Sign and date the Declaration below

I answered YES to any question on Page 1

Check the box below that applies to you:

☐ I have consulted a health care provider or Qualified Exercise Professional (QEP) who has recommended that I become more physically active.

☐ I am comfortable with becoming more physically active on my own without consulting a health care provider or QEP.

Name (+ Name of Parent/Guardian if applicable) (Please print)	Signature (or Signature of Parent/Guardian if applicable)	Date of Birth

Date	Email (optional)	Telephone (optional)

With planning and support you can enjoy the benefits of becoming more physically active. A QEP can help.

☐ Check this box if you would like to consult a QEP about becoming more physically active.
(This completed questionnaire will help the QEP get to know you and understand your needs.)

Appendix F: Participant Screening Form

Filled out by Researcher:

Participant Name: _____

Filled out by Participant:

Information collected on this form will be kept confidential and may only be reviewed by the research team. As a reminder, you have the right to withdraw from participation at any time and may choose not to answer any questions.

Please answer the following questions to determine eligibility for participation in this study:

1. Are you between 18 and 35 years of age?
   - ☐ Yes
   - ☐ No

2. Do you currently meet the following criteria to be deemed physically active?

- Engage in ≥150 minutes of moderate-intensity aerobic activity per week
- Engage in ≥75 minutes of vigorous-intensity aerobic activity per week
  - For at least three consecutive months before participation.

   - ☐ Yes
   - ☐ No

3. Do you have any allergy or hypersensitivity to menthol or menthol-containing products?
   - ☐ Yes
   - ☐ No

4. Have you previously used menthol products during exercise (e.g., menthol spray, gum, mouth rinse, inhalant)?
   - ☐ Yes
   - ☐ No

   If yes, please describe: _____

5. Have you sustained a musculoskeletal injury within the past three months that would limit the ability to perform maximal cycling exercise?
   - ☐ Yes
   - ☐ No

6. Do you currently take medications or supplements that may influence cardiovascular responses or perceptual responses to exercise?
   - ☐ Yes
   - ☐ No

7. Have you been diagnosed with anosmia (loss of smell) or dysgeusia (altered taste)?
   - ☐ Yes
   - ☐ No

The following questions are **optional** and are included to help interpret potential sex-based differences in responses to exercise.

For participants assigned **female** at birth

8. Do you currently use hormonal contraceptives?

   - ☐ Yes, please specify which type **(optional)**: _____
   - ☐ No
   - ☐ Prefer not to say

9. When was the first day of your most recent menstrual period? _____
   - ☐ Prefer not to say

Participant Signature: _____

Researcher Signature: _____

Eligible for participation (YES/NO): _____

Date (dd/mm/yyyy): _____

Appendix G: Standardized Time-Trial Instruction Script

The following standardized instructions were read to all participants prior to the start of each experimental trial.

"You will complete a 15-minute self-paced cycling time trial on the cycle ergometer. Your objective is to cover as much distance as possible during the 15-minute period. You may adjust your cadence throughout the trial as you wish; however, you must always remain seated on the ergometer."

"During the trial, you will be asked to provide ratings of perceived exertion, thermal sensation, and respiratory comfort at several time points. When prompted, please respond as quickly and accurately as possible while continuing to cycle. Please avoid stopping or pausing your cycling unless you feel unable to continue."

"If at any time you experience unusual discomfort, dizziness, or wish to stop, please inform the researcher immediately and the trial will be terminated."

"Do you understand the procedure before starting the time trial?"

"Do you have any questions before we begin?"

"You will not receive feedback regarding elapsed time or performance during the trial."

Appendix H: Perceptual Measurement Scales and Administration Script

Administration Script:

Participants were provided with standardized instructions for each perceptual scale prior to and during the time trial.

Rating of Perceived Exertion (RPE)

“This scale measures how hard you feel your body is working during exercise. The scale ranges from 6 (no exertion) to 20 (maximal exertion). When prompted, please report the number that best reflects your overall effort at that moment.”

Thermal Sensation (TS)

“This scale measures how hot or cold you feel. The scale ranges from −4 (very cold) to +4 (very hot), with 0 representing neutral. When prompted, please report the number that best reflects how you feel at that moment.”

Respiratory Comfort (RC)

“This scale measures how comfortable your breathing feels. The scale ranges from 0 (no discomfort) to 10 (maximal discomfort). When prompted, please report the number that best reflects your breathing comfort at that moment.”

Participants provided ratings at 0, 5, 10, and 15 minutes during the time trial, and responses were recorded by the researcher.

Figure H1

Borg's Original RPE Scale

6	Zero Exertion
7	Extremely light
8	Minimal effort
9	Very light exertion (comfortable)
10	Just start to hear breathing
11	Conversation is easy
12	Light exertion
13	Somewhat hard
14	Breathing hard but not struggling
15	Can converse but not full sentences
16	Hard work
17	Very hard - getting uncomfortable
18	Can no longer converse
19	Extremely hard - body is screaming
20	Maximal exertion

Note. Rating of perceived exertion was assessed using Borg's Original RPE Scale, a valid and reliable measure of perceived exercise intensity (Borg, 1982; Cabral et al., 2020).

Figure H2

ASHRAE Thermal Sensation Scale

Index	Thermal sensation
4	very hot
3	hot
2	warm
1	slightly warm
0	neutral
-1	slightly cool
-2	cool
-3	cold
-4	very cold

Note. Thermal sensation was assessed using the ASHRAE 9-point scale, a validated measure of perceptual thermal response during exercise (Zhang et al., 2004).

Figure H3

Modified Borg Dyspnea Scale

MODIFIED DYSPNEA SCALE	
0	None
0.5	Very, Very Slight (Just noticeable)
1	Very Slight
2	Slight
3	Moderate
4	Somewhat Severe
5	Severe
6	
7	Very Severe
8	
9	Very, Very Severe (almost maximal)
10	Maximal

Note. Respiratory comfort was assessed using the Modified Borg Dyspnea Scale, a valid and reliable measure of perceived breathlessness (Borg, 1982; Mahler & Horowitz, 1994). Lower ratings indicate greater perceived respiratory comfort.

Appendix I: Session Setup Image

Figure I1

Familiarization and Time-Trial Session Setup

Note. The photograph shows the standardized cycle-ergometer setup used during the familiarization and experimental sessions, including the perceptual rating scales positioned within the participant's view.