Cycling Time-trial Performance with Per-cooling via Cold-water in Hot Conditions

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Content List

Abstract

The overall aim of this thesis was to investigate the effect of cold-water ingestion and pouring on 30min cycling time-trial performance in hot and dry, and hot and humid environmental conditions.

Study one (i) determined the impact of multiple vs single feedback on 30min cycling time-trial performance in experienced cyclists-triathletes' and non-cyclists-triathletes', and (ii) investigated experienced cyclists-triathletes' information acquisition during a 30min cycling time-trial. The findings from this study highlighted that experienced cyclists-triathletes' 30 min cycling time-trial performance was impaired with multiple feedback (227.99±42.02W) compared to single feedback (287.9±60.07 W; $p < 0.05$), despite adopting and reporting a similar pacing strategy and perceptual responses ($p > 0.05$). In addition, cyclists-triathlete's primary and secondary objects of regard (i.e. main variable of focus) were power (64.95s) and elapsed time (64.46s). Notably, total glance time during multiple feedback decreased from the first 5 min (75.67s) to the last 5 min (22.34s) which may have resulted from a mental overload (exercise and cognitive task). The findings from this study were used to inform the subsequent studies in this PhD in an attempt to minimise any external impact on performance. Therefore, participants in study 2 and 4 were only given feedback on elapsed time whilst completing the time-trial.

Study two investigate the effect of heat (hot vs thermoneutral) and humidity (dry vs humid) on physiological and perceptual responses during a 30min cycling time-trial in experienced cyclists-triathletes. The findings from this study highlighted that performance was significantly impaired in hot and dry conditions compared to thermoneutral/control conditions (177.35±1.68W vs 236.86±1.83W). This impairment was accompanied by a higher T_{rectal} and thermal discomfort ratings during the TT. T_{rectal} was significantly greater in hot (38.05±0.15°C) compared to control (38.55±0.04°C) throughout the TT p=0.001). Thermal comfort ratings were also significantly lower in thermoneutral/control (0±0(0%)) compared to hot (12±2(60%)) during the TT ($p = 0.003$). Secondly, power was also significantly impaired

in hot and humid compared to thermoneutral/control conditions (160.12±3.43W vs 235±2.48W; p=0.001). This impairment was accompanied by a higher T_{rectal} and thermal discomfort ratings during the TT. T_{rectal} was significantly greater in hot (38.85±0.09°C) compared to control (38.55±0.12°C) throughout the TT (p=0.004). Thermal comfort ratings were also significantly lower in thermoneutral/control (0±0(0%)) compared to hot (19±3(95%)) during the time-trial (p = 0.001). Thirdly, power was significantly impaired in hot and humid compared to hot and dry (160.12±3.43W vs 177.35±1.68W, p =0.038). This impairment was accompanied by a higher T_{rectal} and thermal discomfort ratings during the TT. T_{rectal} was significantly greater throughout the TT in hot and humid (38.7±0.09°C) compared to hot and dry (38.49±0.07°C; p = 0.043). Thermal comfort ratings were significantly higher in hot and humid compared to hot and dry during the TT (19±3(95%)) vs 12±2(60%)); p = 0.029). Overall, cycling power output was significantly impaired in hot and dry and hot and humid conditions compared to thermoneutral conditions, and hot and humid conditions caused a greater impairment to cycling power output compared to hot and dry conditions. All impairments were accompanied by a greater thermal strain (physiological (rectal temperature) and/or perceptual responses (thermal comfort)). The findings from this study highlight an impairment in cycling performance in hot conditions (dry and humid) and therefore athletes should use heat alleviation strategies to minimise this impairment.

Study three investigated (i) the level of perceived heat strain cyclists-triathletes (recreational, competitive and professional) experience during competitions in hot conditions, (ii) which heat alleviation strategies (i.e. hydration and cooling) athletes use during competitions in hot conditions, and (iii) whether or not these strategies are dependent on the environmental heat (i.e. dry vs humid heat). The findings from this study highlighted that the type of per-cooling strategies currently employed by competitive and professional cyclists-triathletes during training and competition are condition (dry vs humid) dependant. Specifically, cold-water ingestion was the most employed strategy in hot and dry conditions (HD), whereas a combination of cold-water ingestion and pouring was the most employed strategy in hot and humid conditions (HH). The timing of application was pre-planned based on ‘distance’ and supplemented with ‘how participants felt during’ and ‘when pit stops were available’ in HD. Whereas timing of application was pre planned based on ‘distance’ and ‘how participants felt during’ only in HH. The justification for type and timing of strategies was previous experience/perceived effectiveness (e.g., trial and error). An additional finding of this study was that competitive athletes found benefits from mental strategies, such as imagery and modelling; whereas professional athletes found benefits from positive self-talk and locus of control during competition in hot conditions. The findings from the questionnaire were used to inform the cooling methods used in study four (i.e. type of cooling, amount of cooling, frequency of cooling etc). Therefore, the two cooling methods that were used in study four were cold-water ingestion and cold-water pouring.

Study four investigated the effect of cold-water ingestion and pouring on 30min cycling time-trial performance in hot and dry, and hot and humid conditions in experienced cyclists-triathletes. Participants were assigned to a group; Group 1 - hot and dry, or group 2 - hot and humid. Within their group participants completed 4 x 30min cycling time-trials on separate occasions: (i) thermoneutral, (ii) hot with no cooling (dry or humid, group dependant), (iii) cold-water ingestion, and (iv) cold-water pouring. The findings from this study showed that cold-water pouring was more beneficial compared to cold-water ingestion for power output in hot and dry conditions (Mean±SD 199.40±0.82W vs 180.35±1.51W, $p = 0.023$). This performance benefit occurred in absence of a significant difference in rectal temperature between cold-water pouring and ingestion (38.18±0.13°C vs 38.38±0.14°C, $p = p=0.121$). There was also no difference in thermal comfort between cold-water pouring and ingestion (11±1(55%) vs 12±2(60%); $p = 0.067$). Conversely, cold-water ingestion was more beneficial compared to cold-water pouring for power output in hot and humid conditions (Mean±SD 173.77±0.97W vs 165.16±1.31W, $p=0.760$). This was supported by physiological responses such as rectal temperature which was significantly lower with cold-water ingestion compared to cold-water pouring (37.9±0.1°C vs 38.5±0.19°C, p = 0.001). This was also supported by perceptual responses such as mean±SD thermal comfort ratings which was significantly greater with cold-water pouring than cold-water ingestion during the time-trial in hot and humid conditions (14±3(70%) vs 12±1(60%); p = 0.004). Power in the hot and dry conditions with cold-water pouring (199.40±0.82W) was significantly greater compared to hot and humid condition with cold-water pouring (165.16±1.31W, p =0.001). This difference occurred in absence of a difference in physiological responses such as rectal temperature as there was no difference between groups respectively (38.18T ±0.13 vs 38.4±0.22, p = 0.253). However, this performance difference was supported by perceptual responses such as thermal comfort ratings which were significantly greater with cold-water pouring during the time-trial in hot and humid conditions compared to hot and dry conditions (14±3(70%) vs 12±2(60%); p = 0.021). In conclusion, cold-water pouring provided a greater ergogenic effect on 30min cycling time-trial performance in HD conditions compared to cold-water ingestion. Whereas cold-water ingestion provided a greater ergogenic effect on power output during a 30min cycling time-trial performance in HH conditions compared to cold-water pouring.

Collectively, the findings from this study show that athletes and coaches should not only consider the condition (dry vs humid) but also which cooling strategy is best suited for said condition (internal vs external) when preparing for training and/or competing in hot conditions.

The distinction of the effect of hot and dry, and hot and humid conditions on 30min cycling time-trial performance and subsequent physiological, and perceptual responses are a particular novel and applicable aspect of this thesis and contribute new data and interpretations to this area of research.

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Declaration

I declare that the research presented within this thesis is the original work of the author unless stated. This work has been submitted solely for the degree of Doctor of Philosophy to London South Bank University.

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List of abbreviations - Words

AF Affect

ANOVA Analysis of variance

BF Blood flow

BM Body mass

BP Blood pressure

BT Body temperature

BV Blood volume

CF Cognitive function

CT Cyclists-triathlete

CTs Cyclists-triathletes

DC Distance covered.

DM Decision-making

EE Energy expenditure

ES Effect size

FeCO2 Fraction of expired carbon dioxide

FeO2 Fraction of expired oxygen

FICO2 Fraction of inspired carbon dioxide

FiO2 Fraction of inspired oxygen

HAS Heat alleviation strategy/strategies

HD Hot and Dry

HE Heat exhaustion

HH Hot and Humid

HS Heat stroke

LSBU London South Bank University

LV Left ventricular

MAP Mean arterial pressure

MBF Muscle blood flow

MAP maximal aerobic power

NBM Nude body mass

NHS National Health Service

O2 Oxygen

O2Hb Oxygenated haemoglobin

Q Cardiac output

RAP Right arterial pressure

RER Respiratory exchange ratio

PANAS Positive and negative affects schedule

PO Power output

RPE Rating of perceived exertion

SBF Skin blood flow

SDM Subjective decision making

SR Sweat rate

SV Stroke volume

T_{core} Core temperature

TM Task motivation

T_{rectal} Rectal temperature

T_{sk} Skin temperature

TT Time-trial

VCO2 Carbon dioxide output

VE Volume expired

VI Volume inspired

VO_2 Oxygen uptake

VO_{2max} Maximum oxygen uptake

VO_{2peak} Peak oxygen uptake

WHO World Health Organisation

WBGT Wet-bulb globe temperature

WS wind speed

List of abbreviations - Units

au Arbitrary units

b.min^{-1} Beats per minute

cm Centimetres

hr Hours

HR Heart rate

HR_{MAX} Maximum heart rate

kcal/min^{-1} Kilocalories per minute

kg Kilograms

II kg/m^{-2} Kilograms per metre squared

Kph Kilometres per hour

L Litres

L/min^{-1} Litres per minute

Lhr Litres per hour

m Metres

min(s) Minute(s)

mL Mililitres

mmHg Millimetre of mercury

mmol/l^{-1} Millimole per litre

ms Milliseconds

RPM Revolutions per minute

s Seconds

SD Standard deviation

W Watt/s

°C Degrees Celsius

[La+] Blood lactate concentration

%rH Relative humidity

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List of Publications

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Conference Proceedings

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Chapter 1. General Introduction

Cycling performance is commonly evaluated as time to exhaustion (TTE) at a constant load (Ely et al., 2010; Peiffer and Abbiss, 2011) or as power output (PO) maintained during a simulated time-trial (TT; Tucker et al., 2004). Both TTE and TT are markedly impaired in hot conditions when compared to thermoneutral/control conditions. For example, Galloway and Maughan (1997) investigated TTE (70% of VO_{2max}) in four temperatures 3.6±0.3, 10.5±0.5, 20.6±0.2, and 30.5±0.2°C with a relative humidity (RH) of 70±2%, reporting that TTE was shortest at 30.5°C (51.6±3.7min) and longest at 10.5°C (93.5±6.2 min). However, exercise intensity in this study was at a constant load (a modality that does not allow power regulation based on physiological responses and perception), and thus self-paced methodologies have been used in more recent studies. Self-paced TTs in hot and humid conditions (HH; 35°C, 60% RH) are impaired in comparison to thermoneutral (18°C, 40% RH) (Periard and Racinais, 2016). Most studies have investigated the consequences of heat alone, not the combined consequences of heat and humidity (i.e., tropical climate). Yet the tropical climate, which is characterized by a temperature of about 30°C and a hygrometry level exceeding 70% RH can be considered an environmental stressor (Robin, Coudevylle, Hue, & Sin napah, 2017). Therefore, it is unclear whether cycling TT performance is impaired further in HH compared to hot and dry (HD). In humans, heat loss by evaporation occurs as a result of a difference in humidity between the skin surface, which is physiologically moistened by eccrine sweating, and ambient air (Jay and Morris, 2018). Thus, in circumstances where all sweat does not readily evaporate and residual sweat sits on the skin (e.g. exercise coupled with high humidity), thermoregulation is challenged (Jay and Morris, 2018). As such, the first aim of this thesis was to characterise the effect of HD and HH conditions on cycling time-trial performance.

In an attempt to mitigate heat-related impairments in aerobic exercise, athletes and sports practitioners regularly employ different cooling strategies both before (pre-cooling) and during (per-cooling) exercise (Binger et al., 2015; Ruddock et al., 2017). Research has shown that pre-cooling athletes, using cold water immersion (2–20°C) (Duffield et al., 2010; Minett et al., 2011), ice vests applied to the torso (Cotter et al., 2001) or neck cooling collars (Tyler and Sunderland, 2011; Sunderland et al., 2015) blunts heat related decrements in performance (Bongers et al., 2015). While likely beneficial, most of these interventions are not particularly feasible in low-resource environments (such as away games, competition in remote areas and amateur sport) and have limited application as a cooling strategy during exercise, especially competition. Arguably, the most practical cooling solution is the ingestion of cold water or an ice slurry (cold water mixed with crushed ice) before and/or during exercise. The evidence supporting the efficacy of ice slurry or cold (10°C) water ingestion for improving endurance exercise performance in hot conditions when employed as a precooling, per-cooling, or recovery between bouts strategy has been comprehensively reported (Jay and Morris, 2018). However, in competition/race settings, it is common to see athletes using pit stops, or water provided on their bikes to ingest or pour over themselves in attempt to cool themselves down whilst competing in hot conditions (Morris and Jay, 2016). However, it is unclear as to whether these strategies actually reduce the amount of heat stored inside the body during exercise in hot conditions, even at a fixed metabolic rate. Therefore, the second aim of thesis was to investigate the effect of both cold-water ingestion and pouring on cycling time-trial performance HD and HH conditions. This information will inform coaches and athletes on cooling strategies to use during major international sporting events such as Los Angeles 2028.

Chapter 2. Narrative Review – Cycling performance in hot conditions (Dry vs Humid)

2.1. Cycling Performance and External Factors

Cycling performance is often characterised by power output (PO), with its relative changes (% of max) used to characterise pacing strategies when applicable. For example, to avoid premature physical fatigue and associated performance decrements, cyclists' pace themselves by adjusting(i.e. increase, maintain, decrease) physical aspects of their performance such as PO, speed or energy expenditure (EE) across an event (Abbiss and Laursen, 2008). The alterations in pacing strategies are negatively affected by external factors such as hot conditions (Junge et al., 2016), hypoxia (Périard and Racinais, 2016), inaccurate feedback (Davies et al., 2016), manipulated feedback/deception (Jones et al., 2016), no feedback/blind (Davies et al., 2016). In addition, cyclists-triathletes' commonly receive feedback verbally (via headpiece from coach) or visually (via wireless network sensors on their bike) during training and/or competition. Therefore, type and quantity of feedback will be considered.

The overall aim of this thesis was to investigate the effect of cold-water ingestion and pouring on 30min cycling time-trial performance in hot and dry, and hot and humid environmental conditions. Therefore, this review is separated into two sections: (I) Cycling performance in hot conditions and (ii) Cycling performance in hot conditions with per-cooling.

2.1.1. Defining Heat Stress and Heat Strain.

The term "hot conditions" has been used to describe a wide range of environmental conditions, for example in Junge et al., (2016) review the term "hot conditions" is used to describe ambient temperatures of ~32-40°C, humidity of ~14-60% rH, and wind speed of 0.5-11m.s. As a result of this, Junge et al., (2016) concludes that self-paced cycling performance is impaired in "hot conditions" compared to thermoneutral/control conditions (~20°C in power output). All impairments were characterized by a progressive decline in PO which has been consistently supported in the literature (Périard and Racinais, 2019 pp 246-247). However, the impairment varied by ~2-25% between the reviewed studies. This variation in impairment cannot be solely dependent on the environmental condition as task duration, fitness level, experience, feedback provided have all been identified as factors that can influence pacing. However, if researchers are aiming to determine the effect of environmental conditions on cycling performance (physical and mental), the term “hot condition” must (i) be defined, and (ii) measured in the same way globally.

2.1.1.1. Heat Stress

According to Taylor, (2014) the most common environmental factors reported in a laboratory setting are:

- Ambient temperature (°C)
- Relative Humidity (%)
- Air velocity/Wind speed (m.s)
- Solar radiation (W/m 2). Notably, radiation is reported in few laboratory studies due to the difficulty in replicating outdoor conditions.

When two or more of these environmental factors are combined at a level that disrupts homeostasis (i.e. thermal equilibrium within the body equalling ~37°C core temperature) they are classed as a “stressor” or “heat stress”. Examples of this can be seen when an organism is subjected to conditions of high exogenous thermal load or are producing large amounts of metabolic heat during high intensity dynamic exercise. To categories heat stress, Yaglou and Minard (1957) combined ambient temperature, humidity, wind speed and radiation to create a heat stress index called wet-bulb globe temperature (WBGT). The aim of this index was to be the “first approximation of the heat stress on a person” (ISO 7243, 2017). WBGT is computed as a weighted average of the dry-bulb ambient temperature, natural wet-bulb temperature (Tw; ambient temperature and relative humidity), and globe temperature (Tg; indicates radiant heat) as follows:

$$\mathrm{WBGT} = 0.7T_w + 0.2T_g + 0.1T_a$$ (Hosokawa et al., 2019)

A WBGT of 34°C positively correlated with exertional heat illnesses (EHI) and exertional heat stroke (EHS) incidence and mortality (Heidari et al., 2020). Therefore, WBGT has been used globally by sporting governing bodies such as Union Cycliste Internationale (UCI) to subjectively decide on whether to reschedule, shorten, or cancel an event (Périard and Racinais, 2019 pp 256). However, Junge et al., (2016) evaluated WBGT in the context of cycling TTs, reporting that WBGT failed to predict the impact of environmental heat stress on prolonged self-paced cycling performance. It was purported that WBGT does not sufficiently afford wind speed an important enough weighting in the formula, as trained cyclists travel at speeds greater than 10m s^{-1}(36km h^{-1}) when cycling outdoors on flat terrain. An elevated speed such as this can enhance convective and evaporative heat loss.

Grundstein et al., (2015) also found a fault with WBGT, outlining that an ambient temperature and relative humidity of 28°C and 60% rH, and 36°C and 15% rH would both constitute to a WBGT of 28°C despite contrasting levels of humidity. Vanos, and Grundstein, (2020) supported these findings stating that equivalent WBGT values occurred across different environmental conditions (warm and humid versus hot and dry), which resulted in different abilities to cool the body during times of heat stress. It was purported that hot and dry (HD) conditions offered a 13%-17% greater ability to cool than warm and humid conditions at an equivalent WBGT value of 32.38°C and activity wind speed of 0.3-0.7 $m.s^{-1}$. This is related to the impairment in evaporation in hot and humid conditions as a result of the greater water vapour content in the air causing sweat to remain on the skin surface rather than evaporating as it does in hot and dry conditions.

As a result of the recently highlighted concerns with using WBGT as a measurement of heat stress in sports such as cycling, researchers should seek to develop a satisfactory index for heat stress that takes into account (i) wind speed whilst cycling (Junge et al., 2016) and (ii) differences in humidity so that the index evokes the same physiological response for all combinations of its constituent variables (Vanos, and Grundstein, 2020). Taking humidity into consideration is key for sporting events such as the Tokyo 2021 Olympics because humid conditions are much more physiologically stressful than dry conditions (Lei et al., 2021). Despite this understanding and succinctly summarized biophysics and thermoregulatory differences between dry and humid conditions in Lei et al., (2021) article, the research in both dry and humid conditions is far from complete. In fact, current studies have yet to determine and compare the exact (i) degree of performance impairments (%) in both conditions, and (ii) heat alleviation strategy that is best suited for endurance performance and thermoregulatory function in both conditions. If this approach (separating HH (>50%) and HD) was applied to Jung et al., (2016) review, the results would show that HH has a greater impairment on PO (2-22%) compared to HD (11-25%) when compared to thermoneutral/control conditions. To contribute to the understanding of heat stress on cycling performance (physical and mental), heat stress will be reported as ambient temperature, humidity and wind speed with conditions separated by humidity (HD vs HH) in this thesis.

2.1.1.2. Heat Strain – Physiological

The impairment in physical performance in hot conditions (not specific to humidity) has historically been accompanied by physiological and perceptual responses (Periard and Racinais, 2019, pp.245). These responses can be described as "heat strain" as they are affected by the magnitude of heat stress and the extent that homeostasis is disturbed (Travers, unpublished work).

Physiological responses can be separated into thermoregulatory, cardiovascular and metabolic. A common trend in thermoregulatory responses during cycling in hot ambient temperatures (not specific to humidity or wind speed) are an increase in core temperature (T_{core})/rectal temperature (T_{rectal}), skin temperature (T_{sk}) and sweat rate (SR). The greater the disturbance in homeostasis (variation in T_{core}/T_{rectal} from resting values of ~37°C; Benzinger, 1969) the greater the heat strain experienced.

Cardiovascular responses stem from a thermoregulatory redistribution of blood towards the periphery and a temperature-mediated increase in intrinsic heart rate (HR), which contribute to compromise central blood volume and the maintenance of cardiac output (Rowell, 1974). Although cutaneous blood flow reaches a virtual plateau, or upper limit when a T_{core} of ~38 C is attained during exercise (Brengelmann et al., 1977), a significant volume of blood perfuses peripheral vascular beds (Rowell, 1974). Moreover, for each 1 C elevation in T_{core}, a ~7 $b.min^{-1}$ increase in HR occurs during passive heat stress (Jose et al., 1970). This suggests that the greater increase in HR during exercise in the heat may stem in part from the direct effects of temperature on cardiac nodal cells, along with adjustments in autonomic nervous system activity (i.e. sympathetic activation and parasympathetic withdrawal; Gorman et al., 1984). Thus, the metabolic and thermoregulatory requirements associated with cycling under heat stress appear to interact and alter cardiac function, modify the distribution of cardiac output, and/or compromise the ability to sustain adequate blood pressure (Rowell, 1986). Moreover, Sawka et al. (2012) have highlighted that high T_{sk} alone may impair aerobic performance, such as prolonged self-paced cycling. This occurs as hot skin narrows the core-to-skin temperature gradient, which increases peripheral thermoregulatory blood flow requirements and in turn circulatory strain—reducing cardiac filling and elevating HR for a given cardiac output (Cheuvront, 2010; Rowell, 1986). As outlined above, the increased cardiovascular strain associated with high T_{sk} may contribute to modulate performance in advance of a rise in T_{core}/T_{rectal} (i.e. hyperthermia).

The most common physiological responses measured in a laboratory setting are T_{core}/T_{rectal}, T_{sk}, SR, HR. Therefore, these physiological measurements will be the main focus of the literature review and thesis.

It should be noted that the way humans handle or respond heat stress and subsequent heat strain can be influenced by fitness level and previous experience of that stressor and strain. For example, Racinais et al., (2019) reported T_{core} values of ≥41.5°C in elite cyclists during the 2016 UCI Road World Championships without suffering any heat related illnesses.

Based on this understanding, physiological responses (i.e. core temperature) alone are not sufficient enough to understand the effects of hot conditions on cycling performance and health in experienced cyclists-triathletes, especially elite/professional. Therefore, we must also consider perceptual responses to determine heat strain experienced.

2.1.1.3. Heat strain – Perceptual

Common perceptual responses measured during cycling performance in hot conditions (not humidity specific) are ratings of perceived exertion (RPE), thermal sensation (TS), thermal comfort (TC), affect (AF), motivation.

RPE is a subjective rating of an athlete’s exertion are a good indicator as to how hard a performance was and are a simple measurement for coaches and practitioners to assess during training and competition(Borg, 1998).

Thermal comfort refers to how comfortable a person feels (Gagge et al., 1967), whereas thermal sensation is how hot or cold a person feels (Young et al. 1987) in the surrounding environment in reference to ambient temperature and humidity.

Affect refers to how a person feels (Hardy & Rejeski, 1989). In regard to exercise, Parfitt, et al., (1994) observed a significantly greater positive affect 5 min postexercise compared to the last 20 sec of exercising at moderate to high intensities. This suggests that affect is influenced by level of physical exertion.

Motivation can be defined as “the investigation of the energ-isation and direction of behaviour” (Roberts & Treasure, 2001, p. 6). Thus, it comprises the reasons or forces that influence behaviour. Briefly, motivation is commonly separated into two categories; internal/intrisnic motives (i.e. need for companionship) and/or external/extrinsic events (i.e. prize money) or amotivation (i.e. unmotivated by anything; Mallett & Hanrahan, 2004) or

Therefore, perceptual responses should be measured to help characterise heat stress and/or heat strain experienced during exercise in hot conditions.

In summary, the literature on cycling performance in hot conditions encompasses a wide range of ambient temperatures, humidity and wind speeds. Therefore, this literature review aims to investigate cycling TT performance in HD and HH conditions and characterise the performance response. This was done by reviewing literature in the area and identifying trends in pace (power output) and performance (completion time or distance covered).

Secondly, heat strain experienced during cycling TTs can be characterised by physiological and perceptual responses. Therefore, this narrative review aimed to characterise these responses during cycling TTs in HD and HH conditions. This was done by extracting physiological (T_{core}/T_{rectal}, T_{sk}, HR, SR) and perceptual responses (RPE,TC,TS,AF, motivation) reported during cycling TTs.

2.2. Literature Search

A literature search was carried out in Google scholar, research gate, Scopus. The following search terms were combined to search for the full text of experimental articles published after 2000 and before January 2020: The following search terms were used: “Cycling” OR “Time-trial” OR “Self-paced” OR “Pacing” AND “Heat” OR “Hot”, “Humid”, “Dry”.

Firstly, titles were assessed for relevance to the topic and selected if they met the inclusion criteria outlined in Table 1. This process was repeated for abstracts and full texts. In addition to the literature search, references were scanned for further relevant articles and were included if they met the inclusion criteria.

2.2.1. Inclusion/exclusion Criteria

Table 1. Table outlines literature search criteria for articles acceptance and rejection.

Inclusion	Exclusion
Published between 2000-2020	Published before 2000 and after 2020
Full text available	No full text available
Written in the English Language.	No English source available
Experimental peer-reviewed research article	Not original or peer-review article
Human population	Animal population
Healthy non-acclimated participants.	Clinical or occupational setting, notable mental or physical

	impairments (i.e. diseases, loss of motor function) and/or heat acclimatised population (Exposure to >30°C in the last 30 days)
Male	Female, transgender.
Assessment of at least one of the following parameters: T_{rectal}, T_{core}, T_{sk}, SR, HR, PO, completion time, DC.	No performance or physiological parameters measured
Self-paced cycling completed	No self-paced cycling completed
Inclusion of at least one task related and unmanipulated feedback variable (elapsed time, distance, HR, PO, cadence, or speed)	Manipulation of feedback, or irrelevant feedback to the task given
Adult participants (≥18yrs)	Children participants (<18yrs)
Ambient temperatures ≥28ºC	Ambient temperatures <28ºC

T_{rectal} = rectal temperature, tcore = core temperature, T_{sk}, skin temperature, SR = sweat rate, HR = heart rate, PO = power output, DC= distance covered.

In this review the thresholds for thermoneutral, HD and HH conditions were set as 21°C, ≤50%, ≥28ºC, ≤50% and ≥28ºC, ≥51% respectively. These thresholds were based off previous literature review criteria's on the topic (Vanos, and Grundstein, 2020; Coudevylle et al., 2021)

2.2.2. Outcome measures

The outcome measures extracted from the eligible articles were:

1. Article characteristics – Number of participants, sex ratio (M:F), Group VO_{2max} (mL.kg.min^{-1})
2. Task and conditions – Task (duration or intensity), indoor/outdoor, ambient temperature (°C), relative humidity (%), wind speed (m/s), WGBT (°C), feedback given.
3. Physical performance – Power Output (W, Completion time (min)/distance (km), PO improvement with intervention (%), Completion time improvement with intervention ()
4. Physiological responses – Rectal/core temperature (°C), skin temperature (°C), sweat rate (L.hr), heart rate (b.min^{-1}).
5. Perceptual responses – Ratings of perceived exertion (% of max), thermal sensation (% of max), thermal comfort (% of max), affect (% of max), task motivation (% of max).

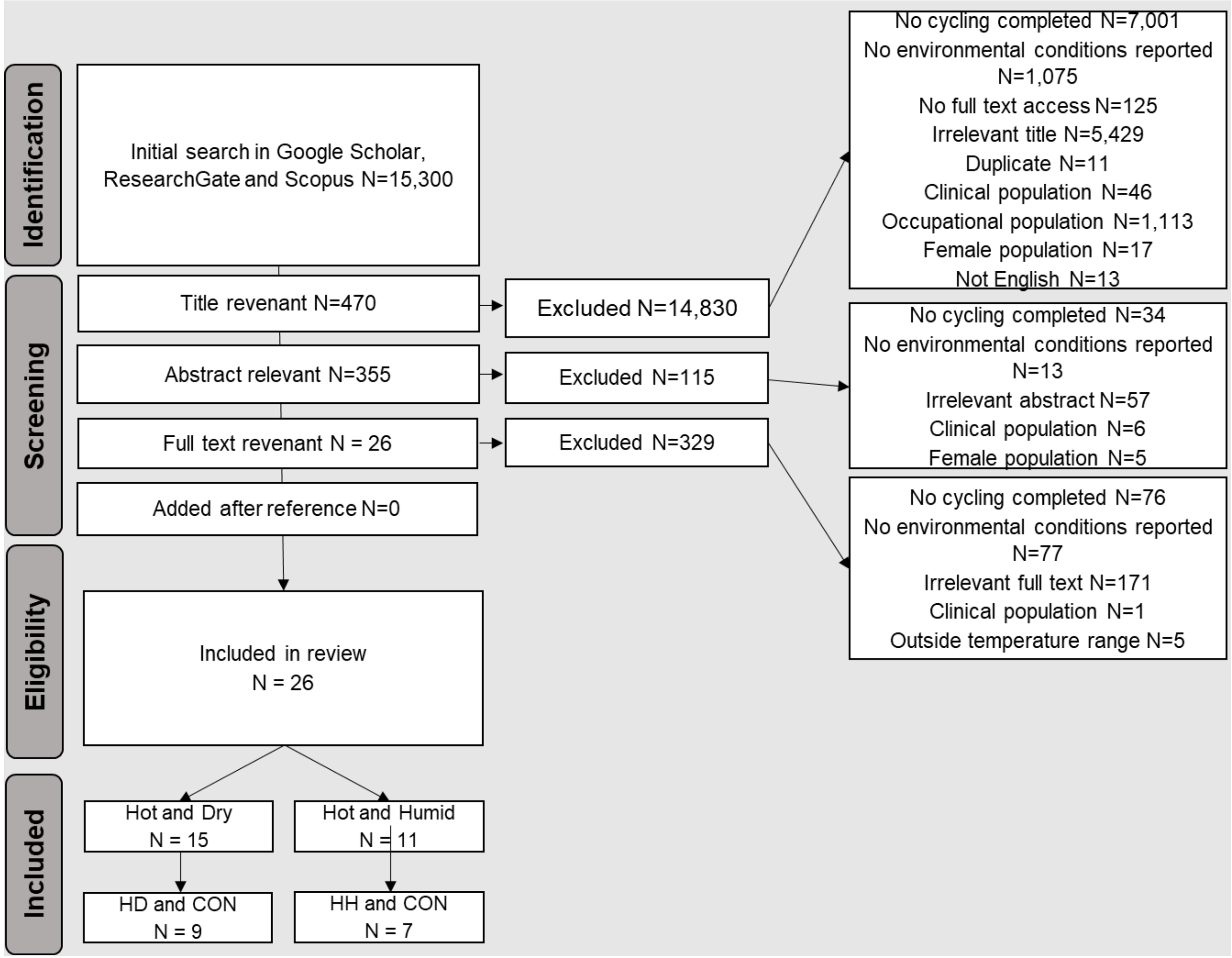

Figure 1. Flowchart of literature search and screening process using PRISMA Protocol.

2.2.3. Article Characteristics

Of the 26 articles included in this report, 15 incorporated a cycling TT in HD (Table 2). 9 of the articles in HD conditions included a control/thermoneutral condition (Peiffer and Abbiss 2011; Schlader et al., 2011; Keiser et al., 2015; Schmit et al., 2016; Racinais et al., 2015b; VanHaitsma et al., 2016; Kent et al., 2018; Munten et al., 2018; English et al., 2019), 4 were the control condition as a result of interventions (i.e. cooling and/or supplementation; Al-Horani et al., 2018; Mejuto et al., 2018; Faulkner et al., 2019; Osborne et al., 2019) and 2 compared performance in HD and HH conditions (Teunissen et al., 2013; Lei et al., 2020)

11 articles incorporated a cycling TT in HH conditions (Table 2). 7 of the articles in HH conditions included a control/thermoneutral condition (Watson et al., 2005; Roelands et al., 2008a; 2008b; Periard et al., 2011a; Periard and Racinais 2015a; Periard and Racinais 2015b; Periard and Racinais 2016). Whereas, 4 of the articles in HH conditions were the control condition as a result of interventions (i.e. cooling and/or supplementation; Cramer et al., 2015; Che Jusoh et al., 2016; Schulze et al., 2016; Maia-Lima, et al., 2017) and 2 article compared HD and HH conditions (Teunissen et al., 2013; Lei et al., 2020).

Table 2. Article characteristics (Sample, Condition and Task) of the 26 articles included in this review.

Condition	Authors	Sample			Condition			Task	
		Participant (N)	Sex Ratio (M/F)	VO$_{2max}$(mL.kg. min-1)	Environmental condition (°C, %, m/s)	WBGT (°C)	Setting (Indoor/Outdoor)	Exercise Length	Feedback given.
Dry	Peiffer and Abbis (2011)	9	9:0	60.5±4.5	32, 40,8.9 (17, 40, 8.9)	24.6 (12)	Indoor	40km TT	Visual elapsed distance.
Dry	Peiffer and Abbis (2011)	9	9:0	60.5	27, 40, 8.9 (17, 40, 8.9)	21.2 (12)	Indoor	40km TT	Visual elapsed distance.
Dry	Schlader et al., (2011d)	11	11:0	59.8±11.6	40,14,1.5 (20.4 ± 0.7 °C, 24% ± 7%)	26.5(16.3)	Indoor	30min	Visual elapsed time.
Dry	Teunissen et al., (2013)	7		-	33,40	26.5	Indoor	15min at starting at 80W and increased by 20W every 3min, followed by 15km TT	Visual elapsed distance.
Dry	Keiser et al., (2015)	8		61.2±4.4	38,30,3 (18, 30, 3)	28.1 (12.1)	Indoor	30min	Visual power output and elapsed time.
Dry	Racinais et al., (2015b)	9	9:0	62.1±28.6	36.0 ±0.4°C,, 13±1%,,6.8 (8.2±3.5°C, 30± 8%, 6.0)	22.6(3.6)	outdoors	43.4km	Visual HR, power output, speed, and elapsed distance.
Dry	VanHaitsma et al., (2015)	20		54.8±5.9	35,25,0.5 (21 °C, ~20 %)	25.4(13.6)	Indoor	40km	Visual power output, speed, cadence and elapsed distance.
Dry	Schmit et al., (2016)	12 (22)	22:0	62.2±3.6 (63.3 ± 2.1)	35,50,12.5 (21°C, 50%, 12.5)	28.6 (16.4)	Indoor	20km	Visual elapsed distance.

Dry	Al-Horani et al., (2018)	9		43.0±5.2	33,40,2.77	25.7	Indoor	16.1km	Not reported.
Dry	Mejuto et al., (2018)	7		59.54	32, 50	26.9	Indoor	10km TT	Visual elapsed distance.
Dry	Kent et al., (2018)	12		65.8±5.5	34.9 ± 0.3°C, 48.0 ± 1.9% (21,52)	~29.2(17.2)	Indoor	14kj.kg-1	Not reported.
Dry	English et al., (2019)	12	3 women, 9 men)	49±8	36,50 (21 °C, 50%)	30.4 (17.1)	Indoor	30min at 50% VO$_{2max}$ followed by a 5min rest and 15min TT	Verbal elapsed time from researcher at 5, 10, 12, 13, 14, 14.30 and 14.50min
Dry	Faulkner et al., (2019)	9		60.6	27,50.7	22.4	Indoor	902.9±127.6kj	Visual work done, target workload and a graphical representation of fluctuations in power output.
Dry	Faulkner et al., (2019)	9		61.3	35,50.6	29.6	Indoor	902.9±127.6kj	Visual work done, target workload and a graphical representation of fluctuations in power output
Dry	Osborne et al., (2019)	12		610±6.2	35,50	29.5	Indoor	20km TT	No feedback.
Dry	Racinais et al., (2019)	5-7		-	37,25	29.7	Outdoor TT	40km TT	Not reported.
Dry	Racinais et al., (2019)	3-10		-	37,25	29.7	Outdoor TT	40km	Not reported.

Dry	Racinais et al., (2019)	1-3		-	37,25	29.7	Outdoor Road Race	257.5km	Not reported.
Dry	Lei et al., (2020)	14		59±9	35,50, 5.27	28.7	Indoor	30min TT	Elapsed work done on completion of every 20%. (not stated whether it was visual or verbal).
Humid	Roelands et al., (2008a)	8	8:0	-	30,50-60% 0.5 (18, 50-16, 0.5)	31.1 (14.5)	Indoor	predetermined amount of work equal to 30 min at 75% Wmax as quickly as possible.	No feedback provided.
Humid	Roelands et al., (2008b)	9	9:0	-	30, 50-60%, 0	31.1	Indoor	predetermined amount of work equal to 30 min at 75% Wmax as quickly as possible.	No feedback provided.
Humid	Périard et al., (2011a)	8	8:0	66.4±6.3	35,60,3.47 (20, 40, 3.47)	30.2(14.6)	Indoor	40km	verbal feedback at 95% to finish the time trial at maximal effort.
Humid	Périard and Racinais (2015a)	10	9:1	-	35°C, 60%, 0.14m/s (18, 40%, 0.14m/s)	30.7(13.5)	Indoor	4 x 16.5-min time trials interspersed by 5 min of passive/active recovery (~75 W).	Visual elapse distance every 5min and verbal encouragement was given, and visual display (power, heart rate, cadence, speed, elapsed distance) was revealed to in the last1.5min of each 16.5min TT.
Humid	Périard and Racinais (2015b)	11		57.1±5.13	35,60,4	30.2	Indoor	750 kJ	Work completed each 10% and verbal feedback at 95% to finish the time trial at maximal effort.
Humid	Watson et al., (2005)	9		67.8±7.5	30,55,0.5	25.3	Indoor	60min at 55% of Wmax followed by 30min TT	No feedback provided.

Humid	Teunissen et al., (2013)	10	10:0	-	28,80	26.2	Indoor	15min at starting at 80W and icreased by 20W every 3min, followed by 15km TT	Elapsed distance.
Humid	Teunissen et al., (2013)	10	10:0	-	33,80,4m/s	30.9	Indoor	15min at starting at 80W and increased by 20W every 3min, followed by 15km TT	Elapsed distance.
Humid	Periard and Racianis, (2016)	12		-	35,60,3.47	30.2	Indoor	750kJ	Visual 10% of elapse work completed and kilojoule countdown was provided upon reaching the last 3% until completion.
Humid	Che Jusoh et al., (2016)	8		65±10	30±2, 78±3, 5.55	27.8	Indoor	15min	Elapsed time every 3mins.
Humid	Maia-Lima, et al., (2017)	8		55.7±7.88	35,68,0.5	31.5	Indoor	30km	Visual elapse distance.
Humid	Lei et al., (2020)	14	14:0	59±9	29.2±0.2°C, 69.4 ± 1.0%, *5.27(*34.9±0.2 ° C, 50.1±1.1%,5.27)	26 (28.7)	Indoor	30min TT	Elapsed work done on completion of every 20% (not stated whether visual or verbal)..

WBGT = Wet-bulb Globe Temperature

2.2.4. Quality Assessment

The methodological quality of the articles included in this review was completed following selection of full text articles. The modified version of PRISMA (10-items) was applied due to the greater representation for experiments employing a training intervention, compared to the Delphi, PEDro and Cochrane scales (Paul et al., 2016). A 10-item quality rating guide included the criteria listed below and guided the assessment scoring of each article as follows: 0 = clearly no; 1 = maybe; 2 = clearly yes. The scores for each item were added together to give an overall rating from 0 (poor)–20 (excellent) reported in Table 3.

Table 3. Results from the article quality assessment based on the following criteria: 1=Inclusion criteria were clearly stated, 2=Subjects were randomly allocated to groups, 3=Intervention was clearly defined, 4=Groups were tested for similarity at baseline, 5=A control group was used (thermoneutral conditions), 6=Outcome variables were clearly defined, 7=Assessments were practically useful, 8=Duration of intervention was practically useful, 9=Between-group statistical analysis was appropriate, 10=Point measures of variability.

Condition	**Authors**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total**
Humid	Peiffer and Abbiss (2011)	1	2	2	2	2	2	2	2	2	2	19
Humid	Schlader et al., (2011d)	1	2	2	2	2	2	2	2	2	2	19
Humid	Teunissen et al., (2013)	2	2	2	2	0	2	2	2	2	2	18
Humid	Keiser et al., (2015)	2	2	2	2	2	2	2	2	2	2	20
Humid	Racinais et al., (2015b)	2	2	2	2	2	2	2	2	2	2	20
Humid	Schmit et al., (2016)	1	2	2	2	2	2	2	2	2	2	17
Humid	VanHaitsma et al., (2016)	1	2	2	2	2	2	2	2	2	2	17
Humid	Al-Horani et al., (2018)	2	2	2	2	0	2	2	2	2	2	18
Humid	Kent et al., (2018)	2	2	2	2	2	2	2	2	2	2	18
Humid	Mejuto et al., (2018)	1	2	2	2	0	2	2	2	2	2	17
Humid	Munten et al., (2018)	2	2	2	2	2	2	2	2	2	2	20
Humid	English et al., (2019)	1	2	2	2	2	2	2	2	2	2	17
Humid	Faulkner et al., (2019)	2	2	2	2	0 (warm)	2	2	2	2	2	18
Humid	Osborne et al., (2019)	2	2	2	2	0	2	2	2	2	2	18

Humid	Racinais et al., (2019)	1	0	2	0	0	2	2	2	2	2	13
Humid	Lei et al., (2020)	2	2	2	2	0	2	2	2	2	2	18
Dry	Watson et al., (2005)	1	2	2	2	2	2	2	2	2	2	19
Dry	Roelands et al., (2008a)	1	2	2	2	2	2	2	2	2	2	18
Dry	Roelands et al., (2008b)	1	2	2	2	2	2	2	2	2	2	18
Dry	Periard et al., (2011a)	2	2	2	2	2	2	2	2	2	2	18
Dry	Cramer et al., (2015)	2	2	2	2	0	2	2	2	2	2	18
Dry	Periard and Racinais (2015a)	2	2	2	2	2	2	2	2	2	2	20
Dry	Periard and Racinais (2015b)	2	2	2	2	2	2	2	2	2	2	20
Dry	Che Jusoh et al., (2016)	1	2	2	2	0	2	2	2	2	2	17
Dry	Periard and Racinais (2016)	2	2	2	2	2	2	2	2	2	2	20
Dry	Schulze et al., (2016)	1	2	2	2	0	2	2	2	2	2	17
Dry	Maia-Lima et al., (2017)	2	2	2	2	0 (warm)	2	2	2	2	2	18
Dry	Lei et al., (2020)	2	2	2	2	0	2	2	2	2	2	18

The results of Table 3 identified that the articles included in this review were of high quality and therefore the results extracted from these articles contributed to the quality of the review.

2.3. Results and Discussion

2.3.1. Physical Performance in Hot and Dry

Six articles compared average PO in HD with CON (Peiffer and Abbiss, 2011; Schlader et al., 2011d; Keiser et al., 2015; Racinais et al., 2015b; VanHaitsma et al., 2015; Schmit et al., 2016; Table 4). Collectively these articles reported an impairment of ~2-23% impairment in HD compared to CON.

Racinais et al., (2015b) and Racinais et al., (2019) were the only studies to be conducted outdoors. Racinais et al., (2015b) reporting a significantly lower average PO in hot and dry conditions compared to control. In addition, PO was remained lower than control from 30% of the distance covered until completion. Whereas, Racinais et al., (2019) reported pacing during a competition setting and therefore the pace reported would have resulted from multiple factors (i.e. condition, competition etc).

Seven articles that compared HD conditions to CON reported pacing data (Pieffer and Abbiss, 2011; Schlader et al., 2011d; Racinais et al., 2015b; Schmit et al., 2016; VanHaitsma et al., 2016; Munten et al., 2018 English et al., 2019). All seven articles reported a progressive decrease in PO over the duration of the TT implying that they were not able to maintain their starting PO throughout the TT (Table 4). Whereas, the control groups reported a J-shape implying that they were able to maintain their pace throughout the TT (Table 4). There was an increase in PO over the last ~10% of all TTs regardless of task length or environmental condition (Table 2).

Six articles compared average CT in HD with CON (Peiffer and Abbiss, 2011; Schlader et al., 2011d; Keiser et al., 2015; Racinais et al., 2015b; VanHaitsma et al., 2015; Schmit et al., 2016; Table 6). Collectively these articles reported an impairment of 1-22% in CT in HD compared to CON. The greatest impairment of ~22% was reported in Schlader et al., (2011d) article which had the highest ambient temperature (40°C) of all of the articles included in this review.

2.3.2. Physical Performance in Hot and Humid

Three articles compared average PO in HH with CON (Roelands et al., 2008a; Roelands et al., 2008b; Périard et al., 2011a; Table 4). Collectively these studies reported an impairment in PO of 7-75% in HH compared to CON. The greatest impairment of 75% was reported in Roelands et al., (2008a) and (2008b) article which may be explained by the heat stress of 30°C, 50-60% rH and 0-0.5m/s (WBGT=~31.1°C) resulting in a rapid increase in heat strain responses such as T_{core}/T_{rectal} (increase of ~2°C and end value of >39°C) in a short period of time (~40min). Notably, Periard et al., (2011a) used a greater heat stress compared to Roeland et al., (2008a;2008b; Table 2) which did not result in a greater heat strain response. This may be explained by location of data collection. For example, Periard et al., (2011a) was conducted in Qatar, which is notably hot throughout the year, whereas Roeland et al., (2008a;2008b) was conducted in Belgium which is hot half of the year.

Five of the seven of the articles that compared HH conditions to CON reported pacing data (Watson et al., 2005; Periard et al., 2011a; Periard and Racinais 2015a; Periard and Racinais 2015b; Periard and Racinais 2016). All five of the articles reported a progressive decrease in PO over the duration of the TT implying that they were not able to maintain their PO throughout the TT (Table 4). Whereas, the control groups reported that pace was maintained through the TT (Table 4). There was an increase in PO over the last ~10% of all TTs regardless of task length or environmental condition (Table 4). Périard and Racinais (2015a) was the only article to report variations in pace relative to average PO showing that the variation was greater in HH (11.7-23.2%) compared to CON (4.5-6.9%). In addition, the pace reported in Cramer et al., (2015) and Maia-Lima et al., (2017) support the trend reported in HH conditions, however, cannot be compared to control conditions because there was no control in these articles. Therefore, the articles included in this review support the common trends of a progressive decline in PO in hot conditions (both HD and HH) highlighted in the literature.

Three articles compared average CT in HH with CON (Roelands et al., 2008a; Roelands et al., 2008b; Périard et al., 2011a; Table 4). Collectively these studies reported an impairment in PO of 13-68% in HH compared to CON. The greatest impairment of 68% was reported in Roelands et al., (2008a) article which may be explained by the heat stress of 30°C, 50-60% rH and 0-0.5m/s (WBGT=~31.1°C) resulting in a rapid increase in T_{core}/T_{rectal} (increase of ~2°C and end value of >39°C) and PO impairment (~64W).

2.3.3. Physical Performance in Hot and Dry and Hot and Humid

Only two articled compared average PO in HD and HH (Teunissen et al., 2013; Lei et al., 2020; Table 6). Both articles reported no significant differences between HD and HH and HH with wind.

Two of the articles compared HH to HD (Teunissen et al., 2013; Lie et al., 2020). Teunissen et al., (2013) specifically compared cycling performance in HH conditions (with and without wind) and HD conditions. The progressive decline in PO occurred much earlier (before 2km) in HH conditions with no wind compared to HH with wind (~after 4km) and HD conditions (after 10km; Table 4). The progressive decline in PO in HH with no wind lasted until 13km (~85% of the TT; 0-13km) whereas the decline only lasted until 10km in HH with wind (~50% of the TT; 2-10km). The decline in PO in HD conditions didn't occur till 10km to similar values as the HH with wind condition which lasted until 13km. All of the TTs ended with an increase in PO regardless of condition, however the increase in PO started at 10km in HH with wind (lasting ~33% of the TT; 10-15km) compared to 13km in HH with no wind and HD (lasting ~15% of the TT; 13-15km; Table 4). Therefore, Teunissen et al., (2013) findings highlight that pace is impaired at earlier stages of a TT in HH conditions with no wind compared to HH with wind and HD. Whereas, Lie et al., (2020) compared performance in HD (34.9±0.2°C, 50.1±1.1%) and HH (29.2±0.2°C, 69.4 ± 1.0%) conditions that were matched for vapor pressure/absolute humidity (2.8±0.1kPa). PO was not significantly different between conditions over the duration of the 30min TT. The findings of Lie et al., (2017;2019;2020) clearly demonstrate that male and female endurance performance in hot conditions is determined by the vapor pressure of the environment, such that even a difference in ambient temperature of ~6°C does not differentially affect exercise performance.

The restricted heat loss capabilities caused by high humidity can result in an impaired exercise performance and capacity. Maughan, Otani and Watson (2012) investigated the effects of 4 seperate relative humidity conditions (24%, 40%, 60% and 80% RH) on cycling TTE at 70% $\dot{V}O_{2max}$ in the heat (30.2±0.2ºC). TTE was progressively impaired at 60% (14.5±8.6min) and 80% RH (22.1±11.0min) when compared to 24% RH (68 ± 19 min). This was supported by Che Muhamed et al. (2016) who stated that an individual's capacity to continue exercising was reduced at 61% and 71% RH compared to 23% and 53% RH. The increasing relative humidity was associated with a linear increase in a thermoregulatory and circulatory strain. Collectively, these findings highlight the importance of absolute humidity on exercise performance in a warm environment.

A novel finding of this section highlighted that the feedback provided to participants during cycling was different (i.e. type and quantity) between articles, regardless of condition (i.e. dry vs humid). Previous findings have demonstrated that end-point knowledge (for example elapsed time and elapsed distance) can significantly improve pacing during training and/or competition (Wingfield et al., 2018; Smits et al., 2016). More recent findings by Boya et al., (2017) highlighted that end point knowledge is often used in conjunction with performance related feedback (for example speed, power output, cadence). Therefore, posing the question as to which feedback type and in what quantity to provide cyclists-triathletes with during training and/or competition for optimal performance.

In summary, average PO is impaired by ~2-23% in HD compared to CON. This impairment is characterised by a progressive decrease in PO over the duration of the TT implying that they were not able to maintain their starting PO throughout the TT. This impairment in PO and pace resulted in a ~1-22% impairment in CT in HD compared to CON. Secondly, average PO is impaired by ~7-75% in HH compared to CON. This impairment is also characterised by a progressive decrease in PO over the duration of the TT implying that they were not able to maintain their PO throughout the TT This impairment in PO and pace resulted in a ~13-68% impairment in CT in HH compared to CON. Thirdly, there was no significant difference in average PO in HD and HH, however, there was a difference in pace, in which the decline in PO in HH occurred earlier than in HD, especially if there was no wind. Fourthly, all TTs finish with an increase in PO (lasting ~10% of the TT) regardless of condition. Fifthly, there is limited research that compares direct WBGT ensuring that thermal stress and strain experienced is similar to be able to draw accurate conclusions. Therefore, future research should investigate this to form stronger conclusions on the effect of HD and HH on cycling TT performance.

Table 4. Physical performance (power output and completion time/distance covered) in hot and dry (HD) and hot and humid (HH) conditions.

Condition	Authors	Timing	Task		Physical Performance				
			Task	Feedback given.	PO (W)	Completion time (min)/distance (km)	Power output deficit compared to control (%)	Completion time deficit compared to control	Pacing Shape
Dry	Peiffer and Abbis (2011)	Start Average End	40km TT	Visual elapsed distance.	309±35 W ((329 ±31)	60.7±2.9min (58.8 ± 2.0 min)	6%	3%	J(progressive decrease in PO until 30km from which point PO was progressively increased in the final 10km)
Dry	Peiffer and Abbi s (2011)	Start Average End	40km TT	Visual elapsed distance.	322 ± 32 W(329 ±31W)	(59.1 ± 2.3 min (58.8 ± 2.0 min)	2%	1%	
Dry	Schlader et al., (2011d)	Start Average End	30min	Visual elapsed time.	154±33 (201±56)	-	23%	22%	progressive decrease in PO until completion of a 30min TT in HD conditions, whereas a J-shaped pacing strategy was adopted in control conditions.
Dry	Teunissen et al., (2013)	Start Average End	15min at starting at 80W and increased by 20W every 3min, followed by 15km TT	Visual elapsed distance.	249±31	-	No Control.	No Control.	maintained after 2km until 10km from which point there was a decrease to similar values as the hot and humid with wind condition until 13km. PO remained greater in the HD condition compared to the two humid conditions until completion.
Dry	Keiser et al., (2015)	Start Average End	30min	Visual power output and elapsed time.	240(210)	-	13%	-	J-shape
Dry	Racinais et al., (2015b)	Start Average End	43.4km	Visual HR, power output, speed, and elapsed distance.	256±19(304±9)	77.17±6.26min(66.13±3.26min)	19%	17%	PO was remained lower than control from 30% of the distance covered until completion.
Dry	VanHaitsma et al., (2015)	Start Average End	40km	Visual power output, speed, cadence and elapsed distance.	157 ± 32.3 (187 ± 40.3)*	79.0 ± 7.20min (75.2 ± 6.58)*	16%	5%	progressive decrease in PO in HD conditions until 25km, followed by a maintenance phase from until 35km and finishing with an end sprint for the final 5km. (J-shpaed)

Dry	Schmit et al., (2016)	Start Average End	20km	Visual elapsed distance.	223±20 (247 ± 42)	33.22±1.58(32.16 ± 2.01)	6%	3%	progressive decrease in pace throughout the TT in hot conditions until 18km, from which point the pace was progressive increased over the last 2km (J-shaped)
Dry	Al-Horani et al., (2018)	Start Average End	16.1km	Not reported.	154±4.32	32.8±4.4min	Control.	Control.	
Dry	Mejuto et al., (2018)	Start Average End	10km TT	Visual elapsed distance.	-	15.75±1.48 min	Control.	Control.	
	Munten et al., (2018)								progressive decrease in PO(J-shaped)
Dry	Kent et al., (2018)	Start Average End	14kj.kg-1	Not reported.	-	58:30 ± 04:48min (54:01 ± 04:05)	-	8%	
Dry	English et al., (2019)	Start Average End	30min at 50% VO_{2max} followed by a 5min rest and 15min TT	Verbal elapsed time from researcher at 5, 10, 12, 13, 14, 14.30 and 14.50min	-168 ± 59 kJ (203 ± 60 kJ)*-		-	21%	
Dry	Faulkner et al., (2019)	Start Average End	902.9±127.6kj	Visual work done, target workload and a graphical representation of fluctuations in power output.	235	63.33	Control.	Control.	progressive decrease in pace until 12min from which point pace was increase for the final 13min of the TT.(Maintained throughout)
Dry	Faulkner et al., (2019)	Start Average End	902.9±127.6kj	Visual work done, target workload and a graphical representation of fluctuations in power output	230	68.33	Control.	Control.	
Dry	Osborne et al., (2019)	Start Average End	20km TT	No feedback.	256± 29	33.22min	Control	Control.	

Dry	Racinais et al., (2019)	Start Average End	40km TT	Not reported.	333	-	No control	No control	
Dry	Racinais et al., (2019)	Start Average End	40km	Not reported.	379	-	No control	No control	
Dry	Racinais et al., (2019)	Start Average End	257.5km	Not reported.	221	-	No control	No control	
Dry	Lei et al., (2020)	Start Average End	30min TT	Elapsed work done on completion of every 20%. (not stated whether it was visual or verbal).	206 ± 37W	371 ± 64kj			Maintained throughout until 24 where there was an increase in PO until the end of the TT
Humid	Roelands et al., (2008a)	Start Average End	predetermined amount of work equal to 30 min at 75% Wmax as quickly as possible.	No feedback provided.	196±35(~260)	45.24±7.18min(~31min)	75%	68%	
Humid	Roelands et al., (2008b)	Start Average End	predetermined amount of work equal to 30 min at 75% Wmax as quickly as possible.	No feedback provided.	189.6 ±49.2 W (250.7±30.9 W)	40.36± 6.24min(18.29±1.18min)	75%	45%	
Humid	Périard et al., (2011a)	Start Average End	40km	verbal feedback at 95% to finish the time trial at maximal effort.	242.1 ±27.3(279.4 ± 22.0 W)*	64.3± 2.8 (59.8 ± 2.6 min)*	7%	13%	progressive decline in pace in the hot condition after 15min compared to control ($P < 0.05$). This decline continued until 50min, from which point the pace was significantly increased until completion (shaped pace in which the pace was maintained until 50min, from which point there was a significant increased in PO)

Humid	Périard and Racinais (2015a)	Start Average End	4 x 16.5-min time trials interspersed by 5 min of passive/active recovery (~75 W).	Visual elapse distance every 5min and verbal encouragement was given, and visual display (power, heart rate, cadence, speed, elapsed distance) was revealed to in the last1.5min of each 16.5min TT.	-	-	-	-	the variation was significantly greater in the hot condition (P 0.01), ranging from 23.2 to 11.7% (during control remained relatively even, varying only by ~11% (range: 6.9 to 4.5%) relative to average PO)
Humid	Périard and Racinais (2015b)	Start Average End	750 kJ	Work completed each 10% and verbal feedback at 95% to finish the time trial at maximal effort.	-	55.8±14.4 min	-	12.50%	decreased from 50% to 90% of work completed, increase form 90-100% (Relative to the first 30% of work completed, PO remained stable in the control condition until 90%, increase form 90-100%)
Humid	Watson et al., (2005)	Start Average End	60min at 55% of Wmax followed by 30min TT	No feedback provided.	279 ± 35	39.8 ± 3.9 min	Control	Control	
Humid	Cramer et al., (2015)						Control	Control	progressive decline in PO over the TT until 30min, from which point PO was increased for the final 10min.
Humid	Teunissen et al., (2013)	Start Average End	15min at starting at 80W and icreased by 20W every 3min, followed by 15km TT	Elapsed distance.	244±26	26:37 ± 3:10-	No control.	No Control.	progressive decline in PO after the first 2km until 13km, finishing with an end sprint for the final 2km.
Humid	Teunissen et al., (2013)	Start Average End	15min at starting at 80W and icreased by 20W every 3min, followed by 15km TT	Elapsed distance.	248 ± 30	26:09 ± 3:26	No control.	No Control.	progressive decreased after 4km until 10km, from which point PO gradually increased until completion of 15km.
Humid	Periard and Racianis, (2016)	Start Average End	750kJ	Visual 10% of elapse work completed and kilojoule countdown was provided upon reaching the last 3% until completion.	230	55.8±14.4min	-	13.62%	
Humid	Che Jusoh et al., (2016)	Start Average End	15min	Elapsed time every 3mins.	221± 33	-	Control.	Control.	

Humid	Maia-Lima, et al., (2017)	Start Average End	30km	Visual elapse distance.	PO continued to decrease after 12km	60.62±3.47	Control	control	progressive decline in PO until 24km, from which PO was gradually increased until the completion of 30km.
Humid	Lei et al., (2020)	Start Average End	30min TT	Elapsed work done on completion of every 20%.	206 ± 37W	- 371 ± 64kj	No control	No control	Maintained throughout until 24 where there was an increase in PO until the end of the TT

WBGT = wet-bulb globe temperature.

2.3.4. Physiological responses

2.3.4.1. Rectal/Core Temperature (T_{rectal}/T_{core})

The change in T_{rectal} /T_{core} during a cycling TT in HD ranged from ~0.8 to 2°C (Table 5). Keiser et al., (2015) was the only article to compare changes in T_{rectal}/T_{core} in HD and CON, reporting a ~2°C increase in CON (37.9±0.1 to 39.2±0.1°C) compared to a~0.8°C (38.8±0.2 to 39.6±0.2°C) increase in HD. Notably end T_{rectal}/T_{core} was not different between studies. Whereas, Racinais et al., (2015b) reported a ~1.6°C greater end T_{rectal}/T_{core} in HD (40.1±0.4°C) compared to CON (38.5±0.6°C). Notably, the greatest T_{rectal}/T_{core} achieved was 41.5°C in Racinias et al., (2019) article which investigated physiological responses during the UCI Road Cycling World Championships. 34 of 40 participants (85%) reached a T_{core} of 39°C and 10 (25%) of those exceeded 40°C. Despite the elevated T_{core}, none of the athletes were admitted to the medical facilities for heat-related illnesses. In addition, T_{core} were greater in TTT and ITT than RR, despite being shorter events. This reinforces the notion that exercise intensity is a more potent parameter than duration for increasing body temperature.

Whereas the change in T_{rectal}/T_{core} in HH ranged from 0.5 to 2.7°C (Table 5). All articles had an increase of ~1°C, apart from Roelands et al., (2008b) with an increase of 0.5°C which may have been related to a high starting T_{rectal}/T_{core} (38.5°C; Table 5). The greatest increase in T_{rectal}/T_{core} was reported in Roelands et al., (2008a) article, in which there was minimal wind speed (0.5m/s), impaired PO (196±35 vs~260W) and CT compared to CON (45.24±7.18 vs ~31min). 4 articles compared the change in Trectal/Tcore in HH compared to CON reporting no difference in the change in T_{rectal}/T_{core} in conditions (Roelands et al., 2008a; Roelands et al., 2008b; Périard et al., 2011a; Périard and Racinais, 2015a).

Collectively, the change in T_{rectal}/T_{core} was greater in HH (1-2.7°C) compared to HD (0.8-2°C) which supports Vanos, and Grundstein, (2020) findings of a greater cooling ability in HD compared to HH. However, when compared in a single article, Teunissen et al., (2013) and Lei et al., (2020) reported that there was no significant difference in average or end T_{rectal}/T_{core} between HD and HH conditions which were matched for WBGT and vapour pressure, respectively (Table 5). Therefore when conditions are not matched for WBGT or water vapour there was a greater heat storage in HH compared to HD and CON. The performance impairment in HH compared to HD stated above may be related to the impairment in heat dissipation via evaporation in HH conditions resulting in a greater internal heat storage (T_{rectal}/T_{core}).

2.3.4.2. Skin Temperature (T_{sk})

Only two articles reported the change in T_{sk} in both HD compared to CON (Table 5). Keiser et al., (2015) reported an increase of ~1.2°C (36.9 ±0.4 to 38.1 ±0.3) in HD compared to an increase of ~3.8°C in CON (32.6 ±0.5 to 36.4 ±0.4°C). Whereas, Kent et al., (2018) reported no change in T_{sk} in both HD (34.6 to 34.6°C) and CON in (31.8 to 32°C). Collectively, the change in T_{sk} in HD was ~1.2°C (Table 5).

Two articles reported the change in T_{sk} in HH compared to CON (Table 5). Périard et al., (2011a) article reported no change in T_{sk} in HH (35 to 35°C) whereas T_{sk} decreased by 3°C in CON (31 to 28°C). Whereas Periard and Racinais, 2015a) reported a ~3.2 increase in T_{sk} in HH (31 to 24.2) compared to a ~4.9°C decrease in T_{sk} in CON (31 to 26.2; Table 5). Collectively the change in T_{sk} in HH ranged from ~0 to 6°C. The greatest increase in T_{sk} was ~6°C (31 to 37) reported in Periard and Racianis, (2016).

Lie et al., (2020) reported no different in the change in T_{sk} between HD (~1.2°C; 34.8 to 36°C) and HH (~1°C; 37.25 to 38.25°C). Notably, the start and end T_{sk} was ~2.4°C and ~2.2°C greater in HH compared to HD, respectively. Whereas, Teunissen et al., (2013) reported a greater change of T_{sk} in HD (~2.35; 37.25-39.6) compared to HH (~2.25°C; 37.25-38.5°C) and HH with wind (~2.3°C; 37.25-38.6°C).

2.3.4.3. Heart Rate (HR)

Three articles compared the change in HR in HD and CON reporting no differences between the conditions (Keiser et al., 2015; Racinais et al., 2015b; Kent et al., 2018; Table 5). Schlader et al., (2011d) was the only article to compare average HR in HD (183±7 $b.min^{-1}$)

and CON (176±10 b.min^{-1}, $P<0.05$; Table 5). The change in HR in HD ranged from 3-102 b.min^{-1}. The smallest change was reported in Racinais et al., (2015b) article of ~4 b.min^{-1} in which starting HR was high (174 b.min^{-1}; Table 5).

Three articles compared the change in HR in HH and CON reporting no differences between the conditions (Roelands et al., 2008b; Périard et al., 2011a; Périard and Racinais, 2015a; Table 5). Collectively the change in HR in HH ranged from 19-100 b.min^{-1}. The greatest change in HR (~100 b.min^{-1}; 70 to 170 b.min^{-1}) was reported in Maia-Lima, et al., (2017) article. This may have been related to the heat stress (31.5°C) and length of task (30km in 60.62±3.47min; Table 5 and 4).

The change in HR in HD and HH was not compared in any of the articles. However, Teunissen et al., (2013) reported a greater end HR in HH (185) compared to HD (180 b.min^{-1}; Table 5).

2.3.4.4. Sweat Rate (SR)

Three articles compared the difference in SR in HD compared to CON (Schlader et al., 2011d; Kent et a., 2018; English et al., 2019; Table 5). SR was ~0.4-0.5L.hr greater in HD compared to CON (Table 5). Kent et al., (2018) reported the greatest difference in SR between HD and CON (~0.5L.hr). Collectively the SR in HD ranges from 0.82-2.2Lhr (Table 5). The greatest SR in HD of 2.2Lhr was reported in Kent et al., (2018) article (Table 5). No firm conclusions can be made on the mechanisms behind the SR reported in Kent et al., (2018) article because no PO was reported in this article and no completion time/DC were reported in Schlader et al., (2011d) and English et al., (2019) article.

Two articles compared SR in HH and CON (Periard et al., 2011a; Periard and Racinais, 2015a; Table 5). Both articles reported a ~0.7-1L.hr greater SR in HH compared CON (Table 5). Collectively, the SR in HH ranged from ~0.79- 2.4L.hr (Table 5). The greatest SR in HH of ~2.4Lhr was reported in Periard and Racinais (2015b) article. In contrast, the lowest SR (0.79L.hr) reported in HH conditions was in Teunissen et al., (2013) article. A contributing factor to the difference in SR between these two articles may be related to the difference in end T_{core} (~1.1°C) and T_{sk} (~0.5°C). This may imply that there was greater amount of heat stored in Periard and Racinais (2015b) article compared to Teunissen et al., (2013) article warranting a greater SR response for thermoregulation.

Lie et al., (2020) reported ~0.13L.hr greater SR in HD (0.97±0.31L.hr) compared to HH (0.84±0.21L.hr). These findings may reflect the impairment of SR in HH conditions compared to HD. (Vanos, and Grundstein, 2020).

In summary, this section highlighted that thermoregulatory responses such as the change in T_{rectal}/T_{core} in HD and HH ranged from ~0.8 to 2°C and ~0.5 to 2.7°C, respectively. Only one article compared change in T_{rectal}/T_{core} in HD and CON reporting a greater change in CON (~2°C) compared to HD (~0.8°C; Keiser et al., (2015). Notably starting T_{rectal}/T_{core} was ~1 higher in HD and end T_{rectal}/T_{core} was not different between conditions. Whereas, there was no difference in the change in T_{rectal}/T_{core} between HH and CON. Secondly, the change in T_{sk} in HD and HH ranged from ~1.2°C and ~0 to 6°C, respectively. However, there were conflicting results regarding the change in T_{sk} in HD and CON, HH and CON and HD and HH. Notably, T_{sk} in CON decreased in both by ~3-4.9°C. Thirdly, the change in HR in HD and HH ranged from 3-102 b.min^{-1} and 19-100 b.min^{-1}, respectively. The change in HR in HD and HH was not compared in any of the articles. Fourthly, SR in HD and HH ranged from 0.82-2.2Lhr and ~0.79- 2.4L.hr, respectively. SR was ~0.13L.hr greater in HD compared to HH.

Collectively this section of the review highlighted that more research needs to be conducted on the change in thermoregulatory responses in HD compared to HH where WBGT is matched to ensure that thermal strain experienced is similar in both conditions to be able to draw accurate conclusions.

Table 5. Physiological responses during cycling time-trial in hot and dry (HD) and hot and humid (HH) conditions.

Condition	Authors	Timing	Condition			Task		Physiological response			
			Environmental condition (°C , %, m/s)	WBGT (°C)	Indoor/Outdoor	Exercise Length	Feedback given.	T_{rectal}/ T_{core} (°C)	Tsk (°C)	HR (b.min^{-1})	SR (L.hr)
Dry	Peiffer and Abbis (2011)	Start Average End	32, 40,8.9 (17, 40, 8.9)	24.6 (12)	Indoor	40km TT	Visual elapsed distance.	37.2 - 39.5	- - -	- - -	-
Dry	Peiffer and Abbis (2011)	Start Average End	27, 40, 8.9 (17, 40, 8.9)	21.2 (12)	Indoor	40km TT	Visual elapsed distance.	37.3 - 39.3	- - -	- - -	-
Dry	Schlader et al., (2011d)	Start Average End	40,14,1.5 (20.4 ± 0.7 °C, 24% ± 7%)	26.5(16.3)	Indoor	30min	Visual elapsed time.	- 37.9±0.4 (37.8±0.4) -	- 36.6 ±0.6 * (31.2±1.5)* -	- 183±7 (176±10)* -	1.38 (0.97)-
Dry	Teunissen et al., (2013)	Start Average End	33,40	26.5	Indoor	15min at starting at 80W and increased by 20W every 3min, followed by 15km TT	Visual elapsed distance.	37.25 - 39.6	35.1 - 36.2	- - 180	0.90±0.17
Dry	Keiser et al., (2015)	Start Average End	38,30,3 (18, 30, 3)	28.1 (12.1)	Indoor	30min	Visual power output and elapsed time.	38.8 0.2 (37.9 0.1) - 39.6 0.2 (39.2 0.1)	36.9 ±0.4 (32.6	79±7(68±5) -	0.82 ±0.09

									±0.5 †) - 38.1 ±0.3 (36.4 ±0.4)*	181 ±2(180 ±1)	
Dry	Racinais et al., (2015b)	Start Average End	36.0 ±0.**4°C**,, 13±1%,,6.8 (8.2±3.5°C, 30± 8%, 6.0)	22.6(3.6)	outdoors	43.4km	Visual HR, power output, speed, and elapsed distance.	38.4 - 40.1± 0.4(38.5± 0.6)	- - -	174(~163) -173± 1(166± 2) 177(163)	-
Dry	VanHaitsma et al., (2015)	Start Average End	35,25,0.5 (21 °C, ~20 %)	25.4(13.6)	Indoor	40km	Visual power output, speed, cadence and elapsed distance.	37 (37) - 39.2 (38.7)		-160 165 ± 15.7(164 ± 15.7) 180	-
Dry	Schmit et al., (2016)	Start Average End	35,50,12.5 (21°C, 50%, 12.5)	28.6 (16.4)	Indoor	20km	Visual elapsed distance.	-	- - -	- - -	-
Dry	Al-Horani et al., (2018)	Start Average End	33,40,2.77	25.7	Indoor	16.1km	Not reported.	36.8 - 38.3		- - 165	1.1
Dry	Mejuto et al., (2018)	Start Average End	32, 50	26.9	Indoor	10km TT	Visual elapsed distance.	37.2 - 38.8	-	- 182 -	-
Dry	English et al., (2019)	Start Average End	36,50 (21 °C, 50%)	30.4 (17.1)	Indoor	30min at 50% VO_{2max} followed by a 5min rest and 15min TT		37.8 (37.6) - 38.4 (38.2)	- - -	- - -	~0.87 (0.55)

Dry	Kent et al., (2018)	Start Average End	34.9 ± 0.3°C, 48.0 ± 1.9% (21,52)	~29.2(17.2)	Indoor	14kj.kg-1		37.6 (37.5) - 39 (38.2)	34.6 (31.8) - 34.6 (32)	~100 (97) - ~165 (160)	2.2 (1.5)
Dry	Lie et al., (2020)	Start Average End	34.9±0.2 °C, 50.1±1.1%,5.27	28.7	Indoor	30min TT	Elapsed work done on completion of every 20%.	37.25 - 38.5	34.8 - 36	- - -	0.97±0.31
Humid	Roelands et al., (2008a)	Start Average End	30,50-60% 0.5 (18, 50-16, 0.5)	31.1 (14.5)	Indoor	predetermined amount of work equal to 30 min at 75% Wmax as quickly as possible (13).	No feedback provided.	36.8(37) - 39.3 (~39)	- - -	- - ~180 (~180)	-
Humid	Roelands et al., (2008b)	Start Average End	30, 50-60%, 0			predetermined amount of work equal to 30 min at 75% Wmax as quickly as possible (13).	No feedback provided.	~38.5(~37.5) - ~39(~38)		~180 (control ~170) - 170 (~180)	
Humid	Périard et al., (2011a)	Start Average End	35,60,3.47 (20, 40, 3.47)	30.2(14.6)	Indoor	40km	verbal feedback at 95% to finish the time trial at maximal effort.	37.1(37) - 39.8(38.7)	35 (31) - 35(28)	165(160) - 184 (180)	1.8 ± 0.5 (1.1 ± 0.4)
Humid	Périard and Racinais (2015a)	Start Average End	35°C, 60%, 0.14m/s (18, 40%, 0.14m/s)	30.7(13.5)	Indoor	4 x 16.5-min time trials interspersed by 5 min of passive/active recovery (~75 W).	Visual elapse distance every 5min and verbal encouragement was given, and visual display (power, heart rate, cadence, speed, elapsed distance) was revealed to in the last1.5min of each 16.5min TT.	36.8(36.8) - 39.4 0.7°C (38.6 0.3°C)*	31(31) - ~34.2(26.2)	160(156) - 185(178)	2.3 0.4 (1.3 0.2)
Humid	Périard and Racinais (2015b)	Start Average End	35,60,4	30.2	Indoor	750 kJ	Work completed each 10% and verbal feedback at 95%	37 - 39.6	31 - 36	158 - 183	2.4±0.8

							to finish the time trial at maximal effort.				
Humid	Watson et al., (2005)	Start Average End	30,55,0.5	25.3	Indoor	60min at 55% of Wmax followed by 30min TT	No feedback provided.	- - 39.7	- - -	- - -	1.8
Humid	Teunissen et al., (2013)	Start Average End	28,80	26.2	Indoor	15min at starting at 80W and icreased by 20W every 3min, followed by 15km TT	Elapsed distance.	37.25 - 38.5	34.5 - 35.5	- - 185	0.79±0.25
Humid	Teunissen et al., (2013)	Start Average End	33,80,4m/s	30.9	Indoor	15min at starting at 80W and icreased by 20W every 3min, followed by 15km TT	Elapsed distance.	37.25 - 38.6	34.8 - 35.6	- - -	0.87 ± 0.19
Humid	Periard and Racianis, (2016)	Start Average End	35,60,3.47	30.2	Indoor	750kJ	Visual 10% of elapse work completed and kilojoule countdown was provided upon reaching the last 3% until completion.	37 - 39.7	31 - 37	153 - 175	2.1
Humid	Che Jusoh et al., (2016)	Start Average End	30±2, 78±3, 5.55	27.8	Indoor	15min	Elapsed time every 3mins.	- - 39.1		-	1.7±0.5
Humid	Maia-Lima, et al., (2017)	Start Average End	35,68,0.5	31.5	Indoor	30km	Visual elapse distance.	37.25 - 39.5	35.1 - 36.5	70 - 170	1.92±0.27
Humid	Lei et al., (2020)	Start Average End	29.2±0.2 °C, 69.4 ± 1.0%, *5.27*	26	Indoor	30min TT	Elapsed work done on completion of every 20%.	37.25 - 38.25	32.2 - 34.2	- - -	0.84±0.21

WBGT = wet bulb globe temperature

2.3.5. Perceptual Responses

2.3.5.1. Ratings of Perceived Exertion (RPE)

Only three articles reported the change in RPE in HD compared to CON in which all articles reported no difference in the change in RPE between conditions (Schlader et al., 2011d; VanHaitsma et al., 2015; Kent et al., 2018; Table 6). Collectively the change in RPE in HD ranged from ~3(15%) to 11(78%). The greatest change (11: 78%) was reported in Racinais et al., (2019).

Only two articles compared the change in RPE between CON and HH (Périard et al., 2011a; Périard and Racinais (2015a; Table 6). Périard et al., (2011a) reported a ~7% greater change in RPE in CON (13-19) compared to HH (14-19; Table 6). Notably there was no difference in end RPE between conditions (19; 93%; Table 6). Whereas, Périard and Racinais (2015a) reported no difference in the change in RPE between conditions (14-19; 36%; Table 6). Collectively the change in RPE in HH ranged from ~4(29%)- 8(58%).

Only one article compared the change in RPE between HD and HH (Teunissen et al., 2013), reporting a ~5% greater change in HH and ~13% greater change in HH with wind compared to HD. Notably ratings of RPE were the same at the end of the TT (19:93% of max).

2.3.5.2. Thermal Sensation (TS)

Only two articles compared TS in HD and CON (Schalder et al., 2011d; Kent et al., 2018; Table 6). Schlader et al., (2011d) reported a ~8% greater change in HD (slightly warm (71% of max) to hot (100% of max)) compared to CON (neutral (50% of max) to slightly warm (71% of max)). Kent et al., (2018) also reported a ~12% greater change in TS in HD (Hot (88% of max) to very hot (100% of max)) compared to CON (warm (75% of max) to warm (75% of max)). Collectively the change in TS in HD ranged from ~15-33% (Table 6).

No articles compared TS in HH and CON. Teunissen et al., (2013) was the only article to report change in TS in HH, showing a ~45% change in HH and ~22% change in HH with wind. The change in TS was ~12% greater in HH (~45%) compared to HD (~33%). Notably the ratings of TS at the end of the TT reached max (very hot) for both HH and HD. Whereas TS reached 88% of max (hot) in HH with wind, highlighting that wind speed may provide beneficial for TS in HH.

2.3.5.3. Thermal Comfort (TC)

Schlader et al., (2011d) was the only article to report change in TC in HD compared to CON, highlighting a ~25% greater change in TS in CON (comfortable: 25% to uncomfortable 75%) compared to HD (uncomfortable: 75% to Very uncomfortable: 100%; Table 6). This finding highlighted that the participants felt more uncomfortable in HD from the onset of cycling compared to CON. Collectively the change in TC in HD ranged from 25-75%. The greatest change of 75% was reported in Lei et al., (2020) article in which participants started the TT feeling comfortable (0% of max) and finished the TT feeling slightly uncomfortable (75% of max).

Five articles compared the change in TC in HH and CON (Périard et al., 2011a; Périard and Racinais 2015a; Périard and Racinais, 2015b; Periard and Racianis, 2016; Maia-Lima, et al., 2017; Table 6). Périard et al., (2011a), Périard and Racinais (2015a) and ; Maia-Lima, et al., (2017) reported a ~10%, 14%, and 28% greater change in TC in HH compared to CON, respectively. Whereas Periard and Racinais (2015b) and (2016) reported ~1% differences between conditions. Collectively the change in TC in HH ranged from ~10-75%. The greatest change of 75% was reported in Teunissen et al., (2013) article in which participants felt very comfortable (25% of max) at the start of the TT and finished the TT feeling very uncomfortable (100% of max).

Teunissen et al., (2013) was the only study to compare the change in TC in HD to HH, reporting a ~25% greater increase in HH compared to HD. Notably, TC finished at “very uncomfortable” (100% of max) in HD, HH and HH with wind.

2.3.5.4. Affect (AF)

Only one article to report changes in AF in HD and CON (English et al., 2019). The findings showed that there was a ~5% greater change in AF in HD compared to CON. AF is negatively affected by HD as AF decreased from good (83% of max) at the start of the TT to fairly good (77% of max) at the end of the TT. Whereas, AF was unaffected in CON and was maintained as good (83% of max) throughout the TT. To date, not articles have investigated the effect of HH on AF during cycling, nor compared HH and HD.

2.3.5.5. Motivation (M)

Schmit et al., (2016) was the only article to measure motivation in HD compared to CON. Participants were asked to use a 5-point Likert scale (5=strongly agree, 4=agree, 3=not sure, 2=disagree, 1=strongly disagree**)** to stated whether they were motivated or not to complete the TT prior to starting. There was no significant difference in motivation to complete the TT prior to HD (agree: 80% of max) or CON (agree: 80% of max). Notably motivation was not measured during the TT and therefore it is unclear whether motivation was effected by the condition.

No articles measured motivation in HH. However, a recent review by Coudevylle et al., (2021) investigated the impact of HH conditions on motivational factors during aerobic performance highlighting that is a relatively under researched area of environmental perception. Coudevylle et al., (2021) suggested that this may be related to the difficulty in measuring motivation, and therefore proposed an integrative theoretical model to better understand the direct and indirect motivational mechanisms that can operate on athletic performances.

Table 6. Perceptual responses during cycling TTs in hot and dry (HD) and hot and humid (HH) conditions.

Condition	**Authors**	**Timing**	**Condition**			**Task**		**Perceptual Responses**				
			Environmental condition (°C, %, m/s)	**WBGT (°C)**	**Indoor/Outdoor**	**Exercise Length**	**Feedback given.**	**RPE (% of max)**	**TS (% of max)**	**TC (% of max)**	**AF (% of max)**	**TM (% of max)**
Dry	Schlader et al., (2011d)	Start Average End	40,14,1.5 (20.4 ± 0.7 °C, 24% ± 7%)	26.5(16.3)	Indoor	30min	Visual elapsed time.	15(75%) (15(75%) - 18(90%) (18(90%)	Slightly warm: 71%(neutral: 50%) - Hot: 100%(slightly warm: 71%)	uncomfortable: 75% (comfortable 25%) Very uncomfortable: 100%(uncomfortable 75%)	- - -	- - -
Dry	Teunissen et al., (2013)	Start Average End	33,40	26.5	Indoor	15min at starting at 80W and increased by 20W every 3min, followed by 15km TT	Visual elapsed distance.	13:50% - 19: 93%	Slightly warm: 67% - Very hot: 100%	Comfortable:50% - Very uncomfortable: 100%	-	-
Dry	VanHaitsma et al., (2015)	Start Average End	35,25,0.5 (21 °C, ~20 %)	25.4(13.6)	Indoor	40km	Visual power output, speed, cadence and elapsed distance.	13:50%(13:50%) 16.4:71%(15.5:64%)* 18:86%(17:79%)	Hot: 88%(Slight warm to hot:66%)	Slightly uncofmrotable: 67% -very uncomfortable: 100%(uncomfortable:83%) -		
Dry	Schmit et al., (2016)	Start Average End	35,50,12.5 (21°C, 50%, 12.5)	28.6 (16.4)	Indoor	20km	Visual elapsed distance.					Agree:80% (Agree:80%)
Dry	Kent et al., (2018)	Start Average End	34.9 ± 0.3°C, 48.0 ± 1.9% (21,52)	~29.2(17.2)	Indoor	14kj.kg-1	Not reported.	15:78%(15:78%) - 19:93%(19:93%)	Hot: 88%(Warm 75%)- Very hot:100%(Warm:75%)			

Dry	English et al., (2019)	Start Average End	36,50 (21 °C, 50%)	30.4 (17.1)	Indoor	30min at 50% VO_{2max} followed by a 5min rest and 15min TT	Verbal elapsed time from researcher at 5, 10, 12, 13, 14, 14.30 and 14.50min				Good:83% (good:83%) - Fairly good: 77%(good:83%)	
Dry	Racinais et al., (2019)	Start Average End	37,25	29.7	Outdoor TT	40km TT	Not reported.	7:7% 18:85%				
Dry	Lei et al., (2020)	Start Average End	35,50, 5.27	28.7	Indoor	30min TT	Elapsed work done on completion of every 20%. (not stated whether it was visual or verbal).	10:29% - 17:79%	Slightly warm: 71% - Too warm:86%	Comfortable: 0% -Slightly uncomfortable: 75%	-	-
Humid	Roelands et al., (2008a)	Start Average End	30,50-60% 0.5 (18, 50-16, 0.5)	31.1 (14.5)	Indoor	predetermined amount of work equal to 30 min at 75% Wmax as quickly as possible (13).	No feedback provided.	- - 17:79%(17:79%)				
Humid	Périard et al., (2011a)	Start Average End	35,60,3.47 (20, 40, 3.47)	30.2(14.6)	Indoor	40km	verbal feedback at 95% to finish the time trial at maximal effort.	14: 57% (13) - 19: 93% (19: 93%)	- - -	comfortably warm: 75% (comfortable:42%) - too warm:85% (comfortable: 42%)		
Humid	Teunissen et al., (2013)							12 - 19: 93%	warm:55% - very hot: 100%	very comfortable:25% - very uncomfortable:100%		
Humid	Teunissen et al., (2013)			wind				11 - 19: 93%	slightly warm:66% - hot:88%	very comfortable:25% - very uncomfortable:100%		
	Périard and Racinais (2015a)	Start Average End	35°C, 60%, 0.14m/s (18, 40%, 0.14m/s)	30.7(13.5)	Indoor	4 x 16.5-min time trials interspersed by 5 min of passive/active recovery (~75 W).	Visual elapse distance every 5min and verbal encouragement was given, and visual display (power, heart rate, cadence, speed, elapsed distance) was revealed to in the last1.5min of each 16.5min TT.	14:57% (14: 57% - 19: 93% (19: 93%)	-	Comfortably warm: 71% (comfortably cool: 42%) - Too warm:85% (comfortably cool: 42%)		

Humid	Périard and Racinais (2015b)	Start Average End	35,60,4	30.2	Indoor	750 kJ	Work completed each 10% and verbal feedback at 95% to finish the time trial at maximal effort.	13: 50% - 19: 93%		Comfortably warm: 71% (comfortably cool: 42%) Too warm: 85% (comfortable: 57%)		
Humid	Periard and Racianis, (2016)	Start Average End	35,60,3.47	30.2	Indoor	750kJ	Visual 10% of elapse work completed and kilojoule countdown was provided upon reaching the last 3% until completion.	14:57% - 19: 93%		Too warm: 85% (comfortable: 57%) - Much too warm: 100% (comfortably warm: 71%)		
Humid	Maia-Lima, et al., (2017)	Start Average End	35,68,0.5	31.5	Indoor	30km	Visual elapse distance.	12:42% - 16:71%	- - -	Comfortable: 57% (comfortable:57%) - Uncomfortable: 85%(comfortable:57%)		

2.3.6. Conclusion

- PO was progressively impaired throughout the trial in HD and HH compared to CON. Although, there was no significant difference in average PO in HD and HH, the decline in PO in HH occurred earlier compared to HD, especially if there was no wind.
- Thermoregulatory responses are impaired in HD and HH compared to CON. For example, more rapid increase in Tc_{ore}/T_{rectal} and T_{sk}, and greater average HR and SR.
- There is a lack of research comparing perceptual responses in HD and CON, HH and CON, HD and HH. Preliminary findings in the area show that HH results in a greater change in thermal perception (RPE, TS, TC) compared to CON and HD. Notably, end thermal perception values (RPE, TS, TC) are equivalent in HD and HH.
- There was limited research that compared performance in conditions that were matched for WBGT to ensure thermal stress and strain experienced were similar between conditions to enable more accurate comparisons and conclusions. Therefore, future research should aim to investigate cycling TT performance in HD and HH conditions were WBGT is matched. However, there is limited research that compares direct WBGT ensuring that thermal strain experienced is similar to be able to draw accurate conclusions. Therefore, future research should measure thermoregulatory responses such as T_{core}/T_{rectal}, T_{sk}, HR and SR, and perceptual responses such as RPE, TS, TC, AF, M during cycling TT performance in conditions were WBGT is matched.
- Collectively these findings demonstrate that there is a difference in physical and mental performance, and thermoregulatory and perceptual responses in HD and HH. Therefore, it would be practical to assume that the heat alleviation strategies used in HD and HH would be different conditions.
- Additional findings from this review highlighted that multiple different scales are used to measure perceptual responses which makes it difficult to compare results between

studies. Future research should investigate the most practical and valid scale for each perceptual variable. It was also noted that the feedback provided in the eligible article’s differed in type (verbal vs visual or performance vs physiological) and quantity (1-4) which could have also influenced performance by adding additional cognitive load.

2.4. Cycling performance in hot conditions (HD vs HH) with per-cooling (cold-water ingestion vs pouring).

To reduce the physiological strain experienced during cycling in hot conditions, numerous heat alleviation strategies have been developed, such as heat acclimation/acclimatization, hydration and cooling (Racinais et al., 2015a; Tyler et al., 2016). Each strategy will be discussed briefly before focusing on cooling as the main strategy in this review.

2.4.1. Heat Acclimation/acclimatization

Heat acclimation (artificial environment i.e. laboratory) and acclimatization (natural environment) involves repeated exposure to competition conditions in the weeks/days (≤14 days) leading up to competition (Racinais et al., 2015a; Periard et al., 2015). Despite the benefits, heat acclimation/acclimatization protocols are often very time consuming (medium-long term adaptation; Moss et al., 2020) and expensive to complete. The adaptation from this strategy can be maintained for ~8weeks with intermittent heat training once a week (Sekiguchi et al., 2021). However, no intermittent heat training following heat acclimation/acclimatisation will result in a loss of adaptations after 4 weeks and even greater losses after 8 weeks (Sekiguchi et al., 2021). Whereas cooling and hydration can be applied easily and cost effectively prior to (pre-cooling) and during (per-cooling) competition in hot conditions (Racinais et al., 2015a).

2.5.2. Hydration

Periard and Racinais (2019) book included a chapter on hydration (Burke, Chapter 6, pp.113-138) which highlighted key hydration terminology, assessment of hydration states and, physiological and performance affects at different hydrated states. When measured via urine specific gravity, hydration is typically categorised into four states; Hyperhydated, euhydrated, hypohydrated and severely hypohydrated. Overall fluid balance and hydration state is affected by the fluid that is taken in and lost from the human body. Fluid out via sweat loss will vary according to features of the exercise, the environment and the athlete.

However, SR does vary from individual to individual ($1Lh^{-1}$ to $4Lh^{-1}$) and depends upon a number of variables including; fitness level, environmental conditions (i.e. temperature, humidity, air velocity), and metabolism (Sawka, Cheuvront and Kenefick, 2015). To replace fluid lost via sweating, athletes can use “ad libitum drinking” (i.e. drink whenever you want) or “drinking to thirst” (i.e. drink when you are thirsty) or “programmed fluid intake” protocols (i.e. drink every 5mins). The best approach will vary according to the factors that influence the relative magnitude of sweat rates and opportunities to drink in the desired sport. Failure to replace fluid lost via sweating will result in hypohydrated/severely hypohydrated/dehydrated states. Dehydration can cause greater levels of fatigue and pain, influencing overall mood state and perceptual ratings during ultra-endurance cycling compared to euhydration (Moyen et al., 2015).

2.4.3. Cooling

Cooling can be administered internally or externally. Internal cooling can be conducted via cold-water or ice-slurry ingestion which activates central thermoreceptors. Whereas, external cooling can be conducted via cold-water immersion, cooling vests, cold-water pouring, etc which decreases tissue temperature and activates peripheral thermoreceptors (Tyler 2019 pp.139; Periard and Racinais, 2019).

2.4.3.1. Performance Response

Multiple reviews and meta-analysis have been conducted on cooling (Tyler et al., 2016; Ruddock et al., 2017; Best et al., 2018; Douzi et al., 2019; Alhadad et al., 2019; Zhang et al., 2019; Golbabei et al., 2020; Douzi et al., 2020; Rodriguez et al., 2020).

Tyler et al., (2016) conducted a meta-analysis on the effect of cooling prior to and during exercise on exercise performance and capacity in hot conditions (WBGT = >26°C). 28 articles were investigated (23 pre-cooling and 5 per-cooling). Overall, precooling had a moderate (d=0.73) effect on subsequent performance, but the magnitude of the effect is dependent on the nature of the test. For example, sprint performance was impaired (d=−0.26) but intermittent performance and prolonged exercise were both improved following cooling (d=0.47 and d=1.91, respectively). In summary, precooling can improve subsequent intermittent and prolonged exercise performance and capacity in a hot environment, but sprint performance is impaired. Cooling during exercise also has a positive effect on exercise performance and capacity in a hot environment.

Douzi et al., (2019) systematic review with meta-analyses found that cooling during exercise enhances performance but the cooled body area matter. Specifically, internal cooling (cold fluid ingestion such as cold water and ice slurry/menthol beverage) and external cooling (face, neck, and torso) provide the greatest performance benefit for ‘aerobic’ performance with a moderate to large effect. For ‘anaerobic’ exercises, wearing a whole-body cooling garment is the best way to enhance exercise performance.

Best et al., (2018) review investigated topical and ingested cooling methodologies for endurance exercise performance in the heat. This systematic review and meta-analysis aimed to assess studies which have investigated cooling methodologies, their timing and effects, on endurance exercise performance in trained athletes (Category 3; VO_{2max} ≥ 55 mL·kg·min−1) in hot environmental conditions (≥28 ◦C). Meta-analyses were performed to quantify the effects of timings and methods of application, with a narrative review of the evidence also provided. 10 articles were investigated. With respect to time trial performance, cooling was shown to result in small beneficial effects when applied before and throughout the exercise bout (Effect Size: −0.44; −0.69 to −0.18), especially when ingested (−0.39; −0.60 to −0.18). Current evidence suggests that whilst other strategies ameliorate physiological or perceptual responses throughout endurance exercise in hot conditions, ingesting cooling aids before and during exercise provides a small benefit, which is of practical significance to athletes’ time trial performance. In line with this, Alhadad et al., (2019) meta-analysis investigated the efficacy of heat mitigation strategies on core temperature and endurance exercise. 118 articles were investigated and assessed according to the intervention's ability to lower core temperature before exercise, attenuate the rise of core temperature during exercise, extend core temperature at the end of exercise and improve endurance. Aerobic fitness (AF) was found to be the most effective in terms of a strategy's ability to favourably alter T_{core}, followed by HA, PC and lastly, FI. Interestingly, a similar ranking was observed in improving endurance, with AF being the most effective, followed by HA, FI, and PC. Knowledge gained from this meta-analysis will be useful in allowing athletes, coaches and sport scientists to make informed decisions when employing heat mitigation strategies during competitions in hot environments.

Zhang, (2019) meta-analysis focused on strategies to optimise ice-slurry ingestion for endurance performance. 16 articles were investigated. Overall, ice-slurry ingestion moderately improved endurance performance in the heat (g=0.54). In line with this, Douzi et al., (2020) narrative review found that per-cooling (Using cooling systems during physical exercise) enhances physical and cognitive performances in hot environments. Specifically, the performance improvements from the per-cooling interventions tend to be larger in TTE (9–51%) than in TTs (3–9%). These results may be explained by the fact that participants in TTEs could not freely choose their self-paced intensity. Whereas, the effects of cooling on ‘anaerobic’ exercise depend on the duration of the cooling method and its impact on decreasing the core and skin temperatures. The efficacy of per-cooling depends on the participant’s core temperature, and it has been hypothesized that a higher core temperature leads to a greater per-cooling impact on performance. Thus, the use of per-cooling should be recommended especially when the ambient temperature is high and/or the core temperature of the subject is expected to be elevated.

Rodriguez et al., (2020) systematic review evaluated the effects of different pre-cooling techniques on sports performance in highly-trained athletes under high temperature conditions. 26 articles were investigated. Overall, cooling prior to exercise concluded increases in distance covered (1.5–13.1%), mean power output (0.9–6.9%), TTE (19–31.9%), work (0.1–8.5%), and mean peak torque (10.4–22.6%), as well as reductions in completion time (0.6–6.5%). Mixed strategies followed by cold water immersion seem to be the most effective techniques, being directly related with the duration of cooling and showing the major effects in prolonged exercise protocols. The present review showed that pre-cooling methods are an effective strategy to increase sports performance in hot environments. This improvement is associated with the body surface exposed and its sensibility, as well as the time of application, obtaining the best results in prolonged physical exercise protocols.

2.4.3.2. Physiology Response

Golbabei et al., (2020) systematic review investigated the effect of cooling vests on physiological and perceptual responses. 63 articles were investigated. A statistically significant difference was observed in body temperature among hybrid cooling garments (HBCGs), phase-change materials (PCMs) and air-cooled garments (ACGs) at 31.56–37 °C (60% relative humidity), evaporative cooling garments at 25.8–28.1 °C and liquid cooling garments at 35 °C (49% relative humidity) compared to without cooling vests ($p < 0.001$). PCMs using ingredients such as water and other additives or compounds that have high latent heat, low melting temperature, low price, ease of use and portability can be used as an alternative to alleviate heat strain. Hence, they can have a beneficial effect on improving human body responses in very hot environments with low to high physical activities and heavy workload, which should be considered in future studies and in real work environments. The type of cooling vests used in different climate conditions and experimental procedures probably will have considerable influence on the result of the studies. In conclusion, future research should standardize the experimental procedure, climate condition, clothing ensemble, subjective ratings and body information based on the majority of occupational workers and working scenarios of the cooling vests.

Morris and Jay (2016) commentary piece discussed the differences between cooling via cold-water ingestion or pouring. Cold-water ingestion improves exercise performance and feelings of thermal comfort independently of any differences in core and skin temperature. However, the effect of cold-water pouring has not been investigated, likely due to the mess that would ensue. More recently, Jay and Morris (2018) investigated whether cold-water or ice-slurry ingestion during exercise elicited a net body cooling effect in the heat. Internal cooling causes a reduction in sweating which results in a decrease in evaporative heat loss from the skin by a magnitude that at least negates the additional internal heat loss as a cold ingested fluid warms up to equilibrate with body temperature. Therefore explaining equivalent core temperature. Internal heat transfer with internal cooling is always 100% efficient, therefore when a decrement occurs in the efficiency that sweat evaporates from the skin surface (i.e. sweating efficiency), a net cooling effect should begin to develop. Based on the relationship between activity, climate and sweating efficiency, the boundary conditions beyond which internal cooling can be beneficial in terms for increasing net heat loss can be calculated. The conditions are warmer and more humid for cycling relative to running because of the greater skin surface airflow, which promotes evaporation for a given metabolic heat production and thus sweat rate. Jay and Morris (2018) suggest that within these boundary conditions, athletes should apply internal cooling at the temperature that they find most palatable which likely varies from athlete to athlete and therefore best maintain hydration status.

2.4.3.3. Perceptual Response

Ruddock et al., (2017) found that cooling during fixed-intensity exercise, particularly before a self-paced exercise trial, improves endurance performance in hot environments by benefiting RPE and thermal perception (i.e. thermal comfort and thermal sensation), but does not appear to attenuate increases in body temperature.

Gibson et al., (2020) review and practitioner guidelines for Heat alleviation strategies for athletic performance included a section on cooling strategies. The review summarised the work discussed above, highlighting that per-cooling during exercise in hot conditions elicits beneficial performance effects and can be used addictively with pre-cooling. Cold-water sprays, sipping and/or pouring, cold/wet/frozen towels or bags of ice may provide greater perceptual benefits (e.g. alleviate thermal discomfort) compared to physiological benefits (e.g. reduction in core temperature).

In contrast, Coudevylle et al., (2019) investigated conventional and alternative strategies to cope with the subtropical climates of Tokyo 2020. The review highlighted that alternative methods such as mental techniques/psychological skills (goal setting, arousal regulation, mental imagery, positive self-talk, mindfullness) have shown positive performance results (Barwood et al. 2008; Haase et al., 2015; Wallace et al., 2016).

Collectively the findings report that the benefit of cooling will depend on extent of heat stress (i.e. ambient temperature, humidity, radiation and wind speed), heat strain (i.e. physiological and perceptual responses), the type (i.e. external or internal), timing (pre-cooling and/or per-cooling), duration (i.e. how long the cooling is applied for), and magnitude (i.e. temperature of cooling). Notably the two most practical strategies during training and/or competing in hot conditions, cold-water ingestion and pouring, have received very little research attention. Therefore, the second aim of this thesis is to investigate the effectiveness of cold-water ingestion and pouring at minimising performance impairments during cycling TTs in HD and HH conditions.

2.4.4. Literature Search

To investigate the second aim of this thesis, a second literature search (Figure 2) was carried out in Google scholar, research gate, Scopus. The following search terms were combined to search for the full text of experimental articles published after 2000 and before January 2020: The following search terms were used: “Cycling” OR “Time-trial” OR “Self-paced” OR “Pacing” AND “Heat” OR “Hot”, “Humid”, “Dry” AND “Cooling” OR “per-cooling” OR “Cooling” OR “Cold-water ingestion” OR “Cold-water pouring”. Firstly, titles were assessed for relevance to the topic and selected if they met the inclusion criteria outlined in Table8. This process was repeated for abstracts and full texts. In addition to the literature search, references were scanned for further relevant articles and were included if they met the inclusion criteria.

2.4.4.1. Inclusion/exclusion

Table 7. Table outlines literature search criteria for articles acceptance and rejection.

Inclusion	**Exclusion**
Published between 2000-2020	Published before 2000 and after 2020
Full text available	No full text available
Written in the English Language.	No English source available
Experimental peer-reviewed research article	Not original or peer-review article
Human population	Animal population
Healthy non-acclimated participants.	Clinical or occupational setting, notable mental or physical impairments (i.e. diseases, loss of motor function) and/or heat acclimatised population (Exposure to >30°C in the last 30 days)
Male	Female, transgender.
Assessment of at least one of the following parameters: T_{rectal}, T_{core}, T_{sk}, SR, HR, PO, completion time, DC.	No performance or physiological parameters measured
Self-paced cycling completed	No self-paced cycling completed
Inclusion of at least one task related and unmanipulated feedback variable (elapsed time, distance, HR, PO, cadence, or speed)	Manipulation of feedback, or irrelevant feedback to the task given
Adult participants (≥18yrs)	Children participants (<18yrs)
Ambient temperatures ≥28ºC	Ambient temperatures <28ºC
Inclusion of one per-cooling method.	No per-cooling included.

T_{rectal} = *rectal temperature,* T_{core} = *core temperature,* T_{sk}*, skin temperature, HR = heart rate, PO = power output, DC= distance covered.*

For the purpose of this review cold-water ingestion was defined as drinking water that was ≤10°C and pouring cold-water was defined as pouring water that was ≤10°C over the head, neck, shoulders, torso or back. Control conditions were defined as conditions in thermoneutral conditions.

2.4.4.2. Outcome Measures

The outcome measures extracted from the eligible articles were:

1. Article characteristics – Number of participants, sex ratio (M:F), Group VO_{2max} ($mL.kg.min^{-1}$)

2. Task and conditions – Task (duration or intensity), indoor/outdoor, ambient temperature (°C), relative humidity (%), wind speed (m/s), WGBT (°C), feedback given.
3. Intervention – Water temperature (°C), amount of water ingested at each interval (L), water ingestion frequency (time or distance), total water ingested (L)
4. Physical performance – Power output (W, Completion time (min)/distance (km), PO improvement with intervention (%), completion time improvement with intervention (%)
5. Physiological responses – Rectal/core temperature (°C), skin temperature (°C), sweat rate (L.hr), heart rate (b.min^{-1}).
6. Perceptual responses – Ratings of perceived exertion (% of max), thermal sensation (% of max), thermal comfort (% of max), affect (% of max), task motivation (% of max)

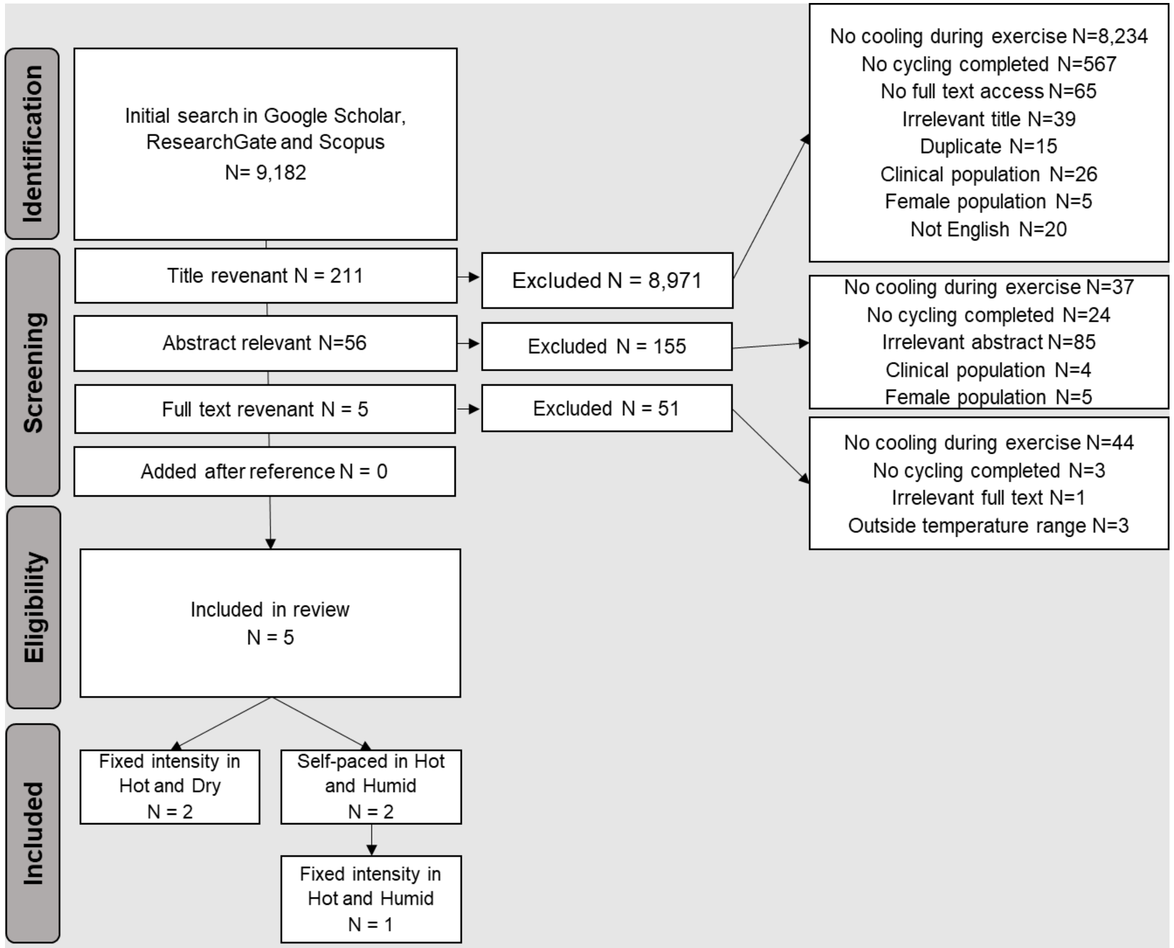
Identification
Screening
Eligibility
Included
Initial search in Google Scholar, ResearchGate and Scopus
N= 9,182
Title revenant N = 211
Abstract relevant N=56
Full text revenant N = 5
Added after reference N = 0
Excluded N = 8,971
Excluded N = 155
Excluded N = 51
No cooling during exercise N=8,234
No cycling completed N=567
No full text access N=65
Irrelevant title N=39
Duplicate N=15
Clinical population N=26
Female population N=5
Not English N=20
No cooling during exercise N=37
No cycling completed N=24
Irrelevant abstract N=85
Clinical population N=4
Female population N=5
No cooling during exercise N=44
No cycling completed N=3
Irrelevant full text N=1
Outside temperature range N=3
Included in review
N = 5
Fixed intensity in Hot and Dry
N = 2
Self-paced in Hot and Humid
N = 2
Fixed intensity in Hot and Humid
N = 1

Figure 2. Flowchart of literature search and screening process using PRISMA Protocol.

2.4.4.3. Article characteristics

Two articles were conducted in HD conditions at a fixed intensity (Mundel et al., 2006; Naito and Ogaki 2017). Both articles were conducted in HD conditions with no control condition.

Two articles included a self-paced cycling TT (Carvalho et al., 2016; Maunder et al., 2016) and one article included fixed intensity cycling in HH conditions (Lee et al., 2008a).

Table 8. Article characteristics from the literature search including sample, condition, task and intervention.

		Sample			Condition			Task		Intervention			
Condition	**Authors**	**Participants (N)**	**Sex Ratio (M/F)**	**Group VO_{2max} (mL.kg. min^{-1})**	**Ambient Temperature (°C) and humidity (%) and wind speed (m/s)**	**WBGT (°C)**	**Indoor/Outdoor**	**Exercise Task**	**Feedback Given**	**Water Temperature (°C)**	**Amount of water ingestion at each interval**	**Water ingestion frequency**	**Total water ingested (L)**
Dry	Mundel et al., (2006)	8	8:0	54 ± 5	34, 27.9, 0.5	25.1	Indoor	65% of VO_{2peak} until exhaustion	-	4	Ad libitum but had to drink 300 mL of water every 15 min to remain euhydrated.		1.3±0.3
Dry	Naito, and Ogaki, (2017)	9		47.7±8.7	35, 30	26.6	Indoor	60% of VO_{2max} until exhaustion	-	4	130–160g	15, 30 and 45min	0.316 ± 0.067L.hr
Humid	Lee et al., (2008a)	8		57.8±5.6	35, 60	30°C	Indoor	65% of VO_{2peak} until exhaustion	-	4	100mL	Every 10min	-
Humid	Riera et al., (2014)	12	12:0	59.9±10.4	30.7±0.8, 78±0.03		indoor	20km at 335±90W	-	3	190 mL of beverage before exercise, 760 mL during the 20 km (every 5km), and 190 mL after the recovery		~0.1
Humid	Carvalho et al., (2016)	10	10:0	67.2±1.8	35, 60, ~0.5	30.5	Indoor	40km self-paced TT	Elapsed distance every 2km	10	Ad- libitum: 0-8km (~50mL), 8-16km (~100mL), 16-24km (~260mL), 24-32km (~230mL), 32-40km (~180mL)		1.1 ± 0.4 L
Humid	Carvalho et al., (2016)	10	10:0	67.2±1.8	35, 60, ~0.5	30.5	Indoor	40km self-paced TT	Elapsed distance every 2km	10	Ad-libitum: 0-8km (~50 mL), 8-16km (~100 mL), 16-24km (~260 mL), 24-32km (~230 mL), 32-40km (~180 mL)		1.1 ± 0.4 L

2.4.4.4. Quality assessment

A modified scale to assess the methodological quality of the articles retrieved in this review was carried out following selection of full text articles. The modified version was applied due to the greater representation for experiments employing a training intervention, compared to the Delphi, PEDro and Cochrane scales (Paul et al., 2016). A 10 item quality rating guide included the criteria listed below and guided the assessment scoring of each article as follows: 0 = clearly no; 1 = maybe; 2 = clearly yes; range = 0 (poor)–20 (excellent) reported in Table 9.

Table 9. Results from the article quality assessment based on the following criteria: *1=Inclusion criteria were clearly stated, 2=Subjects were randomly allocated to groups, 3=Intervention was clearly defined, 4=Groups were tested for similarity at baseline, 5=A control group was used (thermoneutral conditions), 6=Outcome variables were clearly defined, 7=Assessments were practically useful, 8=Duration of intervention was practically useful, 9=Between-group statistical analysis was appropriate, 10=Point measures of variability.*

Condition	**Intensity**	**Author**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Total**
Humid	Self-paced	Carvalho et al., (2016)	1	2	2	2	0	2	2	2	2	1	16
Humid	Self-paced	Maunder et al., (2016)	1	2	2	2	0	2	2	2	2	1	16
Humid	Fixed	Riera et al., (2014)	2	2	2	2	2	2	2	2	2	1	19
Humid	Fixed	Lee et al., (2008a)	1	2	2	2	0	2	2	2	2	1	16
Dry	Fixed	Mundel et al., (2006	1	2	2	2	0	2	2	2	2	1	16
Dry	Fixed	Naito, and Ogaki, (2017)	1	2	2	2	0	2	2	2	2	1	16

The results from Table 10 highlighted that the article quality was extremely high and therefore the results extracted from these articles contributed to the quality of the review.

2.4.5. Results and Discussion

2.4.5.1. Physical Performance in Hot and Dry and Hot and Humid

Cycling capacity was similar in HD conditions (Mundel et al., 2006) and HH conditions (Lee et al., 2008a) at a fixed intensity of 65% of VO_{2max} when cold-water was provided ad libitum (Table 11). Whereas, cycling capacity was impaired in HD conditions at a lower intensity (60% of VO_{2max}) by ~20min when the cold-water was given every 15min (Naito, and Ogaki, 2017; Table 11).

Cycling performance in a 40km TT was not significantly different when cold-water was drunk ad libitum and scheduled (matched to ad libitum; 93.0+3.5min vs 93.4 ± 4.0min) in HH conditions (Table 11; Carvalho et al., 2016). Notably, Carvalho et al., (2016) was the only article to use cold-water at 10°C compared to 4°C (Table 11). Carvalho et al., (2016) found no difference in CT of 40km TT between cold-water and hot-water (93.0+3.5min vs 94.4 ± 12.9 min). During self-paced cycling in HH conditions, Carvalho et al., (2016) reported no significant differences in thermoregulatory, cardiovascular and metabolic responses ($p>0.05$) between ad-libitum cold-water (10°C) and hot water (37°C). The findings may have been related to the fact that water was provided ad libitum instead of periodically throughout the 40km TT, therefore, participants may not have consumed enough cold-water to effectively cause physiological benefits. For example, the number of aliquots ingested showed a significant main effect over time and a greater frequency of water consumed in time points 16 to 24 (200mL) and 24 to 32km(300 mL) when compared with 0 to 8 km (100 mL) and volume ingested per aliquots shows a significant effect for experimental manipulation and a greater volume ingested per aliquots.

Riera et al., (2014) found that 20km cycling TT CT was ~3min faster with cold menthol compared to cold-water only. This has been more recently supported by Jefferies and Waldron (2019) meta-analysis, demonstrating that exercise performance is improved with mentol if taken internally. Notably this also has percpetual benefit on measures such as thermal sensation during exercise.

Table 10. Cycling time-trial performance in hot and dry (HD) and hot and humid (HH) conditions with cold-water ingestion, adapted from Taylor et al., (2016) review.

Condition	Authors	Task		Intervention				Performance			
		Exercise Task	**Feedback Given**	**Water Temperature (°C)**	**Amount of water ingestion at each interval**	**Water ingestion frequency**	**Total water ingested (L)**	**PO (W)**	**Completion time (min)/distance (km)**	**PO improvement with intervention (%)**	**CT improvement with intervention ()**
Dry	Mundel et al., (2006)	65% of VO_{2peak} until exhaustion	-	4	Ad libitum but had to drink 300 mL of water every 15 min to remain euhydrated.		1.3±0.3		62 ± 4 min		-
Dry	Naito, and Ogaki, (2017)	60% of VO_{2max} until exhaustion	-	4	130–160 g	15, 30 and 45min	0.316±0.067L.hr		42.2±10.1min		
Humid	Lee et al., (2008a)	65% of VO_{2peak} until exhaustion	-	4	100 mL	Every 10min	-	-	63.8±4.3 -		-
Humid	Riera et al., (2014)	20km at 335±90W		3	190mL of beverage before exercise, 760 mL during the 20 km (every 5km), and 190 mL after the recovery		~1.14	-	~38.33	-	-
Humid	Carvalho et al., (2016)	40km self-paced TT	Elapsed distance every 2km	10	Ad- libitum: 0-8km (~50 mL), 8-16km (~100 mL), 16-24km (~260 mL), 24-32km (~230 mL), 32-40km (~180 mL)		1.1 ± 0.4 L		93.0+3.5min	-	-
Humid	Carvalho et al., (2016)	40km self-paced TT	Elapsed distance every 2km	10	Ad- libitum: 0-8km (~50 mL), 8-16km (~100 mL), 16-24km (~260 mL), 24-32km (~230 mL), 32-40km (~180 mL)		1.1 ± 0.4 L		93.4 ± 4.0min	-	-

TT time trial, T_{rectal}/T_{core} core temperature, T_{sk} skin temperature, HR heart rate, SR sweat rate, VO2 volume of oxygen, VO_{2max} maximal volume.

**=significant difference between hot and control conditions.*

WBGT was calculated from https://climatechip.org/excel-wbgt-calculator excel spreadsheet if not already stated in the article.

Percentages were calculated by (Xa – Xb)/Xb) then expressed as a percentage.

2.4.5.2. Physiological responses

2.4.5.2.1. Rectal/Core Temperature (T_{rectal}/T_{core})

T_{core}/T_{rectal} increased from baseline to end in both HD and HH and at a fixed intensity and self-paced intensity (Table 12). T_{core}/T_{rectal} increased by ~1.7-2.5°C at a fixed intensity of 60-65% of VO_{2max} in HD, and by ~2°C during a self-paced 40km TT in HH.

The largest increase in T_{core}/T_{rectal} (~2.5°C) from start to end was reported in Lee et al., (2008a) article which may have been related to the environmental condition (HD vs HH) and method of cooling (frequency and quantity). For example, Lee et al., (2008a) provided cold-water (4ºC) every 10min in aliquots of 100mL during a fixed cycling capacity test (65% of VO_{2peak}) in HH. Total water consumption was not reported however cycling capacity terminated at 63.8±4.3 which infers that a minimum of 600mL water was consumed during the trial. This condition and method resulted in a cycing capacity of 63.8±4.3min. Notably, within study, Lee et al., (2008a) compared water temperature, and found that mean±SD T_{rectal} remained lower with cold-water (37.7±0.4°C) compared to warm water (38.0±0.4°C) throughout the TT (Lee et al., 2008a). However, compared to Mundel et al., (2006) article, who provided cold-water (4ºC) ad libitum (however 300mL had to be consumed every 15min to remain euhydrated = 1.3±0.3L.hr (2x greater than Lee et al., (2008a)) during a fixed cycling capacity test (65% of VO_{2peak}) in HD resulted in a similar capacity 62±4min but significantly smaller increase in T_{core}/T_{rectal} (~0.9ºC). This therefore highlighted that the method of cooling used in Lee et al., (2008a) was not sufficient enough to reduce the rise in T_{core}/T_{rectal} in HH.

2.4.5.2.2. Skin Temperature (T_{sk})

T_{sk} increased by ~2.4-3.5°C at a fixed intensity of 60-65% of VO_{2max} in HD, and by ~2.1°C during a self-paced 40km TT in HH. Similar to T_{core}/T_{rectal} responses, the largest increase in T_{sk} (~3.5°C) from start to end were reported in Lee et al., (2008a) article. Lee et al., (2008a) found that cold-water was more effective in attenuating the rise of T_{sk} with the value being significantly lower from 20min onward when ingesting the cold-water compared to warm water. However, there was no significant difference in T_{sk} at the point of exhaustion between the cold and warm, respectively (36.6±0.2°C vs 36.9±0.3°C). This was similar for total heat storage, which was lower after ingestion of cold-water from 10-45min compared to ingestion of warm-water, however there was no significant difference between trials at exhaustion (8987±1024 vs 8993±1032 kJ; $P = 0.812$). These findings further support the conclusion that the frequency and quantity of cooling was insufficient to elicit any physiological benefits to T_{core}/T_{rectal} and T_{sk} whilst cycling at a fixed intensity in HH conditions.

2.4.5.2.3. Heart Rate (HR)

HR increased from baseline to end in both HD and HH and at a fixed intensity and self-paced intensity (Table 12). The largest increases in HR was seen in Lee et al., (2008a) article whichincreased from 60 $b.min^{-1}$ at rest to 180 $b.min^{-1}$ at exhaustion. This increase in HR may be related to the exercise task. For example, Lee et al., (2008a) article was at a fixed intensity (65% of VO_{2peak}) until exhaustion and therefore HR would be near HR_{max} or achieved HR_{max} at exhaustion. Whereas in a self-paced exercise such as a 40km cycling time-trial where intensity is not controlled, HR would vary throughout depending on pacing adopted and would depend on the intensity at the end of the exercise bout which ranged from 165-170 $b.min^{-1}$ in Carvalho et al., (2016) article.

2.4.5.2.4. Sweat Rate (SR)

Only two articles measured and reported SR. Regardless of condition or exercise intensity SR was ~1.4L.hr (Mundel et al., 2006; Carvalho et al., 2016; Table 12). Specifically, Mundel et al., (2006) reported a SR of 1.4±0.1L.hr during a cycling capacity test at 65% of VO_{2peak} until exhaustion in HD. Notably, 1.3±0.3L was consumed during the trial inferring that the participants were able to replish most of the sweat that was lost during the trial which may explain why T_{core}/T_{rectal} and HR only increased by ~0.9ºC and ~23 $b.min^{-1}$ (Table 12).

Carvalho et al., (2016) reported a SR of 1.4±0.1 and 1.3±0.1L.hr during a self-paced 40km cycling time-trial in HH. Similarly, the participants were able to most of the sweat that was lost during the trial however, large increases were seen in T_{core}/T_{rectal} (~2ºC) and T_{sk} (~2ºC). These findings may suggest that the cooling methods used in HH were not suffient in reducing physiological thermal strain (i.e increase in T_{core}/T_{rectal} T_{sk} and HR).

Table 11. Physiological responses such as rectal (T_{rectal})/core (T_{core}) temperature, T_{sk}, sweat rate (SR) and heart rate (HR).

Condition	Authors	Task		Intervention				Physiological			
		Exercise Task	**Feedback Given**	**Water Temperature (°C)**	**Amount of water ingestion at each interval**	**Water ingestion frequency**	**Total water ingested (L)**	**T_{rectal}/T_{core} (°C)**	**T_{sk} (°C)**	**SR (L/hr)**	**HR (b.min^{-1})**
Dry	Mundel et al., (2006)	65% of VO_{2peak} until exhaustion	-	4	Ad libitum but had to drink 300 mL of water every 15 min to remain euhydrated.		1.3±0.3	37 - 37.9	-	1.4 ± 0.1	132 - 155
Dry	Naito, and Ogaki, (2017)	60% of VO_{2max} until exhaustion	-	4	130–160 g	15, 30 and 45min		37.1 - 38.8	34.6 - 37.2	-	140 - 189 ± 5
Humid	Lee et al., (2008a)	65% of VO_{2peak} until exhaustion	-	4	100ml	Every 10min	-	36.5 - 39	32.5 - 36		60 - 180
Humid	Riera et al., (2014)	20km at 335±90W		3	190 mL of beverage before exercise, 760 mL during the 20 km (every 5km), and 190 mL after the recovery		~1.41	37.5 39.2 39	-	-	-
Humid	Carvalho et al., (2016)	40km self-paced TT	Elapsed distance every 2km	10	Ad- libitum: 0-8km (~50mL), 8-16km (~100mL), 16-24km (~260mL), 24-32km (~230mL), 32-40km (~180mL)		1.1 ± 0.4 L	37.0±0.1 - 38.9±0.2	34.7±0.1 - 36.6±0.2	1.4 ± 0.1	53.3±2.5 - 165.9±6.0
Humid	Carvalho et al., (2016)	40km self-paced TT	Elapsed distance every 2km	10	Ad- libitum: 0-8km (~50mL), 8-16km (~100mL), 16-24km (~260mL), 24-32km (~230mL), 32-40km (~180mL)		1.1 ± 0.4 L	36.9±0.1 - 38.9±0.2	34.6±0.1 - 36.7±0.2	1.3 ± 0.1	55.3±3.0 - 168.5±6.6

2.4.5.3. Perceptual Responses

2.4.5.3.1. Ratings of Perceived Exertion (RPE)

Max (100%) RPE was achieved in Naito, and Ogaki, (2017) article which was conducted in HD conditions with no wind (35°C, 30%) and less cold-water was consumed (0.316 ± 0.067L.hr) which may explain why there was a greater increase in RPE and earlier termination in exercise compared to Mundel et al., (2006) article. In addition, Naito and Ogaki (2017) measured TS using Kashimura's (1986) 9-point scale in which TS increased from neutral (50% of max) at the start to very hot (100% of max) at termination with cold-water ingestion. This implies that cold-water ingestion in Naito and Ogaki (2017) article was not effective at minimising thermal perception as max TS and RPE was reached at exercise termination. However, the rate of rise in perceptual responses compared to no cooling is unknown.

2.4.5.3.2. Thermal Sensation (TS)

In HH, Carvalho et al., (2016) reported that affect decreased from good at the start to not good at the end. Maunder et al., (2016) reported that TC was greater (indicating greater thermal discomfort) with ice-slushy compared to cold-water at 10km (5.4±2.1 vs. 4.4±1.7), and 15 km (5.9±1.6 vs. 5.4±1.8). Similarly, TS was greater (indicating greater sensation of warmth) with ice-slushy compared to cold-water at 5, 15, 25, and 35 km, however data was only available for 15km (10.1±1.9 vs. 9.4 ±1.0). TS values at the end of the TT were lower with ice-slushy compared to cold water (10.9±1.4 vs. 11.6±1.0). In addition, AF was lower (indicating a worse feeling state) with ice slushy compared to cold-water at 5, 15, 25, 30, and 35 km, but this difference was unclear at the end of the TT. Overall mean AF was lower with ice slushy compared to cold-water (-2.4±1.1 vs. -1.8±0.9). There was no significant difference between RPE between the two interventions. Therefore, Maunder et al., (2016) findings suggest that cold-water provided greater perceptual benefits compared to ice-slushy ingestion. Lee et al., (2008b) reported TS was significantly lowered with ingestion of cold-water (5±1) than with warm-water (6±1) during the TT. Similarly, RPE was lower during exercise when subjects ingested the cold-water (14±1) than when they ingested the warm-water (15±1). At exhaustion, ratings of TS (9±1; P = 0.081) and RPE (20±1; P = 0.170) were similar between trials.

2.4.5.3.3. Thermal Comfort (TC)

Notably, Carvalho et al., (2016), Maunder et al., (2016) and Lee et al., (2008b) did not include a control condition (thermoneutral and no cooling) or an alternative conditions (hot and dry). Muhamed et al., (2019) previously stated that the efficiency of cold-water ingestion on alleviating thermoregulatory and circulatory stress during prolonged running is potentially dependent on the physical characteristics of the environment. To date, the only article that has taken this into consideration was Coudevylle et al., (2020) article which aimed to determine whether cold-water intake influences environmental perceptions, AF, and attention depending on the condition (HH vs thermoneutral). Coudevylle et al., (2020) administering cold-water (15°C) every 10min for 60min run at 70% of VO_{2max} which failed to provide any ergogenic benefit in alleviating thermoregulatory and circulatory stress during exercise, or capacity in HH (30°C and 71% RH) conditions. In addition, TC and attention performance were lower, TS was greater and AF scores were lower (indicating feeling worse) during HH conditions compared with thermoneutral conditions. However, drinking water at room temperature in HH conditions causes the worst scores which supports Lee et al., (2008b) and Carvalho et al., (2016) findings. Notably this article was conducted with runners, and these conditions are considered warmer and more humid for cycling relative to running by virtue of the greater skin surface airflow, promoting evaporation, for a given metabolic heat production (Jay and Morris 2018). Therefore, the relationship between cold-water ingestion on cycling performance and physiological and perceptual responses in HH conditions (≥28°C and ≥51%) remain unknown.

2.4.5.3.4. Affect (AF)

Only one article measured affect (Carvalho et al., 2016). Affect decreased from “good” at the start of the time-trial to “not good” at the end of the time-trial in HH (Table 13). These findings show that the cooling method was not sufficient at reducing percpetual thermal strain experienced during a 40km cycling time-trial in hot and humid conditions.

2.4.5.3.5. Motivation (M)

No articles measured motivation. As stated earlier, Coudeyville et al., (2021) review highlighted that motivation is an under researched area in environmental perception, especially in terms of the link between motivational factors and exercise performance in HH conditions. For instance, Craig (2003) indicated that perceptions play on the “emotion/motivation” complex. The ingestion of menthol as a cooling technique illustrates this type of relationship. Menthol does not reduce body or skin temperature in athletes (Barwood et al., 2015), but it does stimulate cold receptors (Cheung, 2010) and induces a sensation of coolness (Mündel and Jones, 2010), which alters thermal perceptions. Thus, the use of a psychological technique could favourably influence the motivation to maintain an effort.

Table 12. Perceptual responses reported during cycling TT performance in hot and dry and hot and humid conditions.

Condition	Authors	Task		Intervention				Perceptual Responses				
		Exercise Task	**Feedback Given**	**Water Temperature (°C)**	**Amount of water ingestion at each interval**	**Water ingestion frequency**	**Total water ingested (L)**	**RPE (% of max)**	**TS (% of max)**	**TC (% of max**	**AF (% of max)**	**TM (% of max)**
Dry	Mundel et al., (2006)	65% of VO_{2peak} until exhaustion	-	4	Ad libitum but had to drink 300 mL of water every 15 min to remain euhydrated.		1.3±0.3	12 (42.85%) - 15 (64.28%)		-		
Dry	Naito, and Ogaki, (2017)	60% of VO_{2max} until exhaustion	-	4	130–160 g	15, 30 and 45min	0.316 ± 0.067L.hr	12 (42.85%) - 20 (100%)	Neutral (50%) - Very hot (100%)			
Humid	Lee et al., (2008a)	65% of VO_{2peak} until exhaustion	-	4	100mL	Every 10min	-	11 (35.71%) 14±1 (57.14%) 16 (71.42%)				
Humid	Riera et al., (2014)	20km at 335±90W		3	190 mL of beverage before exercise, 760 mL during the 20 km (every 5km), and 190 mL after the recovery		~0.1	increase	increase	-	-	-
Humid	Carvalho et al., (2016)	40km self-paced TT	Elapsed distance every 2km	10	Ad- libitum: 0-8km (~50mL), 8-16km (~100mL), 16-24km (~260mL), 24-32km (~230mL), 32-40km (~180mL)		1.1 ± 0.4 L					
Humid	Carvalho et al., (2016)	40km self-paced TT	Elapsed distance every 2km	10	Ad- libitum: 0-8km (~50mL), 8-16km (~100mL), 16-24km (~260mL), 24-32km (~230mL), 32-40km (~180mL)		1.1 ± 0.4 L				Good- Not good	

RPE = ratings of perceived exertion, TS = thermal sensation, TC= thermal comfort, AF = affect, TM = task motivation.

2.4.6. Conclusion

- There is limited research that has been conducted on the effect of cold-water ingestion and pouring on self-paced cycling performance. This is surprising as cold-water ingestion and pouring are conventional and practical per-cooling methods. Based on the literature review both strategies have the potential to enhance cycling time-trial performance together with physiological and perceptual responses. However, the effectiveness of these strategies depends on quantity, frequency, magnitude of cooling and condition employed in.

- The optimal quantity and frequency of cold-water ingestion was discussed in Gibson et al., (2020) practitioner guidelines, highlighting that a balance must be found between delivering a large cooling impulse (typically in the region of ~500–700mL) and athlete comfort, avoiding feelings of being bloated and gastrointestinal disturbances. Based on this understanding, Naito et al., (2017) suggests incorporating a smaller dose, relative to the athlete's body mass ($7.5\ g.kg^{-1}$ BM = e.g. 525 g (or 525mL) for a 70kg individual). The benefit of spreading quantity out in small doses ($1.25\ g.kg^{-1}$ BM per 5 min = e.g. 100 g (or 100 mL) for a 70 kg individual), rather than drinking a single bolus, appears to offer greater cooling and is likely to be better tolerated by athletes (Naito et al., 2017).

- The optimal temperature of water used for this strategy was also discussed in Gibson et al., (2020) practitioner guidelines, highlighting that a range of 5–15°C would be sufficient enough to cause a cooling stimulus. One of the main take aways of this review was that it is unclear which strategy is more effective in hot and dry and hot and humid conditions due to the lack of research in this area. In order to answer these questions further research in this area is needed.

- Therefore, the two practical research question arising from this chapter are to investigate the effect of both cold-water ingestion and pouring on cycling TT performance and associated physiological and perceptual responses in both hot and dry, and hot and humid conditions.

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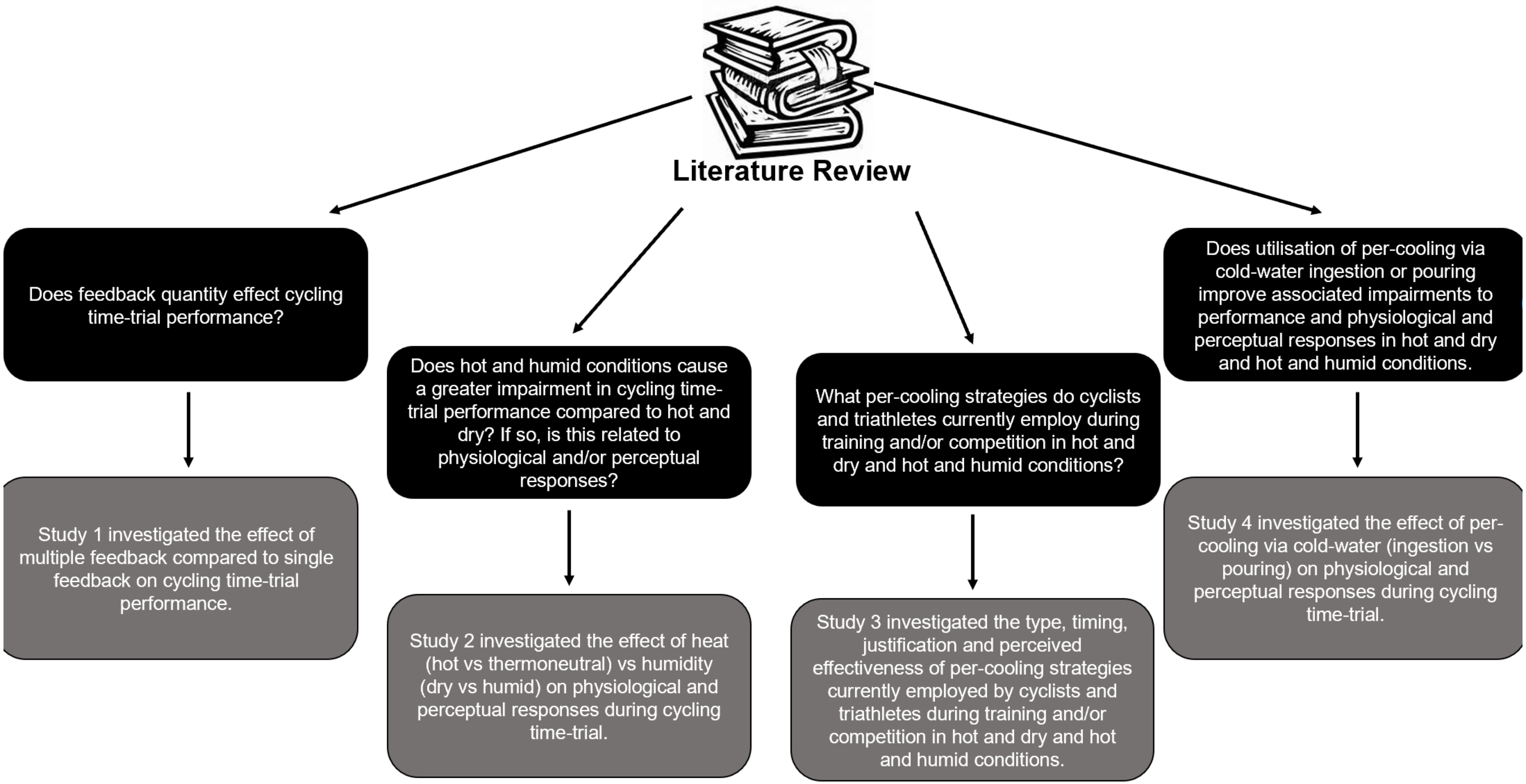
2.4.7. Research questions arising from narrative reviews.



Literature Review

Does feedback quantity effect cycling time-trial performance?

Study 1 investigated the effect of multiple feedback compared to single feedback on cycling time-trial performance.

Does hot and humid conditions cause a greater impairment in cycling time-trial performance compared to hot and dry? If so, is this related to physiological and/or perceptual responses?

Study 2 investigated the effect of heat (hot vs thermoneutral) vs humidity (dry vs humid) on physiological and perceptual responses during cycling time-trial.

What per-cooling strategies do cyclists and triathletes currently employ during training and/or competition in hot and dry and hot and humid conditions?

Study 3 investigated the type, timing, justification and perceived effectiveness of per-cooling strategies currently employed by cyclists and triathletes during training and/or competition in hot and dry and hot and humid conditions.

Does utilisation of per-cooling via cold-water ingestion or pouring improve associated impairments to performance and physiological and perceptual responses in hot and dry and hot and humid conditions.

Study 4 investigated the effect of per-cooling via cold-water (ingestion vs pouring) on physiological and perceptual responses during cycling time-trial.

Figure 3. Overview *of the research question (black boxes) developed from the current literature review, and how the experimental studies within the thesis (light grey boxes) will answer these questions.*

- Four practical research questions have arisen from this chapter (Figure 3). For example, it was noted in Table 3 and 4 that researchers provide cyclists with different types (i.e. PO, elapsed time/distance, cadence etc) and quantities (1-5) of feedback during cycling TT in a laboratory setting. This confounding factor could also influence performance outcomes regardless of environmental conditions (i.e. increase in cognitive load) causing anomalies in the data. Therefore, the first study in this thesis investigated the effect of multiple feedback variables on cycling TT performance compared to a single feedback variable. This information was used to inform what feedback was provide during the main investigations of this thesis:
- The first literature review highlighted that despite the body of research that has been conducted on cycling in hot conditions, the differentiation between performance outcomes in hot and dry and hot and humid conditions are still unclear. Therefore, the second study aimed to characterise the physical (cycling TT) performance outcomes in CON, HD and HH conditions.
- The second literature review highlighted the benefits of using per-cooling strategies during training and/or competitions in hot conditions, however it is unclear from the literature what per-cooling strategies are currently employed by cyclists and triathletes and whether they are effective at minimising performance impairments and heat related illnesses. Therefore, the third study aimed to determine the type, quantity and timing of per-cooling used during training and competitions in HD and HH conditions and their effectiveness at minimising performance impairments and heat related illnesses.
- It was highlighted in the literature review that practical per-cooling strategies such as cold-water ingestion and pouring have received little research attention despite their potential to enhance physical performance. Therefore the final study in this thesis investigated the effect of both cold-water ingestion and pouring on physical (cycling TT) performance in CON, HD, and HH conditions.

Chapter 3. General Methodology

This chapter details the common methodologies carried out in this thesis. General information regarding exercise protocols, environmental conditions, procedures, techniques, and analysis are given. Additional information relating directly to individual studies are provided within each chapter where necessary. All studies were conducted at London South Bank University (LSBU).

3.1 Ethical approval

Ethical approval for experimental studies was obtained from the dedicated ethics committee: ETH1920-0002, ETH2021-0017*, ETH1920-0156*(School of Applied Science, LSBU). All studies referenced and adhered to the Human Rights Act (1998), Freedom of Information Act (2000), Human Tissue Act (2004), Declaration of Helsinki (2013), Global Data Protection Regulation (2018). Laboratory standard operating procedures were also made.

3.2 Participants

3.2.1 Recruitment

Volunteers for physical and online participation were recruited for each study *via* expression of interest in response to a recruitment advertisement poster posted online (social media channels e.g. Twitter, and Instagram), on LSBU campus, and through word-of-mouth with cycling and triathlon clubs.

3.2.2 Eligibility

Volunteers received a participant information sheet containing details of the study so that they could make an informed decision regarding participation. If they decided to participate, volunteers provided written informed consent before enrolling as a participant. For experimental studies including physical exercise, eligibility of participants was assessed in the familiarisation session (VO_{2max} test). Participants were advised that they could withdraw from the study at any point without providing a reason, and there would be no negative implications in doing so.

Inclusion criteria were as follows:

Study 1

Using pilot testing data, subsequent analysis revealed that 20 participants were required for effect size = 0.7 (g*power 3.1.9.2). Therefore 20 participants were recruited for this study.

Non-cyclists-triathletes (NC):

- Male and female
- Aged between 18-55years.
- Physically active individuals were recruited to the NC, who on average trained each week for a total of ≥ 5 h, across a range of different sports (i.e., basketball, football, etc.).
- Performance level ≤2 based on De Pauw et al., (2013; Appendix A).
- Non-smokers, no known history of gastric, digestive, cardiovascular, respiratory or renal disease.
- Healthy adults who have no lack of mental capacity to provide written consent.
- Health status of the participants was checked using the standardized LSBU health screening questionnaire (adapted from the American College of Sports Medicine Health Related Physical Fitness Assessment Manual, pp 10-23).

Experienced cyclists-triathletes

- >2 yrs competing and training in cycling/triathlon events, with >5 events completed in either sport (Smits et al., 2016; Boya et al., 2017).
- VO_{2max} of >50mL.kg.min^{-1} (assessed in the fist visit)
- Performance level ≥3 based on De Pauw et al., (2013; Appendix A).
- Non-smokers, no known history of gastric, digestive, cardiovascular, respiratory or renal disease.

- Healthy adults who have no lack of mental capacity to provide written consent.
- Health status of the participants was checked using the standardized LSBU health screening questionnaire (adapted from the American College of Sports Medicine).

Study 2

Using pilot testing data, subsequent analysis revealed that 24 participants were required for effect size = 0.7 (g*power 3.1.9.2). However, recruitment was significantly impacted by UK COVID-19 lockdown restrictions and therefore only 12 participants participated.

Experienced cyclists-triathletes:

- Male
- Aged between ≥18-55years.
- >2 yrs competing and training in cycling/triathlon events, with >5 events completed in either sport (Smits et al., 2016; Boya et al., 2017).
- VO_{2max} of >50mL.kg.min^{-1}
- Non-smokers, no known history of gastric, digestive, cardiovascular, respiratory or renal disease.
- Healthy adults who have no lack of mental capacity to provide written consent (Health status of the participants was checked using the standardized LSBU health screening questionnaire (adapted from the American College of Sports Medicine).

Study 3

The questionnaire was open to male and female participants aged ≥18yrs. A minimum of 30 participants was required for effect size = 0.7 (g*power 3.1.9.2). The participants were separated into 3 groups based on experience:

Recreational cyclists-triathletes:

- Recreational cyclists-triathletes were classed as active but not competitive (Sanderson et al., 2000) and have an average cycling speed of 26.0 km/h during training, and cycle an average distance of 164 km/week (Priego Quesada et al., 2018)

- Performance level ≤2 based on De Pauw et al., (2013; Appendix A).

Competitive cyclists-triathletes:

- Amateur cyclists-triathletes were classed as active and competitive.
- Cyclists have an average cycling speed of 28.5 km/h during training, and cycle an average distance of 260 km/week (Priego Quesada et al., 2018)
- Triathletes who participate in competitions, have an average cycling speed of 29.2 km/h during training, and cycle an average distance of 175 km/week (Priego Quesada et al., 2018)
- Performance level 3 based on De Pauw et al., (2013; Appendix A).

Professional cyclists-triathletes:

- Professional race license.
- Performance level ≥4 based on De Pauw et al., (2013; Appendix A).

Study 4

Using pilot testing data, subsequent analysis revealed that 24 participants were required for effect size = 0.7 (g*power 3.1.9.2). However, recruitment was significantly impacted by UK COVID-19 lockdown restrictions and therefore only 12 participants participated.

Experienced cyclists-triathletes:

- Male
- Aged between ≥18-55years.
- >2 yrs competing and training in cycling/triathlon events, with >5 events completed in either sport (Smits et al., 2016; Boya et al., 2017).
- VO_{2max} of >50mL.kg.min^{-1} (assessed in the first visit)
- Performance level ≥3 based on De Pauw et al., (2013; Appendix A).

- Non-smokers, no known history of gastric, digestive, cardiovascular, respiratory or renal disease.
- Healthy adults who have no lack of mental capacity to provide written consent (Health status of the participants was checked using the standardized LSBU health screening questionnaire (adapted from the American College of Sports Medicine).

Exclusion criteria for all experimental studies in this thesis were as follows:

- Musculoskeletal injuries and/or abuse of drugs, medicine or alcohol.
- Acclimatization or exposure to heat (no exposure to temperatures >30°C in the month preceding commencement of the study).

3.3. Familiarisation Procedures.

Each experimental study included a familiarisation session. Volunteers received explanations and demonstrations of all equipment and procedures, as well as being familiarised with specialist equipment and measurement tools (i.e., turbo/wattbike, perceptual scales). This session permitted volunteers to ask questions regarding the study demands and requirements, which were answered by the investigator.

In study 3, volunteers were provided with an information page before starting the online questionnaire, which provided guidelines on the structure and how to complete it. Volunteers were also provided with the lead investigators email address which they could use if they had any questions before starting or throughout the completion of the questionnaire.

3.4. Experimental Trial Procedures

3.4.1. Experimental Trial Standardization

Prior to every trial across the experimental studies (1, 2 and 4), participants attended the laboratory after refraining from caffeine, alcohol and vigorous exercise for ≥48hr. This was to minimise the impact of these factors on psycho-physiological responses assessed within the experimental studies. Participants completed all experimental trials at a similar time of day

(±1hrs) to minimise the impact of circadian rhythm variation on measured parameters (Carrier & Monk, 2000). Whilst enrolled in experimental studies, participants were asked to maintain their habitual daily routine of diet, sleep and exercise patterns.

Study 1, 2 and 4 were all conducted in the winter months to avoid seasonal heat acclimatisation (Brown et a., 2022).

3.4.2. Maximal Oxygen Uptake (VO_{2max})[2,4]

At least one week prior to commencement of experimental trials in study 2 and 4, volunteers strapped a HR monitor (polar) around their upper abdomen and then completed a 5-10min self-paced warm-up before completing a maximal oxygen uptake (VO_{2max}) test. The VO_{2max} test started at 100W and was increased by 40W every 4min. After 16min, the load was increased by 30W every minute until volunteers reached volitional exhaustion. Inspired and expired air, and HR was measured during the last minute of each stage (Cortex, Leipzig, Germany). This measurement was used to determine whether volunteers fit the inclusion criteria. Volunteers were then allotted 30min of rest.

Figure 4. Laboratory set-up of VO_{2max} test using a cycle ergometer.

3.4.3. Warm-up

All experimental trials in study 1,2 and 4 began with a standardised 10-min warm-up (3min at 25%, 5min at 60%, and 2min at 80% of maximal aerobic power calculated from the familiarisation visit) followed by a 5min rest before starting the TT (Abbiss et al., 2010). This was completed outside the environmental chamber in laboratory conditions.

3.4.4. Steady-state (pre-load)

Following the 10min warm-up, participants in study 2 and 4 completed a 45min cycling preload at a fixed intensity (50% of maximal aerobic power), followed by a 10min rest before completing any other exercise-based tasks. The purpose of this preload was to assess physiological (T_{rectal}, $T_{sk,}$ HR) responses at a fixed intensity and to induce modest heat storage based off Ely et al., (2010) protocol.

3.4.5. Time-trial

All experimental studies (1,2, and 4) required participants to complete a self-paced 30min cycling TT either directly after the 10min warm-up (study 1) or after the steady-state preload (study 2 and 4; *Figure 5*). The task was to complete as much distance as possible within the 30min. The 30min TT duration was selected as this is a common format used in the UK and one in which the experienced cyclists-triathletes that volunteers for these studies were familiar with completing. In addition, Perrey et al., (2003) findings stated that an individual 30min TT at a self-selected intensity is a good predictor of individual endurance capacity and may be used to estimate racing pace for training purposes.

Figure 5. Laboratory set up of the road bike for the steady state and time-trial in study 2 and 4.

3.4.6 Feedback provided during TT

In the last 2 decades, researchers have extensively investigated the impact of feedback highlighting that exercise performance is impaired with task irrelevant and inaccurate feedback (Nikolopoulos et al., 2001; Ansley et al., 2004; Paterson and Marino 2004; Albertus et al., 2005; Baden et al., 2005; Mauger et al., 2009; Morton 2009; Eston et al., 2012;

Williams et al., 2015; Davies et al., 2016). Moreover, a recent meta-analysis by Davies et al., (2016) provided an overview as to how manipulation of different extrinsic factors affects pacing strategy and exercise performance indicating that (a) pacing strategy selection is based on the perceived distance of a TT rather than the actual distance (Nikolopoulos et al., 2001); (b) athletes deceived of the actual distance completed the subsequent performance trial based on perceived effort rather than on actual distance (Paterson and Marino, 2004); (c) pacing is influenced by an interaction between feedback and previous experience (Micklewright et al., 2010); and (d) TT performance does not differ between accurate and inaccurate split-time feedback conditions (Wilson et al., 2012). Therefore, to minimise influence of feedback on performance only task relevant and accurate feedback was provided in the experimental studies in this thesis. In addition, Bayne et al., (2020) concluded that cyclists-triathletes 30min cycling time-trial performance (distance covered and average power output) was impaired with multiple feedback (elapsed time, elapsed distance, heart rate, power, cadence, and speed) compared to single feedback (time). Therefore, only time feedback was provided to participants during the TTs in this thesis (study 2 and 4).

3.4.7. Cooling Intervention

Study 4 incorporated per-cooling (cooling during exercise), in which participants completed two cooling interventions to compare interval versus external cooling: (i) cold-water ingestion, and (ii) cold-water pouring (head, neck and shoulders).

Fluid ingestion in the preload exercise matched the participant’s specific sweat loss, calculated from the first visit (((pre-preload weight (kg) – post-preload weight (kg)) + fluid consumption (mL))/duration (min) = sweat rate (l/min)). Required fluid volume was divided into 9 equal portions (mL) and provided at 5-minute intervals. Fluid was maintained at the environmental temperature (measured with a kitchen thermometer; Houdian, Uk).

In addition to the 450mL consumed in the preload, group 1 (HD) and 2 (HH) completed two cooling intervention which involved ingestion of cold-water (4°C) and pouring of cold-water (4°C). The timing and quantity of cooling interventions provided were informed from the findings of study 3 (cooling strategies used during training and competition in hot conditions) together with the familiarisation visit for study 4. Therefore, the cold-water was given in quantities of 150mL on completion of every 15min in the 45min preload and every10min in the 30min TT, together with 1L of room temperature water that participants could drink ad libitum.

To control for hydration status the same quantity of water was provided at the same intervals at room temperature in the cold-water pouring condition to match cold-water ingestion. Therefore, total volume of controlled water drunk (excluding ad libitum) would equate to 750mL. All water was provided in a water bottle for ease of access and to replicate a competition setting.

3.4.8. Rest days

Due to the physical demand of each experimental study, participants were allocated rest days (5~7days) between experimental trials. In this period, participants were instructed to refrain from strenuous exercise, heat exposure (specific to study 2 and 4), and alcohol consumption to facilitate recovery and rehydration.

3.5. Environmental conditions

3.5.1 Laboratory conditions

Seated rest for the measurement of resting values and preliminary testing was performed in ambient laboratory conditions at ~18°C and ~30% RH with no wind speed.

3.5.2 Experimental conditions

Study 1 was completed in thermoneutral laboratory conditions (~18°C, ~30% rH, no wind speed), whereas study 2 and 4 included a range of conditions listed below:

- Neutral/dry (18°C, 30%, 2.2m/s, equating to a WBGT of ~20.5°C).
- HD (35°C, 30% 2.2m/s, equating to a WBGT of ~26°C).
- HH (30°C, 70% 2.2m/s, equating to a WBGT of ~27°C).

These conditions were based on WBGT recorded in Tokyo during the month of august (26.6-28.6; Vanos et al., 2020).

3.6. Heat Alleviation Strategy Questionnaire and interviews

3.6.1 Online Questionnaire

Athletes were invited to participate in a questionnaire (onlinesurvey.ac.uk), which aimed to:

1. determine the level of perceived heat strain elite athletes experience during competitions in hot conditions,
2. investigate which heat alleviation strategies athletes use during training and/or competitions in hot conditions, if any, and
3. investigate whether the heat alleviation strategies used change depending on whether the competition is in a HD condition compared to a HH condition.

3.6.2 Case Study Style Interviews

A single case study approach was selected to provide in-depth understanding of the participants experiences and therefore produce high quality theory for future work to expand on. To achieve this, multiple case studies were designed and reported in accordance with McKay and Marshall's (2000) checklist and Keegan's et al., (2017) guidelines. The single case studies consisted of one to one to interviews that were conducted online via zoom (lasting ~20-30min with cameras on). Participants were informed that the interviews were informal, semi-structured, followed a discussion format and that there were no wrong or right answers.

Full list of questions for the questionnaire and interview are provided in Appendix B.

The findings from the questionnaire and interviews, together with the findings of Racinais et al., (2021) questionnaire from 2019 IAAF World championships were used to determine which per-cooling methods were provided in study 4.

3.7 Materials and measurements

3.7.1 Cycle ergometers/bikes

Different ergometers were selected to optimally suit the requirements of the testing procedure. Specific details of the testing procedure are provided in the relevant chapters.

3.7.1.1 Turbo

CPTs and TTs were performed using a stationary bike fitted to a turbo (RacerMate, CompuTrainer, Seattle, WA or Wahoo Kickr). Therefore, cyclists-triathletes were able to fit their own bicycle to the turbo which minimises any influence on performance from using different equipment from a competition setting.

3.7.1.2 Lode Excalibur

VO_{2max} tests were performed using a Lode Excalibur using a pre-programmed incremental file on the Lode software (Lode Ergometer Manager v9.1).

3.7.2 Physiological responses

3.7.2.1 Anthropometric assessment

3.7.2.1.1. Height

Height was measured using a fixed stadiometer (Seca, Germany). Participants were required to stand vertically in the anatomical position facing away from the stadiometer scale into the laboratory. The stadiometer arm was lowered until it rested horizontally on the most superior aspect of the head. The scale was then read to the nearest 0.5 cm.

3.7.2.1.2. Body mass

Nude body mass (NBM) was recorded in Kg using electronic scales (Seca, Germany). The scales were calibrated prior to use, using a 20kg weight. Participants were required to stand nude on the plate until the digital display stabilised. This procedure was carried out by participants in a private room, participants self-reported their body mass.

As outlined above study 2 and 4 involved participants cycling in hot conditions. The change in heat storage required to alter T_{core}/T_{rectal} is dependent on biophysical factors such as BM. An individual's BM represents their heat sink, meaning that changes in T_{core}/T_{rectal} for an absolute amount of heat stored in the body are negatively correlated I.e. a smaller rise is observed with a larger BM for a fixed heat storage (Cramer and Jay, 2014; Ravanelli et al., 2017). In study 2 and 4 participants were separated into different groups in which participants BM was measured and matched (less than ~20% difference between groups; Dervis et al., 2016).

3.7.2.2 Heart rate

In the familiarisation visits, HR was monitored telemetrically with a chest strap (H10, Polar, Finland) connected via Bluetooth to a watch (M400, Polar, Finland) and gas analyser (Cortex Metanalyzer 3b) which manually recorded every 30s. In the experimental trials, HR was monitored telemetrically with a chest strap (Garmin) connected via ANT+ to PerfPRO software (PerfPRO Studio, Dynastream Innovations Inc., Canada), which was continuously recorded throughout each trial and subsequently exported into Excel.

3.7.2.3. Hydration assessment

In study 2 and 4, hydration assessments were completed upon arrival to the laboratory on all visits to the laboratory to ensure equal and adequate hydration between trials. A urine specific gravity (USG) of ≤ 1.020 (Euhydrated; Table 13; Sawka et al., 2007) needed to be achieved for participants to enter the environmental chamber. If this value was not met participants were required to drink 100mL of water and to go to the toilet to provide another urine sample until this value was achieved.

USG was assessed using a visual handheld refractometer (Index Instruments Ltd., Cambridge, UK). The refractometer was calibrated prior to every sample using distilled water (USG 1.000). Approximately 2mL of urine was placed onto a glass lens of the refractometer.

Table 13. Ranges of urine specific gravity, urine osmolality and interpretation adapted from Cheuvron and Sawka (2005).

Urine Specific Gravity	Urine Osmolality (mOsm/kg)	Interpretation
1.001-1.010	<350	Well hydrated/hyper-hydrated
1.011-1.020	350-700	Euhydrated
1.021-1.030	700-1050	Hypohydrated
>1.031	>1050	Severely hypohydrated

3.7.2.4 Rectal temperature (T_{rectal})

In all experimental trials (study 2 and 4), T_{rectal} was measured using the e-celcius pill and e-viewer monitor (BodyCap, Caen, France). The pill was self-inserted ~9cm into the anal sphincter ~5min prior to entering the chamber and recorded continuously (Bongers et al., 2018; Travers et al., 2016; Figure 6).

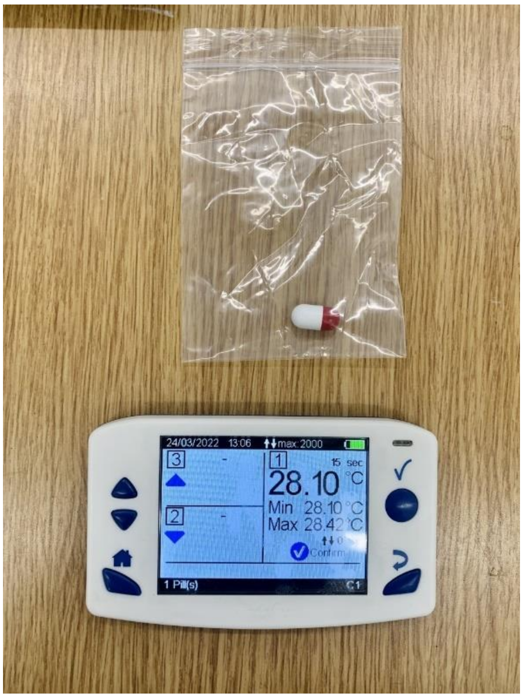


Figure 6. Picture of body cap pill and wireless monitor used to measure rectal temperature during study 2 and 4.

3.7.2.5 Sweat rate (SR)

SR was calculated in absolute (L) and relative (L/Hr). The 6 step process outlined in Periard and Racinais (2020 pp.123) book was used to assess fluid balance and sweat rate across an exercise session:

1. Weigh athlete's body mass (BM) before session, using reliable digital scales (ideally measuring to 0.01 kg). This should be done wearing minimal clothing and after the athlete has gone to the toilet

2. Weigh athlete again after session in the same clothing, and after towelling dry

3. Weigh athlete's drink bottle before and after the session (ideally measuring to 1 g using kitchen scales) to calculate the volume (g/mL) of fluid consumed

4. Note the mass (g) of any foods or sports products (e.g. gels) consumed during the session Extra steps for further accuracy

5. If the athlete has to go to the toilet during the session, weigh in before and after, or collect urine in a beaker to measure the volume/mass

6. Estimate total urine losses during the session by having athlete weigh in post-session, go to the toilet, and reweigh (alternatively, collect urine in beaker and measure the volume). Add this to the volume/mass of urine produced at any mid-session toilet stops.

The following equations were used to determine fluid intake, urine loss and sweat rate:

Fluid intake (mL) = drink bottle before − drink bottle after (g) 705g − 104g = 601g or 601mL

Urine losses (mL) = change in BM due to toilet stops during and/or after the session: kg × 1000 or g e.g. weight change: 60.25 − 60.00 = 0.25kg =250mL or 251g urine in beaker

Fluid deficit (mL) = Pre-session BM −Post-session BM (kg) × 1000. (Note: to measure total fluid deficit which includes sweat and urine losses, use post-session value taken after the toilet visit) 60.50 − 59.05 = 1.45kg=1450mL

Fluid deficit (% BM) = (Fluid deficit [in kg]×100)/pre-session BM (kg) (1.45×100)/(60.50) = 2.4%

Total sweat losses over the session = Fluid deficit (g) + fluid intake (g) + food intake (g)− urine losses (g) 1450+601 + 40g (sports gel) – 250 = 1841mL

Sweat rate over the session = sweat losses converted to mL per hr

Session lasted for 90min: sweat rate= 1841 × 60/90 = 1227 mL or 1.23L/h

3.7.2.6 Skin temperature (T_{sk})

T_{sk} was recorded continuously in study 2 and 4 using four skin thermistors (DS1921H-F5 ibutton, Maxim, USA) placed on the right side at the following sites: mid-calf, midthigh, upper chest/sternal notch, and mid-shin (Ramanathan, 1964). T_{sk} was combined to give an overall T_{sk} = 0.3Tchest + 0.3Tarm, + 0.2Tthigh + 0.2Tleg (Ramanathan, 1964). All skin thermistors were attached via a transparent dressing (Tegaderm, 3M Health Care, USA) and water-proof tape (Transpore, 3M Health Care, USA).

3.7.3 Perceptual responses

3.7.3.1 Ratings of perceived exertion (RPE)

RPE was assessed using a subjective scale 6-20 ranging from no exertion to maximal exertion (Borg, 1982; Figure 7). Participants were asked, "How would you rate your exertion right now?”. All subjects were familiarised with the RPE scale, which was administered in accordance with published standardized instructions (Borg, 1998; Figure 7).

3.7.3.2 Thermal comfort (TC)

As stated in the literature review (Chapter 2), numerous TC scales have been developed (Bedford, 1936; Gagge et al. 1967). Therefore, it is difficult to compare between studies. The most commonly used TC scale involves rating TC from “0 = very comfortable” to “4 = very uncomfortable” (Gagge et al., 1967). However, participants ratings on a numbered scale are often influenced by the prior rating (i.e. increase in incremental stages) independently of the real/true feeling of perception. Therefore, it could be argued that the coloured VAS scales are more representative of true perceptual ratings (Gaoua et al., 2011a; 2011b; Gaoua et al., 2012). Therefore, TC was assessed in this thesis by using a VAS which ranged from black to white equating to a rating of 1-20, 1 = very comfortable to 20 = very uncomfortable (Gaoua et al., 2011a; 2011b; Figure 7). Participants were asked "How comfortable do you feel in this environment?". Participants would give their rating by pinching the scale at the point that corresponded to their thermal comfort which then corresponded to a number on the back.

3.7.3.3 Thermal sensation (TS)

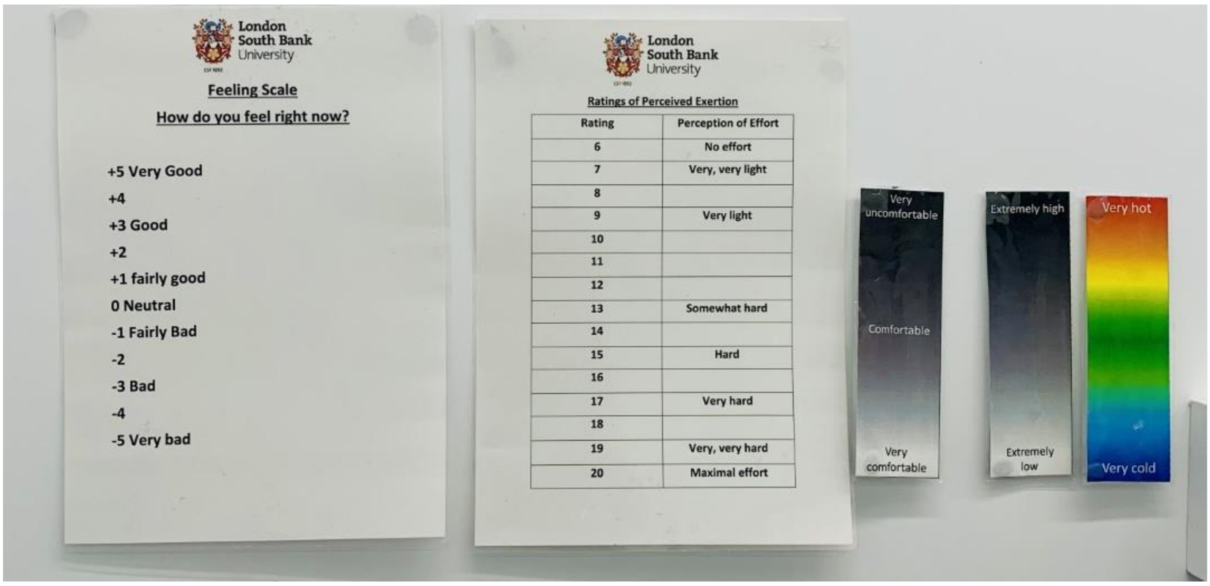
As stated in the literature review (Chapter 2), numerous TS scales have been developed (Bedford, 1936; ASRAE 55, 1966; Rohles and Levins 1971; Toner et al., 1986; Young et al. 1987; Gaoua et al., 2011a; 2011b). The most commonly used TS scale involves rating TS from “-3 cold” to “+3 hot” with the centre of the scale representing neutral conditions (0) (Young et al. 1987). However, participants ratings on a numbered scale are often influenced by the following rating (i.e. increase in incremental stages) independently of the real/true feeling of perception. Therefore, it could be argued that the coloured VAS scales are more representative of true perceptual ratings (Gaoua et al., 2011a; 2011b; Gaoua et al., 2012). Therefore, TS was assessed in this thesis by using a VAS which ranged from blue to red equating to a rating of 1-20, 1 = very cold to 20 = very hot (Gaoua et al., 2011a; 2011b; Figure 7). Participants will be asked, "How hot or cold do you feel in this environment?”. Participants would give their rating by pinching the scale at the point that corresponded to their thermal sensation which then corresponded to a number on the back.

3.7.3.4 Affect (AF)

A well-cited assessment of mood in physical activity/sport setting is the profile of mood state (POMS) (Berger and Motl, 2000). POMS is used to assess the relationship between exercise and acute mood changes however, this does not assess AF explicitly. To evaluate affective state during exercise, researchers commonly use “the feeling scale” (Appendix C: Hardy & Rejeski, 1989). This is an 11-point scale ranging from -5 “Very bad” to +5 “Very good”, with 0 as a neutral midpoint (Hardy & Rejeski, 1989; Figure 7). Participants were asked ‘‘How do you feel right now?’’ and were asked to respond using the 11-point scale (Hardy & Rejeski, 1989). Participants were informed that their response should reflect the affective or emotional components of the exercise and not the physical sensations of effort or strain. Measuring AF using this scale has been considered a reliable and valid measure of affective valence in the exercise domain. Therefore, it has been used in recent investigations examining affect during acute exercise bouts (Rose & Parfitt, 2012) and has been recommended as an appropriate measure of valence in the exercise context (Ekkekakis & Petruzzello, 2002).

3.7.3.5. Task motivation (TM)

Coudevylle et al., (2020) review highlighted that motivation may be a key factor in aerobic performance in tropical climates (for example HH) and therefore, perceived motivation to exercise was assessed via a 20cm VAS (Crewther et al., 2016 Figure 7). Participants were asked ‘how motivated do you feel to exercise right now?’ to which they answered by adjusting the level on the scale between 0 = ‘not very motivated’ (white-coloured) and 20 = ‘very motivated’ (black-coloured).Participants would give their rating by pinching the scale at the point that corresponded to their motivation which then corresponded to a number on the back.



London
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Feeling Scale

How do you feel right now?

+5 Very Good
+4
+3 Good
+2
+1 fairly good
0 Neutral
-1 Fairly Bad
-2
-3 Bad
-4
-5 Very bad

London
South Bank
University

Ratings of Perceived Exertion

Rating	Perception of Effort
6	No effort
7	Very, very light
8	
9	Very light
10	
11	
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Very, very hard
20	Maximal effort

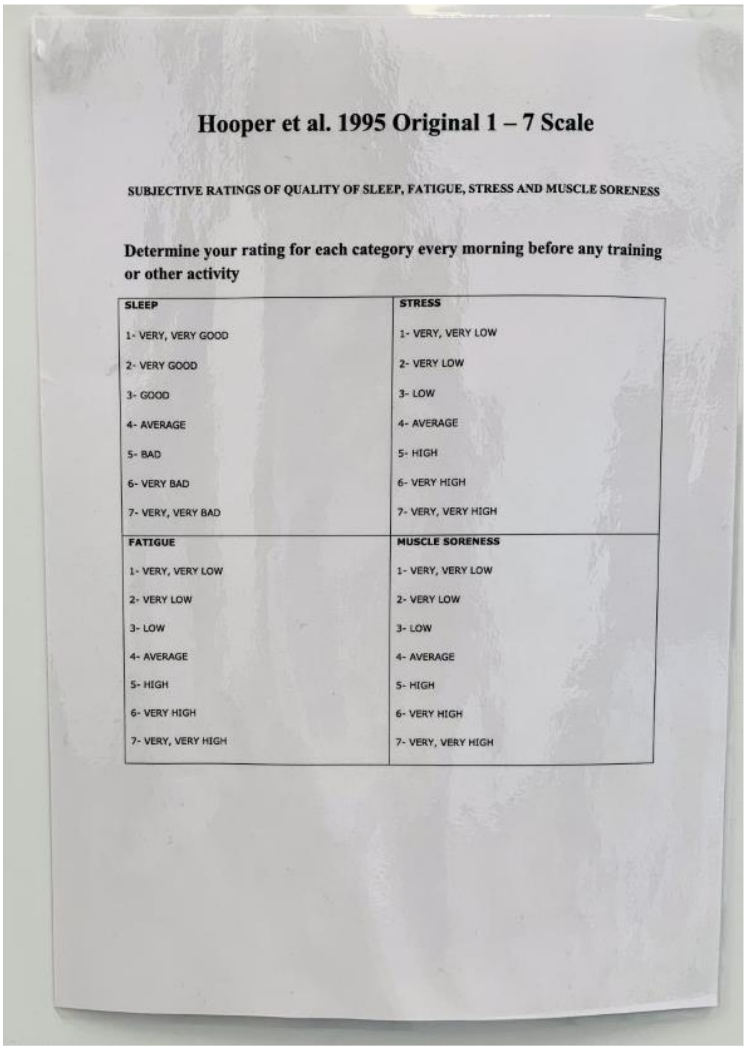
Figure 7. Perpetual scales included in study 2 and 4 from left to right (AF, RPE, TC, TM and TS).

3.7.3.6. Situation motivation (SIMS)

Before each experimental trial in study 1,2, and 4, participants completed a questionnaire titled Situational Motivation Scale (SIMS; 16 Item Scale). This questionnaire was used to measure motivation to exercise before each cycling TT. *“Why are you currently engaged in this activity?”* to which participants answered 16 items. The items were separated into four categories: Intrinsic motivation: Items 1, 5, 9, 13; Identified regulation: Items 2, 6, 10, 14; External regulation: Items 3,7, 11, 15; Amotivation: Items 4, 8, 12, 16. (Guay et al., 2000).

3.7.3.7. Markers of overtraining and recovery.

Before each experimental trial in study 2, and 4, participants completed a questionnaire (Hooper et al., 1995; Figure 8) which included subjective ratings of quality of sleep (1-very, very good to 7-very, very bad), fatigue (1- very, very low to 7- very, very high), stress (1- very, very low to 7- very, very high) and muscle soreness (1- very, very low to 7- very, very high).



Hooper et al. 1995 Original 1 – 7 Scale

SUBJECTIVE RATINGS OF QUALITY OF SLEEP, FATIGUE, STRESS AND MUSCLE SORENESS

Determine your rating for each category every morning before any training or other activity

SLEEP	**STRESS**
1- VERY, VERY GOOD	1- VERY, VERY LOW
2- VERY GOOD	2- VERY LOW
3- GOOD	3- LOW
4- AVERAGE	4- AVERAGE
5- BAD	5- HIGH
6- VERY BAD	6- VERY HIGH
7- VERY, VERY BAD	7- VERY, VERY HIGH
FATIGUE	**MUSCLE SORENESS**
1- VERY, VERY LOW	1- VERY, VERY LOW
2- VERY LOW	2- VERY LOW
3- LOW	3- LOW
4- AVERAGE	4- AVERAGE
5- HIGH	5- HIGH
6- VERY HIGH	6- VERY HIGH
7- VERY, VERY HIGH	7- VERY, VERY HIGH

Figure 8. Hooper et al., (199) original 1-7 scale for sleep, stress, fatigue and muscle soreness.

3.7.4 Eye Tracker

Prior to starting the TT in study 1, participants were fitted with a head-mounted eye tracker (Dikablis Professional wireless Eye-Tracking, Ergoneers) which was worn like glasses. The system consists of three cameras: two that record the eye position of the participant and one forward-looking camera that records the scene at which the participant is looking. The eye position was recorded at 50 Hz, as recommended by the manufacturers. The system tracks eye movements using pupil and corneal reflex so that each participant’s object of regard (OOR) can be superimposed onto the recorded scene, thus enabling timed measurements to be made of eye fixations. OOR can be defined as the main object/variable of focus/being looked at.

Participants were told that this device was used to measure the dilation of their pupils which will be used as an indicator of physical stress on the body to avoid influencing where the cyclists looked during the TT.

The laboratory set up previously used by Boya et al., (2017) was adopted for all studies in this thesis. The monitor was 93cm in width and 52cm in height with the bottom border of the monitor running 2m above and parallel to the floor. The turbo bike was positioned such that the handlebars stem riser was 1m perpendicular to the plane of the screen which itself was offset to the right of the natural forward field of vision of the cyclists with a sector displacement of 8° at 3.03m for the left border of the projection and 40° at 3.91m for the right border (visual arc 32°). Offsetting the screen in this way required participants to rotate their neck to look at the projected information, thus adding confidence that the eye-tracking measurements constituted deliberate attempts to acquire information, rather than information glances just because it happened to fall naturally within participants forward field of vision.

Figure 9. Head mounted eye tracker which was worn like glasses.

3.7.5 Debrief

A debrief was provided to the participants at the end of study 1. Originally participants were disclosed a different title in the information sheet to the actual title of the study to prevent participants from influencing their outcome performance (e.g. focusing on distance over speed because the volunteer believes this may be the more desirable variable for cyclists performance). The debrief revealed the true purpose of the study; The aim of the study was to investigate the differences in pacing strategies with full feedback and time only feedback in novice and experienced cyclists during 30min cycling TT.

3.7.6. Equipment cleaning and control of substances hazardous to health

To avoid contamination all apparatus was cleaned before and after use. Metabolic gas collection equipment such as face-masks, falconia tubing, mouthpieces and nose clips were soaked in Virkon disinfectant (1% Antec Int. Suffolk, UK) for a minimum of 10 minutes, followed by a thorough rinse in cold water and drying prior to use as per manufacturer guidelines. Heart rate monitor straps were soaked for 10 minutes in 1% Virkon disinfectant, rinsed and dried following use.

In order to test under the COVID-19 guidelines, participation in the research studies included in this thesis were not open to:

1. Clinically extremely vulnerable or clinically vulnerable people or individuals who live with such people.
2. People who have travelled abroad in the last 14 days.
3. People who are displaying COVID-19 symptoms or have in the last 7 days.
4. People living in a household where someone else has displayed symptoms in the last 14 days.

In addition, the following procedures were taken to ensure safety to participants and investigators during testing:

1. Social distancing was maintained throughout the testing process. Therefore, there was no physical contact between individuals (i.e. handshakes etc). This infers that all laboratory equipment, such as heart rate monitors and thermal sensors was self-applied by participants. Participants received verbal instructions by the investigator on how to apply equipment in a safe manner.

2. Face masks, eye protection, gloves and gowns were worn during testing to NHS standards as a control measure.

3.7.6.1 Waste disposal

Biological material and waste were handled and disposed of in line with relevant guidelines. Control of Substances Hazardous to Health (COSHH) sheets were completed for the study. Risk assessments were also completed for use of all laboratories, exercise and invasive techniques.

All other non-reusable waste was disposed of by immediate placement in marked biohazard waste containers and incinerated. Sharps, such as venepuncture needles, were also disposed of in marked sharps containers and subsequently incinerated. Electrical equipment contacting the body such as heart rate monitors were cleaned using warm water and soap, followed by alcohol cleaning wipe.

3.7.7. Criteria for termination of experiments

Experiments were stopped if any of the following criteria were met:

- The participant asked to stop the test at any point (participants were not required to give any reason for this).
- The investigator felt it appropriate to stop the test whether it be for equipment issues, or the participant displaying signs of discomfort or illness, including, but not limited to chest pain, dypsnea, nausea, vomiting, generic pain/discomfort, faintness or dizziness.
- A T_{rectal} value of ~39.5°C was reached.

3.7.8. Data processing

Procedures for data processing are detailed within each experimental study chapter.

3.7.9. Eye-Tracking and Video Analysis [1]

Gaze behaviour was evaluated using the following categories: Number of glances, number of glances >2s, and time to first glance. This was calculated participant-by-participant basis for the whole TT and in 5min intervals. The eye gaze was coded by recording the start and end frame of each entry into a new area of interest. This allowed us to determine the periods spent inspecting each of the variables. Eye fixation times were recorded in milliseconds against the six predetermined categories in FF. The total number of glances was defined as the number of separate eye fixations (≥100ms) for each variable. Mean glance was defined as the mean number of eye fixations for each variable. Time to first glance derived from the duration between the beginning of the trial until the first glance to an OOR.

Gaze frequency was reported as total, defined as the accumulated time of all eye fixations and mean glance time for each category. Total glance times were then used to determine what information source that each participant looked at for longest accumulated time (primary), second-longest accumulated time (secondary), third-longest accumulated time (tertiary) and so on until quaternary (4th), quinary (5th), and senary (6th), had all been established.

3.7.10. Data Analysis

Perfpro file including performance (power output, distance, speed, cadence) and physiological responses (heart rate) was downloaded into an excel spreadsheet after each trial.

3.7.11. Statistical analysis

Power analyses were carried out prior to data collection to determine appropriate sample sizes for each experimental study (G*Power 2, HHU, Germany). Please see each chapters statistical analysis section for specific details. In general, sphericity was assessed via a Mauchly test, to consider that variations of differences are equal (Field, 2013). If sphericity was violated, a Greenhouse Geisser correction was applied. Partial eta-squared was calculated as an estimation of effect size (ES). Values of 0.01, 0.06 and above 0.14 were considered as small, medium and large, respectively (Cohen, 2013). If data were not normally distributed, a related-samples nonparametric Friedman's test was used. If any significant effects were found, a further post-hoc analysis was carried out via Bonferroni pairwise comparisons to assess where the significance lay. Pearsons Correlation was conducted between the main performance variable (power output) and main physiological (core temperature) and main percpetual variables (thermal comfort and thermal sensation). Categories for r values (correlation coefficients) ≤0.35 = low/weak correlations, 0.36-0.67 = modest/moderate correlations, 0.68-0.90= strong/high correlation and, >0.90 = very high/very strong correlations (Taylor, 1990). All statistical testing was carried out in SPSS (v21, IBM, Cambridge). All data are presented as mean ± standard deviation (SD) and considered statistically significant if $p < 0.05$ and a trend for significance if $p < 0.07$.

4.Chapter 4. Methodological Study: Less is more – Cyclists-triathletes 30min cycling time-trial performance is impaired with multiple feedback compared to a single feedback.

4.1. Abstract

Purpose: The purpose of this article was to (i) compare different modes of feedback (multiple vs. single) on 30 min cycling time-trial performance in non-cyclist's and cyclists-triathletes, and (ii) investigate cyclists-triathlete's information acquisition.

Methods: 20 participants (10 non-cyclists, 10 cyclists-triathletes) performed two 30 min self-paced cycling time-trials (TT, ~5–7 days apart) with either a single feedback (elapsed time) or multiple feedback (power output, elapsed distance, elapsed time, cadence, speed, and heart rate). Cyclists-triathlete's information acquisition was also monitored during the multiple feedback trial via an eye tracker. Perceptual measurements of task motivation, ratings of perceived exertion (RPE) and affect were collected every 5 min. Performance variables (power output, cadence, distance, speed) and heart rate were recorded continuously.

Results: Cyclists-triathletes average power output was greater compared to noncyclists with both multiple feedback (227.99 ± 42.02 W; 137.27 ± 27.63 W; $P < 0.05$) and single feedback (287.90 ± 60.07 W; 131.13 ± 25.53 W). Non-cyclist's performance did not differ between multiple and single feedback ($p > 0.05$). Whereas, cyclists-triathletes 30 min cycling time-trial performance was impaired with multiple feedback (227.99 ± 42.02 W) compared to single feedback (287.9 ± 60.07 W; $p < 0.05$), despite adopting and reporting a similar pacing strategy and perceptual responses ($p > 0.05$). Cyclists-triathlete's primary and secondary objects of regard were power (64.95 s) and elapsed time (64.46 s). However, total glance time during multiple feedback decreased from the first 5 min (75.67 s) to the last 5 min (22.34 s).

Conclusion: Cyclists-triathletes indoor 30 min cycling TT performance was impaired with multiple feedback compared to single feedback. Whereas non-cyclist's performance did not differ between multiple and single feedback. Cyclists-triathletes glanced at power and time which corresponds with the wireless sensor networks they use during training. However, total glance time during multiple feedback decreased over time, and therefore, overloading athletes with feedback may decrease performance in cyclists-triathletes.

4.2. Introduction

It was highlighted in chapter 2 (literature review) that articles investigating cycling performance in hot conditions provide participants with different types (i.e. elapsed distance, time, PO, cadence, speed, HR) and amounts of feedback (i.e. 1-5). One reason for this may be related to the global use of power meters and cadence sensors within the sport of cycling and triathlon (Gharghan et al., 2015). Wireless sensor networks (WSN) such as these provide cyclists-triathletes with easy access to not only end point knowledge (i.e. elapsed time and distance) but also performance (i.e power output, cadence, speed) and physiological variables (i.e. heart rate; Gharghan et al., 2015).

Within the feedback literature, it has been established that task relevant feedback is needed for optimal performance (Bertollo et al., 2015; Smit et al., 2016). For example, end-point knowledge is essential to inform pace and tactics in sports such as cycling (Bertollo et al., 2015; Smit et al., 2016; Wingfield et al., 2018). Without end point knowledge experienced cyclists pacing decisions are based off physiological and perceptual-driven stimuli alone, which results in adopting a conservative pacing strategy causing the end spurt of a TT to be missed and/or not using all available physiological resources available (Marcora, 2008; Smit et al., 2014; 2016; Wingfield et al., 2018). Despite this understanding, it is currently unknown whether end-point knowledge is one of the main feedback variables used by cyclists-triathletes or whether multiple feedback variables are used simultaneously to inform pace.

Using feedback whilst cycling may be classed as a dual task (motor task combined with a cognitive task). The effect of adding a cognitive load such as attention to a motor task such as walking has been widely explored (Bradford et al., 2019). The findings have shown that pace (i.e. stride or gait velocity) changes when two tasks are performed simultaneously compared to separate task execution (Beauchet et al., 2005; Beurskens and Bock, 2012; Bradford et al., 2019). In tasks such as prolonged cycling, athletes experience neuromuscular fatigue originating from both central (i.e., spinal or supraspinal) and peripheral sites (i.e., within the muscle), which will eventually lead to a reduction in work rate (Chatain et al., 2019). Similarly, prolonged cognitive tasks (i.e., sustained attention) can induce a state of mental fatigue and may also have a detrimental effect on exercise completed after the task (Van Cutsem et al., 2017). Contemporary research showed that the addition of a cognitive task to a motor task impaired endurance capacity (Mehta and Agnew, 2012; Keller-Ross et al., 2014; Pereira et al., 2015). The impairment in endurance capacity may results from limited attentional resources making humans unable to complete two different types of task (i.e. motor and cognitive) to the same standard when performed simultaneously (Pashlet, 1994; Dietrich and Audiffren, 2011). Although this impairment in capacity is well documented during time to exhaustion models, it is unclear if the same responses occurred during a self-paced model similar to competition. An investigation into the effect of multiple feedback variables on cycling performance using a self-paced model would be an ecologically valid method to determine whether there is an overload effect (i.e. increase mental load) experienced by cyclists-triathletes during competition.

Therefore, posing the question as to whether using single feedback (i.e., time only, distance only) may offer greater cycling performance outcomes compared to multiple feedback as there is less chance of developing a cognitive overload. To our knowledge only one article has considered the quantity and type of visual feedback on self-paced cycling performance, which incorporated eye-tracker technology to identify object(s) of regard (OOR; main variable glanced at) during a 10 mile (16.1km) cycling TT.

Boya et al., (2017) provided cyclists with multiple feedback (i.e., power, cadence, speed, heart rate, video simulation, presence of competitor, RPE scale, elapsed distance and time) during a 10mile TT (complete the distance as quickly as possible). The experienced cyclists (EC) completed the 10mile TT significantly faster (27.71 ± 1.5 min) than the novice cyclists (30.26 ± 2.93 min). Boya et al., (2017) determined that NC had a greater dependence upon distance feedback, which they looked at for shorter and more frequent periods of time than EC. Whereas, EC were more selective and consistent in attention to feedback, glancing at speed feedback the most. This study challenged the importance placed on knowledge of the endpoint to pacing in previous models, especially for EC for whom distance feedback was looked at secondary to, but in conjunction with, information about speed. Boya et al. (2017) findings may be related to task type as professional individual TTs are not only distance based (i.e., complete 10 miles as quickly as possible) but can also be time-based (i.e., complete as much distance as possible within 30 min). This therefore poses the question as to whether cyclists information acquisition differs depending on the endpoint knowledge provided.

Therefore, the first aim of the current study was to compare multiple vs. single feedback on 30 min cycling performance to explore whether overload may impair performance. The second aim of the current study was to investigate cyclists-triathletes (CT) information acquisition during a 30 min cycling time-trial. Our first hypothesis was that CT would perform better with single vs. multiple feedback due to the possibility of overload during the dual-task. Based on the previous literature the second hypothesis of the current study was that CT's primary OOR would be one of the cycling specific feedbacks provided (i.e., speed, power, or cadence).

4.3. Methods

4.3.1. Participants

20 participants (NC=10, CT=10), were recruited for this study (effect size = 0.7; g∗power 3.1.9.2).

Table 14. Mean±SD differences in cyclists-triathletes and non-cyclist's sex (F:M), age (yrs), stature(cm), body mass (kg), body mass index (kg/m2), VO_{2peak} (mL.kg.min^{-1}), critical power (w) and prior experience (yrs).

Variables	**Non-cyclists (NC)**	**Cyclists-triathletes (CT)**
Participants	10	10
Sex Ratio (F:M)	1:9	0:10
Age (yrs)	24.2±3.7	25.9±3.6
Stature (cm)	174.1±10.4	181.5±6.2
Body Mass (kg)	76.9±15.8	75.5±7.8
Body Mass Index (kg/m2)	25.1±3.5	22.8±1.8
VO2peak (mL.kg.min-1)	39.4±74.2	55±6.5*
Critical Power (w)	170.8±63.3	213.7±88.9*
Prior Experience (yrs)	0±0	10±6*

**Significant difference between groups.*

4.3.2. Experimental design

A three-way mixed experimental design was used to investigate experience (experienced vs. non) × condition (multiple vs. single) × time interval (six 5 min blocks (B), i.e., B1: 0–5 min, B2: 5–10 min, B3: 10–15 min, B4: 15–20 min, B5: 20–25 min, and B6: 25–30 min). This design required participants to visit the laboratory on 3 separate occasions (Figure 10). The initial visit included a familiarisation in which the study procedures/measures involved, and eligibility was determined (see familiarization section below). Eligible participants were invited to return for 2 more visits which were separated by 5days to allow for sufficient recovery time (Jones et al., 2013). All trials were performed at the same time of day, ±2hr, to control for circadian variation. The two experimental trials included a 30min cycling TT, in which participants were either provided with multiple feedback variables (elapsed distance, elapsed time, heart rate, power-output, speed, cadence) or with a single feedback variable (elapsed time), in a counterbalanced order. To control for the effect of competition all trials were completed individually. To control for the effect of environmental condition all trials were performed in a thermoneutral environment (18◦C, 40% rH) with headwind (2.23 m.s^{-1})

provided by an electrical fan, positioned 0.5m in front of the bike in line with the participant's torso. To prevent any influence on pacing and eye tracking data participants were originally informed of a different study title and purpose in the information sheet: "The reproducibility of 30 min cycling TT performance on a turbo-trainer" In addition, participants were told that the eye tracker device was used to measure the dilation of their pupils, which was a non-invasive indicator of physical stress on the body. This, again was to avoid influencing eye tracking data. A debrief was provided to the participants at the end of the study that revealed the true purpose of the study.

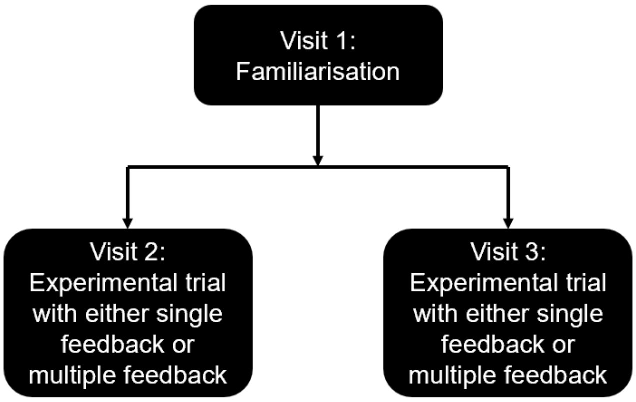


Figure 10. Illustrated structure of study design.

4.3.3. Familiarization, Critical Power Test, and VO_{2peak}

In the initial visit to the laboratory, participants were briefed to the requirements of the study, were given detailed instructions of how to use all perceptual scales and completed a short health screening questionnaire and the consent form. Following this, each participant had their body mass and stature measured. Participants then completed CPT (see general methodology).

4.3.4. Experimental Trials

Participants initiated the second and third visit by performing a standardized warm-up (see general methodology). Participants were then given the following verbal instruction before starting the TT: "*This is a maximal effort time-trial which requires you to complete as much distance as possible within the 30 min.".* Participants were then allowed to ask any further questions before starting the TT. During the TT with a single feedback variable, participants were provided with information of the elapsed time (min) only (Figure 11, panel B). Whereas, with multiple feedback variables, participants were informed of their real time (updated every 0.3 ms) speed (mph), elapsed distance (miles), elapsed time (min) power output (W), pedal cadence (rpm) and heart rate (HR; b.min^{-1}) continuously throughout the TT (Figure 11, panel A). All participants were fitted with a head-mounted eye tracker (Ergoneers Dikablis, Germany) which was light weight and worn like glasses (Figure 11; see general methodology for more details).

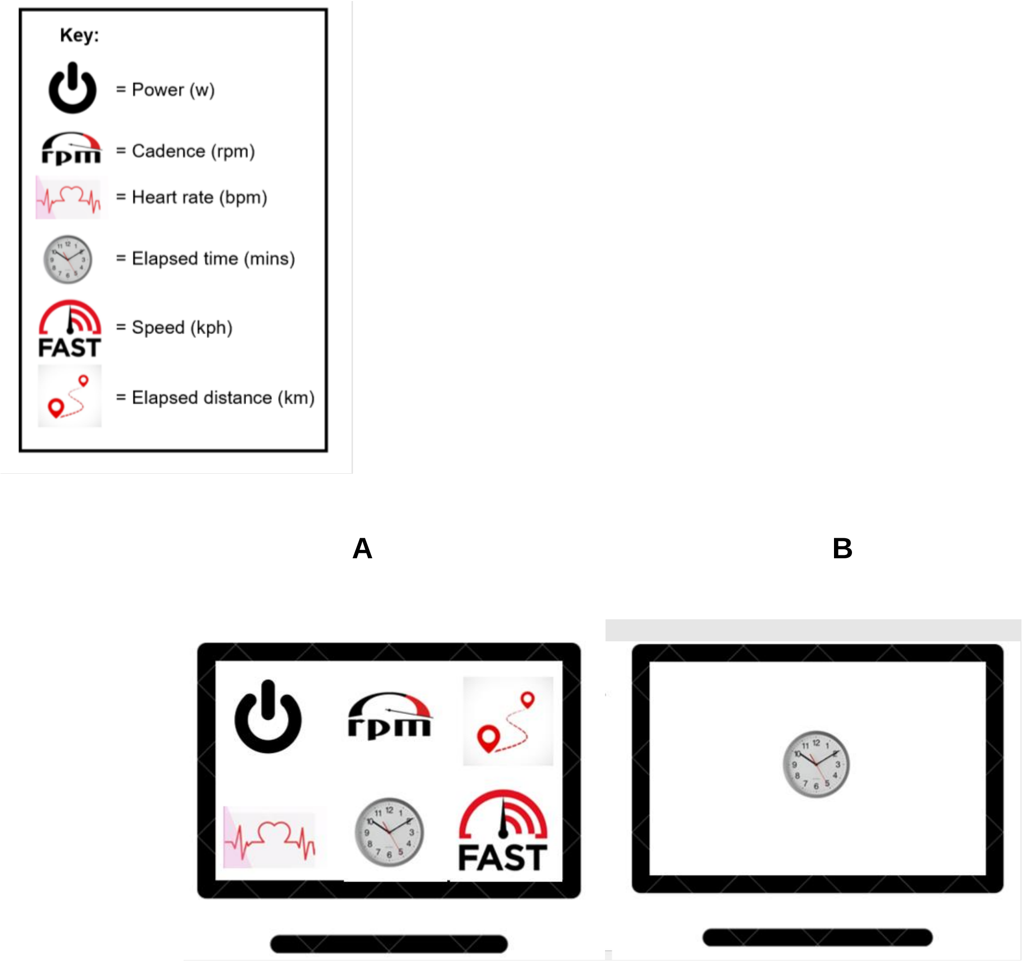


Figure 11. (A) multiple feedback (power, cadence, heart rate, elapsed time, speed, elapsed distance) and (B) single feedback (elapsed time) visual monitors provided throughout the time-trial.

4.3.5. Performance Measurements

Performance variables such as power-output and distance were obtained using PerfPro Software that connected to the turbo-trainer (RacerMate Software, Version 4.0.2, Seattle, United States).

4.3.6. Physiological Measurements

HR was recorded continuously using a chest strap HR monitor (Garmin 705 Edge, Garmin, Southampton, United Kingdom) connected wireless to the PerfPro software (Hartman Technologies, Rockware, Michigan, United States) using an ANT + device.

4.3.7. Percpetual Measurements

Before all TT's participants completed a situational motivation scale. TM and AF were measured at baseline, and TM, AF and RPE were measured every 5 min (at 5, 10, 15, 20, 25, and 30 min).

4.3.8. Statistical Analysis

All statistical analysis was completed using SPSS (version 21, IBM Corporation, Armonk, NY). Shapiro-Wilk's test revealed that all physiological, information acquisition and performance data were normally distributed ($P < 0.05$). Variables that were normally distributed were analyzed using separate twoway mixed ANOVAs for condition (multiple vs. single) and group (experienced vs. non) across the whole TT. Separate three-way mixed (experience x condition x time) ANOVAs was used to test for significant differences, main and interactions effects at time intervals [6 blocks (B) of 5 min each]. To analyze pacing, power output in each 5 min block was expressed as a percentage of the average power during the whole TT. Partial eta-squared (η 2) was calculated as a measure of effect size.

Values of 0.01, 0.06 and above 0.14 were considered as small, medium and large, respectively (Cohen, 1988). A related samples Friedman's non-parametric test (TM, AF, and RPE) was used for data not normally distributed. Bonferroni post hoc pairwise comparisons were used to identify locations of significant effects. Data was considered significant if $p \leq 0.05$. All data are presented as group means ± SD.

4.4. Results

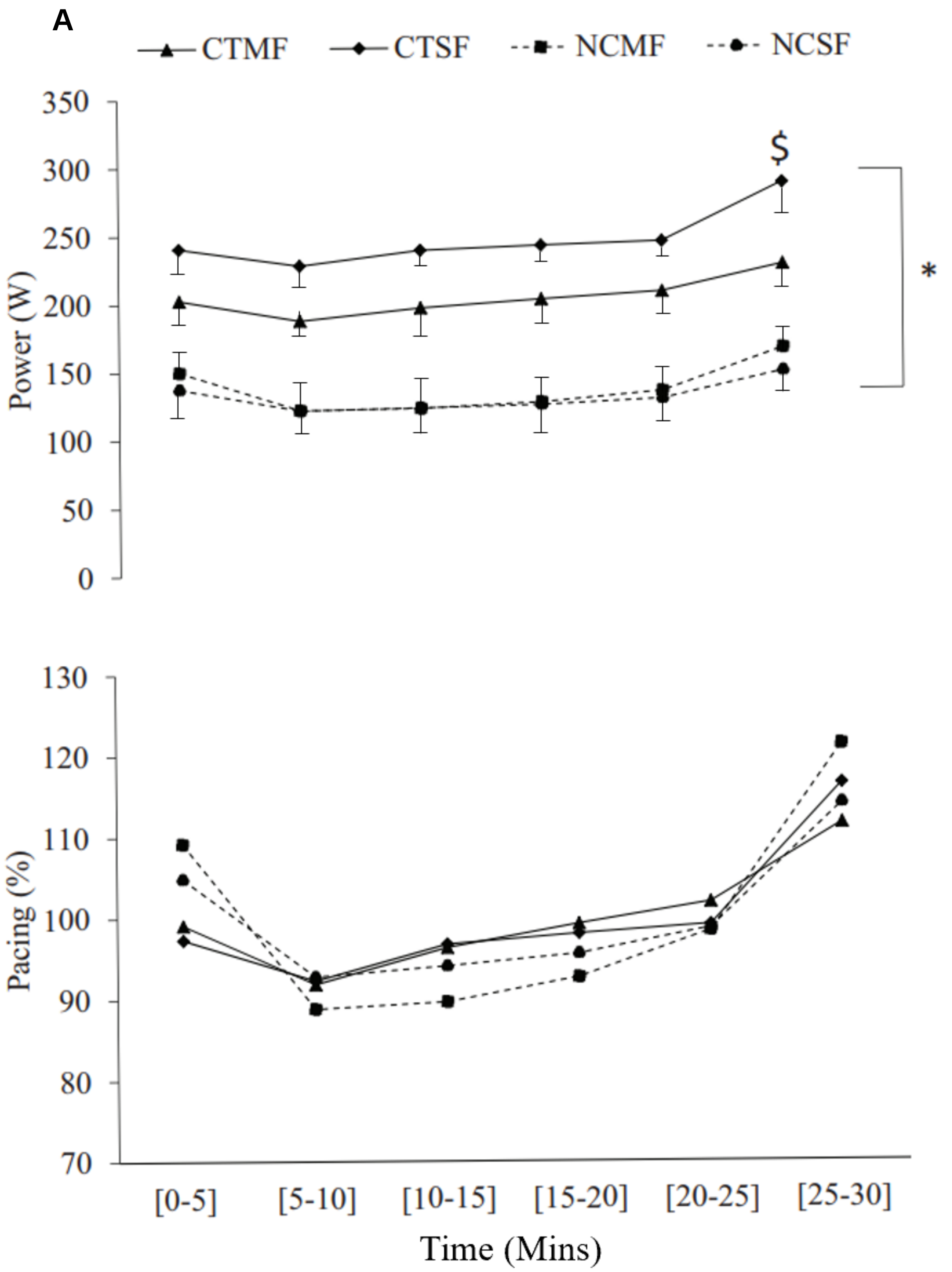
4.4.1. Performance Responses

Table 15. Mean±SD total distance and power output during the 30 min cycling time-trial.

Group and Condition	CTMF	CTSF	NCMF	NCSF
Total Distance Covered (km)	8.1±0.9	8.7±0.7	6.1±1.2	6.0±1.2
Power Output (W)	204.32±41.74	247.13±51.26	137.27±27.36	131.13±25.53

CTMF = cyclists-triathletes multiple feedback, CTSF = cyclists-triathletes single feedback, NCSF = non-cyclists' single feedback, NCMF = non-cyclists multiple feedback.

Overall, CT completed a significantly greater distance than NC with both multiple (8.1 ± 0.9 km vs. 6.1 ± 1.2 km; 20%; $P < 0.05$) and single (8.7 ± 0.7 km vs. 6.0 ± 1.2 km; 32%; $P < 0.05$) feedback. Mean power output (204.32±41.74 vs 247.13±51.26W; $P < 0.05$, η 2 = 25%) and HR ($P < 0.001$, η 2 = 78%) were significantly greater in CT than NC at all-time points in with multiple and single feedback (all $0.0001 < P < 0.028$; 30 and 44%; Figure 16). CT covered a significantly greater distance with single (8.7 ± 0.7 km) compared to multiple feedback (8.1 ± 0.9 km; $P < 0.05$). There was no main effect of condition on power output in CT from B1 to B5, however, there was a significantly greater increase in power output with single compared to multiple feedback in B6 ($P < 0.01$, η 2 = 77%; Figure 16). Moreover, there was no main effect of condition on CT's HR (multiple: 158 ± 14 vs. single: 152 ± 16 $b.min^{-1}$; $P > 0.05$, η 2 = 17%). There was no main effect of condition on NC's distance (multiple: 6.1 ± 1.2 km vs. single: 6.0 ± 1.2 km; $P > 0.05$, η 2 = 15 or HR (multiple: 135 ± 16 vs. single: 141 ± 17 $b.min^{-1}$; $P > 0.05$, η 2 = 17%). Notably, there was >5% difference in CTs power output between conditions and therefore individual differences were explored (Figure 16, Panel B; NC are also represented for clarity of data). All CTs mean±SD PO was greater with single feedback compared to multiple feedback (20%). The average increase with multiple compared to single was ~116W (~11-187W).


A
CTMF
CTSF
NCMF
NCSF
350
300
250
200
150
100
50
0
Power (W)
$
*
130
120
110
100
90
80
70
Pacing (%)
[0-5]
[5-10]
[10-15]
[15-20]
[20-25]
[25-30]
Time (Mins)

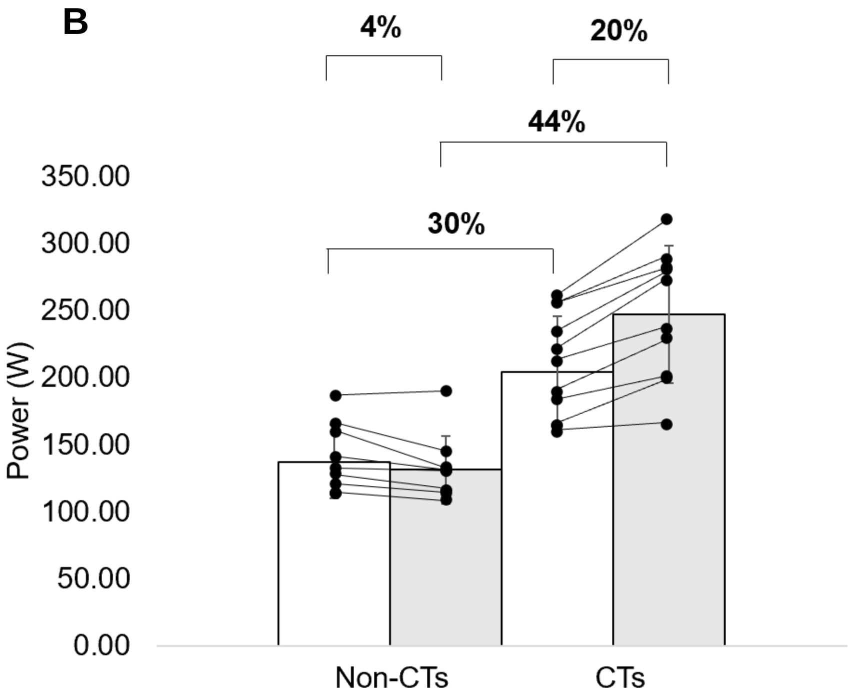


*Figure 12. A) Cyclists-triathletes (CTSF, cyclists-triathletes single feedback; CTMF, cyclists-triathletes multiple feedback) and non-cyclists (NCSF, non-cyclists' single feedback; NCMF, non-cyclists multiple feedback) 5min segment mean±SD power output and pacing used with permission of Bayne et al., (2020). *denotes P <0.05 between groups for both conditions, $ denotes P<0.05 between groups and conditions at a specific time point. B) Cyclists-triathletes (CTSF, cyclists-triathletes single feedback; CTMF, cyclists-triathletes multiple feedback) and non-cyclists (NCSF, non-cyclists' single feedback; NCMF, non-cyclists multiple feedback) mean±SD power output for the whole 30min time-trial with individual data points. White bar = multiple feedback and Grey Bar = Single feedback.*

4.4.2. Psychoperceptual Responses

There was no significant difference in participants SMS scores between visits (Amotivation, identified and external regulation, P > 0.05) except for intrinsic motivation between groups implying that CT were more intrinsically motivated to cycle in the first trial compared to NC (P < 0.05).

CT perceived to be exerting more effort than NC with both multiple and single feedback between B2-6 ($P < 0.05$; Table 17).

However, NC affect scores were lower and therefore perceived to have felt significantly worse than CT with both multiple and single feedback at B1 ($P < 0.05$; Table 17). At B2 NC affect had improved with single feedback, reporting values that were significantly better than CT ($P < 0.05$; Table 17). Whereas with multiple feedback, NC reported feeling worse than CT from B1-B3 ($P < 0.05$; Table 17). Notably, there was a strong negative correlation between affect and power output for EC with mutlitple feedback inferring that the lower power output exerted with multiple feedback was related to feeling worse throughout the time-trial.

NC felt more motivated than CT with single feedback at B1–5 ($P < 0.001$; Table 17). Whereas CT felt more motivated than NC with multiple feedback at all-time points ($P < 0.001$; Table 17). However, overall, there was no significant difference between mean perceptual response and condition in either group ($P > 0.05$; Table 17).

Table 16. Cyclists-triathletes and non-cyclists overall mean±SD and 5min segments for perceived exertion, affect, task motivation used with permission of Bayne et al., (2020).

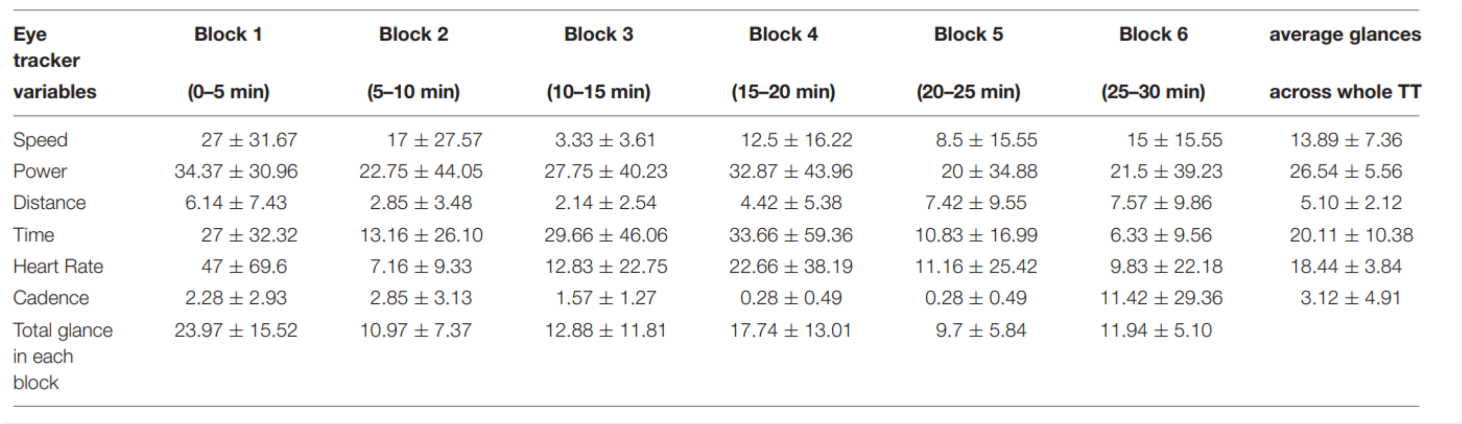
Variables	Conditions	Block 1 (0-5min)		Block 2 (5-10min)		Block 3 (10-15min)		Block 4 (15-20min)		Block 5 (20-25min)		Block 6 (25-30min)		Overall mean±SD		Correlation		ANOVA p-valye (Patial eta squared)		
		NC	EC	NC	EC	NC	EC	NC	EC	NC	EC	NC	EC	NC	EC	NC	EC	Condition	Time	Interaction
Ratings of Perceived Exertion	Single	8.4±1.51	9.95±1.04	11.55±2.58	14.1±1.93	12.85±2.24	14.50±2.16	13.75±2.11	15.00±2.26	14.45±1.94	15.55±2.05	15.15±2.21	16.40±2.00	12.69±2.08	14.25±1.91	-0.19	0.66	0.003 (0.95)	0.009 (0.82)	0.001 (0.80)
						*														
	Multiple	8.95±1.44	9.85±0.91	12.3±2.85	14.15±1.82	13.00±2.59	14.75±1.78	13.9±2.35	15.10±1.96	14.70±2.49	15.60±2.19	15.45±2.72	16.7±2.2	13.1±2.41	14.36±1.82	0.25	0.45			
		*		*		*		*		*		*								
Affect	Single	3.25±1.99	3.35±1.72	3.2±1.57	3.05±1.4	2.95±1.55	2.70±1.84	2.70±1.58	2.45±2.02	2.55±1.59	2.25±2.07	2.20±2.19	2.15±2.53	2.81±1.75	2.66±1.93	-0.26	0.15	0.009 (0.31)	0.004 (0.23)	0.830 (0.02)
		*		*				*				*								
	Multiple	3.65±1.4	3.85±1.43	3.4±0.91	3.4±1.49	2.90±1.20	3.15±1.55	2.35±1.68	2.90±1.71	2.00±2.07	2.55±1.96	1.8±2.31	2.1±2.46	2.68±1.59	2.99±1.77	0.05	-0.72			
		*		*				*				*								
Task Motivation	Single	17.95±0.07	17.00±0.14	17.75±0.21	16.7±0.57	17.35±0.35	16.4±0.14	17.25±0.21	16.50±0.14	7.45±0.07	16.60±0.14			17.55±0.18	16.64±0.20	-0.007	0.14	0.446 (0.02)	0.415 (0.04)	0.523 (0.02)
		*		*		*		*		*										
	Multiple	17.4±0.14	18.05±0.07	17.05±0.35	18.00±0.14	16.9±0.14	17.90±0.10	16.65±0.49	17.95±0.07	16.5±0.28	18.20±0.28			16.9±0.28	18.02±0.11	0.40	-0.30			
		*		*		*		*		*										

**=Denotes a significant difference between groups, red = low correlation with power, yellow =moderate correlation with power, green = strong correlation with power.*

4.4.3. Information Acquisition

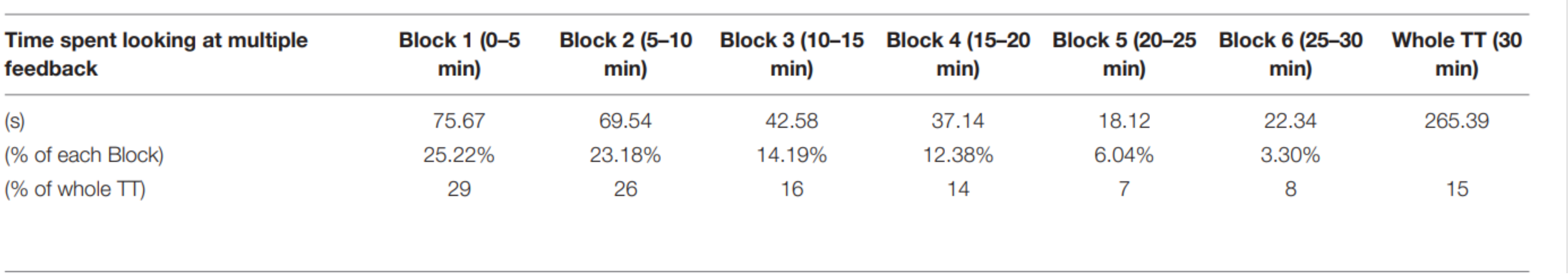
In the multiple feedback trial CT glanced significantly more often at the feedback variable "power output" throughout the TT ($P < 0.05$) compared to "speed," "time," "distance," "HR," and "cadence" ($P > 0.05$; Table 18). CT also spent the most time glancing at power (total glance time: 64.95 s) followed by time (64.46 s; Figure 13). However, there was no significant difference in overall OORs ($P > 0.05$; Figure 13). In contrast to the information acquisition data gathered by the eye tracker, the CT post TT perceived OORs were speed, followed by power. Whereas, NC perceived OORs were distance, followed by HR. Segmental analysis on the top two OOR(s) revealed that CT's total glance time in each time block at power was consistent throughout the TT (Figure 14), which corresponds with the number of glances at power (Table 18). Whereas the total glance time at time peaked in B3 and B4 (Figure 14), which also corresponds with the number of glances at time (Table 3). Notably, CT only spent 15% (265.39 s) of the overall time available in the 30 min (1,800 s) TT looking at multiple feedback (Table 19). Moreover, total glance time(s) at multiple feedback decreased from B1 (75.67 s; 25.22%) to B6 (22.34 s; 3.30%; Table 19).

Table 17. Cyclists-triathletes (N=6) overall mean±SD number of glances and in 5min segments used with permission of Bayne et al., (2020). .



Eye tracker variables	Block 1 (0–5 min)	Block 2 (5–10 min)	Block 3 (10–15 min)	Block 4 (15–20 min)	Block 5 (20–25 min)	Block 6 (25–30 min)	average glances across whole TT
Speed	27 ± 31.67	17 ± 27.57	3.33 ± 3.61	12.5 ± 16.22	8.5 ± 15.55	15 ± 15.55	13.89 ± 7.36
Power	34.37 ± 30.96	22.75 ± 44.05	27.75 ± 40.23	32.87 ± 43.96	20 ± 34.88	21.5 ± 39.23	26.54 ± 5.56
Distance	6.14 ± 7.43	2.85 ± 3.48	2.14 ± 2.54	4.42 ± 5.38	7.42 ± 9.55	7.57 ± 9.86	5.10 ± 2.12
Time	27 ± 32.32	13.16 ± 26.10	29.66 ± 46.06	33.66 ± 59.36	10.83 ± 16.99	6.33 ± 9.56	20.11 ± 10.38
Heart Rate	47 ± 69.6	7.16 ± 9.33	12.83 ± 22.75	22.66 ± 38.19	11.16 ± 25.42	9.83 ± 22.18	18.44 ± 3.84
Cadence	2.28 ± 2.93	2.85 ± 3.13	1.57 ± 1.27	0.28 ± 0.49	0.28 ± 0.49	11.42 ± 29.36	3.12 ± 4.91
Total glance in each block	23.97 ± 15.52	10.97 ± 7.37	12.88 ± 11.81	17.74 ± 13.01	9.7 ± 5.84	11.94 ± 5.10	

Table 18. Cyclists-triathletes (N=6) mean±SD time spent looking at multiple feedback represented as a percentage (%) of overall time available in each 5min block and 30min time-trial used with permission of Bayne et al., (2020). .



Time spent looking at multiple feedback	Block 1 (0–5 min)	Block 2 (5–10 min)	Block 3 (10–15 min)	Block 4 (15–20 min)	Block 5 (20–25 min)	Block 6 (25–30 min)	Whole TT (30 min)
(s)	75.67	69.54	42.58	37.14	18.12	22.34	265.39
(% of each Block)	25.22%	23.18%	14.19%	12.38%	6.04%	3.30%	
(% of whole TT)	29	26	16	14	7	8	15

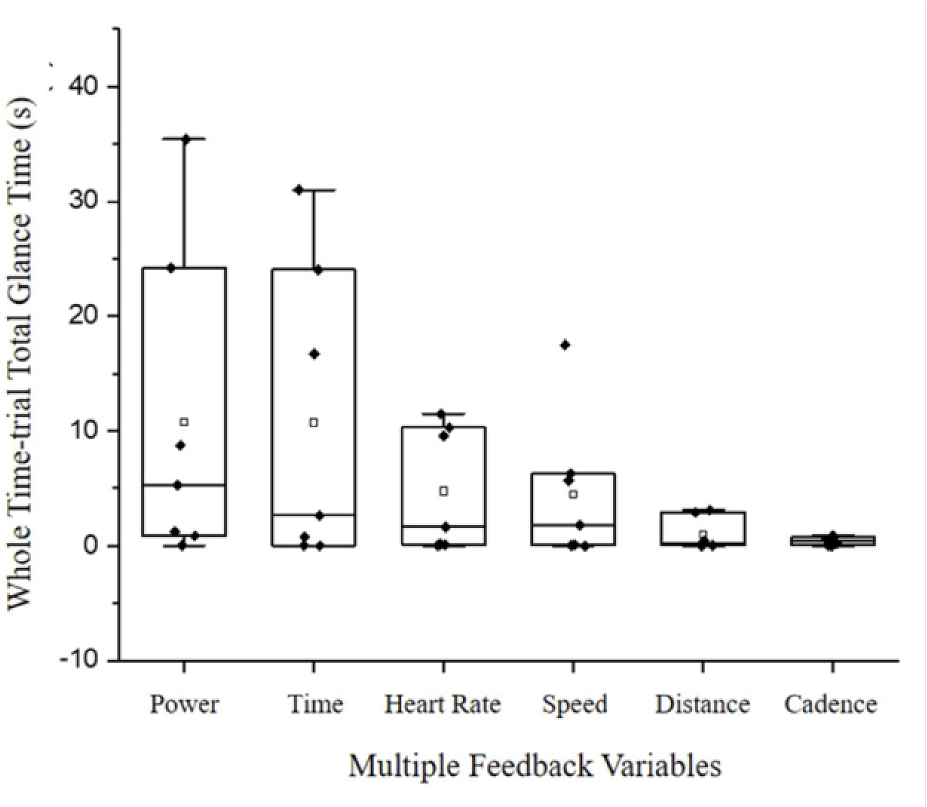


Figure 13. Cyclists-triathletes (N=6) overall mean±SD total glance time (s) at power, time, heart rate, speed, distance and cadence. White circle markers denote group mean. Black diamond makers denote individual differences within the group used with permission of Bayne et al., (2020). .

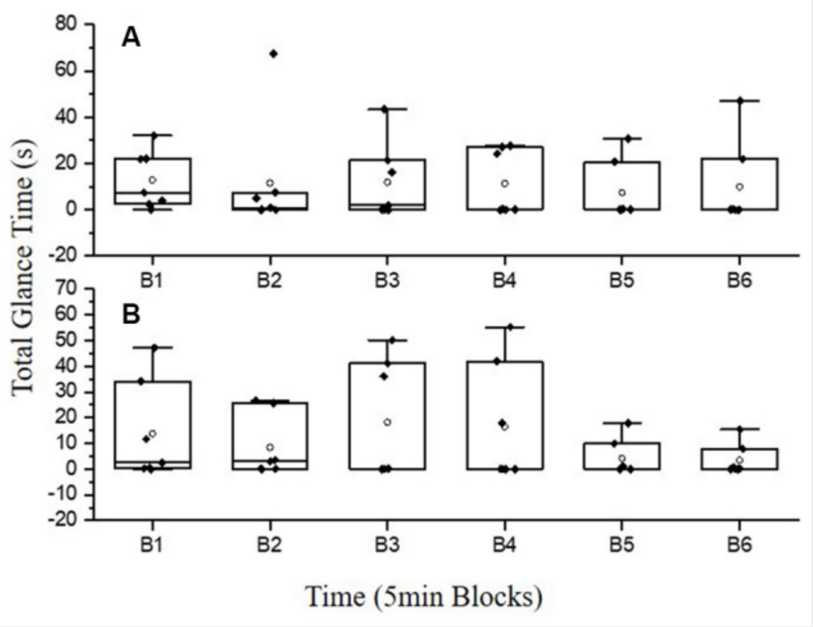


Figure 14. Cyclists-triathletes (N=6) mean±SD total glance time(s) in 5min segments at power (A) and time (B). White circle markers denote group mean. Black diamond markers denote individual differences within the group used with permission of Bayne et al., (2020)..

4.5. Discussion

4.5.1. Main findings

- Cyclists-triathletes mean power output was impaired with multiple feedback compared to single feedback.
- Cyclists-triathletes mean power output was significantly greater compared to non-cyclists with both feedback types.
- Feedback type had no effect on non-cyclists 30min cycling time-trial performance.
- Cyclists-triathletes glanced at power the most followed by time to inform pace.
- The impairment may be related to a mental overload from the multiple feedback variables as information acquisition decreased over time.

Cyclists-triathletes mean power output was significantly greater compared to non-cyclists in both multiple feedback (227.99 ± 42.02 W; 137.27 ± 27.63 W; $P < 0.05$; Figure 2) and single feedback trials (287.9 ± 60.07 W; 131.13 ± 25.53. W; Figure 2). Therefore, the cyclists-triathletes covered a greater distance compared to non-cyclists with both multiple (8.1 ± 0.9 vs. 6.1 ± 1.2 km) and single feedback (8.7 ± 0.7 km vs. 6.0 ± 1.2 km). However, the cyclists-triathlete’s 30 min cycling time-trial performance (power output and distance) was impaired with multiple feedback compared to single feedback ($P < 0.05$; Figure 2). Whereas, the feedback condition had no effect on non-cyclists 30 min cycling time-trial performance (Figure 2). Therefore, the first hypothesis stating that multiple feedback impairs cyclists-triathletes time-trial performance compared with single feedback was accepted.

Cyclists-triathletes average task motivation, RPE and affect with similar with multiple (18.02 ± 0.11; 14.36 ± 1.82; 2.99 ± 1.77; $P > 0.05$; Table 2) and single feedback (16.64 ± 0.20; 14.25 ± 1.91; 2.66 ± 1.93; $P > 0.05$; Table 2). This was most likely as a result of their previous experience and fitness status (Tucker and Noakes, 2009). Given the absence of differences in task motivation, RPE and affect reported by the cyclists-triathletes, the difference in performance between feedback conditions was not related to their perceptual responses or to different levels of fatigue.

It is evident that the cyclists-triathletes were using the multiple feedback variables during the time-trial (Figures 3, 4and Table 4). However, as exercise duration and rating of perceived exertion increased, the time spent looking at multiple feedback decreased (B1: 75.67 s to B6: 22.34 s; Table 4). A possible explanation for this could be that in B6, the cyclists-triathletes were concentrated on internal cues (e.g., the level of psychophysiological resources available) to prepare the end sprint (St Clair Gibson and Noakes, 2004). Alternatively, this could be due to the accumulated mental fatigue from the physical (cycling time-trial) and cognitive load (multiple visual feedback) causing a decrease in performance at the end of the time-trial. Bradford et al., (2019) previously demonstrated in tasks such as walking with a rucksack (40% of body weight), the brain can successfully reallocate resources to perform both motor task and cognitive tasks without any performance hindering accumulation in mental fatigue. Similarly, Kan et al., (2019) demonstrated that in short 20 min eccentric and concentric cycling, aerobic exercise appears to add to the maintenance of vigilance and attention in choice reaction time, and the NASA-task load index tasks after exercise. However, in more physically and mentally demanding dual-tasks such as endurance cycling time-trials (≥30 min) and complex cognitive tasks, mental fatigue can occur more rapidly causing a reduction in exercise intensity and/or a reduction in cognitive performance/attention (Pashler, 1984; McCann and Johnston, 1989, 1992; Dietrich and Audiffren, 2011). For example, Holgado et al. (2019) reported an impairment in accuracy and reaction time with a high cognitive load (2-back) compared to a low cognitive load (1-back) despite no impairments in power-output (217 W:222 W) and RPE during a 20 min self-paced cycling time-trial. Moreover, numerous studies have reported a decline in visual attention when mental load is increased which corresponds with the findings in the current study

(Hancock and McNaughton, 1986; Vickers et al., 1999; Pesce et al., 2003; Bundesen et al., 2005; Diekfuss et al., 2017; Mancioppi et al., 2019). The accumulation in mental fatigue with multiple feedback as the exercise progressed resulted in a lower average power-output (227.99 ± 42.02 W) compared to single feedback (287.9 ± 60.07 W; Figure 2).

Unlike the cyclists-triathletes for whom cycling and looking at feedback are automated and therefore not high in terms of cognitive load, this exercise can be more cognitively challenging for the non-cyclists. However, the non-cyclists did not experience a decrement in performance with multiple feedback which supports the cognitive load theory. Findings such as this have been reported in different domains suggesting that subjects with better skill proficiency and familiarity with the task are less vulnerable to performance decrements in stressful situations or under fatigue. For example, inexperienced drivers are affected more by fatigue (Brown, 1994), and skilled workers appear to be troubled less by stress because of task familiarity (Hancock, 1982). Performing a new task can be cognitively challenging; however, with experience and better skills, the task becomes attention free, automated and performance decrements are reduced (Schneider and Shiffrin, 1977). Given the limited working memory (Miller, 1956) capacity, it is possible that the non-cyclists working memory was already overloaded in the single feedback trial and therefore no differences in performance were observed between the two trials.

The cyclists-triathletes primary and secondary objects of regard were power (64.95 s) and time (64.46 s; Figure 3; $p > 0.05$). Therefore, the second hypothesis stating that the cyclists-triathletes would select a cycling specific feedback such as speed, power or cadence as their primary objects of regard was accepted. In addition to this, the cyclists-triathletes in study 1 similarly glanced at a cycling specific feedback in conjunction with end-point knowledge which supports Boya et al. (2017) findings. However, the cycling specific object of regard glanced at were different, which may be related to differences in task and subsequent end-point knowledge (i.e., 10 mile vs. 30 min) or familiarities with different wireless sensor networks. For example, wireless sensor networks (i.e., power meters and cadence sensors and speed sensors) are among the most commonly used cycling accessories for monitoring the physiological and biomechanical parameters of the athlete and bike, respectively, in order to assess cycling performance (Gharghan et al., 2015). Amongst these, power output (Hettinga et al., 2012) is deemed one of the most important variables for cycling performance. All of the cyclists-triathletes in study 1 reported frequently using power meters for training purposes and thus may explain why they spent the majority of their time glancing at power output, in conjunction with elapsed time.

Notably, the cyclists-triathletes also perceived their primary and secondary object of regards as information that wireless sensor networks commonly provide. These findings highlight the importance of using feedback information that is readily available to cyclist-triathletes in the laboratory to bridge the gap between theory and application. Study 1 used an ecological scenario by using feedback that cyclists-triathletes use frequently during training and competition to investigate the type of feedback used and its effect on performance. Based on these findings, power output and time were the most favoured feedback types by experienced cyclists-triathletes to inform pace during a 30 min time-trial. However, further research needs to be conducted to determine which type of feedback (Power or Time) contributes to optimal performance. Finally, feedback is important but overloading athletes with multiple feedback is not recommended for cycling performance. Especially, during road-based competitions where athletes are also required to focus on additional external factors.

4.5.2. Limitations and Perspectives

- In real-world field-based settings, information acquisition focuses on faraway objects such as racecourse turn/road signs (Foulsham et al., 2011), whereas laboratory information acquisition focuses on closer objects such as computer screen (Foulsham et al., 2011). Road races are commonly based on distance (e.g. 40km), however, study 1 was time-based to determine whether objects of regard changed with end-point knowledge in comparison to Boya et al., (2017). Therefore, future research should investigate information acquisition in real road-based cycling events.

- In addition, during competition experienced cyclists-triathletes may prefer to ride blind (i.e., no wireless network sensors) and rely on concurrent feedback from their coach via an earpiece. However, the benefit of this type of feedback on performance is yet to be explored in a laboratory or real road-based setting.
- A third limitation of the present study was the sample size used for the eye tracker analysis. However, the number of glances reported across the whole TT provide a representative sample of the OOR of cyclists-triathletes exercising in a laboratory. Notably, a larger sample size and an outdoor setting will be required to translate this observation in a competitive setting. In addition, the present study investigated information acquisition during cycling with multiple feedback compared to time only feedback. Moreover, it was clear in the present study that experienced cyclists-triathletes primary and secondary OOR were power and elapsed time during the time-trial. Therefore, future studies should investigate the effect of providing power only, and elapsed time only, as this might provide greater performance outcomes than seen in the current study.
- A recent study by Massey et al., (2020) highlighted the benefit of using think aloud (TA) protocol (continuously verbalise thoughts over the duration of a task; Ericsson & Simon, 1980) together with eye tracking technology to capture the dynamic and complex cognitive processes that underpin decisions in real time. Future research should aim to incorporate this protocol to enhance our understanding of the interaction between visual and cognitive processes that are occurring during an exercise bout. Specifically, the active and overt efforts to acquire and use information from the visual environment.

4.6. Conclusion

Cyclists-triathletes indoor 30min cycling TT performance was impaired with multiple feedback compared to single feedback. Whereas non-cyclist’s performance did not differ between multiple and single feedback. Cyclists-triathletes glanced at power and time which corresponds with the wireless sensor networks they use during training. The impairment may be related to a mental overload from the multiple feedback variables as information acquisition decreased over time. Overloading athletes with feedback is not recommended for cycling performance. Thus, cyclists-triathletes may find benefit from selecting a single feedback variable to inform performance during training and competition compared to using multiple feedback variables together.

4.7. Importance of Findings for Subsequent Chapter and Thesis

The findings from this study were used to inform the subsequent studies in this PhD in an attempt to minimise any external impact on performance. Therefore, participants in study 2 and 4 were only given feedback on elapsed time whilst completing the cycling TT.

5. Chapter 5. Study 2: Hot and humid conditions result in a greater impairment in 30min cycling time-trial performance compared to hot and dry conditions.

5.1. Abstract

Purpose: To investigate the effect of heat (hot vs thermoneutral) and humidity (dry vs humid) on physiological and perceptual responses during a 30min cycling time-trial.

Methods: 12 participants (Group 1: N=6, 29±2yrs, 187±9cm, 78±6kg, 53±4mL.kg.min^{-1}, and Group 2: N=6, 29±2yrs, 186±10cm, 78±6kg, 54±4mL.kg.min^{-1}) visited the laboratory for 1 familiarisation and 2 experimental trials. Participants were assigned randomly into 2 groups: Group 1 – Hot and Dry, and Group 2 – Hot and Humid. Within their groups participants completed 2 x 30min cycling time-trials in thermoneutral and hot (dry or humid depending on group) separated by ~5-7 days. Performance, physiological, perceptual measurements were recorded throughout the preload and TT.

Results: Mean±SD power was significantly impaired in hot and dry conditions compared to thermoneutral/control conditions (177.35±1.68W vs 236.86±1.83W ;p =0.014). This impairment was accompanied by an increase in T_{rectal} and thermal discomfort ratings during the TT. T_{rectal} was significantly greater in hot (38.05±0.15°C) compared to control (38.55±0.04°C) throughout the TT p=0.001). Thermal comfort ratings were also significantly lower in thermoneutral/control (0±0(0%)) compared to hot (12±2(60%)) during the TT (p = 0.003).

Mean±SD power was significantly impaired in hot and humid compared to thermoneutral/control conditions (160.12±3.43W vs 235±2.48W; p=0.001). This impairment was accompanied by an increase in T_{rectal} and thermal discomfort ratings during the TT. T_{rectal} was significantly greater in hot (38.85±0.09°C) compared to control (38.55±0.12°C) throughout the TT (p=0.004). Thermal comfort ratings were also significantly lower in thermoneutral/control (0±0(0%)) compared to hot (19±3(95%)) during the time-trial (p = 0.001).

Mean±SD power was significantly impaired in hot and humid compared to hot and dry (160.12±3.43W vs 177.35±1.68W, p =0.038). This impairment was accompanied by an increase in T_{rectal} and thermal discomfort ratings during the TT. T_{rectal} was significantly greater throughout the TT in hot and humid (38.7±0.09°C) compared to hot and dry (38.49±0.07°C; p = 0.043). Thermal comfort ratings were significantly higher in hot and humid compared to hot and dry during the TT (19±3(95%)) vs 12±2(60%)); p = 0.029).

Conclusion: Cycling power output was significantly impaired in hot and dry and hot and humid conditions compared to thermoneutral conditions. Hot and humid conditions caused a greater impairment to cycling power output compared to hot and dry conditions. All impairments were accompanied by a greater thermal strain (physiological (rectal temperature) and/or perceptual responses (thermal comfort)).

5.2. Introduction

As noted in chapter 2 (literature review), performance (power output/pacing, distance covered/completion time), physiological (T_{core}/T_{rectal}, T_{sk}, HR, SR) and perceptual (RPE, TC, TS, AF) responses are often reported in thermoregulation literature. Common acute trends have been established within the literature for these responses. For example, cycling performance is impaired (power output/distance covered/completion time) in both HD, and HH conditions compared to thermoneutral/control conditions (Peiffer and Abbiss, 2011; Periard and Racinais, 2016). Factors contributing to this impairment were related to the strain experienced (Physiological and perceptual responses). Despite this understanding, few studies have investigated the effect of HH conditions on cycling TT performance compared to HD. This is because a large proportion of previous literature focuses on the difference between a hot ambient temperature alone compared to thermoneutral/control, instead of investigating the specific dose response of ambient temperature and humidity on performance. By quantifying the impact of HD, and HH conditions on cycling TT performance, scientists/researchers will be able to provide athletes and coaches with a more informed understanding of what to expect when training and/or competing in these two very different conditions.

Vanos and Grundstein, (2020) reported that HD offers a ~13-17% greater ability to cool compared to HH at an equivalent WBGT value of 32.38°C and activity velocity of 0.3-0.7 ms^1. When humidity is low and skin temperature (T_{sk}) is high, sweat secreted onto bare skin is readily evaporated and heat can be transferred at high rates from the body to the environment (Maughan et al., 2012). However, when the humidity of the environment is high, the rate at which sweat evaporates from the skin is lower than it would be under HD conditions (Maughan et al., 2012). This impairment in SR results in a rise in core/rectal temperature (T_{core}/T_{rectal}) causing a greater imbalance between heat gain (i.e. metabolic and environmental) and heat loss (i.e. evaporation) during exercise in HH conditions. Based on previous TT literature conducted in hot conditions it could be hypothesised that the extent of performance impairment (reduction in power output) would be greater in HH compared to HD.

Therefore, the aim of this study was to investigate the effect of heat (hot vs thermoneutral) and humidity (dry vs humid) on physiological and perceptual responses during a 30min cycling time-trial.

5.3. Methods

5.3.1.Participants

Pre-recruitment Gpower analysis (Gpower 3.1) revealed that 24 participants were needed for this study to ensure a for a large effect size in t-tests (0.8) and ANOVAs (0.4; Cohen, 1988).12 participants completed study 2 and were recruited using the recruitment methods and inclusion and exclusion criteria outlined in Chapter 3 (general methods). If the inclusion criteria were met, participants were randomly separated into a group (1 or 2) that were matched for age, stature, body mass, experience, training and VO_{2max} (Table 19).

Table 19. Mean±SD differences in cyclists-triathletes in each group for sex, age, stature, body mass, VO_{2max}, prior experience and weekly training.

Groups	**1**	**2**
Participants (N)	6	6
Sex Ration (M:F)	6:0	6:0
Age (Years)	29±2	29±2
Stature (cm)	187±9	186±10
Body Mass (Kg)	78±6	78±6
Body Mass Index (kg/m2)	22±2	21±2
VO_{2max} (mL.kg.min^{-1})	53±4	54±4
Maximal Aerobic Power at VO_{2max} (W)	283.3±51.6	283.3±51.6
Prior Experience (Years)	6±2	6±3
Weekly Training (hrs)	6-8hrs	6-8hrs

**Significant difference between groups.*

5.3.2. Experimental Design

All data was collected at LSBU, outside of the summer months (June to September) to prevent any heat acclimatization effect.

Each participant was invited to visit the laboratory on 3 occasions to complete 1 familiarisation session and 2 experimental trials completed in the environmental condition related to their randomised group allocation and another in thermoneutral conditions (Figure 15).

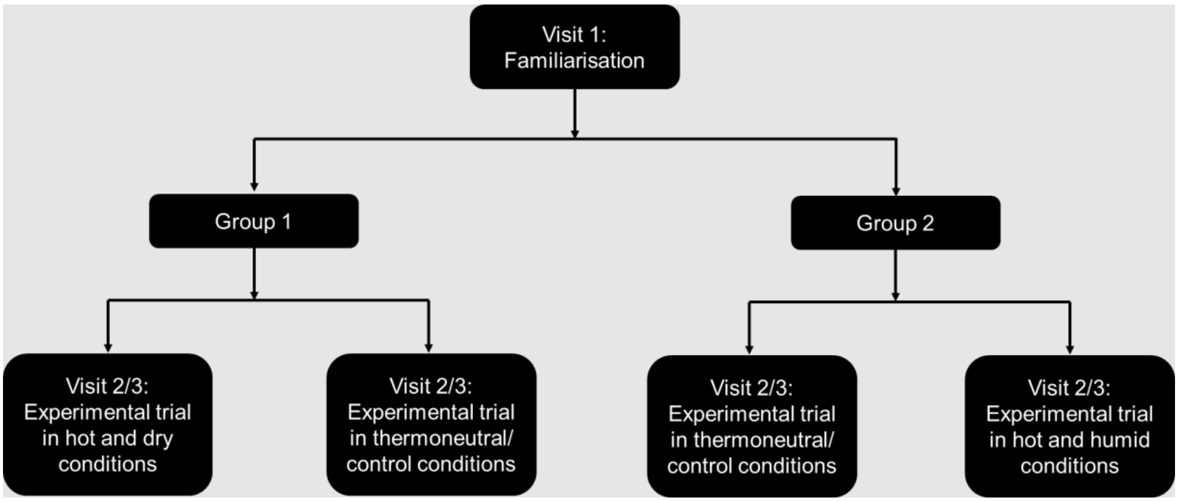


Figure 15. Illustrated structure of Study 2 design outlining that participants were invited to the laboratory for 3 visits.

5.3.3. Familiarisation and Standardization

Upon arrival to the laboratory volunteers received information and explanation regarding the study aims, structure and measurements. Specifically, volunteers received explanations and demonstrations of all equipment and procedures included in the study, as well as being familiarised with specialist equipment and measurement tools (i.e., turbo/wattbike, perceptual scales). All trials were conducted on a turbo, which allowed each participant to bring in and use their own bicycle, or alternatively use the bicycle London South Bank University provided (2019 Specialized Allez Elite). In this time and throughout the study volunteers were permitted to ask questions regarding the study demands and requirements, which were answered by the investigator. If the volunteer was interested and willing to participate then they would complete a health screening questionnaire using a standardised LSBU health screening questionnaire (adapted from the American College of Sports Medicine) and signed an informed consent form.

Volunteer's anthropometric measurements of stature (cm) and body mass (kg) was then collected before completing a VO_{2max} test. Participants were strapped with a HR monitor (polar) and then completed a 5-10min self-paced warm up. The VO_{2max} test started at 100W and was increased by 40W every 4min. After 16min, the load was increased by 30W every minute until participants reached volitional exhaustion. Expired air and HR were measured during the last minute of each stage. After 30min of rest, participants completed a familiarisation with the experimental protocol under the experimental conditions (depending on group allocation).

Prior to every trial across the experimental studies, participants attended the laboratory after refraining from caffeine, alcohol, heat exposure and vigorous exercise for ≥48hr to facilitate recovery and rehydration. In the preliminary visit, all participants completed a food record for the day (24hrs prior to initial familiarisation trial). They were then asked to adopt the same diet on the day before each subsequent trial. In addition, all experimental trials at a similar time of day (±1hrs) to minimise the impact of circadian rhythm variation on measured parameters (Carrier & Monk, 2000). Whilst enrolled in the study, participants were asked to maintain their habitual daily routine of diet, sleep and exercise patterns in a training diary to calculate daily workload (Kj). Finally, to control for hydration status during the preload, participants were required to drink 500mL of thermoneutral room temperature water in all trials. This was all to minimise the impact of these factors on psycho-physiological responses assessed within the experimental studies.

5.3.4. Experimental Trials

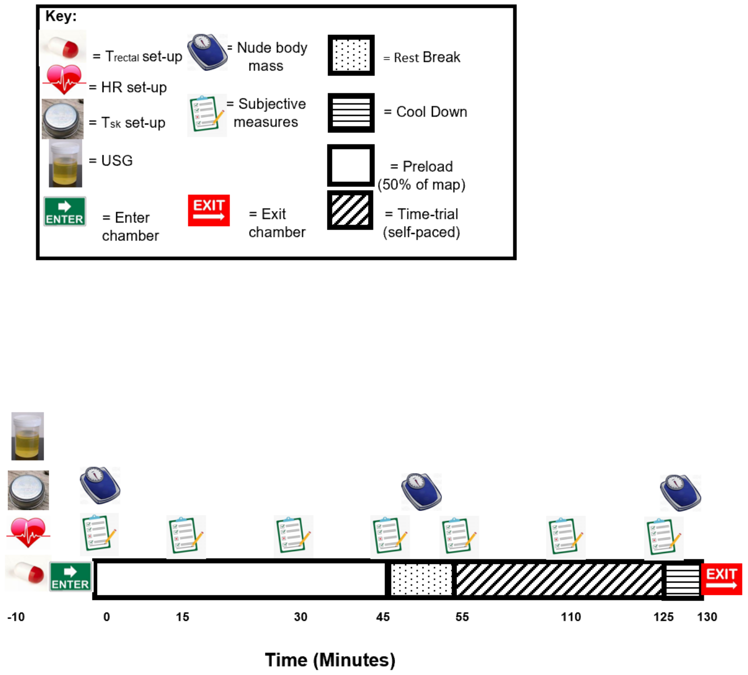


Figure 16. Illustrated figure of experiment trials in study 2 with key. T_{rectal} *= rectal temperature,* T_{sk} *= skin temperature, HR = heart rate, USG = urine specific gravity, map = mean aerobic power, subjective measures = Ratings of perceived exertion, thermal sensation, thermal comfort, and affect.*

Experimental trials started with a 10min standardized warm-up (outside the environmental chamber), followed by a 45min cycle preload at a fixed intensity (50% of maximal aerobic power). On completion of the preload, there was a 10-min rest before completing a 30min self-paced performance test on a turbo. Within this 10-minute rest participants had a nude body mass measurement. The investigator then gave verbal standardised instructions to all participants to complete the greatest distance (km) possible during the 30min TT. From the onset of the TT participants were able to freely increase or decrease PO. There was no motivation given and the only visual feedback was the time they had left to complete the 30min performance test. Distance covered by participants was not revealed until all 3 of the experimental trials were completed. Participants were able to ask any questions before they began. Throughout the experimental trial air flow was provided by a fan (2.2m/s) that was in line with the participants torso (shoulder to waist) providing a headwind effect.

During the performance test, 1L of room temperature water was provided for the participants to drink ad libitum.

5.3.5. Performance measurements

Power output and distance covered were continuously measured using PerfPRO during the experimental trials.

5.3.6. Physiological measurements

Prior trial measurements of USG and NBM were taken before entering the environmental chamber. Throughout the trial, T_{rectal}, T_{sk}, HR were recorded continuously. In the 10min rest between preload and TT a second NBM was taken. Post TT a final NBM measurement was taken after wiping down the sweat on the body using a dry towel. NBM together with fluid intake were used to calculate SR.

5.3.7. Perceptual measurements

Upon arrival to the laboratory for all experimental trials, participants completed a Situational Motivation Scale (Guay et al., 2000) to access for any changes in situational motivation to participate in this study between visits which may influence performance. Participants then sat quietly post warm-up and pre-TT for 2min before baseline measurements of HR, AF, RPE, and TM were assessed. In the 45min preload, RPE, TM, TS, TC and AF were recorded every 15mins (i.e. 0, 15, 30, and 45min), and every 15min in the 30min cycling TT (i.e. 0, 15 and 30min).

5.3.8. Statistical Analysis

All statistical analysis was completed using SPSS (version 21, IBM Corporation, Armonk, NY). Shapiro-Wilk's test revealed that all physiological and performance data were normally distributed ($P > 0.05$). Variables that were normally distributed were analyzed using a three-way repeated measures ANOVA (group (1 or 2) x condition (thermoneutral, hot and dry, and hot and humid) x time (0,5,10,15,20,25,30,35,40,45min)) to test for significant differences, main and interactions effects at time intervals (preload= 10 blocks (B) of 5min (0,5,10,15,20,25,30,35,40,45min) and TT= 7 blocks (B) of 5min(0,5,10,15,20,25,30min)). Partial eta-squared (η 2) was calculated as a measure of effect size. Values of 0.01, 0.06 and above 0.14 were considered as small, medium and large, respectively (Cohen, 1988). A related samples Friedman's non-parametric test (TM, AF, RPE, TS and TC) was used for data not normally distributed. Bonferroni post hoc pairwise comparisons were used to identify locations of significant effects. Data was considered significant if $p \leq 0.05$. All data are presented as group means ± SD.

5.4. Results

5.4.1. The effect of heat and humidity on performance

5.4.1.1. Power Output in Hot and Dry (Group 1)

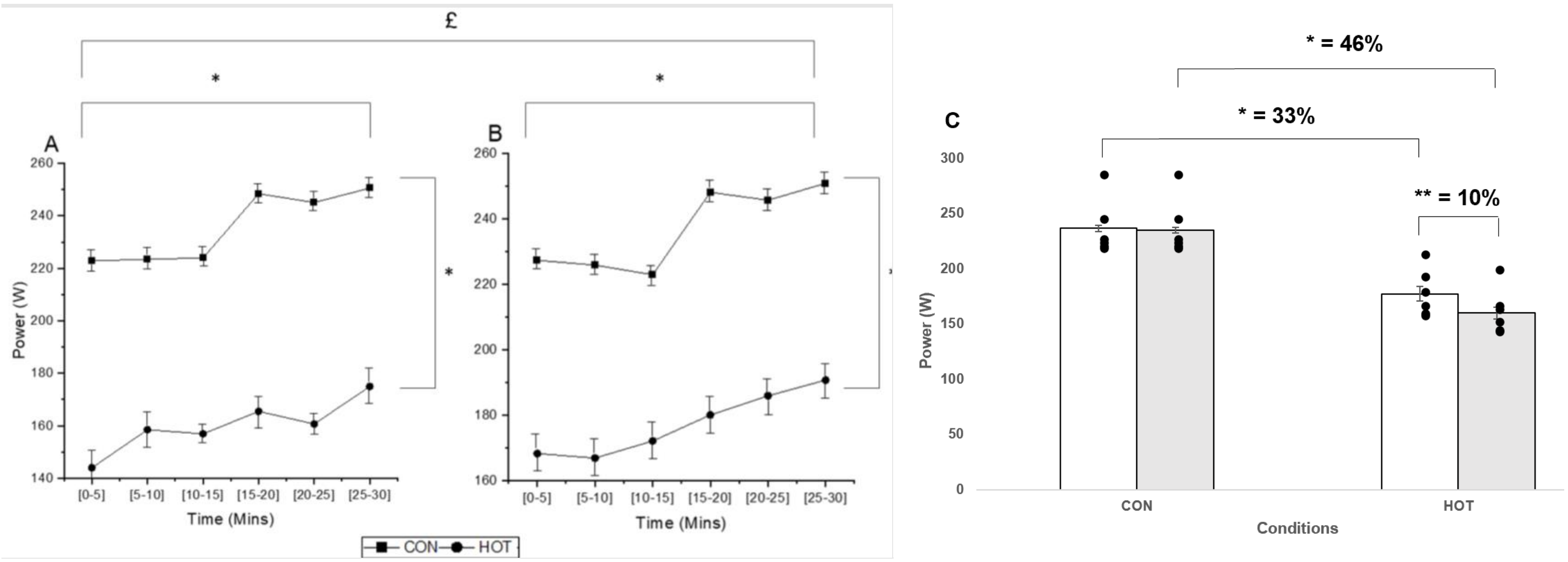


Figure 17. 5min mean±SD power output during 30min cycling time-trial in hot and dry conditions (A) and hot and humid conditions (B). Con = thermoneutral, hot = hot and dry or hot and humid, and (C) mean±SD power output during 30min cycling time-trial in hot and dry and hot and humid conditions (white = group 1 (hot and dry), grey = group 2 (hot and humid).

*Panels A&B *on y axis = significant difference between conditions.*

*Panels A&B * on x axis = significant difference over time.*

Panels A&B £ = difference between groups in the hot conditions only.

*Panel C * = difference between conditions within group.*

*Panel C ** = difference between groups in hot condition only.*

There was a significant interaction between condition and time for power output (f (4,40) = 224.412, p = 0.019, n^2 =0.67). There was a significant main effect for time for power output (f (4,40) = 202.871, p = 0.003, η2 = 0.878) with average power output increasing from start to finish (Figure 17). Post-hoc analysis indicated that in thermoneutral, there was a significant difference between B1 (0 to 5min), B2 (5 to 10min), B3 (10 to 15min) and B4 (15 to 20min), B5 (20 to 25min), B6 (25 to 30min; p=0.046). In hot, there was a significant difference between B1 (0 to 5min), and B4 (15 to 20min), B5 (20 to 25min), B6 (25 to 30min; p=0.003; Figure 17).

There was a significant difference in power output between conditions f (4,40) = 433.521, p = 0.004 and an interaction between condition and time (f (4,40) = 47.92, p =0.001, n^2 = 0.631). Post hoc analysis indicated that average power output in thermoneutral/control (236.86±1.83W) was significantly greater throughout the TT compared to hot (177.35±1.68W, p =0.014; 33%; Table 21 and Figure 17 Panel C).

5.4.1.2. Power Output in Hot and Humid (Group 2)

There was a significant interaction for power output (f (4,40) = 323.613, p = 0.031, n^2 =0.541). There was a significant main effect for time for power output (f (4,40) = 341.245, p = 0.011, η2 = 0.756) with average power output increasing from start to finish (Figure 17). Post hoc analysis indicated that in thermoneutral/control, there was a significant difference between B1 (0to5min), B2(5to10min), B3(10to15min) and B4(15to20min), B5(20to25min), B6(25to30min; p=0.003). In hot, there was a significant difference between B1 (0to5min), and B4(15to20min), B5(20to25min), B6(25to30min; p=0.013).

There was a significant difference in power output between conditions f (4,40) = 455.671, p = 0.006 and an interaction between condition and time (f (4,40) = 42.716, p =0.004). Post hoc analysis indicated that average power output in thermoneutral/control (235±2.48W) was significantly greater throughout the time-trial compared to hot (160.12±3.43W p=0.001;46%; Table 21 and Figure 17 Panel C).

5.4.1.3. Power Output in Hot and Dry and Hot and Humid (Group Comparison)

There was a significant interaction between condition and group f = (3,30) 224.134, p = 0.003, as well as condition, time and group f = (16,160) 15.761, p =0.004). Average power output in the hot and dry (177.35±1.68W) condition was significant greater compared to hot and humid (160.12±3.43W, p =0.038; 10%; Table 21 and Figure 17 Panel C).

5.4.1.4. Distance Covered in Hot and Dry (Group 1)

There was a significant interaction between condition and time for distance covered (f (4,8) = 102.34, p = 0.042, n^2 =0.584).

There was a significant difference between conditions (f (4,8) = 211.87, p = 0.041, n^2 = 0.403). However, the cyclists-triathletes were able to cover a significantly greater distance in thermoneutral/control compared to hot (10.60±0.89 vs 9.55±0.62km; p=0.039; Table 21).

5.4.1.5. Distance Covered in Hot and Humid (Group 2)

There was a significant interaction between condition and time for distance covered (f (4,8) = 106.77, p = 0.041, n^2 =0.588).

There was a significant difference between conditions (f (4,8) = 211.35, p = 0.038, n^2 = 0.266). Post-hoc analysis indicated that the cyclists-triathletes were able to cover a significantly greater distance in thermoneutral/control compared to hot (10.96±0.89 vs 9.23±0.68km; p=0.036; Table 21).

5.4.1.6. Distance Covered in Hot and Dry and Hot and Humid (Group Comparison)

There was no significant interaction between condition and group for distance covered (f (4,8) = 123.51, p = 0.217, n^2 =0.534).

Table 20. Mean±SD total distance and power output during the 30min cycling time-trial.

Group	**1**		**2**	
Condition	**Thermoneutral**	**Hot**	**Thermoneutral**	**Hot**

Total Distance Covered (km)	10.60±0.89	9.55±0.62	10.96±0.89	9.23±0.68
Power Output (W)	236.86±2.83	177.35±6.68	235±2.48	160.12±5.43

5.4.3. The effect of heat and humidity on Physiological Responses

5.4.3.1. Rectal Temperature (T_{rectal})

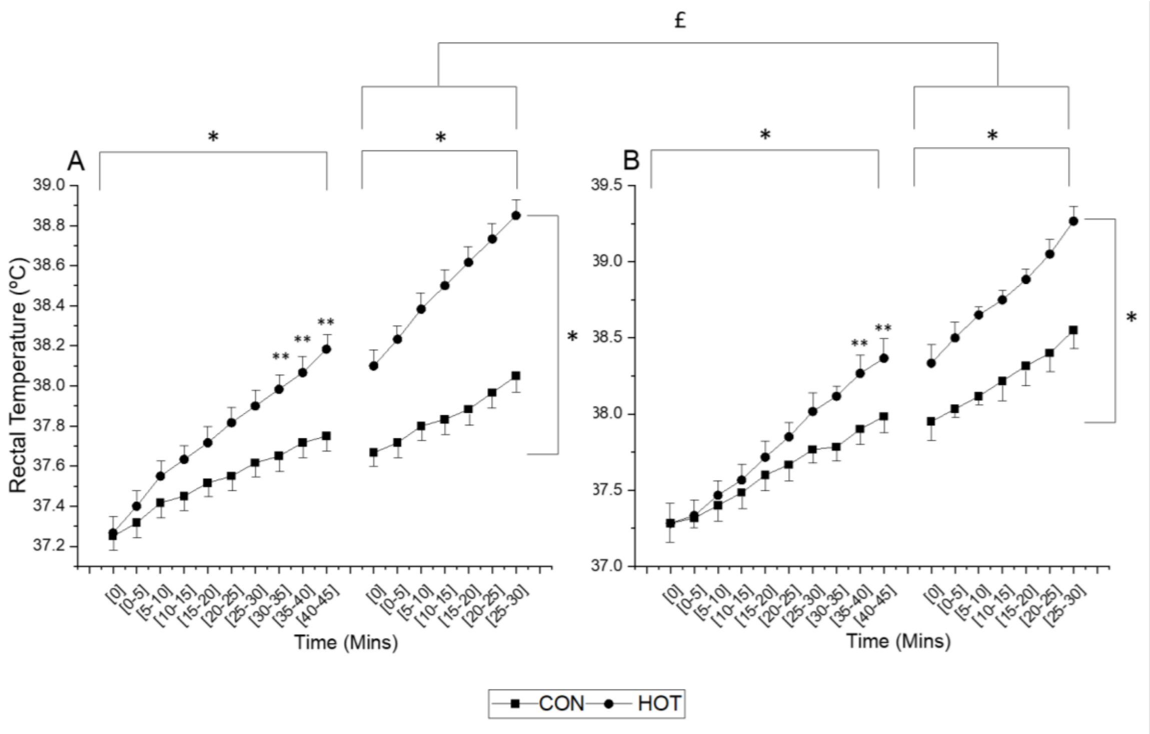


Figure 18. Mean±SD rectal temperature (°C) values during the 45min preload and 30min time-trial in A) hot and dry conditions and B) hot and humid conditions. CON= Control condition, HOT = hot condition (dry or humid)

** on y axis = Significant difference between conditions during time-trial.*

** on the x axis = significant difference between conditions over time.*

*** - Significant difference at a specific time block (i.e. 0-5min).*

£ - Significant difference between groups in hot condition in time-trial only.

£££ - *Significant difference between groups in* HOT at all time blocks

There was a significant interaction for average T_{rectal} during the preload (f= (4,8) 3.146, p = 0.007, n^2 =0.514) and the TT (f= (4,8) 2.901, p = 0.003, n^2 = 0.673). There was a significant main effect for time where average T_{rectal} increased linearly from the start of the preload to the end of the preload (f= (4,8) 2.719, p = 0.005, n^2 = 0.654 Figure 18) and from the start of the TT to the end of the time-trial in both groups and all conditions (f= (4,8) 2.145, p = 0.001, n^2 = 0.764; Figure 18).

5.4.3.1.1. Rectal Temperature (T_{rectal}) in Hot and Dry (Group 1)

There was no significant difference in average T_{rectal} between conditions (thermoneutral vs hot) during the preload (37.7±0.12°C vs 38.1±0.15°C; f = (4,8) 3.647, p = 0.056; Table 22). However, there was a significant interaction between condition and time at Block 8 (30-35min), 9 (35-40min) and 10 (40-45min) where T_{rectal} was significantly greater in hot compared to thermoneutral (p = 0.037, p = 0.034 and p = 0.029; Figure 18). T_{rectal} was significantly greater in hot (38.05±0.15°C) compared to control (38.55±0.04°C) throughout the TT (f= (3,10), 52.656, p=0.001, n^2 = 0.768; Table 22).

There was a positive correlation between core temperature and power output in both conditions infering that core temperature increased together with the increase in power output (Table 22). The strongest correlation was reported in hot and dry (r=0.79).

5.4.3.1.2. Rectal Temperature (T_{rectal}) in Hot and Humid (Group 2)

There was no significant difference in average T_{rectal} between conditions (thermoneutral vs hot) during the pre-load (37.75±0.12°C vs 37.86±0.22°C; f= (4,8) 2.922, p = 0.058, n^2 = 0.634; Table 22). However, there was a significant interaction between condition and time at Block 9 9 (35-40min) and 10 (40-45min) where T_{rectal} was significantly greater in hot compared to thermoneutral (p = 0.036 and p = 0.032; Figure 18).

T_{rectal} was significantly greater in hot (38.85±0.09°C) compared to control (38.55±0.12°C) throughout the TT (f= (4,8), 50.211, p=0.004, n^2 = 0.789; Table 22).

There was a positive correlation between core temperature and power output in both conditions infering that core temperature increased together with the increase in power output (Table 22). The strongest correlation was reported in hot and dry (r=0.79).

5.4.3.1.3. Rectal Temperature (T_{rectal}) in Hot and Dry and Hot and Humid (Group Comparison)

Notably there was also a difference in average T_{rectal} between groups during the TT only (f = (6,18) 15.334, p = 0.005. T_{rectal} was significantly greater throughout the TT in hot and humid (38.7±0.09) compared to hot and dry (38.49±0.07°C; p = 0.043, n^2 = 0.362; Figure 18).

Table 21. Mean±SD rectal temperature (°C) during the preload and time-trial.

Group	**1**		**2**	
Condition	**Thermoneutral**	**HD**	**Thermoneutral**	**HH**
Preload	37.5±0.16	37.5±0.28	37.6±0.19	37.4±0.38
Time-trial	37.8±0.12	38.49±0.07	38.2±0.17	38.7±0.09
Correlation coefficent with power output (significance)	0.66 (0.05)	0.79 (0.03)	0.67 (0.05)	0.77 (0.03)

Red = low correlation, yellow = moderate correlation, green = strong correlation, blue = very strong correlation

5.4.2.2. Heart Rate

There was no significant interaction between condition, group and time for HR (F (4,8) = 3.409, p = 0.376, n^2 =0.398). However, there was a significant main effect for time where average HR increased linearly from the start of the preload to the end of the preload (f (4,8 = 1.325, p = 0.032, n^2 =0.477) and from the start of the time-trial to the end of the time-trial in both groups and all conditions (f (4,8 = 1.267, p = 0.029, n^2 =0.401).

5.4.2.2.1. Heart Rate (HR) in Hot and Dry (Group 1)

There was no significant difference in mean±SD HR between conditions during the preload (151±10 b.min^{-1} (79.47%) vs 167±7 b.min^{-1} (87.89%); f= (4,8) 3.091, p = 0.134, n^2 = 0.396) or time-trial (166±10 $b.min^{-1}$ (87.36%) vs 178±8 $b.min^{-1}$ (93.68%); f= (4,8) 2.135, p = 0.232, n^2 = 0.376; Table 23).

5.4.2.2.2. Heart Rate (HR) in Hot and Humid (Group 2)

There was no significant difference in mean±SD HR between conditions during the preload (158±9 $b.min^{-1}$ (82.29%) vs 173±7 $b.min^{-1}$ (90.10%); f= (4,8) 2.881, p = 0.147, n^2 = 0.403) or time-trial (171±8 $b.min^{-1}$ (89.06%) vs 182±6 $b.min^{-1}$ (94.79%); f= (4,8) 2.889, p = 0.242, n^2 = 0.339; Table 23).

5.4.2.2.3. Heart Rate (HR) in Hot and Dry and Hot and Humid (Group Comparison)

There was no significant difference in mean±SD HR between groups during the preload in thermoneutral (151±10 $b.min^{-1}$ (79.47%) vs 158±9 $b.min^{-1}$ (82.29%); f= (8,16) 3.098, p = 0.246, n^2 = 0.567) or hot (167±7 $b.min^{-1}$ (87.89%) vs 173±7 $b.min^{-1}$ (90.10%); f= (8,16) 3.243, p = 0.278, n^2 = 0.539; Table 23).

There was no significant difference in mean±SD HR between groups during the time-trial in thermoneutral (166±10 $b.min^{-1}$ (87.36%) vs 171±8 $b.min^{-1}$ (89.06%); f= (8,16) 2.997, p = 0.308, n^2 = 0.597) or hot (178±8 $b.min^{-1}$ (93.68%) vs 182±6 $b.min^{-1}$ (94.79%); f= (8,16) 2.983, p = 0.314, n^2 = 0.486; Table 23).

Table 22. Mean±SD ($b.min^{-1}$; % of HR_{max} at VO_{2max}) HR during the preload and time-trial.

Group	**1**		**2**	
Condition	**Thermoneutral**	**Hot**	**Thermoneutral**	**Hot**
Preload	151±10 (79.47%)	167±7(87.89%)	158±9 (82.29%)	173±7 (90.10%)
Time-trial	166±10(87.36%)	178±8 (93.68%)	171±8 (89.06%)	182±6 (94.79%)

5.4.2.3. Hydration Status (Urine Specific Gravity and Sweat Rate)

Table 23. Mean±SD Urine Specific Gravity (USG) and sweat rate (L.hr) values across all experimental trials.

Group	Condition	Urine Specific Gravity	Sweat Rate (L.hr)
1	Thermoneutral	1.005±0.4	1.4±0.4
	Hot	1.004±0.3	1.8±0.3
2	Thermoneutral	1.003±0.4	1.2±0.3
	Hot	1.004±0.2	1.0±0.2

USG of <1.020 = Euhydrated.

USG of >1.021 = Hypohydrated.

All USG values regardless of group or condition fell between the ranges of 1.001-1.010 which meant that all participants started the experimental trial in a well hydrated/hyper-hydrated state (Table 24). There was no significant difference in USG between conditions or groups (f (4,8), 1.878, p = 0.344, n= 0.593) which meant that any changes reported in physiological, perceptual or performance were not a result of participants hydration status at the start of the experimental trial.

5.4.2.3.1. Hydration Status in Hot and Dry (Group 1)

There was no significant difference in sweat rate between conditions (thermoneutral vs hot) during the time-trial (1.4±0.4 vs 1.8±0.3Lhr; f = (4,8) 1.344, p = 0.237, n^2 = 0.456; Table 24).

5.4.2.3.2. Hydration Status in Hot and Humid (Group 2)

There was no significant difference in sweat rate between conditions (thermoneutral vs hot) during the time-trial (1.2±0.3 vs 1.0±0.2Lhr ; f = (4,8) 1.458, p = 0.263, n^2 = 0.468; Table 24).

5.4.2.3.3. Hydration Status in Hot and Dry and Hot and Humid (Group Comparison)

There was a significant interaction between group and condition for SR (f (4,8) 1.030, p = 0.031, n^2 = 0.698). Sweat rate was significantly greater in hot and dry conditions compared to hot and humid (1.8±0.3 vs 1.0±0.2Lhr; f = (8,16), 1.231, p = 0.038, n^2 = 0.656; Table 24).

5.4.3. The Effect of Heat and Humidity on Perceptual Responses

5.4.3.1. Perceptual Responses Prior to Experimental Trials

There were no significant differences in participants SMS (instrinstic, amotivation, identified and external regulation) scores between visits within group 1 ($p = 0.245$), group 2($p = 0.277$) or between groups ($p = 0.189$).

Table 24. Mean±SD hours of sleep(hrs), quality of sleep, stress, fatigue and muscle soreness ratings across all trials using Hooper et al., (1995) markers for monitoring overtraining and recovery scale.

Group	Condition	Hours of Sleep (hrs)	Sleep quality	Stress	Fatigue	Muscle soreness
1 – Hot and Dry	Thermoneutral	6.3±0.4	3±0.1	2±0.2	2.2±0.4	1.1±0.1
	Hot with no cooling	6.3±0.6	3.2±0.2	2.2±0.2	2.1±0.5	1.3±0.4
2 – Hot and Humid	Thermoneutral	6.8±0.1	3.6±0.1	3.1±0.1	2.8±0.4	2.4±0.4
	Hot with no cooling	6.8±0.2	3.5±0.1	3.0±0.2	2.7±0.2	2.2±0.5

There were no significant interactions between groups or condition for hours of sleep (f (4,10) 2.343, $p = 0.641$, $n^2 = 0.611$), quality of sleep (f (4,10) 2.098, $p = 0.589$, $n^2 = 0.601$), stress (f (4,10) 2.374, $p = 0.412$, $n^2 = 0.678$), fatigue and muscle soreness (f (4,10) 2.547, $p = 0.628$, $n^2 = 0.578$). Therefore, any differences reported in performance, physiological responses or perceptual responses during the experimental trials were not a result of differences in hours slept, quality of sleep, stress, fatigue or muscle soreness.

5.4.3.2. Perceptual Responses During Experimental Trials

Table 25. Mean±SD ratings of perceived exertion (RPE), thermal comfort (TC), thermal sensation (TS), task motivation (TM) and affect (AF) during the 45min preload and 30min cycling time-trial (A.U. (% of max value on the scale).

Variables	Group	Intervention	Preload					Time-Trial						
			0	15	30	45	Mean±SD	0	10	20	30	Mean±SD	Correlation with Power	Correlation with Core Temperature
RPE	**1 – Hot and Dry**	Thermoneutral	6±0(0%)	8±1 (14.28%)	10±1(28.57%)	13±2(50%)	10±3(28.57%)	6±0(0%)	11±1(35.71%)	15±1 (64.28%)	18±2 (85.71%)	13±5(50%)	0.32 (0.24)	0.63 (0.07)
		Hot	6±0(0%)	10±2(28.57%)	12±3(42.85%)	14±2(57.14%)	12±2(42.85%)	6±0(0%)	12±2(42.85%)	16±1(71.42%)	20±2(100%)	16±2 (71.42%)	0.78 (0.04)	0.98 (0.02)
	2 – Hot and Humid	Thermoneutral	6±0(0%)	10±1(28.57%)	13±1(50%)	15±1(64.28%)	11±4(35.71%)	6±0(0%)	12±1(42.85%)	13±1(5)%)	18±2(85.71%)	12±5(42.85%)	0.32 (0.22)	0.53 (0.10)
		Hot	6±0(0%)	10±2(28.57%)	14±1(57.14%)	16±2(71.42%)	12±4(42.85%)	6±0(0%)	14±2(57.14%)	16±2(71.42%)	20±0(100%)	14±6(57.14%)	0.52 (0.10)	0.70 (0.03)
TC	**1 – Hot and Dry**	Thermoneutral	0±0(0%)	0±0(0%)	0±0(0%)	0±0(0%)	0±0(0%)	0±0(0%)	0±0(0%)	0±0(0%)	0±0(0%)	0±0(0%)	0.00 (0.98)	0.00 (0.98)
		Hot	10±0 (50%)	10±1(50%)	12±1 (60%)	15±1(75%)	12±2(60%)	10±0(50%)	15±1(75%)	15±1(75%)	20±1(60%)	15±4(75%)	-0.55 (0.06)	0.81 (0.02)
	2 – Hot and Humid	Thermoneutral	0±0(0%)	0±0(0%)	0±0(0%)	0±0(0%)	0±0(0%)	0±0(0%)	0±0(0%)	0±0(0%)	0±0(0%)	0±0(0%)	0.00 (0.98)	0.00 (0.98)
		Hot	10±0(50%)	10±1(50%)	12±1(60%)	15±2(75%)	12±2(60%)	15±1(75%)	20±1(100%)	20±1(100%)	20±1(100%)	19±3(95%)	-0.52 (0.06)	0.84 (0.01)
TS	**1 – Hot and Dry**	Thermoneutral	10±0(50%)	10±0(50%)	10±0(50%)	12±1(60%)	11±1(55%)	10±0(50%)	10±0(50%)	10±1(50%)	12±1(60%)	11±1(55%)	0.32 (0.25)	0.38 (0.27)
		Hot	10±0(50%)	15±1(75%)	15±1(75%)	15±1(75%)	14±3(70%)	10±0(50%)	15±2(75%)	15±2(75%)	16±1(80%)	14±3(70%)	0.35 (0.27)	0.52 (0.06)
	2 – Hot and Humid	Thermoneutral	10±0(50%)	10±0(50%)	10±0(50%)	12±1(60%)	11±1(55%)	10±0(50%)	10±0(50%)	10±0(50%)	12±1(60%)	11±1(55%)	0.10 (0.87)	0.38 (0.27)
		Hot	10±0(50%)	15±1(75%)	15±1(75%)	17±1(70%)	14±3(70%)	15±2(75%)	15±1(75%)	18±1(90%)	20±2(100%)	17±2(85%)	0.10 (0.87)	0.49 (0.07)
TM	**1 – Hot and Dry**	Thermoneutral	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	0.00 (0.98)	0.00 (0.98)
		Hot	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	0.00 (0.98)	0.00 (0.98)
	2 – Hot and Humid	Thermoneutral	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	0.00 (0.98)	0.00 (0.98)
		Hot	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	0.00 (0.98)	0.00 (0.98)
AF	**1 – Hot and Dry**	Thermoneutral	3±1 (81.81%)	3±1(81.81%)	3±1(81.81%)	2±1(72.72%)	3±1(81.81%)	3±1(81.81%)	3±1(81.81%)	2±1(72.72%)	1±1(63.63%)	2±1(72.72%)	-0.35 (0.19)	-0.33 (0.22)
		Hot	2±1(72.72%)	1±1(63.63%)	0±1(54.54%)	-1±1(45.45%)	1±1(63.63%)	1±1(63.63%)	0±1(54.54%)	-1±1(45.45%)	-2±1(36.36%)	-1±1(45.45%)	0.40 (0.11)	-0.45 (0.9)
	2 – Hot and Humid	Thermoneutral	3±1(81.81%)	3±1(81.81%)	3±1(81.81%)	2±1(72.72%)	3±1(81.81%)	3±1(81.81%)	3±1(81.81%)	3±1(81.81%)	2±1(72.72%)	3±1(81.81%)	-0.51 (0.06)	-0.40 (0.11)
		Hot	3±1(81.81%)	2±1(72.72%)	1±1(63.63%)	0±1(54.54%)	2±1(72.72%)	1±1(63.63%)	0±1(54.54%)	-1±1(45.45%)	-2±1(36.36%)	-1±1(45.45%)	0.52 (0.06)	-0.67 (0.05)

RPE = ratings of perceived exertion, thermal sensation = TS, TC = thermal comfort, TM = task motivation, AF = affect, red = low correlation, yellow =moderate correlation, green = strong correlation, blue = very strong correlation.

5.4.3.2.1. Ratings of Perceived Exertion (RPE)

There was significant interaction between group, condition and time (f = (4,16) 3.401, p = 0.023, n^2 = 0.615). There was a main effect for time where ratings of perceived exertion increased from the start of the preload to the end of the preload (f = (4,16) 2.976, p = 0.003, n^2 = 0.754; Table 26) and from the start of the time-trial to the end of the time-trial (f (4,16), p = 0.003, n^2 = 0.723; Table 26).

5.4.3.2.1.1. Ratings of Perceived Exertion (RPE) in Hot and Dry (Group 1)

Ratings of perceived exertion were significantly lower throughout the preload in thermoneutral/control compared to hot (10±3(28.57%) vs 12±2(42.85%); p = 0.03; Table 26). Ratings of perceived exertion were also significantly lower throughout the time-trial in thermoneutral/control compared to hot (13±5(50%) vs 16±2 (71.42%); p = 0.02; Table 26).

Ratings of perceived exertion increased together with the increase in core temperature in both thermoneutral and hot conditions (r=0.63 and 0.98; Table 26). Similarly, ratings of perceived exertion increased together with the increase in power output in both thermoneutral and hot conditions, however the correlation was stronger in hot compared to thermoneutral (r=0.78 and 0.32; Table 26).

5.4.3.2.1.2. Ratings of Perceived Exertion (RPE) in Hot and Humid (Group 2)

There was no significant difference in mean±SD ratings of perceived exertion between conditions in the preload (11±4(35.71%) vs 12±4(42.85%); p= 0.070) or time-trial (12±5(42.85%) vs 14±6(57.14%); p = 0.92; Table 26).

Ratings of perceived exertion increased together with the increase in core temperature in both thermoneutral and hot conditions (r=0.53 and 0.70; Table 26). Similarly, ratings of perceived exertion increased together with the increase in power output in both thermoneutral and hot conditions, however the correlation was stronger in hot compared to thermoneutral (r=0.52 and 0.32; Table 26).

5.4.3.2.1.3. Ratings of Perceived Exertion (RPE) in Hot and Dry and Hot and Humid (Group Comparison)

There was no significant difference between groups (dry vs humid) in the hot condition during the preload (12±2(42.85%) vs 12±4(42.85%); p= 0.246; Table 26). However, ratings of perceived exertion were significantly greater during the time-trial in hot and dry compared to hot and humid conditions (16±2 (71.42%) vs 14±6(57.14%); p= 0.014; Table 26).

5.4.3.2.2. Thermal Comfort (TC)

There was significant interaction between group, condition and time (f = (4,16) 2.560, p = 0.011, n^2 = 0.788). There was a main effect for time where thermal comfort increased from the start of the preload to the end of the preload (f =(4,16) 2.435, p = 0.031, n^2 = 0.668; Table 26) and from the start of the time-trial to the end of the time-trial (f (4,16), p = 0.037, n^2 = 0.692; Table 26).

5.4.3.2.2.1. Thermal Comfort (TC) in Hot and Dry (Group 1)

Thermal comfort ratings were significantly lower in thermoneutral/control (0±0(0%)) compared to hot (12±2(60%)) during the preload (p = 0.003; Table 26). Notably, thermal comfort was unchanged throughout the preload ((0±0(0%); Table 26). Thermal comfort ratings were also significantly lower in thermoneutral/control (0±0(0%)) compared to hot (12±2(60%)) during the time-trial (p = 0.003; Table 26). Notably, thermal comfort was unchanged throughout the preload ((0±0(0%); Table 26).

There was no correlation between core temperature and thermal comfort, and power output and thermal comfort in hot and dry conditions (both r=0.00; Table 26). However, thermal comfort increased (felt worse) as core temperature increased (r=0.81; Table 26). This was supported by correlations with power output, as thermal comfort decreased together with the decrease in power output (r=-0.55).

5.4.3.2.2.2. Thermal Comfort (TC) in Hot and Humid (Group 2)

Thermal comfort ratings were significantly lower in thermoneutral/control (0±0(0%)) compared to hot (15±4(75%)) during the preload (p = 0.002; Table 26). Notably, thermal comfort was unchanged throughout the preload ((0±0(0%); Table 26). Thermal comfort ratings were also significantly lower in thermoneutral/control (0±0(0%)) compared to hot (19±3(95%)) during the time-trial (p = 0.001; Table 26). Notably, thermal comfort was unchanged throughout the preload ((0±0(0%); Table 26).

There was no correlation between core temperature and thermal comfort, and power output and thermal comfort in hot and dry conditions (both r=0.00; Table 26). However, thermal comfort increased (felt worse) as core temperature increased (r=0.84; Table 26). This was supported by correlations with power output, as thermal comfort decreased together with the decrease in power output (r=-0.52).

5.4.3.2.2.3. Thermal Comfort (TC) in Hot and Dry and Hot and Humid (Group Comparison)

There were no significant differences between groups in the thermoneutral/control condition during the preload (0±0(0%) vs 0±0(0%) p = 0.167) or time-trial (0±0(0%) vs 0±0(0%); p = 0.167; Table 26). Whereas thermal comfort ratings were significantly higher in hot and humid compared to hot and dry during the preload (15±4(75%) vs 12±2(60%); p = 0.037) and the time-trial (19±3(95%)) vs 12±2(60%)); p = 0.029; Table 26).

5.4.3.2.3. Thermal Sensation (TS)

There was significant interaction between group, condition and time (f (8,24), p = 0.012, n^2 = 0.701). There was a main effect for time where thermal sensation increased from the start of the preload to the end of the preload (f (8,24), p = 0.018, n^2 = 0.796; Table 26) and from the start of the time-trial to the end of the time-trial (f (8,24), p = 0.017, n^2 = 0.713; Table 26). This inferred that the participants felt hotter over time.

5.4.3.2.3.1. Thermal Sensation (TS) in Hot and Dry (Group 1)

Thermal sensation ratings were significantly lower in thermoneutral/control compared to hot during the preload (11±1(55%) vs 14±3(70%); p = 0.034;) and the time-trial (11±1(55%) vs 14±3(70%); p = 0.034; Table 26).

Thermal sensation increased together with the increase in core temperature in both conditions (Table 26). The correlation was strongest in hot with no cooling (r=0.52). Similarly, thermal sensation increased together with the increase in power output in both conditions, however the correlation was similar between thermoneutral and no cooling (r=0.32 vs 0.35; Table 26).

5.4.3.2.3.2. Thermal Sensation (TS) in Hot and Humid (Group 2)

Thermal sensation ratings were significantly lower in thermoneutral/control compared to hot during the preload (11±1(55%) vs 14±3(70%); p = 0.034;) and the time-trial (11±1(55%) vs 17±2(85%); p = 0.021; Table 26).

Thermal sensation increased together with the increase in core temperature in both conditions (Table 26). The correlation was strongest in hot with no cooling (r=0.49). Similarly, thermal sensation increased together with the increase in power output in both conditions, however the correlation was similar between thermoneutral and no cooling (r=0.10 vs 0.10; Table 26).

5.4.3.2.3.3. Thermal Sensation (TS) in Hot and Dry and Hot and Humid (Group Comparison)

There were no significant differences between groups in the thermoneutral/control condition during the preload ((11±1(55%) vs 11±1(55%); p = 0.178) or time-trial (11±1(55%) vs 11±1(55%); p = 0.178; Table 26). There was no significant differences between groups in hot (dry vs humid) conditions during the preload (14±3(70%) vs 14±3(70%); p = 0.231; Table 26). However, thermal comfort ratings were significantly higher in hot and humid compared to hot and dry during the time-trial (17±2(85%) vs 14±3(70%); p = 0.037; Table 26).

5.4.3.2.4. Task Motivation (TM)

There was no significant interaction between group, condition and time for task motivation (f (4,16), p = 0.367, n^2 = 689). Task motivation remained 20±0(100%) throughout the preload and time-trial in both groups and all conditions (Table 26). This infers that the participants were highly motivated throughout the preload and the time-trial regardless of heat (hot vs con) or humidity (dry vs humid).

5.4.3.2.5. Affect (AF)

There was significant interaction between group, condition and time (f = (4,16) 3.011, p = 0.019, n^2 = 0.746). There was a main effect for time where affect increased or decreased from the start of the preload to the end of the preload (f =(4,16) 3.241, p = 0.035, n^2 = 0.620; Table 26) and from the start of the time-trial to the end of the time-trial (f =(4,16)3.679, p = 0.033, n^2 = 0.645; Table 26).

There was no correlation between core temperature and motivation or power output and motivation because motivation remained unchanged in all conditions (r=0.00; Table 26).

5.4.3.2.5.1. Affect (AF) in Hot and Dry (Group 1)

Affect ratings were significantly greater in thermoneutral/control compared to hot during the preload (3±1(81.81%) vs 1±1(63.63%); p = 0.011;) and the time-trial (3±1(81.81%) vs 2±1(72.72%); p = 0.028; Table 26).

There was a negative low and moderate correlation between affect and core temperature in thermoneutral and no cooling (r=-0.33 vs -0.45; Table 26). There was also a low negative correlation between affect and power output (r=-0.35) and moderate positive correlation between power output and no cooling (r=0.40).

5.4.3.2.5.2. Affect (AF) in Hot and Humid (Group 2)

Affect ratings were significantly greater in thermoneutral/control compared to hot during the preload (2±1(72.72%) vs -1±1(45.45%); p = 0.006;) and the time-trial (3±1(81.81%) vs -1±1(45.45%); p = 0.002; Table 26).

There was a negative moderate and large correlation between affect and core temperature in both thermoneutral and no cooling (r=-0.40 vs -0.67; Table 26). There was also a moderate negative correlation between affect and power output (r=-0.51) and moderate positive correlation between power output and no cooling (r=0.52).

5.4.3.2.5.3. Affect (AF) in Hot and Dry and Hot and Humid (Group Comparison)

There was no significant difference in mean±SD affect ratings between groups (dry vs humid) in thermoneutral/control during the preload (3±1(81.81%) vs 2±1(72.72%); p = 0.247 or time-trial (3±1(81.81%) vs 3±1(81.81%) p = 0.345; Table 26). There was no significant difference in mean±SD affect ratings between groups (dry vs humid) in hot during the preload (1±1(63.63%) vs -1±1(45.45%); p = 0.069; Table 26). However hot and humid had a significantly lower rating of affect during the time-trial compared to hot and dry (2±1(72.72%) vs -1±1(45.45%); p = 0.39; Table 26).

5.4. Discussion

5.4.1. Main findings:

- Cyclists covered a significantly lower distance and significantly lower power output in hot conditions (independently on humidity) compared to thermoneutral conditions. This was accompanied by greater average rectal temperature as well as thermal discomfort in hot conditions compared to thermoneutral conditions.
- Humidity level had no significant impact on distance covered, however cyclists retained significantly greater power in hot and dry compared to hot and humid. This was accompanied by lower average rectal temperature as well as thermal discomfort in hot and dry compared to hot and humid.

5.4.2 The Effect of Humidity on Performance Response (dry vs control)

In the current study, group 1 was exposed to hot and dry conditions (35°C, 30%, 2.2m/s ^{1}, equating to a WBGT of ~27°C). Average power output was significantly impaired in hot and dry conditions compared to thermoneutral conditions (177.35±1.68W vs 236.86±1.83W ;p = 0.014; 33%; Table 21). This impairment was accompanied by increased T_{rectal} and thermal discomfort during the TT. For example, T_{rectal} was significantly greater in hot (38.05±0.15°C) compared to thermoneutral (38.55±0.04°C) throughout the TT (f= (3,10), 52.656, p=0.001, n^2 = 0.768; Table 21). Thermal comfort ratings were also significantly lower in thermoneutral (0±0 (0%)) compared to hot (12±2(60%)) during the TT (p = 0.003; Table 20). Thermal comfort increased (felt worse) as core temperature increased (r=0.81; Table 26).

This supported Racinais et al., (2015) findings which found a decrement in power output of ~16±5% (256±19 vs 304±9W) during a 43.4km cycling time-trial in hot and dry (36.0±0.4°C, 13±1%) compared to thermoneutral (8.2±3.5°C, 30±8%) conditions. This was accompanied by a significantly greater finishing T_{rectal} in hot and dry compared to thermoneutral conditions (40.2±0.4vs38.5±0.6°C; p =0.001).

5.4.3. The Effect of Humidity on Performance Response (humid vs con).

In the current study, group 2 were exposed to hot and humid conditions (30°C, 70%, 2.2m/s, equating to a WBGT of ~26°C). Average power was significantly impaired in hot and humid compared to thermoneutral/control conditions (160.12±3.43W vs 235±2.48W; p=0.001; 46%; Table 21). This impairment was accompanied by an increase in T_{rectal} and thermal discomfort ratings during the TT. T_{rectal} was significantly greater in hot (38.85±0.09°C) compared to control (38.55±0.12°C) throughout the TT (f= (4,8), 50.211, p=0.004, n^2= 0.789; Table 21). Thermal comfort ratings were also significantly lower in thermoneutral/control (0±0(0%)) compared to hot (19±3(95%)) during the time-trial (p = 0.001; Table 21). Thermal comfort increased (felt worse) as core temperature increased (r=0.84; Table 26).

Previous literature supports these findings, showing an impairment in cycling power output in hot (35◦C, 60% RH) compared to thermoneutral (20◦C, 40% RH) conditions during a 40km TT, respectively (242.1 ± 27.3W vs 279.4 ± 22.0 W ; P < 0.01; Periard et al., 2011). At TT completion, T_{rectal} was significantly greater in hot compared to thermoneutral conditions (39.8 ± 0.3 vs 38.9 ± 0.2◦C; P < 0.01; Periard et al., 2011). Similar values were reported in the current study showing a greater T_{rectal} in hot compared to thermoneutral (39.3±0.1°C vs 38.6±0.2°C; Table 21). Similar to the current study, Periard et al., (2011) reported a significantly greater thermal discomfort in hot compared to thermoneutral throughout the TT (P < 0.01).

5.4.4. The Effect of Humidity on Performance Response (humid vs dry).

Average power output was significantly impaired in hot and humid compared to hot and dry (160.12±3.43W vs 177.35±1.68W, p =0.038; 10%; Figure 17). This impairment was accompanied by an increase in T_{rectal} and thermal discomfort ratings during the TT. Specifically, T_{rectal} was significantly greater throughout the TT in hot and humid (38.7±0.09°C) compared to hot and dry (38.49±0.07°C; p = 0.043, n^2 = 0.362; Figure 22). Thermal discomfort ratings were significantly higher in hot and humid compared to hot and dry during the TT (19±3(95%)) vs 12±2(60%)); p = 0.029; Table 25).

Teunissen et al., (2022) investigated the impact of 8 different climatic conditions specific to Tokyo (best case (25.1°C, 39%, 0.2m/s) to worse case (37.5°C, 79%, 0.2m/s)) on peak T_{core} of elite athletes during cycling. In control conditions a peak T_{core} of 38.9±0.5°C was achieved. This was similar to the peak T_{rectal} values found in the control conditions for both groups (dry and humid) in the current study (38.05±0.17°C and 38.6±0.2°C; Figure 22). At greater simulations with a higher ambient temperature (38°C), there was a higher peak T_{core} compared with control (~39.5±0.3°C vs 38.9±0.5°C), whereas a higher RH (90%) hardly affected peak T_{core} (~39±0.1°C) but it still increased. Similar to Teunissen et al., (2022), a greater ambient temperature caused a greater peak T_{rectal} in hot and dry (38.8±0.11°C) compared to thermoneutral (38.05±0.17°C) in the current study (Table 21). However, unlike Teunissen et al., (2022), a greater humidity caused a significantly greater peak T_{rectal} compared to dry and thermoneutral conditions, respectively (39.3±0.1°C vs 38.8±0.11°C and 38.6±0.2°C; Table 21). In addition, greater sweat rates were achieved in hot and dry (1.8±0.3Lhr) compared to hot and humid (1.0±0.2Lhr) which allowed for greater heat loss via evaporation, and therefore attenuated the rise in T_{rectal} in hot and dry conditions compared to hot and humid (Table 22 and Figure 18).

5.4.5.. Limitations and Perspectives

- The number of recruited participants was below the amount needed for an effect size of 0.7 because data collection of study 2 and 4 were combined and therefore the results may have changed if a larger sample size was used.
- The study design required participants to be separated into two groups (dry vs humid). If participants completed both dry and humid conditions then the comparisons between conditions and conclusions made would be stronger.
- Future research should investigate this comparison further with a repeated measures design including both hot conditions to be able to form stronger conclusion on which conditions causes a greater strain (performance, physiological and perceptual responses).

5.5. Conclusion

Cycling performance is significantly impaired in HD and HH conditions compared to thermoneutral conditions. This impairment was associated with a significantly greater increase in T_{rectal} and thermal discomfort in both hot conditions compared to thermoneutral.

Cycling performance is significantly impaired in HH compared to HD conditions. This impairment was associated with a significantly greater increase in T_{rectal} and thermal discomfort in HH compared to HD.

5.6. Importance of Findings for Subsequent Chapter and Thesis

- The findings from the current study contributed to the environmental physiology literature on the effect of HD and HH conditions as an external stressor on physical (cycling TT) performance.
- The novel finding of the current study highlighted that cyclists in the HH condition experienced greater impairments in cycling (e.g. power out put and pacing) performance, which were related to physiological (i.e. T_{rectal}), and perceptual responses (i.e. TC).
- Therefore competing in HH conditions poses two potential issues (i) performance impairment (i.e. missing out on a potential medal placing), and (ii) health related risks (i.e. heat related illnesses caused by a rise in T_{rectal}). Therefore, a means for alleviating these heat related challenges is needed.

Chapter 6. Study 3 – Cyclists-triathletes use cold-water ingestion during training and/or competitions in hot and dry conditions compared to cold-water ingestion and pouring in hot and humid conditions.

6.1 Abstract

Purpose: To investigate the type, timing, justification and perceived effectiveness of per-cooling strategies employed by cyclists-triathletes during training and/or competition in HD and HH.

Methods: 35 cyclists-triathletes completed an online questionnaire on the type, timing and justification of per-cooling strategies employed during past training and/or competitions in HD and HH. 3 cyclists-triathletes completed a one to one follow up interview.

Results: Comparisons between strategies employed in all conditions were based on N=14 (40%). Cold-water pouring was the most employed (N= 4; 21%) strategy during training and/or competing in hot conditions. The timing of the strategies employed were based on pitstops only (N= 7; 50%). The justification for strategies employed were based on trial and error (N=9, 42.85%: N=10, 47.61%). All cyclists-triathletes rated strategies employed as 1 (“not effective for minimizing performance impairments and heat related illnesses). Comparisons between HD and HH were based on N=21 (60%) who employed different per-cooling strategies based on condition (HD or HH). Cold-water ingestion was the most employed (N=9, 43%) strategy in HD, whereas a combination of cold-water ingestion and pouring was the most employed (N=9, 43%) strategy in HH. The timing of strategies employed in HD were split; pre-planned by distance but were modified based on how athletes felt during (N=8, 38%), and pre-planned by distance and pit stops (N=8, 38%). The timing of strategies employed in HH were pre-planned based on distance and how athletes felt during (N=9, 42%). 57% (N=12) of the 60% (N=21) perceived effectiveness in HD and HH as 3 (“Sometimes effective and sometimes not effective”) whereas, 43% (N=9) of the

60% (N=21) perceived effectiveness in HD and HH as 4 (“Effective for minimizing performance impairments”).

Conclusion: Cold-water ingestion is the preferred strategy by cyclists-triathletes in HD compared to a combination of cold-water ingestion and pouring in HH conditions. All strategies were pre-planned and trialled based on distance and how cyclists-triathletes felt during training and/or competition. These strategies were perceived as effective for minimizing performance impairments but not heat related illnesses. This may suggest that aspects of these per-cooling strategies have yet to be mastered to ensure optimal effectiveness (minimizing performance impairments and heat related illnesses). Therefore, future research should evaluate the effectiveness of these per-cooling strategies on performance and thermoregulatory responses in HD and HH to inform future employment during training and/or competition.

6.2 Introduction

As outlined in chapter 4 (study 2), the physiological and perceptual responses followed similar trends in both HD and HH conditions however the thermal strain was greater in HH compared to HD. This was shown with a greater average T_{rectal} and thermal discomfort reported in HH compared to HD. This resulted in an impairment to performance, specifically power output during the 30min TT.

Athletes can incorporate heat mitigation strategies, such as heat acclimation/acclimatisation (chronic heat mitigation strategies), cooling (acute heat mitigation strategies), and/or hydration before or during training and/or competition (acute heat mitigation strategies; Gibson et al., 2020). Due to the length, nature, and cost of chronic heat mitigation strategies, some athletes opt for acute heat mitigation strategies, such as cooling and/or hydration that can be applied easily and cost-effectively during training and/or competition (Gibson et al., 2020). However, it is unclear what type and timing of acute strategies that are currently being employed by cyclists-triathletes during training and/or competition in hot conditions.

Internal cooling was the most commonly planned for cooling strategy by athletes prior to the 2015 IAAF World Championships in Beijing (Periard et al., 2017). Ice slurry ingestion was the most employed strategy for long distance sports specifically. This is supported by Morris and Jay (2016) findings, showing that cold-water ingestion should provide mechanistic benefits (greater heat loss than gain) in hot and humid conditions. This paper focused on pre-cooling only and therefore it is unclear what strategies currently used for per-cooling.

An investigation of the hydration and cooling strategies employed during the Doha 2019 IAAF World Athletics Championships (Hot and Dry conditions), revealed that 93% of endurance athletes employed a pre-planned drinking strategy including water (85%), electrolytes (83%), and carbohydrates (81%; Racinais et al., 2021). Moreover, 80% of endurance athletes employed pre-cooling (mainly ice-vest 53% and cold-towel 45%), and 93% employed per-cooling [mainly head/face water dousing/pouring (65%) and cold-water ingestion (52%)], which were widely pre-planned by athletes. Ice-slurry ingestion (11–21%) and menthol-based interventions (1–2%) were less common. The strategies employed by this elite population in HD coincide with Morris and Jay's (2016) recommendations that cold-water pouring/dousing provides mechanistic benefits (e.g. greater heat loss than gain) in HD conditions. This paper provides an insight into the type and timing of strategy, however there could still be interpersonal differences in regard to timing e.g. every 10km, when they felt thirsty, when pitstops were available etc.

It is not only important to understand what and when strategies are being used but also why they are being used. Racinais et al., (2021) found that strategies were based on personal experience (e.g trial and error) rather than evidence-based (e.g. scientific papers), which suggests a gap between theory and application. If an athlete chooses to use a specific type of strategy that goes against evidence-based practice it may relate to the practicality of that strategy (e.g. easier to pour water over yourself whilst cycling compared to putting on a cooling vest) or its perceived effectiveness. Perceptual responses such as TC, TS, RPE can offer an insight into the perceived effectiveness of cooling strategies during training and/or competition. For example, a review by, Douzi et al. (2020) stated that per-cooling strategies improved perceptual measures such as thermal perception and RPE, thereby inducing better self-selected intensities during TTs.

Therefore, the purpose of this study was to investigate the type, timing, justification and perceived effectiveness of per-cooling strategies currently employed by cyclists-triathletes during training and/or competitions in HD and HH.

6.3. Methods

6.3.1. Participants

This study was aimed at cyclists and triathletes who have trained or competed in hot conditions. The questionnaire was sent via email to cycle and triathlon clubs and advertised on social media channels, such as Twitter©, Instagram©, and Facebook©. Participation in the questionnaire was open to all genders, all levels of participation, and ages (Table 27). It was advised that participation was not permitted, or data was rejected if the participant had not trained or competed in hot conditions before (≥28°C; Table 27).

The 35 participants were separated into three categories: recreational, competitive, and professional. Recreational athletes were classed as individuals that participate in the sport for enjoyment, fitness, and/or social reasons (N = 10; Table 28). Competitive athletes were classed as individuals who competitively participate in and train for competition (N = 15; Table 28); whereas. professional athletes held a pro licence and participated in competitions for fiscal rewards and/or representation of their country (N = 10; Table 28).

37% of participants reported experiencing symptoms of HRI during training and/or competing in hot conditions (Table 28). HRI were most prevalent in the competitive group (Table 28).

Table 26. Participant Inclusion and Exclusion Criteria.

Inclusion	Exclusion
Train and/or compete in hot conditions (≥28°C WBGT)	Do not train and/or compete in hot conditions (≥28°C WBGT)
Live in countries that are not hot (<28°C WBGT) more than half of the year.	Live in countries that are hot (≥28°C WBGT) more than half of the year (acclimatization effect).
All sex (M:F) and genders (transgender males, transgender females, non-binary)	
All levels of participation (recreational, competitive, professional)	
Sporting background: Cycling and/or Triathlon.	Sporting background: non-cyclists or triathletes (i.e. basketball, football, etc).
≥18yrs	<18yrs

WBGT = Wet-bulb globe temperature.

Table 27. Participant characteristics including number of participants, sex ratio (M:F), country participants live in, years of experience (yrs), number of competitions competed in, number of training sessions in hot conditions, percentage of group that have experienced symptoms related to heat related illnesses (%).

Category	No. of Participants	Sex ratio (% of M:F)	Age (yrs)	Country participants live in	Experience (yrs) (N=13)	No. of competitions competed in	No. of training sessions or competitions in hot conditions	Percentage of group that have experienced symptoms related to heat related illnesses (%)
All	35	71 (30% was T):29	35±12	UK = 89% Germany = 7% Romania = 2%	8±5	18±15	4±2	37

				Slovenia = 2%				
Recreational	10	80 (10% was T):20	43±17	UK=80% Germany = 10% Romania = 10%	9±6	0	2±1	40
Competitive	15	74:26	33±10	UK=87% Slovenia =7% Germany=7%	8±6	26±15	3±1	53%
Professional	10	60:40	30±4	UK=100%	6±2	28±2	6±4	10%

*M=Male, F=female, T=transgender, yrs = years, No.=Number. *Significant difference between groups.*

6.3.2. Experimental Design

The study had a mixed-methods design. To meet the aim of the current study, 35 participants (Recreational = 10, Competitive = 15, and Professional = 10; Table 2) completed an online questionnaire (Figure 1). To support the questionnaire findings and gain an in-depth understanding of the participant's experience, the investigators "deliberately sought out individuals or groups who fit the bill" (Greenhalgh, 1997; p.157). Therefore, convenience sampling was employed to select 3 of the 35 athletes who best represented their sub-groups (1 = Recreational, 1 = Competitive, and 1 = Professional). For the 3 case studies, a follow-up focused interview was used (Figure 19).

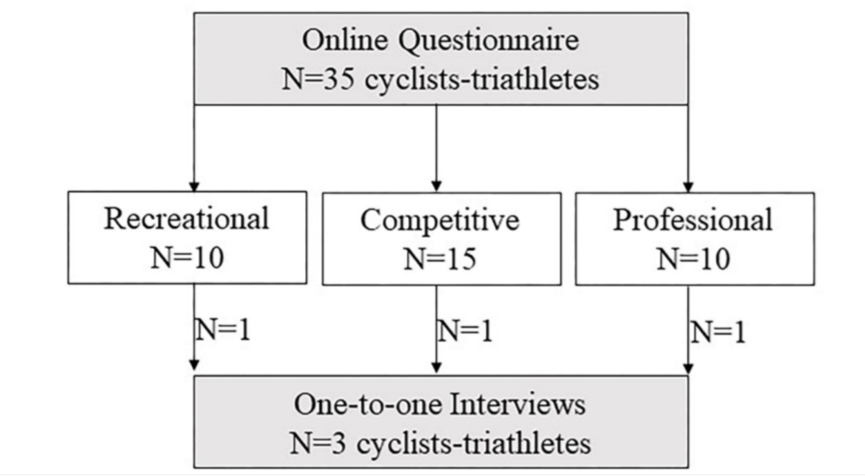


Figure 19. Methodological flow chart of the study design. Grey boxes = data collection; white boxes = participants.

6.3.3. Design of Questionnaire

The questionnaire was created using the online platform https:// www.onlinesurveys.ac.uk/ (Figure 20). The scope of the questionnaire was to identify heat mitigation strategies type, the timing of application, justification for type and timing, and perceived effectiveness in HD and HH conditions. All questions allowed for text box answers for participants to describe strategies in more detail. The questionnaire was piloted and reviewed by two members of staff at LSBU (external to the research project) who were familiar with both cycling exercises and conducting and interpreting questionnaires. It was suggested to adapt questions from a previous questionnaire used in the literature (Racinais et al., 2021) to allow for reflective practise. Briefly, reflective practice is an active and deliberate cognitive process involving sequences of interconnected ideas that take account of underlying beliefs and knowledge and typically addresses practical problems, allowing for doubt and perplexity before possible solutions are reached (Edwards, 1999). While the focus of the study of Racinais et al. (2021) was to investigate heat mitigation strategies before and during the 2019 Doha World Championships in HD, our study investigated per-cooling strategies (only) during training and/or competition in both HD and HH. Type: Racinais et al. (2021) asked “what pre-cooling method(s) are you planning on using during the time-trial?” which was adapted to “What per-cooling method(s) did you use during training and/or competition in hot and dry conditions?” Timing: When was this (these) strategy (ies) applied during hot and dry conditions? Justification: What was your justification (“why?”) for using this type of strategy and the timing of application in hot and dry conditions? Perceived effectiveness: Please rate the effectiveness of the strategy employed (type and timing together) in hot and dry conditions on a scale from 1 to 5 (1 = Not effective for minimising performance impairments and suffering heat-related illnesses, 2 = Not effective for minimising performance impairments, 3 = Sometimes effective and sometimes not effective, 4 = Effective for minimising performance impairments, 5 = Effective for minimising both performance impairments and suffering from any heat-related illnesses). Perceived effectiveness was defined as the athlete’s opinion based on their own experiences without an objective measure of performance of heat-related illness. Participants were also asked to respond to these questions for hot and humid (HH) conditions or hot conditions in general if no difference in condition was perceived at the start of the questionnaire.

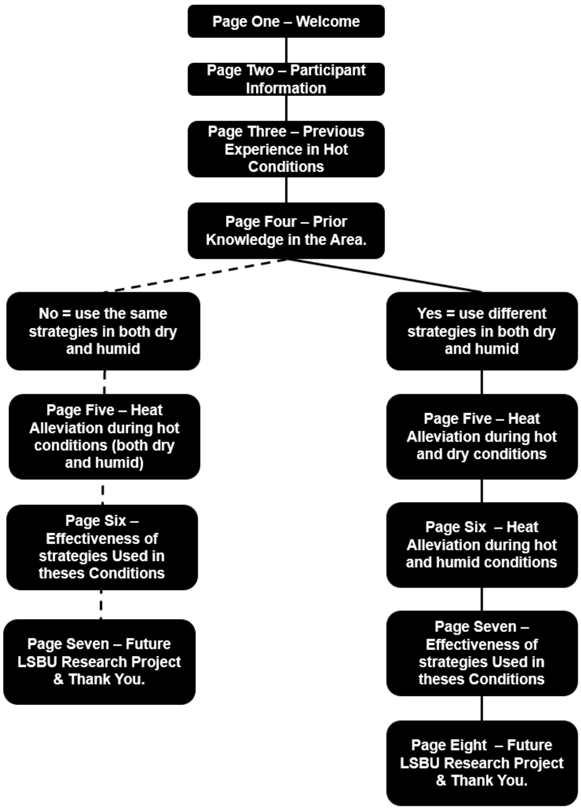


Figure 20. Question design outlining the page by page flow. Blue boxes = page number, section number and focus. Dashed lines =custom pathways between pages, for example in 'page 4, section 3 – prior knowledge in the area' if the participants selected that they used the same strategy regardless of environmental condition they would be taken on a different pathway and answer the questions on 'heat alleviation strategies in all hot conditions' rather than hot and dry and hot and humid.

6.3.4. Design of Case Study Interviews

A single case study approach was selected to provide an in-depth understanding of the participant's experiences and therefore produce a high-quality theory for future work to expand on. To achieve this, the single case studies were designed and reported in accordance with McKay and Marshall's (2000) checklist and Keegan et al. (2017) guidelines. The single case study consisted of one-to-one interviews that were conducted online via zoom (lasting ~30min with cameras on). Participants were informed that the interviews were informal, semi-structured, followed a discussion format, and that there were no wrong or right answers. The interview questions were developed based on answers reported in the questionnaires together with information gathered from a pilot interview conducted with members of staff at LSBU who were familiar with conducting interviews. Therefore, the questions related to the research topic (type, timing, justification, and perceived effectiveness of heat mitigation strategies in HD and HH) are based on the reviewer's feedback. It was also highlighted that the questions needed to be reworded for clarification of different conditions that are related to the interviewee: Therefore, the interviewer gave examples of locations and events that the athletes may have trained or competed in to ensure the interviewee's understanding of environmental conditions.

Based on this information the participants selected specific training sessions and/or competitions to discuss for the interview. If known, dates of training and/or competitions were provided by participants, and weather conditions were cross-referenced by two investigators using https://www.metoffice.gov.uk/ and databases (scopus) were searched for any journal articles published from the selected competitions.

Key terminology was also defined at the start of the questionnaire and interview. For example, cold water was defined as water at 9◦C (Gibson et al., 2020) and represented temperature at the start of ingestion and not throughout the exercise entirety.

6.3.5. Data Analysis

The questionnaire was analysed using the analyse function on https://www.onlinesurveys.ac.uk/, which expressed values as percentages. This was subsequently extracted into Excel. The outcome variables from the questionnaire were:

1. Percentage of participants that employed a specific type of strategy (for example, cold-water ingestion, cold-water pouring, ice packs, ice vests, cooling collars, ice slushy ingestion, menthol, etc.).

2. Percentage of participants that employed a specific time to apply strategies (for example, pre-planned based on distance, pre-planned based on time, pit stops, and how they felt during, etc.).

3. Percentage of participants that had specific justifications for type and timing of strategy (for example, personal reading, sports scientist, previous experience, etc.).

4. Percentage of participants based on ratings of perceived effectiveness (1 = Not effective for minimising performance impairments and suffering heat-related illnesses, 2 = Not effective for minimising performance impairments, 3 = Sometimes effective and sometimes not effective, 4 = Effective for minimising performance impairments, and 5 = Effective for minimising both performance impairments and suffering from any heat-related illnesses).

The interviews were recorded (video and audio). At the start of the transcription stage, the participants were anonymised through pseudonyms. Transcriptions were imported to NVIVO software for thematic coding. Coding is the process of exploring the diversity and patterning of meaning from the dataset, developing codes, and applying code labels to specific segments of each data item (Braun and Clarke, 2021; pp 53). A code is an output of the coding process; an analytically interesting idea, concept of meaning associated with particular segments of data; often refined during the coding process (Braun and Clarke, 2021; pp 53). Whereas a code label is an output of the coding process; a succinct phase attached to a segment of data, as a shorthand tag for a code; often refined during the coding process (Braun and Clarke, 2021; pp 53). Braun and Clarke's (2006) six-phase analysis process was adopted:

1. Familiarising/immerse yourself with your data: The primary and secondary investigators separately read through the interview transcripts at least 3 times.

2. Generating initial codes: The primary and secondary investigators generated initial codes separately, and then, came together to discuss and determine codes.

3. Searching for themes: The primary and secondary investigators drew out common themes and meanings within each interview separately, and then, came together to discuss and determine themes.

4. Reviewing themes: Common patterns in the data were identified and organised into themes and sub-themes to connect shared experiences in the different interviews.

5. Defining and naming themes: The primary and secondary investigators defined and named themes separately and then came together to discuss and determine definitions and names for themes.

6. Producing the report: These themes were examined to conclude the data, which reflected the different perspectives on training and competing in hot conditions.

6.4. Results

The case study interview was conducted to support the questionnaire findings and therefore the questionnaire and interview results will be reported together in this section. Themes were identified based on the 3 interviews (Figure 19). These interviews were used to have a more in depth insight into the experience and belief of the participants and therefore this data cannot be generalised to the whole group of participants. The main themes that were developed were “experience of training and/or competition in hot conditions”, “strategies employed prior to and during training and/or competing in hot conditions” and “knowledge/understanding of cooling strategies and hot conditions” (Figure 21).

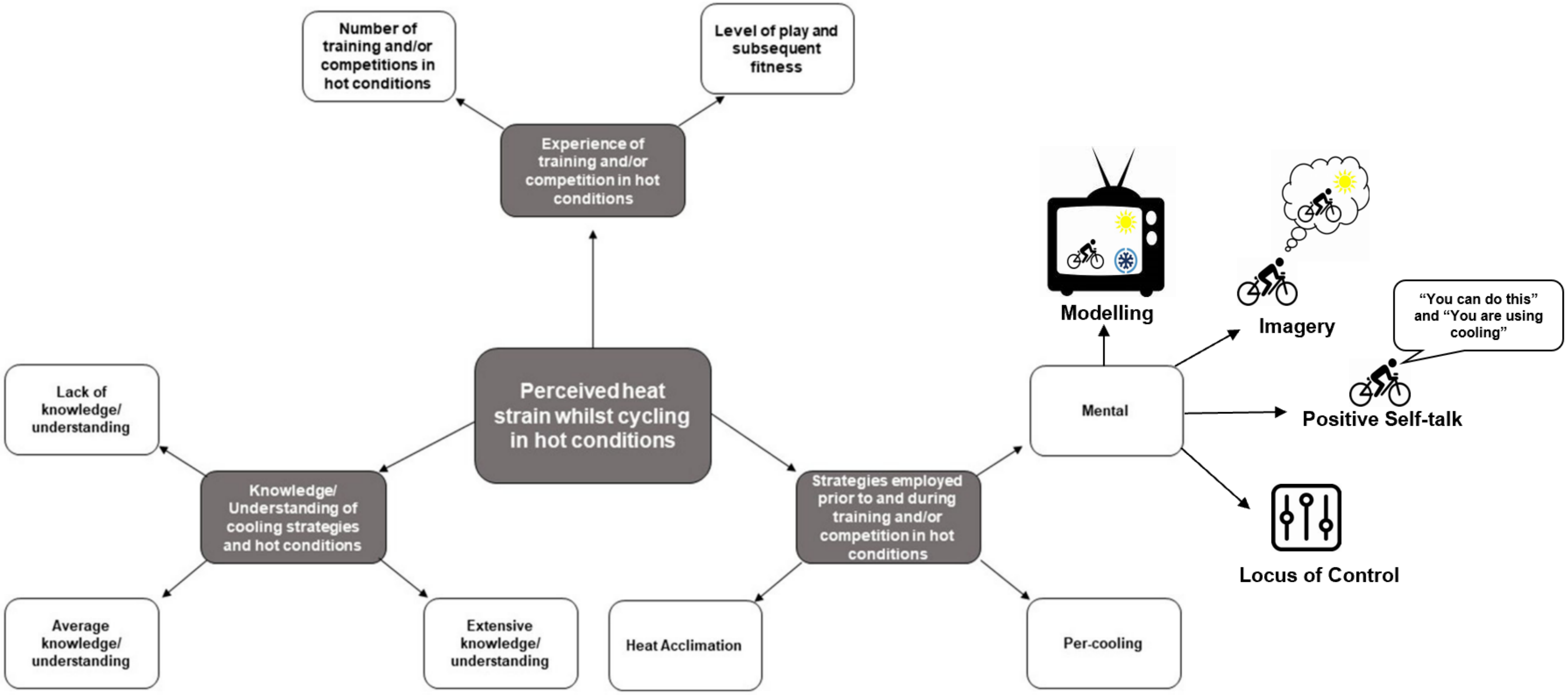


Figure 21. Potential factors influencing perceived heat strain during cycling in hot conditions based on the experiences of 3 cyclists-triathletes. Themes are shaded in grey boxes and subthemes are in white boxes

6.4.1. Understanding of Hot Conditions.

86% (N = 31) of participants perceived that there is a difference in thermal stress experienced between HD and HH (Figure 22A). 80%(N = 28) of the participants that perceived a difference reported that HH provided greater thermal stress compared to HD (Figure 22B). Despite this understanding, only 60% (N = 21) of participants reported employing different strategies depending on the environmental condition (HD or HH; Figure 22C). Therefore, the results will focus on this 60% (N = 21) because the 40% (N = 14) that reported employing the same strategies in both HD and HH were due to lack of experience (competitive/recreational level) and were not interested in performance outcomes.

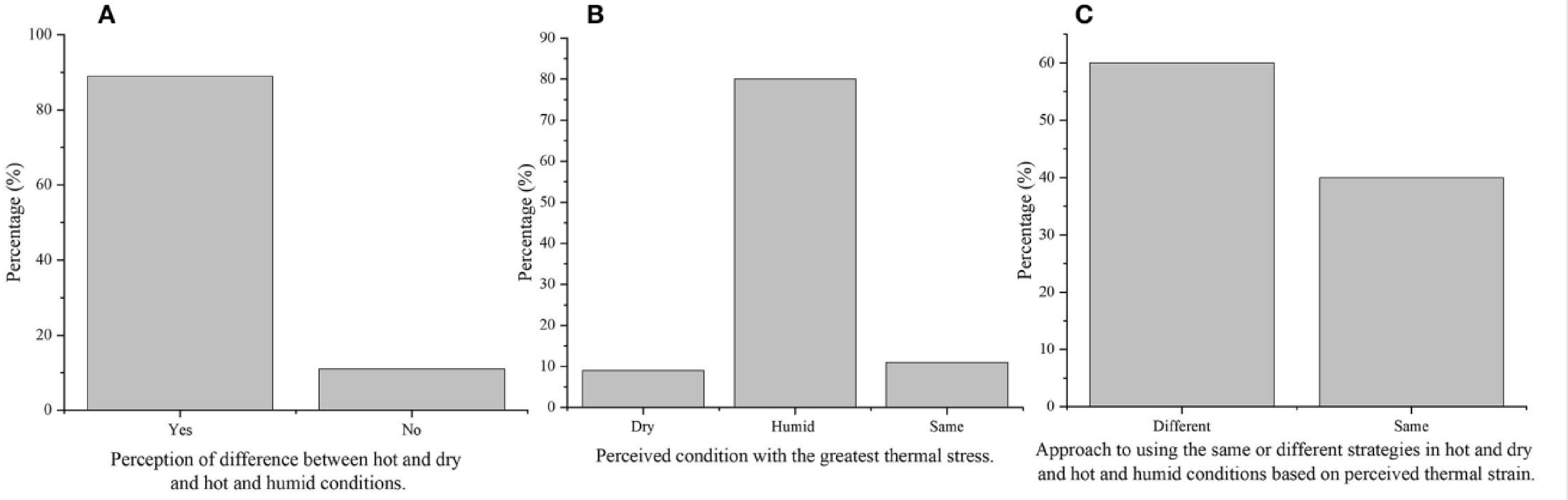


Figure 22. (A) Perceived difference between hot and dry and hot and humid conditions, (B) perceived condition with the greatest thermal stress, and (C) approach to using the same or different strategies in hot and dry and hot and humid conditions based off perceived thermal strain. Figure used with permission of Bayne et al., (2022)

6.4.2. Type of Per-Cooling Strategy

Of the 60% (N = 21), participants reported 7 main strategies employed for cooling during training and/or competition in HD conditions (Table 29). In HD the prevailing preference was cold-water ingestion [43% (N = 9); Figure 23A], followed by cold-water ingestion and pouring [19% (N = 4); Figure 3A]; whereas in HH a combination of cold-water ingestion and pouring was the prevailing preference [43% (N = 9); Figure 23B], followed by cold-water and ice-slushy ingestion [14% (N = 3); Figure 23B].

There was a difference in the strategies employed in HD by athletes from different levels of play. For example, a competitive athlete stated:

> "I feel like I ended up using everything possible, I had cold water in coolers at transition, which I would use to drink and pour over myself, and I also had cold towels to apply during the transition."

Whereas a professional athlete stated:

> "For IRONMAN Oman everything was about drinking cold water for me."

Notably, the strategies employed in HH conditions were different compared to HD for both the competitive and professional athletes. The competitive athlete employed a combination of cold water (ingestion and pouring) and ice slushies:

> "I used cold-water ingestion, cold-water pouring, and also ice slushies."

Whereas the professional athlete employed cold-water only (ingestion and pouring):

> "I was drinking cold water again like I did at OMAN but this time I also poured cold water over myself on the bike and the run." and "I try to target my head, face, neck, and back."

In addition to physical strategies, mental strategies were also employed. For example, the competitive athlete reported using imagery, reframing and modelling:

> “I think because I have gotten used to using the cooling strategies and focusing on implementing them into my races that I actually think about and imagine using them throughout the race so if I know I have a transition coming up where I have an opportunity to use a cooling strategy like a cold towel or cold-water from my cooler then I think about that when I am racing…. I also found that I was imagining myself cycling in a cold country with snow around me”

Whereas the professional athlete reported using positive self-talk (Latinjak et al., 2018) and locus of control (Lefcourt, 2014):

> “For me, it’s about going into a race feeling confident. I remember when I had just started racing and I went to IRONMAN NICE which was HD I think, and I was talking to some of the other competitors before the race and they were talking about other competitions that they had done before whereas I hadn’t really done any, but I said to them that I had come to the race to win and that I was going to win [. . .], I make sure that I have controlled everything that I can control prior to the race so that on race day I feel confident that I will win.”

Table 28. Athletes' classification and their most prevalent descriptive key terms.

Themes	Type	Timing	Justification	Perceived Effectiveness
Different Heat Alleivation Strategies used in Hot and Humid Conditions	1. Cold-water ingestion and pouring 2. Cold-water ingestion and ice-slushy 3. Cold-towels only 4. Cold-water ingestion, pouring and ice-slushy 5. Cold-water ingestion only 6. Cold-water pouring and cold-towels	1. Preplaned by distance and pitstops 2. Pitstops only 3. How they felt during and pitstops 4. Pre-planned by distance and how they felt during performance	1. Previous experience/perceived effectiveness 2. Personal research 3. Support staff 4. Previous experience/perceived effectiveness and support staff 5. Cooling availability	57% (N=12) or the 60% (N=21) = 3 ("Sometimes effective and sometimes not effective" 43% (N=9) of the 60% (N=21) = 4 ("effective for minimizing performance impairments").
Different Heat Alleivation Strategies used in Hot and Dry Conditions	1. Cold-water ingestion and pouring 2. Cold towels only 3. Ice-vest only 4. Cold-water ingestion and cold-towels 5. Cold-water pouring and cold-towels 6. Cold-water ingestion, pouring and cold-towels	1. Pre-planned by distance and how they felt during 2. Pre-planned by distance and pitstips 3. Pre-planned by distance, pitstops and how they felt during performance 4. How they felt during performance only	1. Previous experience/perceived effectiveness 2. Personal research 3. Support staff 4. Cooling availability 5. No justification/unsure	57% (N=12) or the 60% (N=21) = 3 ("Sometimes effective and sometimes not effective" 43% (N=9) of the 60% (N=21) = 4 ("effective for minimizing performance impairments").

		5. Pre-planned by distance only		
Same Heat Alleivation Strategy used regardless of Humidity.	1. Cold-water pouring only 2. Cold-towels only 3. No per-cooling 4. Cold-water ingestion and pouring 5. Ice-slushy ingestion only 6. Cold-water pouring and cold-towels	1. Pitstops only 2. How they felt during performance 3. Pre-planned by elapsed time	1. Previous experience/perceived effectiveness 2. Previous experience/perceived effectiveness and cooling availability 3. No justification/unsure 4. Cooling availability	100% (N=14) = 1 ("not effective for minimizing performance impairments and heat related illnesses").

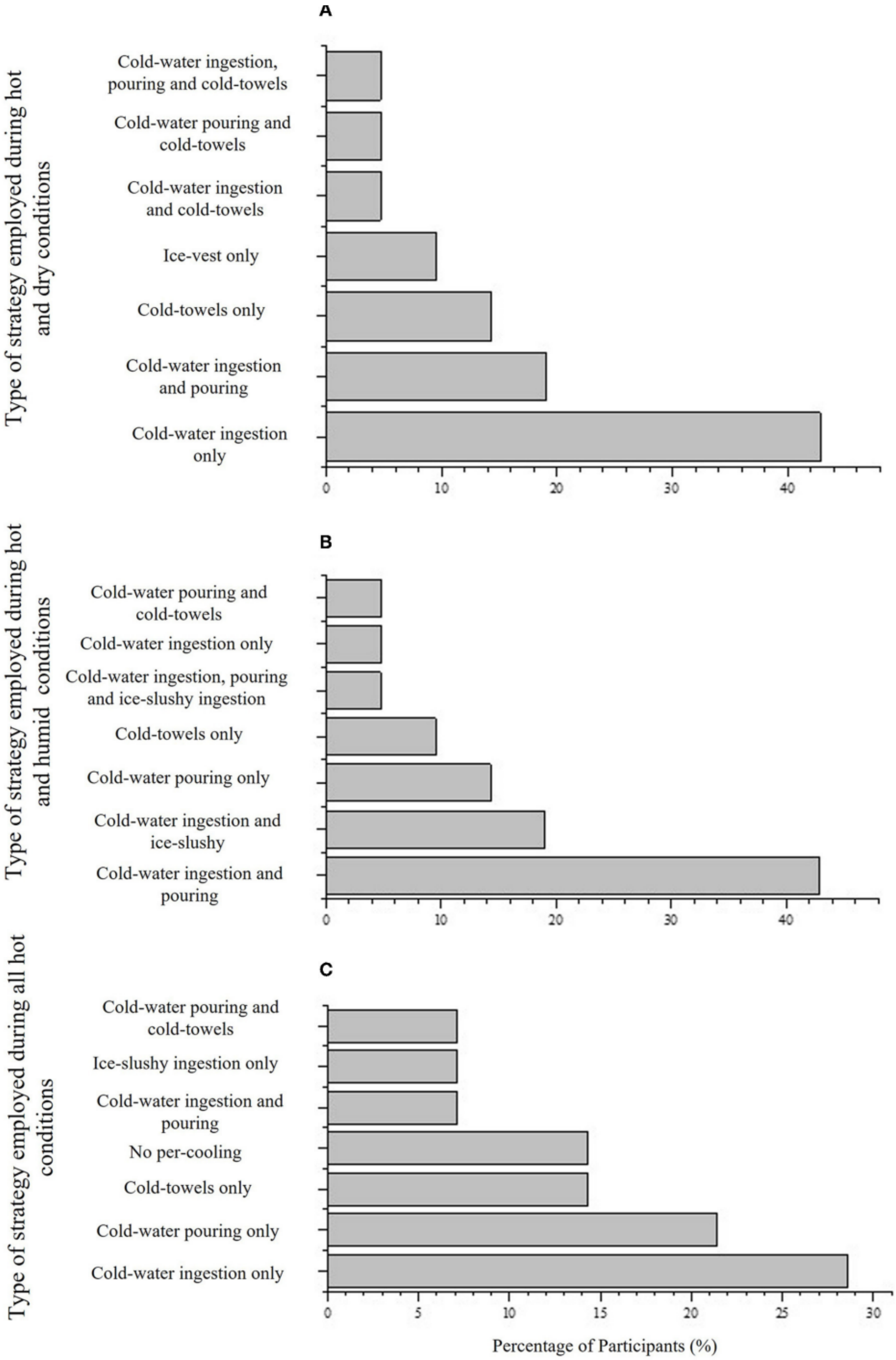

A
Type of strategy employed during hot and dry conditions
Cold-water ingestion, pouring and cold-towels
Cold-water pouring and cold-towels
Cold-water ingestion and cold-towels
Ice-vest only
Cold-towels only
Cold-water ingestion and pouring
Cold-water ingestion only
0
10
20
30
40
B
Type of strategy employed during hot and humid conditions
Cold-water pouring and cold-towels
Cold-water ingestion only
Cold-water ingestion, pouring and ice-slushy ingestion
Cold-towels only
Cold-water pouring only
Cold-water ingestion and ice-slushy
Cold-water ingestion and pouring
0
10
20
30
40
C
Type of strategy employed during all hot conditions
Cold-water pouring and cold-towels
Ice-slushy ingestion only
Cold-water ingestion and pouring
No per-cooling
Cold-towels only
Cold-water pouring only
Cold-water ingestion only
0
5
10
15
20
25
30
Percentage of Participants (%)

Figure 23. (A) Strategies employed in hot and dry conditions by 60% (N = 21) participants who use different strategies depending on condition, (B) strategies employed in hot and humid conditions by 60% (N = 21) participants who use different strategies depending on condition, and (C) strategies employed in all hot conditions by 40% (N = 14) participants who employed the same strategy regardless of condition. Figure adapted from Bayne et al., (2022).

6.4.3. Timing of Per-Cooling Strategy

Participants selected five defining factors that influenced the timing of application in HD (Table 29); whereas only 4 defining factors were reported in HH (Table 29). The prevailing factors in HD were pre-planned by distance and how they felt during performance [38% (N = 8); Figure 4A], and pre-planned by distance and pitstops [38% (N = 8); Figure 24A], whereas the prevailing factors in HH were split; pre-planned by distance and how they felt during performance [43% (N = 9); Figure 24B], and pre-planned by distance and pitstops [33% (N = 7); Figure 24B]. The timing of application of per-cooling strategies were not different in HD and HH by the 60% (N = 21) that reported using different strategies in both conditions (Figure 4). The interview findings showed that in HD, the competitive athlete based the timing on elapsed distance, how they felt during the race and when pits stop (transition) were available: “Well, I would drink the cold-water and pour the cold-water when I was on the bike, which I used in distance as my guide, and then, applied more if I felt like I needed more. The cold-towels were in transition, so that was between swim and bike, and bike and run and I would quickly just press it on my face wiping the sweat away, and then, place it on the back of my neck whilst I checked into my bike and running shoes.” Thereby, in HH, the competitive athletes based the timing of strategy on distance and how they felt during the race only: “I based the timing off distance that I was covering on the bike, and then, also off how I felt, so, again, if I was feeling uncomfortable, I would drink and pour more over myself.” and “one thing that was different to the Barcelona race in HD conditions was that I used a lot more water in the Hawaii race compared to the Barcelona race.” And “I think I used about 1L more water in Kona because I kept feeling like I wanted to pour more water over myself to make me feel more comfortable.” In HD, the professional athlete based the timing of their strategies on elapsed distance only: “I drank periodically on the bike based on the distance that I was covering” and “Well the bike leg of an IRONMAN is 180.25 km, so every 10 km I would have about 2 sips of my cold-water and I had 2 × 2 L bottles on my bike. I would easily get through 1 and half of those before I get on the run.” In HH, the professional athlete utilised the same timing as in HD conditions, however, they incorporated ingestion and pouring at each interval:

“I drank periodically on the bike based on the distance that I was covering” and “Well the bike leg of an IRONAMN is 180.25 km, so every 10 km I would have about 2 sips of my cold-water, and then, pour some on myself. I would roughly get through 2 × 2 L bottles.” These findings show that the competitive and professional athlete employed similar or the same timings for cold-water ingestion and/or pouring in both HD and HH conditions however, the quantity of water used in HH conditions was greater (~1L and ~0.5L) compared to HD.

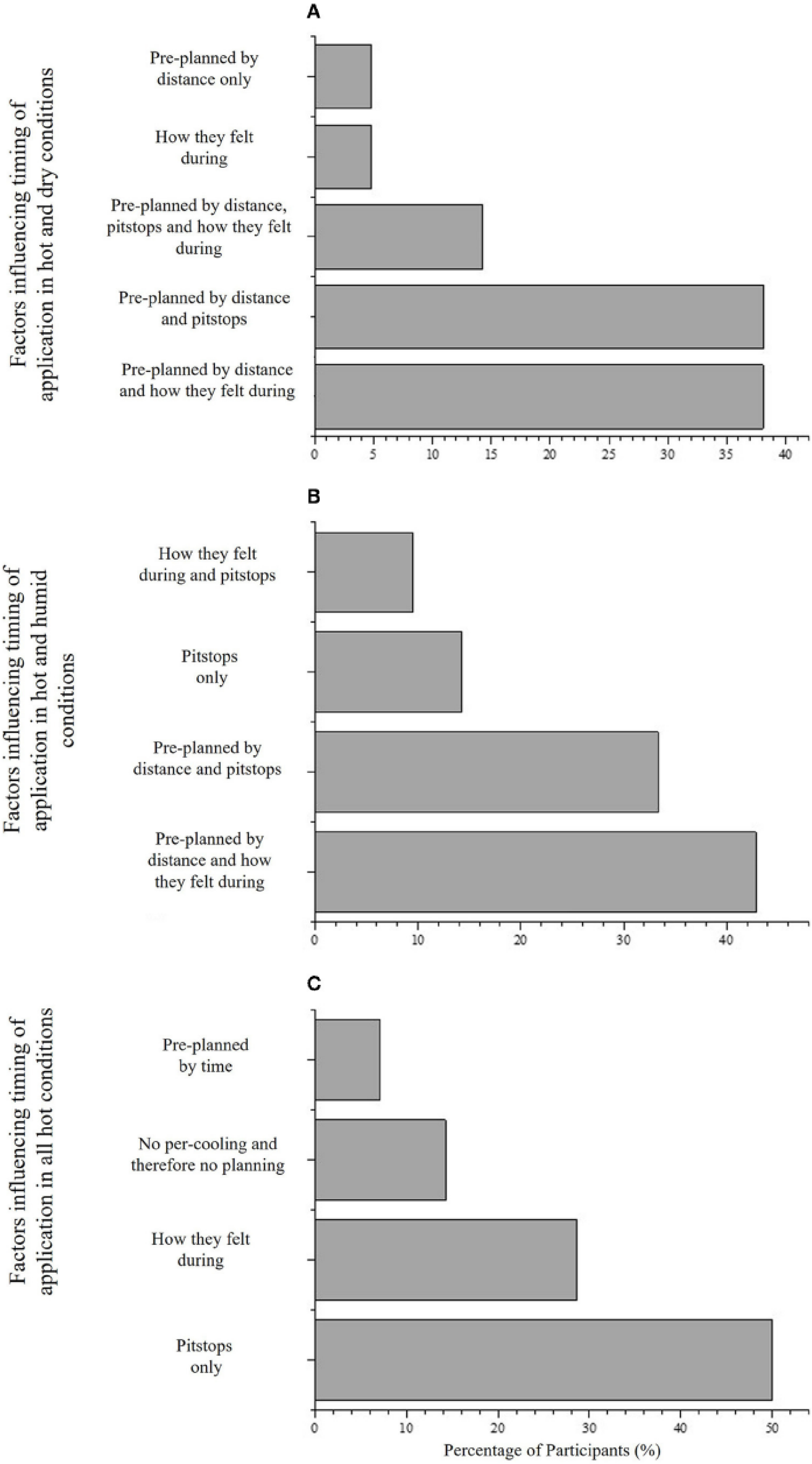

A
Factors influencing timing of application in hot and dry conditions
Pre-planned by distance only
How they felt during
Pre-planned by distance, pitstops and how they felt during
Pre-planned by distance and pitstops
Pre-planned by distance and how they felt during
0
5
10
15
20
25
30
35
40
B
Factors influencing timing of application in hot and humid conditions
How they felt during and pitstops
Pitstops only
Pre-planned by distance and pitstops
Pre-planned by distance and how they felt during
0
10
20
30
40
C
Factors influencing timing of application in all hot conditions
Pre-planned by time
No per-cooling and therefore no planning
How they felt during
Pitstops only
0
10
20
30
40
50
Percentage of Participants (%)

Figure 24. Timing of cooling strategies employed in hot and dry conditions by 60% (N = 21) participants who use different strategies depending on condition, (B) timing of cooling strategies employed in hot and humid conditions by 60% (N = 21) participants who use different strategies depending on condition, and (C) timing of strategies employed in all hot conditions by 40% (N = 14) participants who employed the same strategy regardless of condition.

6.4.4. Justification of Per-Cooling Strategy

Participants reported four justifications for type and timing of strategies used in HD (Table 29). The prevailing justification in HD was previous experience/perceived effectiveness (43% of participants; Figure 25A), followed by personal research (29% of participants; Figure 5A). There were five justifications for type and timing of strategies employed in HH (Table 3). Similarly, the prevailing justification in HH was previous experience/perceived effectiveness (48%; Figure 25B), followed by personal research (23% of participants; Figure 25B). There were seven justifications for type of strategies employed in all hot conditions (Table 29). The prevailing justification in all hot conditions was previous experience/perceived effectiveness (50%; Figure 25C). In HD, the competitive athlete established which strategy to employ and when to apply it based on experience and personal research: “I typically use the event website together with footage from past races. For example, for IRONMAN Barcelona I watched footage from the year before, and I saw that one of the professional athletes were utilising the transitions to drink and pour cold-water over themselves and had cold towels in coolers. So, I thought I would try that out and see whether it worked for me.” In HH, the competitive athlete established which strategy to use and when to apply it based experience and personal research: “Again, I use the event website in combination with footage of past races in the conditions that I am racing in [....] I was watching some footage of the race in Hawaii from the year before and I saw one of the professional athletes using ice slushy ingestion, so I thought it might work for me as well.” On the other hand, in HD, the professional athletes established which strategies to use and when to apply based on experience and support staff (e.g., sport scientists): “After competing in the KONA world championships, I wanted to work with my sport scientist again ahead of competing in the IRONMAN OMAN to trial different cooling methods again, such as cold-water ingestion and pouring in the simulated conditions that I would be competing in using an environmental chamber [....] This trial-and-error approach has really helped me figure out which method is not only beneficial but also practical.”

The justification was the same in HH for professional athletes: “Before competing in the IRONMAN World Championships in KONA, I worked closely with my sport scientist to trial different cooling methods such as cold-water ingestion and pouring in the simulated conditions that I would be competing in using an environmental chamber [....] I found this an effective method to determine which method would best work for me.”

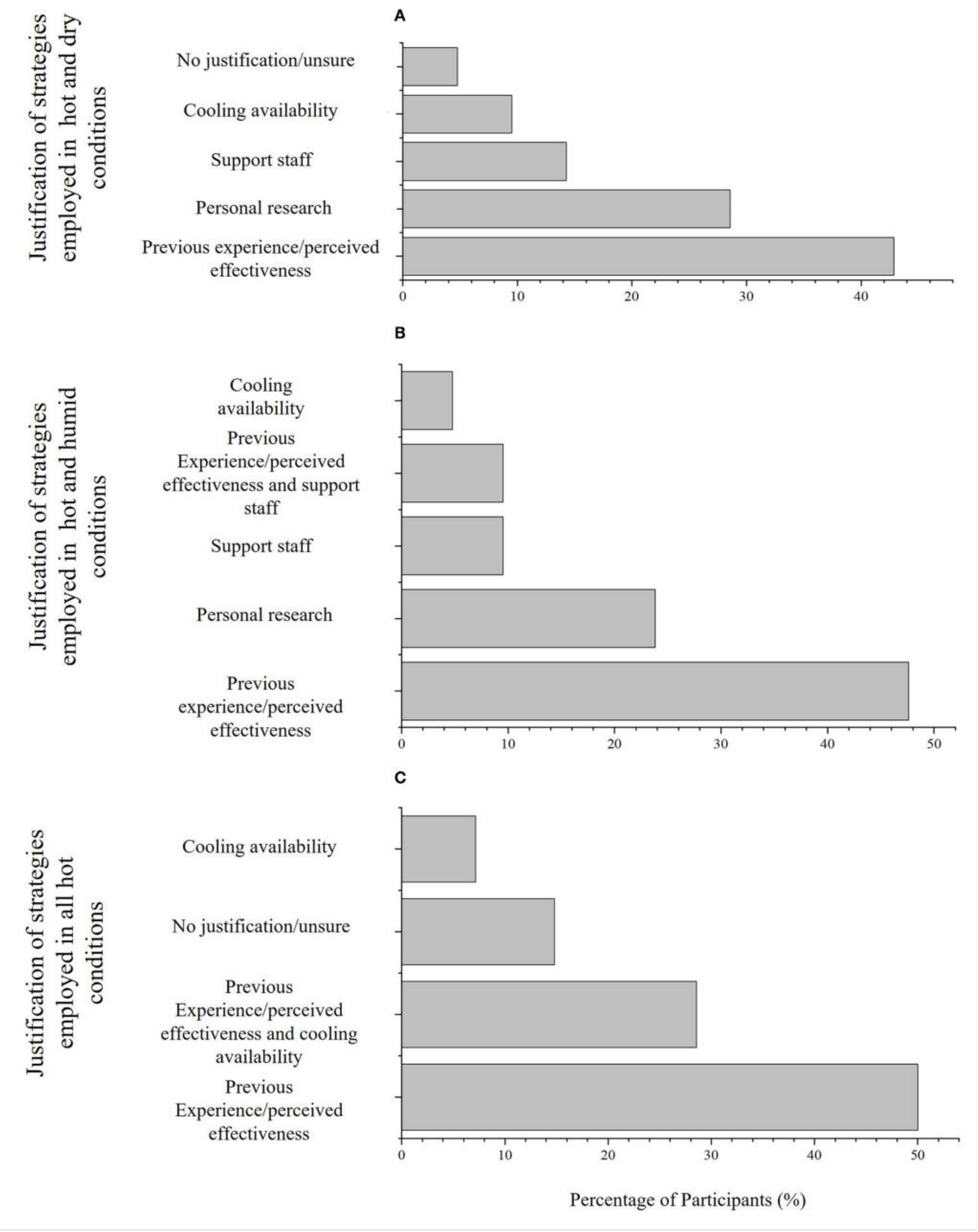


Figure 25. (A) How the type and timing of strategies employed in hot and dry conditions by 60% (N = 21) participants who use different strategies depending on condition were established, (B) how the type and timing of strategies employed in hot and humid conditions by 60% (N = 21) participants who use different strategies depending on condition were

established, and (C) how the type and timing of strategies employed in in all hot conditions by 40% (N = 14) participants who employed the same strategy regardless of condition were established.

6.4.5. Perceived Effectiveness of Per-Cooling Strategy

There was no difference between perceived effectiveness of heat mitigation strategies by the 40% (N = 14) that employed the same heat mitigation strategies in all hot conditions. One hundred percent (N = 14) rated their heat mitigation strategies as 1 ("not effective for minimising performance impairments and heat related illnesses"). There was no difference between perceived effectiveness in HD and HH in the 60% (N = 21) of participants that employed different heat mitigation strategies depending on the condition. Fifty-seven percent (N = 12) of the 60% (N = 21) rated their strategies in HD and HH as 3 ("Sometimes effective and sometimes not effective"); whereas, 43% (N = 9) of the 60% (N = 21) rated their strategies in HD and HH as 4 ("Effective for minimising performance impairments").

The competitive athlete perceived the effectiveness of type and timing of strategies in HD to be 3 ("Sometimes effective and sometimes not effective") which was related to experience:

"I think in terms of performance there were positives and negatives of the strategies that I used. I think the cold-water ingestion and pouring water worked and it really helped me on the bike leg; for example, whenever I did not feel comfortable from the heat I would drink and pour again, which reset me back to feeling comfortable again, so that was a positive.... the cold towels provided an instant benefit, but the benefits did not last very long and made me uncomfortable if I was wearing them for a long period of time [...] On reflection I should have practised this strategy before competing as it was new to me."

The competitive athlete perceived the effectiveness of type and timing of strategies in HH to be 4 ("Effective for minimising performance impairments"):

"I think the cold-water ingestion and pouring worked well for me [. . . ..] I felt a lot better and more comfortable using that strategy after more practise, and that helped with my performance during this race."

On one hand, the professional athlete thought that the effectiveness of their type and timings of strategies in HD was 4 ("Effective for minimising performance impairments"):

"I felt really comfortable in terms of the conditions when I was there and during the race, I actually felt good, the best that I have felt whilst competing in hot conditions for sure, which I think was reflected in the race outcome."

The professional athlete thought that the effectiveness of their type and timings of strategies in HD was 4 ("Effective for minimising performance impairments"):

"...with cold-water my performance has continued to improve." Both competitive and professional athlete agree that mental heat mitigation strategies can be effective in both conditions (Figure 6). The competitive athletes found imagery beneficial for minimising heat related illnesses and performance impairments:

> "It makes me feel better because I know that when I use that cooling, I will feel more comfortable, and I think knowing what the cooling strategies feel like because I have used them a lot helps with my performance because it gives me something to work towards, i.e., getting to the transition sooner."

On the other hand, the professional athletes also found positive self-talk and locus of control beneficial for minimising performance impairments:

"I had come to the race to win and that I was going to win, and I did win. So, now when I go into a race, I make sure that I have controlled everything that I can control prior to the race, so that on race day I feel confident that I will win."

6.4.6. Comparison of Participant Level

Recreational athletes employ the same type of strategies regardless of environmental condition (N = 10). The most reported strategy was cold-water ingestion (N = 7). The timing of application was based on when pit stops were available only (N = 7). There was no clear justification for strategy type and timing. As a result, recreational athletes' performance was perceived as impaired, and they suffered from heat related illnesses. Majority of competitive athletes employed different strategies depending on environmental condition (N = 11/15). The most reported strategy (N = 9) was cold-water ingestion and pouring. The timing of application was pre-planned based on distance, how they felt during and pitstop availability (N = 9). Justification of the type and timing of strategies was based on previous experience/perceived effectiveness (N = 9). Additional strategies (e.g., cold towels, ice vests) were sometimes added with cold-water ingestion and/or pouring based on perceived effectiveness (N = 6). The interview findings revealed that using professional athletes as role models influenced their heat mitigation strategy's type and timing. The perceived effectiveness of these strategies was sometimes effective and sometimes not effective for minimising impairments to performance and heat related illnesses. Therefore, the competitive athletes in this sample have yet to master their heat mitigation strategies for training and/or competing in hot conditions (HD and HH). All professional athletes employed different strategies depending on environmental condition (N = 10). Cold-water ingestion and pouring was the most reported strategy in both HD and HH. Timing of application was pre-planned based on distance and how they felt during (N = 10). The justification of strategies used was based on previous experience/perceived effectiveness.

6.5. Discussion

The aim of this study was to investigate the type, timing, and justification of per-cooling strategies employed by athletes (cyclists-triathletes) during training and/or competitions in hot and dry (HD) and hot and humid (HH) conditions.

6.5.1. Main findings

1. Cold-water ingestion was the most employed strategy in HD, whereas a combination of cold-water ingestion and pouring was the most employed strategy in HH.
2. Timing of application was pre-planned based on distance in both conditions, supplemented with how participants felt during when pit stops are available in HD, and how participants felt during in HH.
3. The prevailing justifications for type and timing of strategies was previous experience/perceived effectiveness (e.g., trial and error).
4. There was no difference in perceived effectiveness of type and timing of strategies employed in HD and HH.
5. There is a difference in the type, timing, justification, and perceived effectiveness of heat mitigation strategies between recreational, competitive, and professional athletes.
6. Competitive athletes found benefits from mental strategies, such as imagery and modelling; whereas professional athletes found benefits from positive self-talk and locus of control during competition in HD and HH.

Cold-water ingestion has previously been shown to directly cool core organs and circulating blood, which enhances thermal sensation through thermoreceptors in the mouth and gut, and can be complementary to existing hydration and/or nutrition supplementation strategies used pre-event and during event (e.g., combine with carbohydrates and minerals; James et al., 2015; Bongers et al., 2017). Mechanistically, the thermal stimulus to elicit a phase change from cold to warm water draws heat from internal tissue, reducing temperatures proximal to the gut directly and indirectly cools other regions, as blood of a lower temperature circulates the body. Therefore, unlike external cooling, internal cooling often displays insignificant changes in T_{sk}, but does induce changes in T_{core}/T_{rectal}, reflecting the cooling site proximity to core organs, and typical $T_{core/}T_{rectal}$ measurements in the gut (e.g., pill) or rectum (e.g., thermistor probe). Perceptual benefits of reduced thermal strain (i.e. comfort and sensation) can also be achieved via mouth and gut cooling as a consequence of the relative prominence of thermoreceptors in these regions (Villanova et al., 1997; Flouris, 2011).

In contrast to the strategies employed in the current study, previous findings have highlighted that HD greatly favours evaporation, so cycling in the desert may be an ideal situation for cold-water pouring, as most of it is likely to evaporate (Morris and Jay, 2016). Despite this understanding, a combination of strategies was employed by endurance athletes in Racinais et al. (2021) study, showing that 93% of participants employed per-cooling (mainly head/face water dousing/pouring and cold-water ingestion) at IAAF World Athletics Championships in HD. Collectively these findings highlight that there is a lack of consensus between which strategy to use (i.e. cold-water ingestion only, cold-water pouring only, or a combination of the two) during training and/or competition in HD conditions by endurance athletes.

In contrast to HD, HH conditions make the process of evaporation increasingly difficult, therefore, mechanistically, cold-water pouring wouldn't offer any significant evaporative heat loss whilst cycling in HH (Morris and Jay, 2016). This poses the question as to whether internal cooling via cold-water ingestion would be more favourable during HH. Morris et al. (2014) examined local sweating activity, as well as T_{core} and T_{sk}, and found that immediately after cold-water ingestion, a sudden drop in local sweat rates occurred at the back, forehead, and forearm. All of which remained depressed for several minutes, despite the fact that T_{core} and T_{sk} were unaltered throughout. Upon further investigation by administering aliquots of water of equal volume and temperature to the mouth via swilling or directly into the stomach via a nasogastric tube, it was determined that the reductions in sweating were due to signalling from independent thermoreceptors that are probably located in the stomach and/or small intestine without input from thermoreceptors located in the deep body core or skin (Morris et al., 2014). Morris et al. (2016) conducted a subsequent study examining ice slurry ingestion during exercise and found similar results, with sweating drastically reduced following ingestion, without changes in T_{core}/T_{rectal} or T_{sk}. Perhaps more important than the changes in local sweat rate, Morris et al. (2016) also measured environmental parameters, such as air velocity, ambient temperature and humidity, and designed the experiment in order to estimate heat loss from all avenues of heat transfer. Critically, alterations in evaporative potential due to differences in sweating were determined (Bain et al., 2012). The findings showed that compared to a 37◦C drink, the reduction in evaporative heat loss with 1.5 and 10◦C fluid ingestion was approximately equal to the additional internal heat transfer obtained with these drinks. Notably in the follow up study where the participants ingested ice slurry drinks, the reduction in sweating compared to a 37◦C drink was so great that it exceeded the internal heat transfer to the ice slurry, despite the extra internal heat loss due to the latent heat fusion. As such, ice slurry ingestion led to a greater, not smaller, net heat storage compared to a 37◦C drink. However, it should be noted that a distinct advantage of cold-water ingestion is that all internal heat transfer is 100% efficient, whereas reductions in sweating in an HH condition may not mean that evaporation will be equally impacted.Sweat must evaporate to provide a cooling effect, and if it is simply sweat that will ultimately drip off the body anyway that is reduced then cold-water ingestion will likely confer an advantage. Collectively, these mechanistic findings suggest that the cyclists-triathletes in the current study are using the incorrect per-cooling strategies for the condition that they are training and/or competing in. Specifically, cold-water pouring should be employed in HD and cold-water ingestion should be employed in HH. The impact of these strategies on cycling performance have yet to be investigated.

In addition to physical strategies, the competitive and professional athletes reported using mental strategies, such as imagery, reframing, modelling, positive self-talk (PST) and locus of control (LOC), respectively, when preparing for competitions in hot conditions (Figure 21). These strategies helped to cope with the thermal discomfort experienced during cycling in HD and HH by creating a perceived “cold feeling”. This concept was explored in Coudevylle et al. (2019) review, in which the benefits of mental techniques (such as hypnosis) in relation to heat or heat exposure were discussed. For example, Jussiau et al. (2002) showed an increase in heat detection and heat-pain thresholds after a hypnosis intervention. In addition, Younus et al. (2003) showed that the frequency, duration, and severity of the hot flashes were significantly reduced after hypnosis (4 × 1-h/week). These studies demonstrate that mental strategies can be applied and provide benefits in relation to thermoregulation.

Future research should aim to investigate whether this also works for cold interventions and whether there were any specific effects on psychological markers (i.e. TC, TS, AF) and the motivation to perform exercise in hot conditions (HD and HH) compared to a thermoneutral/control condition (Coudevylle et al., 2019). The mental strategies employed by professional cyclists-triathletes are supported by previously work demonstrating that PST improved running performance in HD by 8% (Barwood et al., 2008).

Therefore, it could be hypothesised that this mental strategy may prove beneficial for other endurance sports such as cycling, and other hot conditions such as HH, however, this has yet to be investigated.

In addition to PST, the professional athlete reported controlling as many factors as possible to increase self-confidence going into a competition. This behaviour is classed as locus of control - the extent to which people see the environment as controllable (Schippers and Van Lange, 2006). It has been argued that people who see the environment as controllable feel less tension and are more self-confidence before a competition (Schippers and Van Lange, 2006). Phillips and Hopkins (2020) highlighted that self-confidence had a positive effect on cycling performance. These findings suggest that improving locus of control to view the environment as controllable may improve self-confidence and prove beneficial for cycling performance in hot conditions. Therefore, the current study contributes to the early findings in this research area, demonstrating the potential benefit of using mental strategies/psychological skills training (for example imagery, modelling, PST, LOC) during cycling in hot conditions. In addition to the type of strategy employed, the current study also highlighted the timing of application in HD and HH. Previous research in the area that is conducted in a laboratory setting commonly provides cold-water ad-libitum (Dugas et al., 2009). For example, provided ad libitum cold-water (10◦C) during a 40-km cycling TT in HH conditions to investigate the frequency and quantity of water consumed. The findings highlighted that cold water was consumed on completion of every 2 kms. The current study supported these findings, highlighting that cold water was ingested based on elapsed distance and how athletes felt in HH (42.85%, N = 9; Figure 24). Athletes felt in HH (42.85%, N = 9; Figure 24). Athletes also consumed cold water based on elapsed distance and how they felt in HD, with the addition of ingestion at pit stops during competition (38.09%; Figure 24). However, in the athletes that employed the same strategies regardless of competition, cold water ingestion was completed at pit stops only (50%, N = 7; Figure 24). Therefore, the optimal timing of cold-water ingestion for thermoregulatory and performance benefits during a self-paced cycling TT in HD and HH are still unknown. The athletes in the current study relied on previous experience/perceived effectiveness when selecting type and timing of strategies.

Mechanistically the strategies selected were not the most effective for alleviating heat strain (i.e. greater heat loss than heat gain) for the desired conditions, however, the effectiveness of these strategies on minimising performance impairments and heat related illnesses have yet to be investigated in these conditions. There was no difference in perceived effectiveness of strategies employed in HD and HH by the 60% (N = 21) of participants that reported using different strategies depending on condition. However, the interview findings revealed that there was a difference between perceived effectiveness of strategies between HD and HH for the competitive and professional athlete. The professional athlete stated using a trial-and-error approach with heat mitigation strategies with the support of a sport scientist. The competitive and recreational athletes had less experience and support compared to the professional athlete, which may explain why 80% of recreational and 60% of competitive athlete employed the same heat mitigation strategy regardless of the condition. Surprisingly, the competitive athlete chose to use the same heat mitigation strategy in both conditions despite their understanding of perceived heat stress (Figure 22).

This highlights that there may be a lack of understanding among competitive athletes in what heat mitigation strategies to use (e.g., type and timing) in different conditions (e.g., HD vs. HH) (Figure 22). The interview findings highlighted that the competitive athletes use modelling of professional athletes' behaviour to obtain information on which heat mitigation strategies to use. It is common for fans of elite/professional athletes to mimic behavioural cues (Lynch et al., 2014) or use copying as an effective skill development technique (Abraham and Collins, 2011). However, the use of modelling to determine heat mitigation strategies was a novel finding of the current study. In addition, the recreational athlete' strategies were perceived as not effective for minimising performance impairments and heat related illnesses. Shendell et al. (2010) identified adult recreational endurance athletes, and in particular less experienced (e.g., first time) participants, as a susceptible and vulnerable population subgroup to heat related illnesses (Shendell et al., 2010). These findings were related to a lack of knowledge in exercising in hot conditions mostly from lack of experience and education on heat related illnesses (Shendell et al., 2010). An additional factor that contributes to this is that recreational athletes train less and at a lower intensity than competitive and professional athlete, implying that they would have a lower physical fitness and/or higher BMI which are risk factors for heat exhaustion (Winkenwerder and Sawka, 2007). The findings of the current study support Shendell et al. (2010) study demonstrating that recreational athletes are at a higher risk compared to competitive and professional athletes due to knowledge/understanding and experience. Therefore, it is important that recreational and competitive athletes are educated on the impairment effect of HD and HH on performance and risk of heat related illnesses together with strategies on how to compete this impairment effect. This education should also cover the risk of modelling wrong heat mitigation strategies in different environmental conditions.

7.6. Limitations and Perspectives

Despite being derived from a relatively small sample size (N = 35), the findings of this study highlight the existing strategies employed by cyclists-triathletes during training and/or competitions in hot and dry and hot and humid conditions. The importance of this is that different types of strategies are employed depending on the condition however the effectiveness of these strategies in these conditions have yet to be explored. Therefore, future larger scale studies should explore the effectiveness of these heat mitigation strategies in hot and dry and hot and humid conditions. The study of Racinais et al. (2021) had an effective approach to pre-race questionnaires. This would also allow for exact conditions on competition day to be recorded and related to questionnaire findings.

As noted in the methodology, questions related to quantity and magnitude of cooling employed were removed from the questionnaire/interview to focus on type, timing, justification, and perceived effectiveness in hot and dry and hot and humid conditions. Carvalho et al., (2014) reported the quantity of water consumed during a cycling time-trial, which increased over time [0– 8 km (~50 mL), 8–16 km (~100 mL), 16–24 km (~260 mL), 24– 32 km (~230 mL), and 32–40km (~180mL)] equating to a total consumption of 1.1 ± 0.4 L. This strategy contributed to a completion time of 93 + 3.5min, however, few studies have investigated the impact of cold-water ingestion on performance and, therefore, it is unclear whether this method was effective at improving TT performance in HH conditions. In contrast to self-paced protocols, exercise to exhaustion protocols often base consumption of cold-water (4◦C) on time, with every 15mins being the most reported strategy in both HD (Mündel et al., 2006; Naito and Ogaki, 2017) and HH (Lee et al., 2008). Therefore, the optimal quantity of cold-water to ingest and/or pour in HD and HH conditions is unknown and should be an area for future research to explore.

It was also reported that cyclists-triathletes do not only use physical heat mitigation strategies, but also mental strategies when preparing for training and/or competitions in hot conditions. Therefore, future research should investigate the mental strategies employed and their effectiveness on minimising performance impairments and heat related illnesses.

Finally, the results suggest the need to educate competitive and recreational athletes on heat strain and heat mitigation strategies. Based on the competitive athletes’ use of modelling to obtain information on heat mitigation strategies, it may suggest that the best approach to educate competitive and recreational athletes is through role-models (for example professional athletes). This could be conducted through professional athletes together with their support staff giving talks/webinars, which reflect on current and past practise.

7.7. Conclusion

Using mixed-method methodology and a population of cyclists-triathletes, this study identified that cold-water ingestion was the prevalent cooling strategy employed in hot and dry, whereas a combination of cold-water ingestion and pouring was the most reported strategy in hot and humid. In HD, the timing of application was based on elapsed distance, how they felt during and when pitstops were available, compared to elapsed distance and how they felt during in HH. The type and timing of strategies were based on previous experience and perceived effectiveness. There was no difference in the perceived effectiveness of strategies employed in HD and HH. However, the type and timing of strategies have yet to be investigated in the favoured conditions for their effect on minimising performance impairments and heat related illnesses. Mental strategies seem to be promising methods that require further investigation in hot and dry and hot and humid conditions. Future research should investigate the effectiveness of cold-water ingestion and pouring on performance in hot and dry and hot and humid conditions to determine the optimal type of strategy for cyclists-triathletes to use during training and/or competition in these conditions. The impact of mental strategies should also be investigated further in both isolation and combination with cold-water ingestion, pouring and combined ingestion, and pouring.

7.8. Importance of Findings for Subsequent Chapter and Thesis

- Cold-water ingestion was the most employed strategy in HD, whereas a combination of cold-water ingestion and pouring was the most employed strategy in HH. This was associated with perceived effectiveness of these strategies. However, the actual effectiveness of these strategies (i.e. affect on performance reducing thermal strain) have yet to be investigated. Therefore, these two strategies will be employed in study 4 to investigate their effect on cycling performance in both HD and HH conditions. This will also be conducted on a competitive cyclist/triathlete group as this had the largest participation number of all groups (recreational, competitive, professional).

- Timing of application was pre-planned based predominantly by distance in both conditions and supplemented with how participants felt during and when pit stops are available in HD, and how participants felt during in HH. Periard et al., (2020) suggested that if exercise intensity is moderate to high, exercise duration is >60min and the environmental condition is warm to hot then a drinking strategy should be pre-planned. Therefore per-cooling via cold-water ingestion and pouring in study 4 is based on timing as it is a time-based time-trial (45min preload, and 30min TT = 75min) instead of distance.

Chapter 7. Study 4: To drink or to pour? Per-cooling cold-water ingestion has a greater ergogenic effect on 30min cycling time-trial performance in hot and dry and hot and humid environmental conditions compared to cold-water pouring.

7.1. Abstract

Purpose: To investigate the effect of per-cooling via cold-water ingestion compared to cold-water pouring on physiological and perceptual responses during a 30min cycling time-trial in hot and dry and hot and humid conditions.

Methods: 12 participants (Group 1: N=6, 29±2yrs, 187±9cm, 78±6kg, 53±4mL.kg.min^{-1}, and Group 2: N=6, 29±2yrs, 186±10cm, 78±6kg, 54±4mL.kg.min^{-1}) visited the laboratory for 1 familiarisation and 4 experimental trial. Participants were assigned randomly into 2 groups: Group 1 – Hot and Dry, and Group 2 – Hot and Humid. Within their groups participants completed 4 x 30min cycling time-trials in neutral with no cooling, hot with no cooling, hot with cold-water ingestion and hot with cold-water pouring, separated by ~5-7 days. Performance, physiological, perceptual measurements were recorded throughout the preload and TT.

Results: Cold-water pouring was more beneficial compared to cold-water ingestion for power output in hot and dry conditions (Mean±SD 199.40±0.82W vs 180.35±1.51W, p = 0.023). This performance benefit occurred in absence of a significant difference in rectal temperature between cold-water pouring and ingestion (38.18±0.13°C vs 38.38±0.14°C, p = p=0.121). There was also no difference in thermal comfort between cold-water pouring and ingestion (11±1(55%) vs 12±2(60%); p = 0.067).

Whereas cold-water ingestion was more beneficial compared to cold-water pouring for power output in hot and humid conditions (Mean±SD 173.77±0.97W vs 165.16±1.31W, p=0.760). This was supported by physiological responses such as rectal temperature which was significantly lower with cold-water ingestion compared to cold-water pouring (37.9±0.1°C vs 38.5±0.19°C, p = 0.001). This was also supported by perceptual responses

such as mean±SD thermal comfort ratings which was significantly greater with cold-water pouring than cold-water ingestion during the time-trial in hot and humid conditions (14±3(70%) vs 12±1(60%); p = 0.004).

Power in the hot and dry conditions with cold-water pouring (199.40±0.82W) was significantly greater compared to hot and humid condition with cold-water pouring (165.16±1.31W, p =0.001). This difference occurred in absence of a difference in physiological responses such as rectal temperature as there was no difference between groups respectively (38.18T ±0.13 vs 38.4±0.22, p = 0.253). However, this performance difference was supported by perceptual responses such as thermal comfort ratings which were significantly greater with cold-water pouring during the time-trial in hot and humid conditions compared to hot and dry conditions (14±3(70%) vs 12±2(60%); p = 0.021).

Conclusion: Cold-water pouring provided a greater ergogenic effect on 30min cycling time-trial performance in HD conditions compared to cold-water ingestion. This was accompanied by improvements in thermal comfort and in the absence of a reduction in rectal temperature. Whereas cold-water ingestion provided a greater ergogenic effect on power output during a 30min cycling time-trial performance in HH conditions compared to cold-water pouring. This was related to a reduction in rectal temperature and thermal discomfort with cold-water pouring.

7.2. Introduction

The findings of chapter 5 (Study 2) highlighted that average power output during a 30min cycling time-trial was significantly impaired in HH compared to HD conditions. This impairment was related to the imbalance between heat gain (I.e. environmental and metabolic) and heat loss (I.e. evaporation) resulting in a significantly higher mean±SD T_{rectal} , thermal sensation and thermal discomfort in HH conditions.

In an attempt to mitigate heat-related impairments in performance during training and/or competitions in hot conditions (both dry and humid), athletes regularly employ different cooling strategies both before (pre-cooling) and during (per-cooling) exercise (Bongers et al., 2015). Pre-cooling athletes, using cold water immersion (2–20°C) (Duffield et al., 2010), ice vests (I.e. applied to the torso; Cotter et al., 2001) or neck cooling collars (Tyler and Sunderland, 2011; Sunderland et al., 2015) blunts heat related decrements in performance. While likely beneficial, most of these interventions are not particularly feasible in low-resource environments (such as away competitions, competition in remote areas and amateur level sports). Typically, during endurance events drink stations/transition stops or support cars are available where athletes are able to pick up or restock their water supply. In chapter 6 (Study 3) cyclists-triathletes reported performance benefits whilst using cold-water ingestion and pouring during cycling competitions in HD and HH conditions. These findings supported Racinais et al., (2021) article which reported that 93% of athletes at the Doha (hot and dry) 2019 IAAF World Athletics Championships planned to use water for per-cooling (65% = head/face water dousing/pouring and 25% = cold-water ingestion). Despite the readily available nature of water at these events, little research has been conducted on the efficacy of cold-water ingestion and pouring for improving endurance performance in hot conditions and the mechanisms behind this.

The aim of all cooling strategies is to alleviate heat stress, however the mechanisms behind internal and external cooling are different and therefore may trigger different responses (Jay and Morris, 2016). Cold-water ingestion is considered as the most straight forward way to cool via conduction. The amount of heat lost is determined by the temperature difference between the ingested water and the body core, the volume of water drunk, and the specific heat capacity of water, i.e. the amount of heat energy needed to warm up 1g of water by 1°C, which is 4.184 J/g/°C. In comparison, cold-water pouring (sometimes referred to as ‘dousing’) is considered as the most straight forward way to cool via convection. The effectiveness of heat loss is dependent on how likely the water is to evaporate. For example, dry air and high wind speeds greatly favour evaporation, so cycling in HD conditions may be an ideal situation for cold-water pouring. Conversely, high levels of ambient humidity and low air speeds make it increasingly difficult for evaporation to occur and may result in greater heat storage. Therefore, cold-water pouring may not be the best method to incorporate whilst cycling in HH conditions, posing the question as to which method is the most effective for different environmental conditions.

To investigate the effect of per-cooling via cold-water ingestion compared to cold-water pouring on physiological and perceptual responses during a 30min cycling time-trial in hot and dry and hot and humid conditions.

7.3 Methodology

7.3.1. Participants

12 participants completed study 4 and were recruited using the recruitment methods and inclusion and exclusion criteria outlined in the general methodology section (Chapter 3). If the inclusion criteria were met, participants were randomly separated into 2 groups:

1. Hot and Dry conditions (35°C, 30%, 2.2m/s^{1}, equating to a WBGT of ~27°C)

2. Hot and Humid conditions (30°C, 70%, 2.2m/s, equating to a WBGT of ~26°C)

The groups were matched for age, stature, body mass, experience, training and VO_{2max} (Table 30).

Table 29. Mean±SD differences in cyclists-triathletes in each group for sex(M:F), age(yrs), stature(cm), body mass(kg), VO_{2max}(mL.kg.min^{-1}), maximal aerobic power at VO_{2max} (W), prior experience(yrs) and weekly training(hrs).

Groups	1 = Hot and Dry Conditions	2 = Hot and Humid Conditions
Participants (N)	6	6
Sex Ration (M:F)	6:0	6:0
Age (Years)	29±2	29±2
Stature (cm)	187±9	186±10
Body Mass (Kg)	78±6	78±6
Body Mass Index (kg/m2)	22±2	21±2
VO_{2max} (mL.kg.min^{-1})	53±4	54±4

MAP at VO_{2max} (W)	283.3±51.6	283.3±51.6
MAX HR at VO_{2max} ($b.min^{-1}$)	190±3	192±4
Prior Experience (Years)	6±2	6±3
Weekly Training (hrs)	6-8hrs	6-8hrs

7.3.2. Experimental Design

All data was collected between the winter and spring months of January-May (2021), to prevent any heat acclimatization effect.

Each participant was invited to visit the laboratory on 5 occasions to complete 1 familiarisation and 4 experimental trials (Figure 27). Each group completed 4 experimental trials in a randomised order all in their designated environmental condition. This included 2 control trial ((i) thermoneutral and no cooling and (ii) hot with no cooling) and 2 cooling intervention trials ((i) cold-water ingestion and (ii) cold-water pouring; Figure 27). Each session lasted ~1.5hrs.

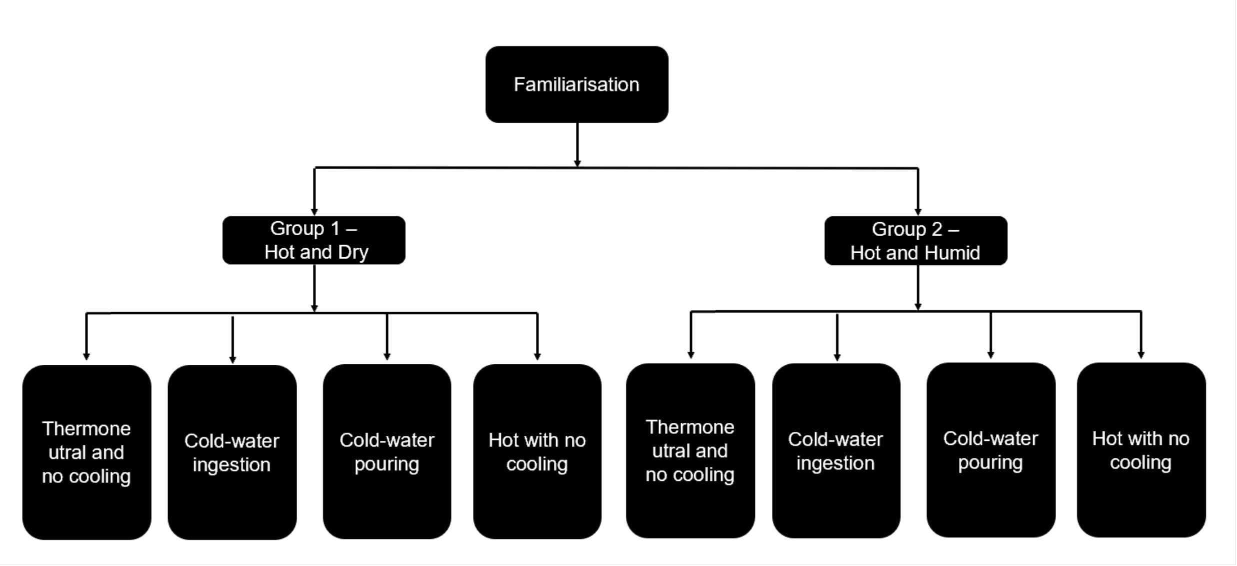


Figure 27. Illustrated structure of study design outlining the 4 experimental trials completed within each group ((i) thermoneutral and no cooling, (ii) hot with no cooling, (iii) hot with cold-water ingestion, and (iv) hot with cold-water pouring).

7.3.3. Familiarisation and Standardization

Upon arrival to the laboratory volunteers received information and explanation regarding the study aims, structure and measurements. Specifically, volunteers received explanations and demonstrations of all equipment and procedures included in the study, as well as being familiarised with specialist equipment and measurement tools (i.e., turbo/wattbike, perceptual scales). All trials were conducted on a turbo (Wahoo, Kickr, Atlanta, USA), which allowed each participant to bring in and use their own bicycle, or alternatively use the bicycle London South Bank University provided (2019 Specialized Allez Elite). In this time and throughout the study volunteers were permitted to ask questions regarding the study demands and requirements, which were answered by the investigator. If the volunteer was interested and willing to participate then they would complete a health screening questionnaire and consent form.

Volunteers anthropometric measurements of stature (cm) and body mass (kg) was then collected before completing a VO_{2max} test. Participants were strapped with a HR monitor (polar) and then completed a 5-10min self-paced warm up. The VO_{2max} test started at 100W and was increased by 40W every 4min. After 16min, the load was increased by 30W every minute until participants reached volitional exhaustion. Expired air and HR was measured during the last minute of each stage. After 30min of rest, participants completed a familiarisation with the experimental protocol under the experimental conditions (depending on group allocation).

Prior to every trial across the experimental studies, participants attended the laboratory after refraining from caffeine, alcohol, heat exposure and vigorous exercise for ≥48hr to facilitate recovery and rehydration. In the preliminary visit, all participants complete a food record for the day (24hrs prior to initial familiarisation trial). They were then asked to adopt the same diet on the day before each subsequent trial. In addition, all experimental trials at a similar time of day (±1hrs) to minimise the impact of circadian rhythm variation on measured parameters (Carrier & Monk, 2000). Whilst enrolled in the study, participants were asked to maintain their habitual daily routine of diet, sleep and exercise patterns in a training diary to calculate daily workload (Kj). Finally, to control for hydration status during the preload, participants were required to drink 500mL of thermoneutral room temperature water in all trials. This was all to minimise the impact of these factors on psycho-physiological responses assessed within the experimental studies.

7.3.4. Experimental Trials

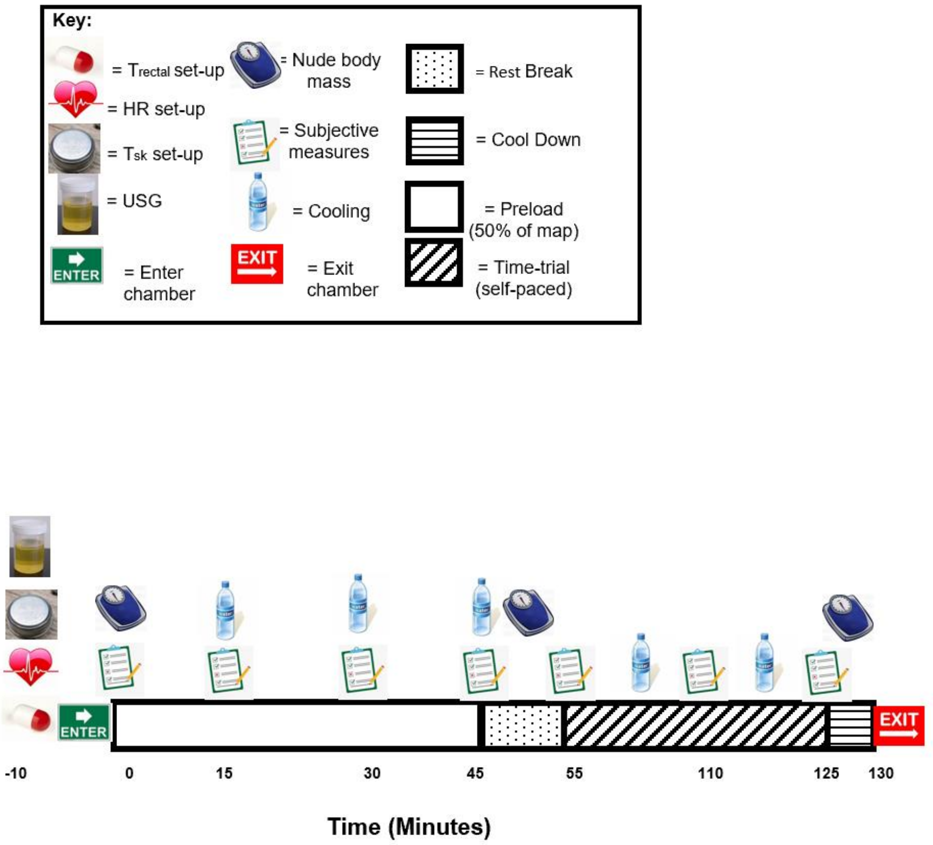


Figure 28. Illustrated figure of experiment trials in study 4 with key above. T_{rectal} = rectal temperature, T_{sk} = skin temperature, HR = heart rate, USG = urine specific gravity, map = mean aerobic power, subjective measures = Ratings of perceived exertion, thermal sensation, thermal comfort, and affect. In non-cooling trials the water bottle icon represents hydration timings so that trials were matched for hydration status.

Experimental trials started with a 10min standardized warm-up (outside the environmental chamber), followed by a 45min cycle preload at a fixed intensity (50% of maximal aerobic power) (Figure 28). On completion of the preload, there was a 10-min rest before completing a 30min self-paced performance test on a turbo. Within this 10-minute rest participants had a nude body mass measurement. The investigator then gave verbal standardised instructions to all participants to complete the greatest distance (km) possible during the 30min TT. From the onset of the TT participants were able to freely increase or decrease PO. There was no motivation given and the only visual feedback was the time they had left to complete the 30min performance test. Distance covered by participants was not revealed until all 3 of the experimental trials were completed. Participants were able to ask any questions before they began. Throughout the experimental trial air flow was provided by a fan (2.2m/s) that was in line with the participants torso (shoulder to waist) providing a headwind effect.

During the performance test, 1L of room temperature water was provided for the participants to drink ad libitum.

7.3.5. Cooling intervention

2 cooling interventions were used in this study (i) ingestion of cold-water (4°C) and (ii) pouring of cold-water (4°C) over the participants neck, shoulders and back (based on study 3 findings). Due to the nature of the TT (complete as much distance as possible within 30min), the cooling intervention in this study was applied on completion of every 15min in the 45min preload (i.e. 15, 30 and 45min) and 10min in the 30min cycling time-trial (i.e. 0, 10, and 20min). In addition, the quantities of the water ingested and poured was based on study 3 findings. For example, cyclists and triathletes reported using aliquots of <500mL of water when consuming or pouring (based on long distance events of ~180km), therefore the volume of water used for the cooling intervention was ~150ml each time. In total participants were given 5 x 150mL = 750mL (450mL during the preload and 300ml during the performance test). The participants in group 2 (cold-water pouring) also received 750mL of

room temperature water to drink at the same time as pouring cold-water to control for any hydration status differences between the groups.

7.3.6. Performance Measurements

Power output and distance covered were continuously measured using PerfPRO during the experimental trials.

7.3.7. Physiological Measurements

Prior trial measurements of USG and NBM are taken before entering the environmental chamber. Throughout the trial, T_{rectal}, T_{sk}, HR were recorded continuously. In the 10min rest between preload and TT a second BM is taken. Post TT a final NBM measurement is taken after wiping down the sweat on the body using a dry towel. NBM together with fluid intake were used to calculate SR. All body mass measurements were taken nude in a private room.

7.3.8. Perceptual Measurements

Upon arrival to the lab for all experimental trial's participants completed a Situational Motivation Scale (Guay et al., 2000) to access for any changes in situational motivation to participate in this study between visits which may influence performance. Participants then sat quietly post warm-up and pre-TT for 2min before baseline measurements of HR, AF, RPE, and TM were assessed. In the 45min preload, RPE, TM, TS, TC and AF were recorded every 15mins (i.e. 0, 15, 30, and 45min), and every 15min in the 30min cycling TT (i.e. 0, 15 and 30min).

7.3.9. Statistical analysis

All statistical analysis was completed using SPSS (version 21, IBM Corporation, Armonk, NY). Shapiro-Wilk's test revealed that all physiological and performance data were normally distributed ($P > 0.05$). Variables that were normally distributed were analyzed using a three-way repeated measures ANOVA (group (1 or 2) x condition ((i) thermoneutral with no cooling, (ii) hot with no cooling, (iii) hot with cold-water ingestion, and (iv) hot with cold-water pouring) x time (0,5,10,15,20,25,30,35,40,45min)) to test for significant differences, main and interactions effects at time intervals (preload= 10 blocks (B) of 5min (0,5,10,15,20,25,30,35,40,45min) and TT= 7 blocks (B) of 5min(0,5,10,15,20,25,30min)). Partial eta-squared (η 2) was calculated as a measure of effect size. Values of 0.01, 0.06 and above 0.14 were considered as small, medium and large, respectively (Cohen, 1988). A related samples Friedman's non-parametric test (TM, AF, RPE, TS and TC) was used for data not normally distributed. Bonferroni post hoc pairwise comparisons were used to identify locations of significant effects. Data was considered significant if $p \leq 0.05$. All data are presented as group means ± SD.

7.4. Results

7.4.2. The Effect of Cooling on Performance

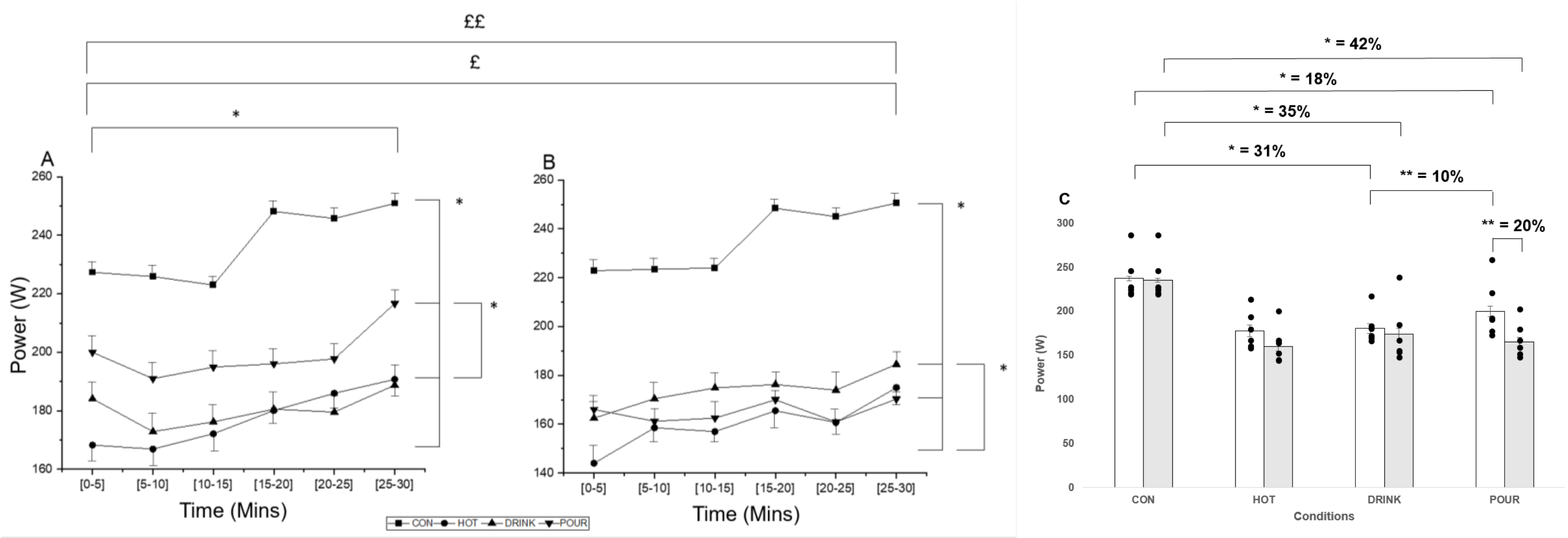


Figure 29. 5min mean±SD power output during 30min cycling time-trial in hot and dry conditions (A) and hot and humid conditions (B). Con = thermoneutral, hot = hot and dry or hot and humid, drink = cold-water ingestion, pour = cold-water pouring, and (C) mean±SD power output during 30min cycling time-trial in hot and dry and hot and humid conditions (white = group 1 (hot and dry), grey = group 2 (hot and humid).

*Panels A&B *on y axis = significant difference between conditions.*

*Panels A&B * on x axis = significant difference over time.*

Panels A&B £ = difference between groups in the hot conditions only.

*Panel C * = difference between conditions within group.*

*Panel C ** = difference between groups in hot condition only*

*Panels A&B *on y axis = significant difference between conditions.*

*Panels A&B * on x axis = significant difference over time.*

Panels A&B £ = difference between groups in the hot conditions only.

*Panel C * = difference between conditions within group.*

*Panel C ** = difference between groups in hot condition only*

Table 30. Mean±SD total distance (km) and power (W) during the 30min cycling time-trial.

Group	**1**				**2**			
Condition	**Thermoneutral**	**Hot**	**Hot with cold-water ingestion**	**Hot with cold-water pouring**	**Thermoneutral**	**Hot**	**Hot with cold-water ingestion**	**Hot with cold-water pouring**
Total Distance Covered (km)	10.60±0.89	9.55±0.62	9.90±0.63	10.21±0.64	10.96±0.89	9.23±0.68	9.93±0.18	9.42±0.22
Power Output (W)	236.86±2.83	177.35±6.68	180.35±5.51	199.40±5.82	235±2.48	160.12±5.43	173.77±6.97	165.16±5.31

7.4.2.1. Power Output in Hot and Dry (Group 1)

There was a significant interaction between condition and time for power output (f (5,50) = 331.095, p = 0.036, n^2 =0.573). There was a significant main effect for time for power output (f (5,50) = 360.800, p = 0.001, η2 = 0.973) with average power output increasing from start to finish (Figure 29). Post-hoc analysis indicated that in control with no cooling, there was a significant difference between B1 (0to5min), B2(5to10min), B3(10to15min) and B4(15to20min), B5(20to25min), B6(25to30min; p=0.046). In cold-water ingestion, there was a significant difference between B1 (0to5min) and B6(25to30min, p=0.003). In cold-water pouring, there was a significant difference between B1 (0to5min) and B2(5to10minp=0.014). In hot with no cooling, there was a significant difference between B1 (0to5min), and B4(15to20min), B5(20to25min), B6(25to30min; p=0.003) showing that power output was greater in the first 5mins compared to 15-25min.

There was a significant difference in power output between conditions (f (3,30) = 4179.291, p = 0.000) and an interaction between condition and time (f (15,50) = 45.910, p =0.000. Post hoc analysis indicated that average power output in control (236.86±1.83W) was significantly greater throughout the TT compared to hot with no cooling (177.35±1.68W, p =0.014; 33%), cold-water ingestion (180.35±1.51W p =0.023; 31%) and POUR (199.40±0.82W p =0.035; 18%;Table 30 and Figure 29 Panel C). Average power output in cold-water pouring (199.40±0.82W) was significantly greater throughout the TT compared to cold-water ingestion (180.35±1.51W, p = 0.023; 10%; Table 30 and Figure 29 Panel C). This inferred that cold-water pouring was more effective at reducing the impairment shown in power output in hot and dry conditions compared to cold-water ingestion.

7.4.2.2. Power Output in Hot and Humid (Group 2)

There was a significant interaction for power output (f (5,50) = 331.095, p = 0.036, n^2 =0.573). There was a significant main effect for time for power output (f (5,50) = 360.800, p = 0.000, η2 = 0.973) with average power output increasing from start to finish (Figure 29). Post hoc analysis indicated that in control with no cooling, there was a significant difference between B1 (0to5min), B2(5to10min), B3(10to15min) and B4(15to20min), B5(20to25min), B6(25to30min; p=0.003). In cold-water ingestion, there was a significant difference between B1 (0to5min) and B6(25to30min, p=0.011). There was no significant difference over time for cold-water pouring (p=0.161). In hot with no cooling, there was a significant difference between B1 (0to5min), and B4(15to20min), B5(20to25min), B6(25to30min; p=0.013).

There was a significant difference in power output between conditions (f (3,30) = 4179.291, p = 0.001) and an interaction between condition and time (f (15,50) = 45.834, p =0.001). Post hoc analysis indicated that average power output in control with no cooling (235±2.48W) was significantly greater throughout the time-trial compared to hot with no cooling (160.12±3.43W p=0.001; 46%), cold-water ingestion (173.77±0.97W, p=0.006; 35%) and cold-water pouring (165.16±1.31W p=0.004; 42%;Table 30 and Figure 29 Panel C). Average power output was significantly greater in cold-water ingestion compared to hot with no cooling at all time points (p = 0.033) except for B6 (25to30min, p=0.054; 8%). However, there was no significant difference between cold-water ingestion and cold-water pouring (173.77±0.97W vs 165.16±1.31W, p=0.760; 4%; Table 30 and Figure 29 Panel C), and cold-water pouring and hot with no cooling (165.16±1.31W vs 160.12±3.43W, p=0.976; 3%; Table 30 and Figure 29 Panel C). Therefore, cold-water ingestion was more effective at reducing the impairment in power output in hot and humid conditions compared to no cooling at all.

7.4.2.3. Power Output in Hot and Dry and Hot and Humid (Group Comparison)

There was a significant interaction between condition and group (f = (3,30) 237.085, p = 0.000), as well as condition, time and group f = (15,150) 11.660, p =0.000). Average power output in the hot and dry (177.35±1.68W) condition was significantly greater compared to hot and humid (160.12±3.43W, p =0.003; 10%). Average power in the hot and dry conditions with cold-water pouring (199.40±0.82W) was significantly greater compared to hot and humid condition with cold-water pouring (165.16±1.31W, p =0.000; 20%; Table 30 and Figure 29 Panel C). There was no significant difference between groups for control with no cooling (236.86±1.83 vs 235±2.48W, p=0.746; 1%) and cold-water ingestion (180.35±1.51 vs 173.77±0.97W, p =0.644; 4%).

7.4.2.4. Distance Covered in Hot and Dry (Group 1)

There was a significant interaction between condition and time for distance covered (f (8,16) = 112.04, p = 0.047, n^2 =0.573).

There was a significant difference between conditions (f (8,16) = 206.83, p = 0.044, n^2 = 0.267). However, the cyclists-triathletes were able to cover a significantly greater distance in control with no cooling compared to hot and dry conditions with no cooling (p=0.046; 10%). This was supported by the greater mean±SD power output values reported in the control conditions compared to hot and dry conditions (Table 30). There was no significant difference between control with no cooling and cold-water ingestion (p=0.634; 7%), and control with no cooling and cold-water pouring (p=0.621; 3%) for distance covered (Table 30). Cyclists-triathletes were able to cover a greater distance in cold-water pouring compared to hot and dry with no cooling, and cold-water ingestion, however there was no significant difference (p=0.645 and p = 0.662; 6 and 3 %;Table 30).

Distance Covered in Hot and Humid (Group 2)

There was a significant interaction between condition and time for distance covered (f (8,16) = 112.04, p = 0.047, n^2 =0.573).

There was a significant difference between conditions (f (8,16) = 203.86, p = 0.042, n^2 = 0.237). Post-hoc analysis indicated that the cyclists-triathletes were able to cover a significantly greater distance in control with no cooling compared to hot and humid with no cooling (p=0.036; 18%), cold-water ingestion (p=0.047; 10%) and cold-water pouring (p=0.041; 16%). This was supported by the greater mean±SD power output values reported in the control with no cooling compared to all hot conditions (Table 30). Cyclists-triathletes were able to cover a greater distance in cold-water ingestion compared to hot and humid with no cooling and cold-water pouring however there was no significant difference between these conditions (p=0.645 and p = 0.662; 7 and 5 %; Table 30).

Distance Covered in Hot and Dry and Hot and Humid (Group Comparison)

There was no significant interaction between condition and group for distance covered (f (8,16) = 112.04, p = 0.198, n^2 =0.573).

The Effect of Cooling on Physiological Responses

7.4.2.5. Rectal Temperature (T_{rectal})

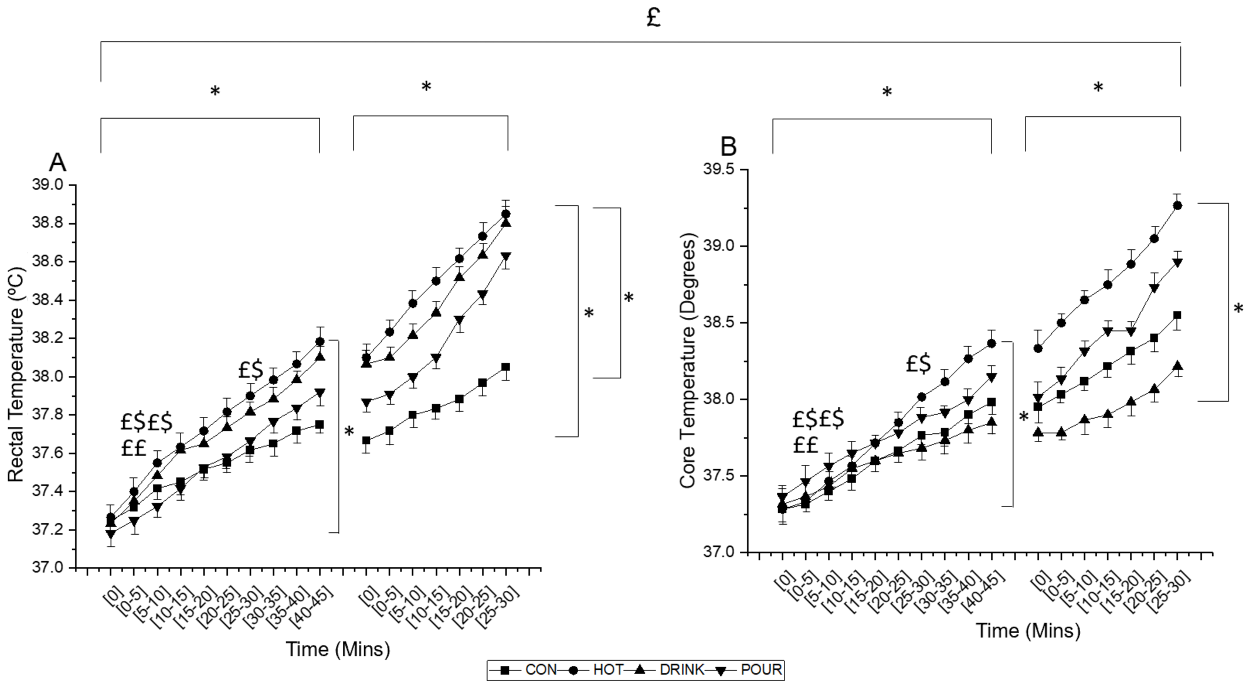


Figure 30. Mean±SD rectal temperature (°C) values during the 45min preload and 30min time-trial in A) hot and dry conditions and B) hot and humid conditions. CON= Control condition, HOT = hot condition with no cooling, DRINK = cold-water ingestion, POUR = cold-water pouring.

** on y axis = Significant difference between conditions.*

** on the x axis = significant difference between conditions over time.*

£ - Significant difference between groups in HOT at all time blocks.

*££ - significant difference in C*ON at time block 2 (0-5min).

£$ - *Significant difference between groups in* DRINK at time block 2(0-5min) and 3(5-10min) and 7(25-30min).

Table 31. Mean±SD rectal temperature (°C) during the preload and time-trial.

Group	**1**				**2**			
Condition	**Thermoneutral**	**Hot**	**Ingestion**	**Pouring**	**Thermoneutral**	**Hot**	**Ingestion**	**Pouring**
Preload	37.5±0.16	37.5±0.28	37.5±0.24	37.7±0.28	37.6±0.19	37.4±0.38	37.7±0.1	37.6±0.1
Time-trial	37.8±0.12	38.49±0.07	38.38±0.14	38.18±0.13	38.2±0.17	38.7±0.09	37.9±0.1	38.4±0.22
Correlation coefficent with power output (significance)	0.66 (0.05)	0.79 (0.03)	0.28 (0.13)	0.14 (0.34)	0.67 (0.05)	0.77 (0.03)	0.63 (0.05)	0.35 (0.57)

Red = low correlation, yellow = moderate correlation, green = strong correlation, blue = very strong correlation

There was a significant interaction for average T_{rectal} (F(6,10) = 2.098, p = 0.006, n^2 =0.523). There was a significant main effect for time where average T_{rectal} increased linearly from the start of the preload to the end of the preload and from the start of the TT to the end of the time-trial in both groups and all conditions (f= (6,10) 2.875, p = 0.000; Figure30).

7.4.3.3.1. Rectal Temperature (T_{rectal}) in Hot and Dry (Group 1)

Post hoc analysis indicated that there was no significant difference in average T_{rectal} between conditions during the pre-load (f= (6,10) 3.563, p>0.053; control with no cooling: 37.7±0.12°C; hot with no cooling: 38.1±0.15°C; cold-water ingestion: 37.7±0.11°C; cold-water pouring: 37.6±0.12°C; Table 31). However, there was a significant difference in T_{rectal} between conditions during the TT (f= (3,10), 52.656, p=0.000). Mean±SD T_{rectal} in control with no cooling (38.05±0.15°C) was significantly lower than hot with no cooling (38.55±0.04°C; p=0.000), cold-water ingestion (38.43±0.13°C; p=0.018) and cold-water pouring (38.23±0.12°C;p = 0.000) at all time points during the TT (p<0.33). Mean±SD T_{rectal} in the hot with no cooling (38.55±0.04°C) was significantly greater compared to cold-water pouring (38.23±0.12°C;p=0.003) but not cold-water ingestion (38.43±0.13°C; p=0.414) at all time points (p<0.35). However, there was no significant difference in T_{rectal} between cold-water pouring and cold-water ingestion (38.23±0.12°C vs 38.43±0.13°C; p=0.121).

There was a positive correlation between core temperature and power output in all conditions, infering that core temperature increased together with the increase in power output (Table 31). The strongest correlation was reported in hot with no cooling (r=0.79). Notably the correlation between core temperature and power output was low for cold-water infegestion and pouring (r=0.28 and 0.14; Table 31).

7.4.3.3.2. Rectal Temperature (T_{rectal}) in Hot and Humid (Group 2)

There was no significant difference in average T_{rectal} between conditions during the pre-load (f= (6,10) 2.875, p>0.056; control with no cooling: 37.75±0.12°C; hot with no cooling: 37.86±0.22°C; cold-water ingestion: 37.64±0.94°C; cold-water pouring: 37.78±0.06°C).

Mean±SD T_{rectal} was significantly greater between 30-35 to 40 to 45 compared to 0 to 35mins in the hot with no cooling condition ($p<0.32$).

There was a significant difference in average T_{rectal} between conditions during the time-trial (control with no cooling: 38.55±0.12°C; hot with no cooling:38.85±0.09°C; cold-water ingestion: 37.97±0.19°C; cold-water pouring: 38.50±0.19°C; $p<0.036$). Drinking cold-water had the greatest benefit on reducing T_{rectal} during the time-trial as this was significantly lower throughout (37.97±0.19°C) compared to control with no cooling (38.55±0.12°C; $p=0.013$), cold-water pouring (38.50±0.19°C; $p=0.000$) and hot with no cooling (38.85±0.09°C $p=0.000$).

There was a positive correlation between core temperature and power output in all conditions infering that core temperature increased together with the increase in power output (Table 31). The strongest correlation was reported in hot with no cooling ($r=0.77$). Notably, the correlation was stronger with cold-water ingestion compared to pouring ($r=0.63$ vs 0.35).

7.4.3.3.3. Rectal Temperature (T_{rectal}) in Hot and Dry and Hot and Humid (Group Comparison)

Notably there was also a difference in average T_{rectal} between groups during the TT (f = (1,10) 15.510, $p = 0.003$). This was in control with no cooling at time point 2 ($p=0.045$), hot with no cooling at all time points ($p<0.040$), cold-water ingestion at time point 2 and 3 and 7 ($p<0.049$). There was no difference in T_{rectal} with cold-water pouring in hot and dry and hot and humid conditions (38.18±0.13 vs 38.4±0.22, $p = 0.253$). However T_{rectal} was significantly greater with cold-water ingestion in hot and dry compared to hot and humid (38.38±0.14 vs 37.9±0.1, $p = 0.044$).

7.4.3.2. Heart Rate

Table 32. Mean±SD (b.min^{-1}; % of HRmax at VO_{2max}) HR during the preload and time-trial.

Groups	**1**				**2**			
Condition	**Thermoneutral**	**Hot**	**Ingestion**	**Pouring**	**Thermoneutral**	**Hot**	**Ingestion**	**Pouring**
Preload	151±10 (79.47%)	167±7 (87.89%)	161±6 (84.73%)	168±5 (88.42%)	158±9 (82.29%)	173±7 (90.10%)	171±6 (89.06%)	172±6 (89.58%)
Time-trial	166±10 (87.36%)	178±8 (93.68%)	173±5 (91.05%)	177±6 (93.15%)	171±8 (89.06%)	182±6 (94.79%)	178±5 (92.70%)	181±4 (94.27%)

There was no significant interaction between condition, group and time for HR (F (8,17 = 3.120, p = 0.346, n^2 =0.401). However, there was a significant main effect for time where average HR increased linearly from the start of the preload to the end of the preload (f (8,17 = 1.444p = 0.038, n^2 =0.489) and from the start of the time-trial to the end of the time-trial in both groups and all conditions (f (8,17 = 1.232, p = 0.034, n^2 =0.426; Table 32).

7.4.3.3.4. Heart Rate (HR) in Hot and Dry (Group 1)

There was no significant difference in mean±SD HR between cooling during the preload (161±6 vs 168±5 b.min^{-1}; f= (8,17) 2.841, p = 0.113, n^2 = 0.402) or time-trial (173±5 vs 172±6 b.min^{-1}; f= (8,17) 2.455, p = 0.256, n^2 = 0.398).

7.4.3.3.5. Heart Rate (HR) in Hot and Humid (Group 2)

There was no significant difference in mean±SD HR between cooling during the preload (171±6 vs 172±6 b.min^{-1}; f= (8,17) 2.930, p = 0.134, n^2 = 0.380) or time-trial (178±5 vs 181±4 b.min^{-1}; f= (8,17) 2.873, p = 0.201, n^2 = 0.357).

7.4.3.3.6. Heart Rate (HR) in Hot and Dry and Hot and Humid (Group Comparison)

There was no significant difference in mean±SD HR between groups for ingestion during the preload (161±6 vs 171±6 b.min^{-1}; f= (8,17) 3.002, p = 0.219, n2 = 0.413) or time-trial (173±5 vs 178±5 b.min^{-1}; f= (8,17) 3.015, p = 0.288, n2 = 0.458).

There was no significant difference in mean±SD HR between groups for pouring during the preload (168±5 vs 172±6 b.min^{-1} ; f (8,17) 2.990, p = 0.202, n2 = 0.405) or time-trial (177±6 vs 181±4 b.min^{-1}; 2.997, p = 0.217, n2 = 409).

7.4.3.4. Hydration Status (Urine Specific Gravity and Sweat Rate)

Table 33. Mean±SD Urine Specific Gravity (USG) and sweat rate (L.hr) values across all experimental trials.

Group	Condition	Urine Specific Gravity	Sweat Rate (L.hr)
1	Thermoneutral	1.005±0.4	1.4±0.4
	Hot with no cooling	1.004±0.3	1.8±0.3
	Cold-water Ingestion	1.004±0.3	1.3±0.3
	Cold-water pouring	1.005±0.3	1.8±0.4
2	Thermoneutral	1.003±0.4	1.2±0.3
	Hot with no cooling	1.004±0.2	1.0±0.2
	Cold-water Ingestion	1.005±0.3	1.1±0.3
	Cold-water pouring	1.004±0.3	0.9±0.1

USG of <1.020 = Euhydrated.

USG of >1.021 = Hypohydrated.

All USG values regardless of group or condition fell between the ranges of 1.001-1.010 which meant that all participants started the experimental trial in a well hydrated/hyper-hydrated state (Table 34). There was no significant difference in USG between conditions or groups (f (8,10) = 2.091, p = 0.236, n= 0.587) which meant that any changes reported in physiological, perceptual or performance were not a result of participants hydration status at the start of the experimental trial.

There was a significant interaction between group and condition for sweat rate (f (8,10) = 1.018, p = 0.35, n=0.679).

7.4.3.3.1. Sweat Rate in Hot and Dry (Group 1)

SR was significantly greater with cold-water pouring compared to cold-water drinking (1.8±0.4 vs 1.3±0.3L.hr; p= 0.003) and no cooling (1.8±0.4 vs 1.4±0.4L.hr; p=0.024). This demonstrates that cold-water pouring offered additional benefits in regard to evaporative cooling in hot and dry conditions. There was no significant difference between hot with no cooling and cold-water drinking (1.4±0.4 vs 1.3±0.3, p = 0.245) which meant that cold-water ingestion did not offer any additional benefit in regard to evaporative cooling in hot and dry conditions.

7.4.3.3.2. Sweat Rate in Hot and Humid (Group 2)

There was no significant difference in SR between ingestion and pouring (1.1±0.3 vs 0.9±0.1Lhr; p = 0.020). However, SR was significantly greater with no cooling compared to pouring (1.2±0.3 vs 0.9±0.1L.hr; p=0.020). This demonstrates that cold-water pouring did not offer an additional benefit in regard to evaporative cooling in hot and humid conditions. There was no significant difference in SR between no cooling and cold-water ingestion (1.2±0.3 vs 1.1±0.3L.hr, p =0.763) which demonstrates that cold-water ingestion offers no additional benefit in regard to evaporative cooling in hot and humid conditions.

7.4.3.3.3. Sweat Rate in Hot and Dry and Hot and Humid (Group Comparison)

Notably, all mean±SD SR were greater in hot and dry compared to hot and humid regardless of cooling type. However, the only significant difference between groups was reported with cold-water pouring, where SR was significantly greater with cold-water pouring in hot and dry conditions compared to hot and humid (1.8±0.4 vs 0.9±0.1L.hr). This demonstrates that cold-water pouring was more beneficial for evaporative heat loss in hot and dry conditions compared to hot and humid conditions.

7.4.4. The Effect of Cooling on Perceptual Responses

7.4.4.1. Perceptual Responses Prior to Experimental Trials

There was no significant difference in participants SMS (instrinstic, amotivation, identified and external regulation) scores between visits within group 1 (p = 0.245), group 2(p = 0.277) or between groups (p = 0.189). This implies that all participants motivation prior to the task was not different and therefore any differences in performance were not a result of differences in motivation prior to task.

Table 34. Mean±SD hours of sleep(hrs), quality of sleep, stress, fatigue and muscle soreness ratings across all trials using Hooper et al., (1995) markers for monitoring overtraining and recovery scale.

Group	**Condition**	**Hours of Sleep (hrs)**	**Sleep quality**	**Stress**	**Fatigue**	**Muscle soreness**
1 – Hot and Dry	Thermoneutral	6.3±0.4	3±0.1	2±0.2	2.2±0.4	1.1±0.1
	Hot with no cooling	6.3±0.6	3.2±0.2	2.2±0.2	2.1±0.5	1.3±0.4
	Cold-water Ingestion	6.4±0.6	3.1±0.1	2.4±0.4	2.2±0.2	1.5±0.5
	Cold-water pouring	6.4±0.6	3.1±0.1	2.2±0.2	2.2±0.2	1.5±0.5
2 – Hot and Humid	Thermoneutral	6.8±0.1	3.6±0.1	3.1±0.1	2.8±0.4	2.4±0.4
	Hot with no cooling	6.8±0.2	3.5±0.1	3.0±0.2	2.7±0.2	2.2±0.5
	Cold-water Ingestion	6.7±0.3	3.5±0.1	2.9±0.1	2.7±0.3	2±0.4
	Cold-water pouring	6.7±0.3	3.6±0.1	3±0.1	2.8±0.2	2.1±0.1

There were no significant interactions between groups or condition for hours of sleep (f (8,30) 2.116, $p = 0.695$, $n^2 = 0.683$), quality of sleep (f (8,30) 2.334, $p = 0.564$, $n^2 = 0.557$), stress (f (8,30) 2.590, $p = 0.424$, $n^2 = 0.649$), fatigue and muscle soreness (f (8,30) 2.527, $p = 0.607$, $n^2 = 0.578$). Therefore, any differences reported in performance, physiological responses or perceptual responses during the experimental trials were not a result of differences in hrs slept, quality of sleep, stress, fatigue or muscle soreness (Table 35).

7.4.4.2. Perceptual Responses During Experimental Trials

Table 35. Mean±SD ratings of perceived exertion (RPE), thermal comfort (TC), thermal sensation (TS), task motivation (TM) and affect (AF) during the 45min preload and 30min cycling time-trial (A.U. (% of max value on the scale).

Variables	Group	Intervention	Preload					Time-Trial						
			0	15	30	45	Mean±SD	0	10	20	30	Mean±SD	Pearsons Correlation coefficient with Power (significance)	Pearsons Correlation coefficient with Core Temperature (significance)
RPE	**1 – Hot and Dry**	Thermoneutral	6±0(0%)	8±1 (14.28%)	10±1(28.57%)	13±2(50%)	10±3(28.57%)	6±0(0%)	11±1(35.71%)	15±1 (64.28%)	18±2 (85.71%)	13±5(50%)	0.32 (0.24)	0.63 (0.07)
		Hot with no cooling	6±0(0%)	10±2(28.57%)	12±3(42.85%)	14±2(57.14%)	12±2(42.85%)	6±0(0%)	12±2(42.85%)	16±1(71.42%)	20±2(100%)	16±2 (71.42%)	0.78 (0.04)	0.98 (0.02)
		Cold-water Ingestion	6±0(0%)	10±2(28.57%)	12±3(42.85%)	14±2(57.14%)	12±2(42.85%)	6±0(0%)	10±2(28.57%)	15±1(64.28%)	18±2(85.71%)	13±3(50%)	0.03 (0.75)	0.74 (0.04)
		Cold-water pouring	6±0(0%)	8±1(14.28%)	10±2(28.57%)	13±2(50%)	10±3(28.57%)	6±0(0%)	10±2(28.57%)	13±2(50%)	15±3(64.28%)	11±4(35.71%)	0.12 (0.66)	0.96 (0.02)
	2 – Hot and Humid	Thermoneutral	6±0(0%)	10±1(28.57%)	13±1(50%)	15±1(64.28%)	11±4(35.71%)	6±0(0%)	12±1(42.85%)	13±1(5)%)	18±2(85.71%)	12±5(42.85%)	0.32 (0.22)	0.53 (0.10)
		Hot with no cooling	6±0(0%)	10±2(28.57%)	14±1(57.14%)	16±2(71.42%)	12±4(42.85%)	6±0(0%)	14±2(57.14%)	16±2(71.42%)	20±0(100%)	14±6(57.14%)	0.52 (0.10)	0.70 (0.03)
		Cold-water Ingestion	6±0(0%)	10±1(28.57%)	13±1(50%)	15±1(64.28%)	12±3(42.85%)	6±0(0%)	12±1(42.85%)	13±2(50%)	18±1(85.71%)	12±5(42.85%)	0.11 (0.69)	0.50 (0.12)
		Cold-water pouring	6±0(0%)	10±2(28.57%)	14±1(57.14%)	16±2(71.42%)	12±4(42.85%)	6±0(0%)	14±2(57.14%)	16±2(71.42%)	20±0(100%)	14±6(57.14%)	0.12 (0.70)	0.77 (0.03)
TC	**1 – Hot and Dry**	Thermoneutral	0±0(0%)	0±0(0%)	0±0(0%)	0±0(0%)	0±0(0%)	0±0(0%)	0±0(0%)	0±0(0%)	0±0(0%)	0±0(0%)	0.00 (0.98)	0.00 (0.98)
		Hot with no cooling	10±0 (50%)	10±1(50%)	12±1 (60%)	15±1(75%)	12±2(60%)	10±0(50%)	15±1(75%)	15±1(75%)	20±1(60%)	15±4(75%)	-0.55 (0.06)	0.81 (0.02)
		Cold-water Ingestion	10±0(50%)	12±1(60%)	12±1(60%)	12±1(60%)	12±1(60%)	10±0(50%)	12±1(60%)	12±1(60%)	10±1(50%)	11±1(55%)	0.20 (0.31)	0.34 (0.25)
		Cold-water pouring	10±0(50%)	10±1(50%)	10±1(50%)	10±1(50%)	10±0(50%)	10±0(50%)	12±1(60%)	12±1(60%)	15±1(75%)	12±2(60%)	0.02 (0.94)	0.38 (0.27)
	2 – Hot and Humid	Thermoneutral	0±0(0%)	0±0(0%)	0±0(0%)	0±0(0%)	0±0(0%)	0±0(0%)	0±0(0%)	0±0(0%)	0±0(0%)	0±0(0%)	0.00 (0.98)	0.00 (0.98)
		Hot with no cooling	10±0(50%)	10±1(50%)	12±1(60%)	15±2(75%)	12±2(60%)	15±1(75%)	20±1(100%)	20±1(100%)	20±1(100%)	19±3	-0.52 (0.06)	0.84 (0.01)
		Cold-water Ingestion	10±0(50%)	12±1(60%)	12±1(60%)	12±1(60%)	12±1(60%)	10±0(50%)	12±1(60%)	12±2(60%)	12±2(60%)	12±1(60%)	0.12 (0.45)	0.35 (0.26)
		Cold-water pouring	10±0(50%)	12±1(60%)	15±1(75%)	15±2(75%)	13±2(65%)	10±0	15±1(75%)	15±2(75%)	15±2(75%)	14±3(70%)	0.18 (0.41)	0.62 (0.05)
TS	**1 – Hot and Dry**	Thermoneutral	10±0(50%)	10±0(50%)	10±0(50%)	12±1(60%)	11±1(55%)	10±0(50%)	10±0(50%)	10±1(50%)	12±1(60%)	11±1(55%)	0.32 (0.25)	0.38 (0.27)
		Hot with no cooling	10±0(50%)	15±1(75%)	15±1(75%)	15±1(75%)	14±3(70%)	10±0(50%)	15±2(75%)	15±2(75%)	16±1(80%)	14±3(70%)	0.35 (0.27)	0.52 (0.06)
		Cold-water Ingestion	10±0(50%)	8±2(40%)	8±2(40%)	8±2(40%)	9±1(45%)	10±0(50%)	8±2(40%)	8±2(40%)	8±2(40%)	9±1(45%)	0.51 (0.06)	0.31 (0.24)
		Cold-water pouring	10±0(50%)	6±1(30%)	6±2(30%)	6±2(30%)	7±2(35%)	10±0(50%)	6±2(30%)	6±2(30%)	6±2(30%)	7±2(35%)	0.02 (0.91)	0.86 (0.01)

	2 – Hot and Humid	Thermoneutral	10±0(50%)	10±0(50%)	10±0(50%)	12±1(60%)	11±1(55%)	10±0(50%)	10±0(50%)	10±0(50%)	12±1(60%)	11±1(55%)	🟥 0.10 (0.87)	🟨 0.38 (0.27)
		Hot with no cooling	10±0(50%)	15±1(75%)	15±1(75%)	17±1(70%)	14±3(70%)	15±2(75%)	15±1(75%)	18±1(90%)	20±2(100%)	17±2(85%)	🟥 0.10 (0.87)	🟨 0.49 (0.07)
		Cold-water Ingestion	10±0(50%)	8±2(40%)	8±2(40%)	8±2(40%)	9±1(45%)	10±0(50%)	8±2(40%)	8±2(40%)	8±2(40%)	9±1(45%)	🟨 0.52 (0.06)	🟥 0.33 (0.22)
		Cold-water pouring	10±0(50%)	12±1 (60%)	12±1 (60%)	12±1 (60%)	12±1(60%)	11±1 (55%)	12(60%)	12(60%)	12(60%)	12±1(60%)	🟨 0.49 (0.07)	🟥 0.32 (0.21)
TM	**1 – Hot and Dry**	Thermoneutral	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	🟥 0.00 (0.98)	🟥 0.00 (0.98)
		Hot with no cooling	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	🟥 0.00 (0.98)	🟥 0.00 (0.98)
		Cold-water Ingestion	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	🟥 0.00 (0.98)	🟥 0.00 (0.98)
		Cold-water pouring	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	🟥 0.00 (0.98)	🟥 0.00 (0.98)
	2 – Hot and Humid	Thermoneutral	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	🟥 0.00 (0.98)	🟥 0.00 (0.98)
		Hot with no cooling	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	🟥 0.00 (0.98)	🟥 0.00 (0.98)
		Cold-water Ingestion	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	🟥 0.00 (0.98)	🟥 0.00 (0.98)
		Cold-water pouring	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	20±0(100%)	🟥 0.00 (0.98)	🟥 0.00 (0.98)
AF	**1 – Hot and Dry**	Thermoneutral	3±1 (81.81%)	3±1(81.81%)	3±1(81.81%)	2±1(72.72%)	3±1(81.81%)	3±1(81.81%)	3±1(81.81%)	2±1(72.72%)	1±1(63.63%)	2±1(72.72%)	🟥 -0.35 (0.19)	🟥 -0.33 (0.22)
		Hot with no cooling	2±1(72.72%)	1±1(63.63%)	0±1(54.54%)	-1±1(45.45%)	1±1(63.63%)	1±1(63.63%)	0±1(54.54%)	-1±1(45.45%)	-2±1(36.36%)	-1±1(45.45%)	🟨 0.40 (0.11)	🟨 -0.45 (0.9)
		Cold-water Ingestion	3±1(81.81%)	3±1(81.81%)	3±1(81.81%)	2±172.72	3±1(81.81%)	2±1(72.72%)	3±1(81.81%)	3±1(81.81%)	2±172.72	3±1(81.81%)	🟨 0.51 (0.06)	🟥 -0.34 (0.22)
		Cold-water pouring	3±1(81.81%)	4±1(90.90%)	4±1(90.90%)	4±1(90.90%)	4±1(90.90%)	3±1(81.81%)	4±1(90.90%)	4±1(90.90%)	3±1(81.81%)	4±1(90.90%)	🟥 0.24 (0.35)	🟩 0.67 (0.05)
	2 – Hot and Humid	Thermoneutral	3±1(81.81%)	3±1(81.81%)	3±1(81.81%)	2±1(72.72%)	3±1(81.81%)	3±1(81.81%)	3±1(81.81%)	3±1(81.81%)	2±1(72.72%)	3±1(81.81%)	🟨 -0.51 (0.06)	🟨 -0.40 (0.11)
		Hot with no cooling	3±1(81.81%)	2±1(72.72%)	1±1(63.63%)	0±1(54.54%)	2±1(72.72%)	1±1(63.63%)	0±1(54.54%)	-1±1(45.45%)	-2±1(36.36%)	-1±1(45.45%)	🟨 0.52 (0.06)	🟩 -0.67 (0.05)
		Cold-water Ingestion	3±1(81.81%)	3±1(81.81%)	3±1(81.81%)	2±1(72.72%)	3±1(81.81%)	2±1(72.72%)	3±1(81.81%)	3±1(81.81%)	2±1(72.72%)	3±1(81.81%)	🟨 -0.52 (0.06)	🟥 0.08 (0.89)
		Cold-water pouring	3±1(81.81%)	2±1(72.72%)	1±1(63.63%)	0±1 (54.54%)	2±1(72.72%)	3±1(81.81%)	2±1(72.72%)	1±163.63	-1±1(45.45%)	1±2(63.63%)	🟥 0.18 (0.64)	🟨 -0.62 (0.05)

RPE = ratings of perceived exertion, thermal sensation = TS, TC = thermal comfort, TM = task motivation, AF = affect. Red = low correlation, yellow = moderate correlation, green = strong correlation, blue = very strong correlation.

7.4.4.2.1. Ratings of perceived Exertion (RPE)

There was significant interaction between group, condition and time (f (8,24), p = 0.011, n^2 = 0.584). There was a main effect for time where ratings of perceived exertion increased from the start of the preload to the end of the preload (f (8,24), p = 0.005, n^2 = 0.782; Table 36) and from the start of the time-trial to the end of the time-trial (f (8,24), p = 0.005, n^2 = 0.702; Table 36).

7.4.4.2.1.1. Ratings of Perceived Exertion (RPE) in Hot and Dry (Group 1)

Ratings of perceived exertion were significantly lower throughout the preload in control with no cooling (10±3(28.57%)) compared to cold-water ingestion (12±2(42.85%)) and hot with no cooling respectively (12±2(42.85%); p = 0.036 and p = 0.036 Table 36). Ratings of perceived exertion were significantly lower throughout the preload in cold-water pouring (10±3(28.57%) compared to cold-water ingestion (12±2(42.85%) and hot with no cooling 12±2(42.85%) respectively (p = 0.032 and p = 0.032; Table 36). There was no significant difference between pouring cold-water and control condition during the pre-load ((10±3(28.57%) vs (10±3(28.57%); p = 0.124; Table 36).

Ratings of perceived exertion were significantly greater in hot conditions (16±2 (71.42%)) compared to control (13±5(50%); p = 0.043), cold-water ingestion (13±5(50%); p = 0.043), and cold-water pouring during the time-trial (11±4(35.71%); p = 0.032; Table 36). Ratings of perceived exertion was significantly lower in cold-water pouring compared to cold-water ingestion during the time-trial (11±4(35.71%) vs 13±5(50%); p = 0.039;Table 36).There was no significant difference between ingesting cold-water and control condition during the time-trial (11±4(35.71%) vs 13±5(50%); p = 0.135).

Ratings of perceived exertion increased together with the increase in core temperature in all conditions (Table 36). The strongest correlations were reported in hot with no cooling (r=0.98) and cold-water pouring (r=0.96).

Ratings of perceived exertion increased together with the increase in core temperature in all conditions (Table 36). The strongest correlations were reported in hot with no cooling (r=0.70) and cold-water pouring (r=0.77), where as thermoneutral, ingestion and pouring were all low correlations (r <0.32; Table 36).

7.4.4.2.1.2. Ratings of Perceived Exertion (RPE) in Hot and Humid (Group 2)

There was no significant difference in mean±SD ratings of perceived exertion between conditions in the preload (p >0.070; Table 36). However, mean±SD ratings of perceived exertion were significantly lower in control with no cooling (12±5(42.85%)) compared to hot with no cooling 14±6(57.14%); p= 0.035; Table 36) and pouring cold-water (14±6(57.14%); p= 0.035;Table 36) during the time-trial. Similarly, mean±SD ratings of perceived exertion were significantly lower in cold-water ingestion (12±5(42.85%)) compared to hot with no cooling (14±6(57.14%); p= 0.034; Table 36) and pouring cold-water (14±6(57.14%); p= 0.034; Table 36) during the time-trial. Whereas there was no significant difference between mean±SD rating of perceived exertion in control with no cooling and cold-water ingestion during the time-trial (12±5(42.85%) vs 12±5(42.85%); p= 0.167; Table 36). There was also no significant difference between hot with no cooling and hot with cold-water pouring during the time-trial (14±6(57.14%) vs 14±6(57.14%); p = 0.235; Table 36).

Ratings of perceived exertion increased together with the increase in core temperature in all conditions (Table 36). The strongest correlations were reported in hot with no cooling (r=0.70) and cold-water pouring (r=0.52), where as thermoneutral, ingestion and pouring were all low correlations (r <0.32; Table 36).

7.4.4.2.1.3. Ratings of Perceived Exertion (RPE) in Hot and Dry and Hot and Humid (Group Comparison)

Mean±SD ratings of perceived exertion were significantly greater during the preload and time-trial with cold-water pouring in hot and humid conditions compared to hot and dry conditions ((12±4(42.85%) vs 10±3(28.57%)); p= 0.012) and (14±6(57.14%) vs 11±4(35.71%); p = 0.014, respectively; Table 36).

There was no significant difference between ratings of perceived exertion with ingestion in hot and dry and hot and humid during the preload (12±3 vs 12±2, p = 0.234) and time-trial (11±4 vs 12±5; p = 0.119).

There was no significant difference between groups (dry vs humid) in the hot condition during the preload (12±2(42.85%) vs 12±4(42.85%); p= 0.246; Table 36). However, ratings of perceived exertion were significantly greater during the time-trial in hot and dry compared to hot and humid conditions (16±2 (71.42%) vs 14±6(57.14%); p= 0.014; Table 36).

7.4.4.2.2. Thermal Comfort (TC)

There was significant interaction between group, condition and time (f (8,24), p = 0.017, n^2 = 0.762). There was a main effect for time where thermal comfort increased from the start of the preload to the end of the preload (f (8,24), p = 0.037, n^2 = 0.654; Table 36) and from the start of the time-trial to the end of the time-trial (f (8,24), p = 0.033, n^2 = 0.681; Table 36).

7.4.4.2.2.1. Thermal Comfort (TC) in Hot and Dry (Group 1)

Mean±SD thermal comfort ratings were significantly lower during the preload and time-trial, respectively in the control condition (0±0(0%) and 0±0(0%)) compared to hot and dry with no cooling (12±2(60%); p = 0.001, and 15±4(75%); p = 0.002), cold-water ingestion (12±1(60%); p = 0.001 and 11±1(55%); p = 0.002), and cold-water pouring (10±0(50%); p = 0.001 and 12±2(60%);p = 0.003; Table 36). In addition, there was no significant difference between thermal comfort with ingestion vs pouring in hot and dry conditions during the preload (11 vs 12, p =0.69).

Mean±SD thermal comfort ratings in hot with no cooling (15±4(75%)) was significantly greater than cold-water ingestion (11±1(55%); p= 0.013) and cold-water pouring (12±2(60%); p= 0.020) during the time-trial (Table 36). However, there was no significant difference in thermal comfort ratings between cold-water ingestion and cold-water pouring (11±1(55%) vs 12±2(60%); p = 0.67; Table 36).

Thermal comfort increased together with the increase in core temperature in all conditions (except thermoneutral) infering that the greater the core temperature the more thermally uncomfortable the athlete felt (Table 36). The strongest correlation was reported in hot with no cooling (r=0.81), however correlation was similar for both ingestion and pouring (r= 0.34 vs r=0.38).

Thermal comfort decreased as power output decreased in hot with no cooling (r=-0.55; Table 36). Notably, ingestion and pouring were both low correlations (r <0.20; Table 36).

7.4.4.2.2.2. Thermal Comfort (TC) in Hot and Humid (Group 2)

Mean±SD thermal comfort ratings were significantly lower during the preload and time-trial, respectively in the control condition (0±0(0%) and 0±0(0%)) compared to hot and humid with no cooling (12±2(60%); p = 0.009, and 19±3(95%); p = 0.007), cold-water ingestion (12±1(60%); p = 0.008 and 12±1(60%); p = 0.011), and cold-water pouring (13±2(65%); p = 0.008 and 14±3(70%); p = 0.009; Table 36).

Mean±SD thermal comfort ratings in hot and humid with no cooling (19±3(95%)) was significantly greater than cold-water ingestion (12±1(60%); p= 0.010) and cold-water pouring (14±3(70%); p= 0.022) during the time-trial (Table 36). Mean±SD thermal comfort ratings were significantly greater with cold-water pouring than cold-water ingestion during the time-trial in hot and humid conditions (14±3(70%) vs 12±1(60%); p = 0.004; Table 36).

Thermal comfort increased together with the increase in core temperature in all conditions (except thermoneutral), infering that the greater the core temperature the more thermally uncomfortable the athlete felt (Table 36). The strongest correlation was reported in hot with no cooling (r=0.84). Notably, the correlation was stronger with cold-water pouring compared to cold-water ingestion (r=0.62 vs 0.35).

Thermal comfort decreased as power output decreased in hot with no cooling (r=-0.52; Table 36). Notably, ingestion and pouring were both low correlations (r <0.18; Table 36).

7.4.4.2.2.3. Thermal Comfort (TC) in Hot and Dry and Hot and Humid (Group Comparison)

There was no significant difference in mean±SD thermal comfort ratings between groups in the control condition (p= 0.376) or cold-water ingestion (p = 0.123) during the preload (Table 36). There was no significant difference in mean±SD thermal comfort ratings between groups in the control condition (p = 0.386) or cold-water ingestion (p=0.135) during the time-trial (Table 36).

Whereas mean±SD thermal comfort ratings were greater with cold-water pouring during the time-trial in hot and humid conditions compared to hot and dry conditions (14±3(70%) vs 12±2(60%); p = 0.021; Table 36). Thermal comfort ratings were significantly higher in hot and humid compared to hot and dry during the preload (15±4(75%) vs 12±2(60%); p = 0.037) and the time-trial (19±3(95%)) vs 12±2(60%)); p = 0.029; Table 36).

7.4.4.2.3. Thermal Sensation (TS)

There was significant interaction between group, condition and time (f (8,24), p = 0.012, n^2 = 0.701). There was a main effect for time where thermal sensation increased from the start of the preload to the end of the preload (f (8,24), p = 0.018, n^2 = 0.796; Table 36) and from the start of the time-trial to the end of the time-trial (f (8,24), p = 0.017, n^2 = 0.713; Table 36). This inferred that the participants felt hotter over time.

7.4.4.2.3.1. Thermal Sensation (TS) in Hot and Dry (Group 1)

Mean±SD thermal sensation ratings were significantly lower with cold-water pouring during the preload and time-trial compared to cold-water ingestion (7±2(35%) vs 9±1(45%); p= 0.047 and 7±2(35%) vs 9±1(45%); p = 0.047), hot with no cooling (7±2(35%) vs 14±3(70%);

p= 0.013 and 7±2(35%) vs 14±3(70%); p=0.013) and control (7±2(35%) vs 11±1(55%); p =0.032 and 7±2(35%) vs11±1(55%); p= 0.032; Table 36).

The greatest mean±SD thermal sensation ratings were reported in hot with no cooling during the preload and time-trial which was significantly greater than control (14±3(70%) vs 11±1(55%); p = 0.037 and 14±3(70%) vs 11±1(55%);p = 0.037), cold-water ingestion (14±3(70%) vs 9±1(45%);p = 0.020 and 14±3(70%) vs 9±1(45%);p= 0.021) and cold-water pouring (14±3(70%) vs 7±2(35%);p = 0.013 and 14±3(70%) vs 7±2(35%);p=0.013; Table 36).

Thermal sensation increased together with the increase in core temperature in all conditions (except thermoneutral), infering that the greater the core temperature the more hot the athlete felt (Table 36). The strongest correlation was reported with cold-water pouring (r=0.86).

Thermal sensation increased together with the increase in power output in all conditions (Table 36). The strongest correlation was reported with cold-water ingestion (r=0.51). Notably, the correlation was very low with cold-water pouring (r=0.02) suggesting that this cooling method was effective for reducing thermal sensation (i.e. felt cooler) despite the increase in power output (i.e. greater physiological strain).

7.4.4.2.3.2. Thermal Sensation (TS) in Hot and Humid (Group 2)

Mean±SD thermal sensation ratings were significantly lower with cold-water ingestion during the preload and time-trial compared to cold-water pouring (p= 0.032 and p=0.032), hot with no cooling (p=0.012 and p=0.019) and control (p =0.044 and p=0.043; Table 36).

The greatest mean±SD thermal sensation ratings were reported in hot with no cooling during the preload and time-trial which was significantly greater than control (14±3(70%) vs 11±1(55%); p = 0.027 and 17±2(85%) vs 11±1(55%);p = 0.021), cold-water ingestion (14±3(70%) vs 9±1(45%); p=0.012 and 17±2(85%) vs 9±1(45%); p=0.019) and cold-water pouring (14±3(70%) vs 12±1(60%); p = 0.025 and 17±2(85%) vs 12±1(60%); p=0.025; Table 36).

Thermal sensation increased together with the increase in core temperature in all conditions (except thermoneutral), infering that the greater the core temperature the more hot the athlete felt (Table 36). The strongest correlation was reported in hot with no cooling (r=0.49). Notably, the correlation was similar between core temperature and cold-water ingestion and cold-water pouring (r=0.33 vs 0.32).

Thermal sensation increased together with the increase in power output in all conditions (Table 36). The strongest correlation was reported with cold-water ingestion (r=0.51). Notably, the correlation was similar for cold-water ouring (r=0.49).

7.4.4.2.3.3. Thermal Sensation (TS) in Hot and Dry and Hot and Humid (Group Comparison)

There was no significant difference in mean±SD thermal sensation ratings between groups (dry vs humid) during the preload and the time-trial in control ((11±1(55%) vs 11±1(55%); p = 0.178 and (11±1(55%) vs 11±1(55%); p = 0.178) or cold-water ingestion (9±1(45%) vs 9±1(45%); p = 0.123 and 9±1(45%) vs 9±1(45%); p = 0.123;Table 36).

There was no significant differences between groups in hot (dry vs humid) conditions during the preload (14±3(70%) vs 14±3(70%); p = 0.231; Table 36). However, thermal comfort ratings were significantly higher in hot and humid compared to hot and dry during the time-trial (17±2(85%) vs 14±3(70%); p = 0.037; Table 36).

Mean±SD thermal sensation ratings were greater during the preload and time-trial with cold-water pouring in hot and humid conditions compared to hot and dry conditions (12±1(60%) vs7±2(35%); p = 0.009 and 12±1(60%) vs 7±2(35%); p = 0.009; Table 36).

7.4.4.2.4. Task Motivation (TM)

There was no significant interaction between group, condition and time for task motivation (f (8,24), p = 0.328, n^2 = 675). This infers that the participants were highly motivated (20±0 (100%); Table 36) throughout the preload and the time-trial regardless of intervention (i.e. cooling) or condition (i.e. hot vs con or dry vs humid). Therefore, any differences found in physiological responses or performance data were not a result of differences in participants task motivation.

Notably there was no correlation between the core temperature and motivation, power output and motivation because motivation remained unchanged (highly motivated as stated above) in all conditions (r=0.00; Table 36).

7.4.4.2.5. Affect (AF)

There was significant interaction between group, condition and time (f (8,24) = 1.023, p = 0.024, n^2 = 0.756). There was a main effect for time where affect increased or decreased from the start of the preload to the end of the preload (f (8,24) = 1.005, p = 0.037, n^2 = 0.617; Table 36) and from the start of the time-trial to the end of the time-trial (f (8,24), p = 0.032, n^2 = 0.645; Table 36).

7.4.4.2.5.1. Affect (AF) in Hot and Dry (Group 1)

Mean±SD affect ratings were significantly lower in hot and dry with no cooling during the preload and the time-trial compared to cold-water ingestion (1±1(63.63%) vs 3±1(81.81%); p = 0.0.21 and -1±1(45.45%) vs 3±1(81.81%);p = 0.016), cold-water pouring (1±1(63.63%) vs 4±1(90.90%);p = 0.007 and -1±1(45.45%) vs 4±1(90.90%);p = 0.001) and control (1±1(63.63%) vs 3±1(81.81%);p = 0.022 and -1±1(45.45%) vs 2±1(72.72%);p=0.038; Table 36).

The greatest mean±SD affect ratings were reported in cold-water pouring during the preload and time-trial which was significantly greater than control (4±1(90.90%) vs 3±1(81.81%); p = 0.027 and 2±1(72.72%) vs 4±1(90.90%) vs p = 0.028) and hot with no cooling (4±1(90.90%) vs 1±1(63.63%);p = 0.007 and 4±1(90.90%) vs -1±1(45.45%); p = 0.001; Table 36).

However, there was no significant difference between cold-water ingestion and cold-water pouring for the preload or time-trial (3±1(81.81%) vs 4±1(90.90%); p = 0.078 and 3±1(81.81%) vs 4±1(90.90%); p =0.080; Table 36).

As core temperature increased, AF decreased (felt worse) in all conditions except for cold-water pouring (Table 36). As core temperature increased, AF increased (felt better) with cold-water pouring (R=0.67). This may suggest that this cooling strategy masked the physiological strain (i.e. increase in core temperature).

Affect increased together with the increase in power output in all conditions except thermoneutral where affect decreased together with the decrease in power output (Table 36). The strongest correlation was reported with cold-water ingestion (r=0.51). Notably, the correlation was similar for hot with no cooling (r=0.49).

7.4.4.2.5.2. Affect (AF) in Hot and Humid (Group 2)

There was no significant difference in AF with ingestion vs pouring in the preload (3±1 (81.81%) vs 2±1 (72.72%); p = 0.91). However, AF was significantly higher (felt better) with ingestion compared to pouring ((3±1 (81.81%) vs 1±1 (63.63%); p = 0.03) in the time-trial.

However, mean±SD affect ratings were significantly lower during the time-trial in hot and humid conditions with no cooling compared to control (p = 0.022), cold-water ingestion (p = 0.022) and cold-water pouring (p = 0.39; Table 36). There was no significant difference between mean±SD affect ratings during the time-trial in control and with cold-water ingestion (p = 0.244). Therefore, the stimulus from the cold-water ingestion was effective at increasing affect ratings to the same as those rated in control conditions.

As core temperature increased, AF decreased (felt worse) in all conditions except for cold-water ingestion where there was no correlation (Table 36). The strongest correlation was reported in hot with no cooling (r=-0.67) which was similar to correlation values reported with cold-water pouring (r=-0.62).

Affect increased together with the increase in power output in hot with no cooling and with cold-water pouring whereas, affect decreased together with the decrease in power output in thermoneutral and with cold-water ingestion (Table 36). The strongest correlation was reported with cold-water ingestion (r=-0.52). Notably, the correlation was low for cold-water pouring (r=0.18).

7.4.4.2.5.3. Affect (AF) in Hot and Dry and Hot and Humid (Group Comparison)

There was no significant difference in mean±SD affect ratings between groups (Dry vs Humid) during the preload or time-trial for cold-water ingestion (3±1(81.81%) vs 3±1(81.81%); p = 0.396 and 3±1(81.81%) vs 3±1(81.81%)p = 0.396) and control (3±1(81.81%) vs 2±1(72.72%); p = 0.391 and 3±1(81.81%) vs 3±1(81.81%)p = 0.377; Table 36). There was no significant difference in mean±SD affect ratings between groups (dry vs humid) in hot during the preload (1±1(63.63%) vs -1±1(45.45%); p = 0.069; Table 36). However hot and humid had a significantly lower rating of affect during the time-trial compared to hot and dry (2±1(72.72%) vs -1±1(45.45%); p = 0.39; Table 36).

Mean±SD affect ratings were significantly greater during the preload and the time-trial with cold-water pouring in hot and dry and hot and humid conditions (4±1(90.90%) vs 2±1(72.72%);p = 0.012 and 4±1(90.90%) vs 1±2(63.63%);p = 0.009;Table 36).

7.5. Discussion

7.5.1. Main findings

- Power output was significantly greater (10%) with cold-water pouring compared to cold-water ingestion in hot and dry conditions. These performance differences occurred irrespective of no changes in rectal temperature or thermal comfort. However percpetual thermal strain was reduced for ratings of perceived exertion with cold-water pouring.
- There was no significant differences (4%) in power output between cold-water ingestion and pouring in hot and humid conditions. This result occurred despite a reduced physiological thermal strain (i.e. rectal temperature) with cold-water ingestion compared to pouring. However perceptual thermal strain (i.e. thermal comfort) was the same in both conditions. These findings suggest that the optimal cooling strategy in hot and humid conditions is still unknown.
- Power output was signfiicantly greater (10%) with cold-water pouring in hot and dry compared to hot and humid. This was accompanied by no differenced in physiological thermal strain (i.e. rectal temperature) but a reduced percpetual thermal strain (i.e. thermal discomfort) in hot and humid compared to hot and dry.

7.5.2. The Effect of Cooling on Performance Responses in Hot and Dry

Power output was significantly greater with cold-water pouring (199.40±5.82W) compared to cold-water ingestion (180.35±5.51W) in hot and dry conditions (10%). As outlined in the introduction, there is a difference between internal and external cooling. Cooling via cold-water pouring is linked to direct conduction (cold-water on skin), and convective (relies on the water being poured to be evaporated into the surrounding environment) pathways. This enables the removal of heat by the water temperature (direct) and evaporation (indirect) and subsequent circulation of the cooler peripheral blood to central regions of the body to reduce rectal temperature (Jay and Morris, 2018). To date, no studies have investigated the same method employed in this study (i.e. cold-water pouring in a laboratory setting) for comparison. A similar method that has been investigated in the literature is face spraying/dousing (Stevens et al., 2017). Stevens et al., (2017) found 3% performance benefit during a 5km running time-trial with cold water spray on the face (every 1km) during hot and dry conditions (33°C, 46% and 15km.h^{-1}).

Notably, in the current study performance differences were found regardless of no significant difference in mean±SD rectal temperature during the time-trial between cold-water pouring (38.18±0.13°C) and cold-water ingestion (38.38±0.14°C). Stevens et al., (2017) also found no significant differences in core temperature with and without facial water spray every 1km during a 5km time-trial in hot and dry conditions. These findings suggest that per-cooling via these cooling methods were not suffient enough to cause changes in rectal temperature. This infers that the performance differences between cooling strategies were not a result of differences in core temperature during the time-trial. Notably, Stevens et al., (2017) did find a significant difference in skin temperature at the site of cooling (i.e. forehead). Based on Schlader et al., (2011) findings, a reduction in skin temperature is linked with higher selection of exercise intensity at the start of exercise. Skin temperature was not measured in the current study but it could be hypothesised that this could explain the greater starting intensity exhibited in the cold-water pouring trial compared to ingestion in Figure 29 Panel A.

This was supported by a reduced percpetual strain experienced with cold-water pouring. For example, mean±SD ratings of perceived exertion were greater with cold-water ingestion (13±3(50% of max)) compared to cold-water pouring (11±4(35.71% of max)), inferring that participants felt like they were exerting more effort whilst ingesting water compared to pouring. Therefore, cold-water pouring was effective for reducing mean±SD ratings of perceived exertion during a 30min cycling time-trial in hot and dry conditions. This may explain why participants were able to provide a greater power output with cold-water pouring (199.40±5.82W) compared to cold-water ingestion (180.35±5.51W). However, the greater power produced and subsequent metabolic heat production with cold-water pouring may have contributed to a greater thermal discomfort (12±2(60% of max)) compared to ingestion (11±1(55% of max)). Therefore there seems to be a trade off in heat storage between reduction in perceptual strain and exercise intensity exerted/produced. Notably, Stevens et al., (2017) did not measure ratings of perceived exertion or thermal comfort but they did measure thermal sensation. They found that facial water spray every 1km during a 5km time-trial in hot and dry conditions reduced thermal sensation (i.e. felt cooler).

7.5.3. The Effect of Cooling on Performance Responses in Hot and Humid

There was no significant difference in power output between cold-water ingestion and cold-water pouring (173.77±0.97W vs 165.16±1.31W, p=0.760; 5%). This result occurred despite a reduced physiological thermal strain (i.e. rectal temperature) with cold-water ingestion compared to pouring. Notably, there have been discrepancies within the literature regarding whether cold-water ingestion can successfully reduce core body temperature. Differences in findings are a result from differences in dosage provided (i.e. temperature, quantity and timing). As discussed in section 2.5, Carvalho et al., (2016) found no difference in 40km cycling time-trial completion time when cold-water (10°C) was consumed ad libitum and scheduled in hot and humid conditions. Power output was not reported in Carvalho et al., (2016) study and therefore cannot be directly compared to the current study. However, more cold-water was ingestion (1.1 ± 0.4L) was consumed in Carvalho et al., (2016) study compared to the 750mL ingested in the current study and the temperature of the water was higher (10°C) compared to the current study (4°C). Therefore two conclusions can be drawn based on methodology; 1) the temperature of the water in Carvalho et al., (2016) study was not cold enough to elicit a a significant reduction in thermal strain (i.e. rectal temperature) and performance impairment in completion time, 2) the amount of water consumed in the current study was not enough to elicit any performance benefits.

Despite no differences in performance, cold-water ingestion was effective at reducing ratings of perceived exertion compared to pouring (12±5(42.85%) vs 14±6(57.14%)) in hot and humid conditions. This inferred that cyclists felt like they were exerting less effort with cold-water ingestion compared to pouring even though they were exerting a similar effort in with both cooling strategies.

As discussed above skin temperature was not measured in the current study. However, if there was no significant differenced reported in skin temperature at the start of the time-trial then starting exercise intensity would be similar with both cooling strategies which matches values reported in Figure 29 panel B. Therefore, these findings suggest that the optimal cooling strategy in hot and humid conditions is still unknown and future research in this area should focus on using per-cooling strategies that elicit alterations in skin temperature.

7.5.4. The Effect of Cooling on Performance Responses in Hot and Dry and Hot and Humid

There was no significant difference in power output with cold-water ingestion in hot and dry compared to hot and humid (180.35±1.51 vs 173.77±0.97W, p =0.644). No performance differences occurred regardless of a reduced thermal strain (i.e. rectal temperature) with cold-water ingestion in hot and humid compared to hot and dry (37.9±0.1 vs 38.38±0.14, p = 0.044). This may have been a result of similar perceptual thermal strain (i.e. thermal comfort). There was no significant difference in thermal comfort with cold-water ingestion in hot and dry and hot and humid conditions (11±1(55%) vs 12±1(60%), p=0.135). To date no studies have compared per-cooling via cold-water ingestion during cycling in hot and dry compared to hot and humid conditions and therefore the findings of the current study cannot be directly compared. Based on previous findings that have investigated per-cooling via cold-water ingestion in either hot and dry or hot and humid conditions, the concensis is that there are mixed results in terms of its effectiveness in reducing rectal temperature which are dependant on doseage. As a result of this majotity of literature in the area reports no changes in performance (Carvalho et al., 2016) or small changes (2.5%; Maunder et al, 2016). As highlighted in the second literature review, more research into cold-water ingestion is needed to find the optimal dosage to elicit physiological alternations (i.e. reduce core temperature and maintain the reduction in core temperature throughout an exercise bout).

Whereas, power output was significantly greater with cold-water pouring in hot and dry compared to hot and humid (199.40±0.82 vs 165.16±1.31W, $p = 0.000$; 20%). This performance differenced occured regardless of no differences in physiological thermal strain (i.e. rectal temperature). For example, there were no signfiicant differences in rectal temperature with cold-water pouring in hot and dry compared to hot and humid (38.18±0.13 vs 38.4±0.22, $p = 0.253$). Therefore the performance difference was not a result of differences in rectal temperature. An alternative reason for the performance difference may be related to a reduction in perceptual thermal strain (i.e. thermal comfort). For example, mean±SD thermal discomfort ratings were greater with cold-water pouring during the time-trial in hot and humid conditions compared to hot and dry conditions (14±3(70%) vs 12±2(60%);Table 36). This inferred that the cyclists' felt more uncomfortable with cold-water pouring in hot and humid conditions compared to hot and dry conditions. This may have been linked to the environmental conditions as previously stated, hot and humid conditions have a greater water vapour content compared to hot and dry conditions which impairs sweat evaporation and contributes to a greater heat storage and subsequent greater thermal discomfort.

7.5.5. Limitations and Perspectives

- A typical repeated measures study design was not used (e.g. same participants completed all conditions). An interdependent repeated measures design was selected as (i) it was not deemed practical for participants to visit the laboratory 9 times and (ii) to minimise a heat acclimation effect from 6/10 trials in hot conditions (Moss et al., 2020).
- Due to equipment failure with skin temperature no skin temperature values could be presented. This meant that mean body temperature (Tb) could not be calculated using the formula from Colin et al. (1971) $\triangle Tb = 0.8 \times (\triangle Tre) + 0.2 \times (\triangle T_{sk}) + 0.4$. As a result of this heat storage could not be calculated using the formula described by Adams et al. (1992) heat storage = $0.965 \times m \times \triangle Tb/AD$, where 0.965 is the specific

heat storage capacity of the body (W/kg/°C), m is the mean body mass (kg) over the duration of the trial, and AD is the body surface area (m2): AD = 0.202 × m0.425 × height$^{0.725}$. In addition, measuring skin temperature would have allowed us to explore another mechanistic avenue. For example, Sawka et al., (2012) found that elevated skin temperature alone may impair aerobic performance such as self-paced cycling. This occurs as hot skin narrows the core to skin temperature gradient which increases peripheral thermoregulatory blood flow requirements and in turn circulatory strain, reducing cardiac filling and elevating heart rate for a given cardiac output (Cheuvront et al., 1985). The increased cardiovascular strain associated with high skin temperatures may contribute to modulate performance in advance of a rise in core body temperature (i.e. hyperthermia).

7.6. Conclusion

Cold-water pouring provided a greater ergogenic effect on 30min cycling time-trial performance in HD conditions compared to cold-water ingestion which was accompanied by physiological benefits. There was no difference in performance with cold-water ingestion compared to pouring in hot and humid conditions and therefore the optimal cooling strategy in this condition is still unknown.

7.7. Importance of findings for subsequent chapter and thesis

The findings of the current study have highlighted that:

- Internal per-cooling via cold-water ingestion should be utilised during cycling in HH conditions to reduce elevated physiological (i.e. rectal temperature) and pereptual thermal strain (i.e. thermal discomfort and ratings of perceived exertion) compared to no cooling in HH. However, the dosage should be investigated further as no performance benefits were reported with cold-water ingestion compared to cold-water pouring in HH.

- External per-cooling via cold-water pouring should be utilised during cycling in HD conditions compared to cold-water ingestion to reduce impairments in power output and percpetual strain (i.e. thermal discomfort and ratings of perceived exertion). Notably, cold-water pouring resulted in significant differences in physiological thermal strain experienced.
- No differences in power output were reported with internal per-cooling via cold-water ingestion in HD compared to HH. This result occurred despite a reduced physiological thermal strain (i.e. rectal temperature) in HH compared to HD. However perceptual thermal strain (i.e. thermal comfort) was the same in both conditions.
- Power output was signfiicantly greater with external per-cooling via cold-water pouring in HD compared to HH. This was accompanied by no differenced in physiological thermal strain (i.e. rectal temperature) but a reduced percpetual thermal strain (i.e. thermal discomfort) in HH compared to HD.
- This information should be used to inform coaches and athletes on what type (external vs internal) per-cooling strategies to use during major sporting events that take place in countries with hot environmental conditions (HD vs HH).

Chapter 8. General discussion

8.1. Thesis Aims and Main Findings

The overall aim of this thesis was to investigate the effect of cold-water ingestion and cold-water pouring on 30min cycling time-trial performance in HD, and HH conditions. To do this, a narrative review (chapter 2) was first completed to identify common trends (i.e. thermal stress and strain) within the literature. The review highlighted that (i) a range of hot conditions (i.e. ambient temperatures and humidities) have been utilised to investigate the effect of hot conditions on cycling performance, (ii) hot and dry and hot and humid conditions provide a different thermal stress (i.e. humidity level) and therefore result in different thermal strain (i.e. physiological and perceptual) experienced by an athlete, (iii) few studies have compared the effect of HD and HH on cycling performance in the same study (i.e. often only one condition is investigated) and therefore it is difficult to form firm conclusions on the thermal stress and strain. Therefore, the first aim of the thesis was to charactise the effect of HD and HH conditions on cycling time-trial performance (Study 2). Before exploring the first aim of the thesis it should be noted that an additional finding was noted in the narrative review which highlighted that different quantities of visual feedback have been utilised in previous literature. Therefore, the pilot study (chapter 4) submitted as part of this thesis highlighted that experienced cyclists 30min cycling time-trial performance was impaired with multiple feedback (elapsed distance, elapsed time, power output, cadence, speed and heart rate) compared to single feedback (elapsed time only). This finding was/is vital in understanding cycling performance and to inform future methodologies investigating cycling performance (including study 2 and 4 included as part of this thesis).

The findings from study 2 (Chapter 5) showed that (i) cycling performance is significantly impaired in hot and dry, and hot and humid conditions compared to thermoneutral conditions which supports previous findings (Racinais et al., 2015), (ii) cycling performance is significantly impaired in hot and humid compared to hot and dry conditions, (iii) both impairments were accompanied with a significantly greater increase in rectal temperature and thermal discomfort. These findings demonstrate that training and/or competing in (i) HD and HH conditions compared to thermoneutral will result in performance impairments (i.e. which could mean missing out on a potential medal placing), and (ii) HH conditions will cause a greater performance impairment compared to HD conditions. The greater impairment in HH conditions is linked to the greater water vapour content in the air in comparison to HD, which impairs sweat evaporation and contributes to a greater heat storage and subsequent greater thermal discomfort. Therefore, a means for alleviating this heat related performance impairments is needed in both HD and HH compared to thermoneutral, and these methods may have to be different to account for the difference in thermal stress and strain experienced.

Athletes and coaches use heat alleviation strategies prior to and during training and/or competitions in hot conditions to alleviate performance impairments and reduce the risk of heat related illnesses (Gibson et al., 2020). Therefore, the second aim of the thesis was to determine (i) which heat alleviation strategy cyclists-triathletes currently employ during training and/or competitions in hot conditionsm (HD and HH), (ii) when cyclists-triathletes apply them, (iii) why cyclists-triathletes use this strategy, and (iv) the percieved effectiveness of these strategies at minimising performance impairments and heat related illnesss. To do this, an online questionnaire was created and follow up interviews were conducted. The findings of study 3 (Chapter 6) highlighted that 60% of cyclistst‑triathletes per-cooling strategies differ depending on condition (hot and dry vs hot and humid), whereas the other 40% used the same per-cooling strategies regardless of condition (hot and dry vs hot and humid). Cold-water ingestion was the most employed strategy in hot and dry, whereas a combination of cold-water ingestion and pouring was the most employed strategy in hot and humid. These findings supported Racinais et al., (2020) study, showing that 93% of athletes competing at the DOHA 2019 IAAF World Athletics Championships (hot and dry conditions) employed per-cooling. 65% used head/face water dousing/pouring and 52% used cold-water ingestion. The timing of application in study 3 was pre-planned based on distance in both conditions, which was supplemented with how participants felt during and when pit stops are available in hot and dry, and how participants felt during in hot and humid. The prevailing justifications for type and timing of strategies was previous experience/perceived effectiveness (i.e. trial and error). There was no difference in perceived effectiveness of the strategies (time and timing combined) employed in HD and HH. 57% (N=12) of the overall 60% (N=21) = 3/5 ("Sometimes effective and sometimes not effective" and 43% (N=9) of the overall 60% (N=21) = 4/5 ("effective for minimizing performance impairments but not heat related illnesses") for both conditions.

Based on study 3 (Chapter 6) findings, Study 4 (chapter 7) investigated the effect of cold-water ingestion and cold-water pouring on cycling time-trial performance in hot and dry and and hot and humid conditions. The findings showed that power output was significantly greater with cold-water pouring compared to cold-water ingestion in hot and dry conditions. These performance differences occurred irrespective of no changes in rectal temperature or thermal comfort. However, percpetual thermal strain was reduced for ratings of perceived exertion. These findings contradict strategies that are currently used by cyclists-triathletes in HD (reported in study 3, chapter 6). For example, cyclists-triathletes selected cold-water ingestion as their main per-cooling strategy in HD which was based on perceived effectiveness. However, study 4 has shown that cold-water pouring provides a reduced performance impairment and percpetual thermal strain compared to cold-water ingestion in HD. Cold-water pouring promotes heat loss via evaporation as water will sit on the skin surface (i.e. head, neck and back) and readily evaporate into the surrounding environment (Morris and Jay , 2016). Therefore, the cyclists-triathletes in study 3 are currently not employing the most effective per-cooling strategy for cycling time-trial performance in HD conditions.

There were no differences in power output between cold-water ingestion and pouring in hot and humid conditions. This finding occurred despite a reduction in rectal temperature with cold-water ingestion compared to pouring. This therefore suggests that the reduction in rectal temperature with cold-water ingestion was not sufficient enough to elicit any performance benefits. This has been supported in the literature with descripenses on whether cold-water ingestion is successful at reducing core temperature (literature review 2). This has resulted from a range of different methodologies/dosages that have been used (i.e. temperature, frequency, magnitude). Cyclists-triathletes in study 3 reported using a combination of cold-water ingestion and cold-water pouring in hot and humid conditions which was not investigated in study 4 and therefore perceived effectiveness vs actual effectiveness at reducing thermal strain cannot be directly compared. Based on study 4 findings, cold-water ingestion alone was not sufficient to elicit any performance benefits in comparison to cold-water pouring alone. However as previously stated cold-water pouring promotes heat loss via evaporation, and in hot and humid conditions sweat/water on the skin surface cannot be evaporated as readily as it can in hot and dry conditions (Morris and Jay, 2016). Therefore if cold-water ingestion and pouring were used incombination during a cycling time-trial in hot and humid conditions it would be practical to suggest that the pouring aspect of the cooling would not elicit any physiological benefits as evaporative cooling would be limited. If anything only perceptual benefits would occur linking to previous findings of Stevens et al., (2017) who found that despite no reductions in core temperature, face water spray every 1km reduced thermal sensation (i.e. felt cooling) during a 5km running time-trial in hot and humid conditions. Notably, Stevens et al., (2017) found a significant improvement in 5km completion time with face water spray compared to no face water spray which contributed to a reduction in skin temperature at the cooling site (i.e. forehead) and subsequent reduction in thermal sensation and selection of a higher exercise intensity at the start of the time-trial. Notably, skin temperature was not measured in study 4 and therefore no firm conclusions can be made in regard to it’s affect on performance differences. However, as stated in study 4, it could be hypothesised that the greater starting intensity exhibited with cold-water pouring compared to ingestion in hot and dry conditions (Figure 29 Panel A) may have resulted from a reduction in skin temperature and subsequent reduction in perceptual strain. Similarly, starting intensity was similar with both cooling strategies in hot and humid conditions (Figure 29 Panel B) which may suggest that there was no significant differences in skin temperature which subsequently explain why no differences occurred in the overall performance. Therefore, these findings suggest that the optimal cooling strategy in hot and humid conditions is still unknown and future research in this area should focus on using per-cooling strategies that elicit alterations in skin temperature. Whereas, cold-water pouring should be utilised during cycling time-trials in hot and dry conditions compared to cold-water ingestion.

In the group comparison, there were no significant differences in power output with cold-water ingestion in hot and dry and hot and humid conditions. This result occurred despite a reduced physiological thermal strain (i.e. rectal temperature) in hot and humid compared to hot and dry. Despite differences in rectal temperature, perceptual thermal strain (i.e. thermal comfort) was the same in both conditions. This finding suggests that the dose of cold-water ingestion was not sufficient enough to provide a reduction in thermal strain (both physiological and perceptual) to elicit performance benefits. Whereas, power output was signfiicantly greater with cold-water pouring in hot and dry compared to hot and humid. This was accompanied by no differences in physiological thermal strain (i.e. rectal temperature) but a reduced percpetual thermal strain (i.e. thermal discomfort). This finding suggests that the dose of cold-water pouring was sufficient enough to elicit a performance benefit without reductions in physiological thermal strain. As previously stated skin temperature was not measured in study 4 and therefore we cannot conclude as to whether skin temperature was reduced which may have contributed to the performance benefits found in hot and dry compared to hot and humid condition with cold-water pouring.

Collectively, per-cooling may disrupt pacing strategies (i.e. produce greater power output as a result of allievated thermal discomfort or ratings of perceived exertion at the start or throughout a cycling time-trial) and/or impair the ability to self-detect physiological thermal strain (i.e. increase in rectal temperature) which may put an athlete at a greater risk of heat related illnesses (Racinais and Periard, 2020, pp. 152).Therefore, optimal per-cooling strategies should aim to alleviate both physiological and perceptual thermal strain, and not just perceptual as seen in study 4 with cold-water pouring in hot and dry conditions.

8.2. Real-world Availability and Application of Cooling

The findings of the current thesis contribute to the understanding of how cycling performance is influenced by feedback (quantity), hot conditions (HD vs HH) and per-cooling (cold-water ingestion and pouring). The following guidelines can be used by cyclists-triathletes and coaches to improve cycling performance:

- Use single visual feedback (time only) during training and/or competion compared to multiple feedback (i.e. elapsed distance, time, speed, power, heart rate, cadence).
- Consider the difference in thermal stress between hot and dry and hot and humid conditions before training and/or competion.
- The type (internal vs external) of per-cooling should depend on the condition you are competing in (HD vs HH).
- Cold-water pouring provides a reduced performance impairment and percpetual thermal strain in HD compared to cold-water ingestion. However, this dose (4°C of 150mL targeted at the head, neck and shoulders every 15min during the preload and every 10min during the time-trial) was not sufficient to reduce physiological thermal strain and therefore the optimal strategy has not yet been determined.

- There were no differences in power output between cold-water ingestion and pouring in hot and humid conditions. Therefore the optimal strategy to be utilised in hot and humid conditions is still unknown.

8.3. Limitations

The methodology, findings and interpretations of the experimental studies within this thesis naturally include limitations. These limitations are outlined below:

- Across all experimental studies composed within this thesis, participants were instructed to refrain from caffeine and alcohol for ≥48hr prior to each experimental trial and maintain a habitual diet whilst enrolled onto the study, as described in Chapter 3 (General Methods). Although advised to maintain their diet, the total daily calorie intake and meal timing may have varied between participants.
- Physical activity outside of experimental trials/exercise sessions were quantified in terms of work completed (kj). Although unlikely, there is potential that participants may have increased their calorie intake or became more/less active during their time spent enrolled onto a study, which could have impacted the findings reported regardless of the extent of advice given by the investigators (particularly study 1,2 and 4).
- It has been demonstrated that a ~20% difference in body fat percentage is sufficient to independently yield ~0.2-0.3°C greater rises in T_{core} during moderate exercise at a fixed metabolic heat production of 6W/kg of total body mass in healthy males (mean body fat % of 10.8 versus 32.0%) in a 28°C environment (Dervis et al., 2016). Secondly, large differences in the specific heat of the tissues of the body (Cp) caused by marked differences in body composition can also alter Tcore despite a similar heat storage. A Cp of 3.47kJ.kg−1°C−1 is assumed for the average person (Geddes, 1967). However, owing to the different Cp of fat tissue (2.97kJ.kg−1°C−1) and lean mass (3.64kJ.kg−1°C−1) overall Cp can vary depending on adiposity. Body fat percentage and Cp were not measured in any of the experimental studies included in

this thesis. However, BM was measured which is a representation of a humans heat sink, meaning that changes in T_{core}/T_{rectal} for an absolute amount of heat stored in the body are negatively correlated I.e. a smaller rise is observed with a larger BM for a fixed heat storage (Cramer and Jay, 2014; Ravanelli et al., 2017). Therefore, BM was measured at the start and end of every experimental trial and different in BM within and between groups was controlled to ~20%.

- All experimental trials included psychological measures such as ratings of perceived exertion and study 2 and 4 includes psychological measures such as thermal sensation and thermal comfort which are subjective psychological measure. Therefore ratings of these measures will be different from person to person (Gaoua et al., 2021).

8.4. Conclusions and Future Research Direction

In conclusion, this thesis has highlighted the effect of thermal stress (HD vs HH) and per-cooling (cold-water ingestion and pouring) on thermal strain (physiological and perceptual) during cycling time-trial performance.

Collectively, these findings indicate that

1. Consider the difference in thermal stress between hot and dry and hot and humid conditions before training and/or competion.
2. The type (internal vs external) of per-cooling should depend on the condition you are competing in (HD vs HH) as these two conditions offer different thermal stresses.
3. Per-cooling via cold-water pouring reducing performance impairments in HD compared to HH. Whereas there was no difference in performance with cold-water ingestion in HD and HH.

Future research should be directed towards the specific methodologies involved in cold-water ingestion and pouring i.e. quantities of water consumed during exercise, when the cooling is administered, the temperature of water provided, and the site of cooling if pouring to identify the optimal cold-water ingestion and pouring intervention.

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10. Appendix

Appendix A – Participation Level based on De Pauw et al., (2013).

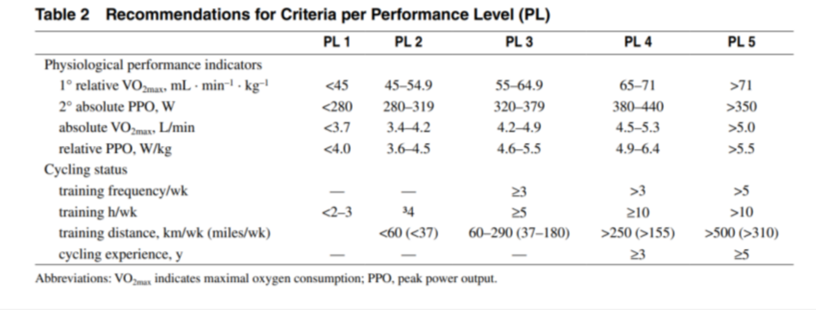


Table 2 Recommendations for Criteria per Performance Level (PL)

	PL 1	PL 2	PL 3	PL 4	PL 5
Physiological performance indicators					
1° relative VO_{2max}, mL · min^{-1} · kg^{-1}	<45	45–54.9	55–64.9	65–71	>71
2° absolute PPO, W	<280	280–319	320–379	380–440	>350
absolute VO_{2max}, L/min	<3.7	3.4–4.2	4.2–4.9	4.5–5.3	>5.0
relative PPO, W/kg	<4.0	3.6–4.5	4.6–5.5	4.9–6.4	>5.5
Cycling status					
training frequency/wk	—	—	≥3	>3	>5
training h/wk	<2–3	^{3}4	≥5	≥10	>10
training distance, km/wk (miles/wk)		<60 (<37)	60–290 (37–180)	>250 (>155)	>500 (>310)
cycling experience, y	—	—	—	≥3	≥5

Abbreviations: VO_{2max} indicates maximal oxygen consumption; PPO, peak power output.

Appendix B – Heat alleviation strategy questionnaire.

<u>Section 1 - Background Information</u>

I understand that all of my answers will be anonymous, and my identity will be anonymised.

- Yes
- No

Please select the 'yes' option below if you agree to participate in this questionnaire and to have your answers used for research purposes that aim to optimize the use of heat alleviation strategies.

- Yes
- No

What gender do you identify as?

- Female.
- Male.
- Transgender.
- Prefer not to answer.

What is your current age (yrs)?

- *text box answer*

What country do you currently live in?

- *text box answer*

What is your main sport? (please include specific event distance (km)/time(mins) if applicable)

- *text box answer*

What level do you play/compete at?

- Recreational
- Amateur
- Professional
- Other

How much previous experience (yrs) do you have playing/competing in this sport?

- *text box answer*

Before the COVID-19 pandemic in 2020, how many competitions in hot conditions would you participate in one year?

- 0
- 1
- 2
- 3
- 4
- 5

- More than 5

Have you ever experienced any of the following symptoms whilst training or competing in hot conditions? (select all that apply).

- Cramping
- Vomiting
- Nausea
- Severe headache
- Collapsing – fainting
- Other
- None

If you selected Other, please specify below and please give details below of the competition(s) in which they happened and the conditions (temperature and humidity) if known.

Do you think there is a difference between how HD conditions (i.e. desert conditions like Morocco) and hot and humid conditions (i.e. tropical conditions like Tokyo) impact sports performance?

- Yes
- No

If you answered 'yes' to the last question, which option below do you think places a greater thermal strain on athletes during competition?

- HD conditions.
- HH conditions.
- They are the same.

Would you say that you use the same heat alleviation strategies (i.e. cooling) during competitions in HD conditions as you do in hot and humid conditions? *Required*

- Yes, I use the same strategies for all competitions in hot conditions regardless of humidity level.
- No, I use different strategies.

If participants answered “No I use different strategies” they would be taken to:

Section 2 - Heat Alleviation Strategies During Competitions Are Different

In this section, it is important that you refer to any competitions that you have previously competed in that were in hot and dry conditions when you answer the questions. The subsequent section will then refer to the strategies that you use during hot and humid conditions so that the two conditions are separated.

If any, what per-cooling (within race cooling) method(s) do you use during your competitions? (select all that apply).

- Ice slurry ingestion.
- Cold water ingestion.
- Head or face cooling via water dousing/pouring.
- Cold towels.
- Cooling vest.
- Cooling collar.
- Menthol mouth rinse.
- Other menthol applications.
- None.
- Other

If you selected an option that involved per-cooling, when to apply it/them? (select all that apply).

- Pre-planned by distance covered (km)
- Pre-planned by elapsed time (min)
- Mixture of pre-planned and how you feel.
- When pitstops or rest breaks are available.
- None.
- Other

If you use a pre-planned cooling strategy, how did you establish the type, timing, and amount/length of the cooling? (select one option that applies).

- Previous experience (i.e. trial and error).
- Cooling availability (i.e. when you have access to cooling).
- Coach recommendation.
- Sports scientist recommendation.
- Personal reading (i.e. based off your own research).
- I do not plan my cooling ahead of time.
- Other/combination

In the questions below, it is important that you refer to any competitions that you have competed in that were in hot and humid conditions when you answer the questions.

If any, what per-cooling (within race cooling) method(s) do you use during your competitions? (select all that apply).

- Ice slurry ingestion.

- Cold water ingestion.
- Head or face cooling via water dousing/pouring.
- Cold towels.
- Cooling vest.
- Cooling collar.
- Menthol mouth rinse.
- Other menthol applications.
- None.
- Other

If you selected an option that involved per-cooling, when to apply it/them? (select all that apply).

- Pre-planned by distance covered (km)
- Pre-planned by elapsed time (min)
- Mixture of pre-planned and how you feel.
- When pitstops or rest breaks are available.
- None.
- Other

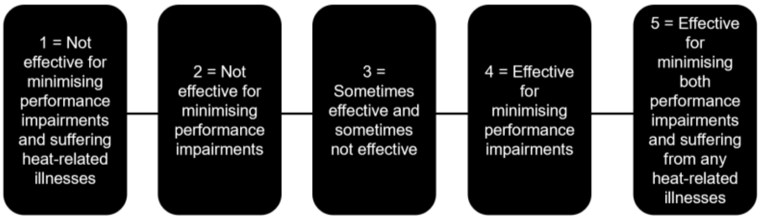
If you use a pre-planned cooling strategy, how did you establish the type, timing, and amount/length of the cooling? (select one option that applies).

- Previous experience (i.e. trial and error).
- Cooling availability (i.e. when you have access to cooling).
- Coach recommendation.
- Sports scientist recommendation.
- Personal reading (i.e. based off your own research).

- I do not plan my cooling ahead of time.
- Other/combination

Which of these options below best describes how well your previous heat alleviation strategies have worked for you in both conditions? (Please select one option).

Required



Please outline below in a few sentences why you think this worked or didn't work for you in previous competitions or training?

- Text box answer.

However, if participants answered "Yes, I use the same strategies for all competitions in hot conditions regardless of humidity level." they would be taken to: Section 2 - Heat Alleviation Strategies During Competitions Are The Same

In this section, it is important that you refer to any competitions that you have competed in that were in hot conditions when you answer the questions.

In your own words, please use the text box below to explain why you use the same strategies for competitions in both conditions?

If any, what per-cooling (within race cooling) method(s) do you use during your competitions? (select all that apply).

- Ice slurry ingestion.
- Cold water ingestion.
- Head or face cooling via water dousing/pouring.
- Cold towels.
- Cooling vest.
- Cooling collar.
- Menthol mouth rinse.
- Other menthol applications.
- None.
- Other

If you selected an option that involved per-cooling, when to apply it/them? (select all that apply).

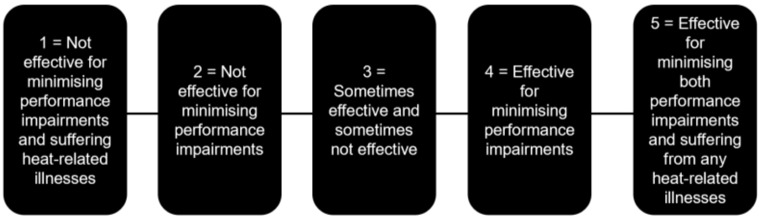
- Pre-planned by distance covered (km)
- Pre-planned by elapsed time (min)
- Mixture of pre-planned and how you feel.
- When pitstops or rest breaks are available.
- None.
- Other

If you use a pre-planned cooling strategy, how did you establish the type, timing, and amount/length of the cooling? (select one option that applies).

- Previous experience (i.e. trial and error).

- Cooling availability (i.e. when you have access to cooling).
- Coach recommendation.
- Sports scientist recommendation.
- Personal reading (i.e. based off your own research).
- I do not plan my cooling ahead of time.
- Other/combination

Which of these options below best describes how well your previous heat alleviation strategies have worked for you? (Please select one option).



Please outline below in a few sentences why you think this worked or didn't work for you in previous competitions or training?

- *Text box answer*

Appendix C – Interview questions

1. Tell me about a standout competition or training session for you that was in hot and dry conditions such as a heat wave in the UK/Barcalona/Oman, how did you feel during it? What strategies did you use if any?

2. Now tell me about a standout competition for you that was in hot and humid condition such as Kona Hawaii, how did you feel during the competition? What strategies did you use if any? And how did that compare to the previous competition you were talking about?
3. Where do you get your information about these strategies from?
4. How have these experiences shaped your preparation for future events?

Appendix D – Warm Up pre CPT

Warm up used for feedback study pre CPT (Tomaras and MacIntosh, 2011). Based of maximum heart rate which will be estimated from the commonly used formula: 220-age.

Time (min)	Classifcation	Instruction
0-5	General warm-up	60% HRmax
5-10		65% of HRmax
10-15		70% HRmax
15-15:30	Acceleration	Progressive acceleration ot 35km/h
15:30-15:36	Sprint	6s sprint
15:36-17:00	Recovery	Cycle lightly as if preparing to stop

Appendix E – Study 1 Supplementary Data

1. Participant Characteristics

There was a significant difference between the two groups for VO_{2peak}, critical power and years of experience ($P < 0.05$).

Appendix F - Study 2 Supplementary Data

1. Participant characteristics

The groups were matched and therefore there were no significant differences between groups for sex, age, stature, body mass, VO_{2max}, prior experience and weekly training. Therefore, any differences reported in performance, physiological responses and/or perceptual responses were not because of differences between groups.

Appendix G – Study 3 Supplementary Data

Appendix H - Study 4 Supplementary Data

2. Participant characteristics

The groups were matched for age, sex, height, weight and training status, and therefore there were no significant differences between groups for sex, age, stature, body mass, VO_{2max}, prior experience and weekly training. Therefore, any differences reported in performance, physiological responses and/or perceptual responses were not because of differences between groups.

3. Peak Rectal temperature

Table 37. mean±SD peak rectal temperature (°C) during the preload and time-trial.

Group	**1**				**2**			
Condition	**Thermoneutral**	**Hot**	**Ingestion**	**Pouring**	**Thermoneutral**	**Hot**	**Ingestion**	**Pouring**
Preload	37.75±0.17	38.18±0.24	37.92±0.21	38.10±0.18	37.98±0.24	37.73±0.6	37.9±0.1	38.15±0.12
Time-trial	38.05±0.17	38.8±0.11	38.8±0.2	38.6±0.2	38.6±0.2	39.3±0.1	38.2±0.1	38.9±0.4

There was a significant interaction between condition and group for peak T_{rectal} during time-trial (F(6,10) = 3.011, p = 0.016, n^2 =0.741) but not the preload (F(6,10) = 3.688, p = 0.233, n^2 =0.627)

Group 1 – Hot and Dry

There was no significant difference in peak T_{rectal} in the preload between conditions f= (1,10), 37.870, p=0.66; (control with no cooling: 37.78±0.13°C; hot with no cooling: 38.18±0.15°C; cold-water ingestion: 38.11±0.14°C; cold-water pouring: 37.92±0.14°C; Table 37).

There was a significant difference in mean±SD T_{core} during the time-trial between conditions f= (1,10), 38.630, p=0.003). The highest mean±SD peak T_{rectal} was reported in hot with no cooling (38.87±0.08°C) which was signficiantly greater than peak T_{rectal} in control with no cooling (38.05±0.15°C). There was no significant difference in mean±SD peak T_{rectal} in hot with no cooling (38.87±0.08°C), cold-water ingestion (38.8±0.08°C) and cold-water pouring (38.63±0.1°C; p=0.76).

Group 2 – Hot and Humid

There was no significant difference in mean±SD peak T_{rectal} during the preload between conditions f= (1,10), 37.860, p=0.073; Table 37). However, there was a significant difference in mean±SD peak T_{rectal} during the time-trial between conditions (f= (1,10), 38.834, p=0.030; Table 37). The highest mean±SD peak T_{rectal} was reported in hot with no cooling (39.27±0.08°C) which was significantly greater than peak T_{rectal} in control with no cooling (38.55±0.12°C, p=0.024), cold-water ingestion (38.21±0.01°C, p=0.019) and cold-water pouring (38.9±0.27°C, p=0.036).

Group Comparison

There was a significant difference between groups for average peak T_{rectal} in control with no cooling, hot with no cooling and cold-water ingestion (f= (1,10), 38.633, p=0.004) during the time-trial. This was reported in control with no cooling at all time points during the time-trial (p=0.010), hot with no cooling at all time points during the time-trial (p=0.05) and cold-water ingestion at all time points during the time-trial (p=0.05).

4. Change in rectal temperature

Table 38. Mean±SD change in rectal temperature (°C) from the start of the preload till the end of preload and start of the time-trial till the end of the time-trial.

Group	**1**				**2**			
Condition	**Thermoneutral**	**Hot**	**Ingestion**	**Pouring**	**Thermoneutral**	**Hot**	**Ingestion**	**Pouring**
Preload	0.5±0.1	0.92±0.12	0.87±0.18	0.74±0.2	0.7±0.15	1.08±0.15	0.78±0.13	0.58±0.08
Time-trial	0.38±0.15	0.75±0.16	0.76±0.1	0.73±0.14	0.6±0.06	0.93±0.05	0.88±0.22	0.43±0.12

There was a significant interaction for condition and group for change in T_{rectal} during the preload (f= (1,10), 20.011, p=0.005; Table 38) and time-trial (f= (1,10), 20.901, p=0.003; Table 38).

Group 1 – Hot and Dry

The greatest change in T_{rectal} during the preload was reported in hot with no cooling (0.93±0.10°C) compared to control with no cooling (0.53±0.08°C), cold-water ingestion (0.09±0.13°C) and cold-water pouring (0.74±0.23°C; p = 0.002). Similarly, the greatest change in T_{rectal} during the time-trial was reported in hot with no cooling (1.04±0.11°C) compared to control with no cooling (0.65±0.16°C), cold-water ingestion (0.76±0.01°C), and cold-water pouring (0.80±0.14°C; p = 0.005). There was no significant difference in change in core between cold-water ingestion (0.76±0.01°C) and cold-water pouring (0.80±0.14°C; p = 0.104). Therefore both per-cooling strategies were effective at attenuating the rise in T_{rectal}.

Group 2 – Hot and Humid

The greatest change in T_{rectal} during the preload was reported in cold-water pouring (0.75±0.11°C). This was significantly greater than control with no cooling (0.42±0.17°C, p = 0.014) and cold-water ingestion (0.38±0.67°C; p = 0.001). Whereas, the rate of change in T_{rectal} was very similar and not significantly different in cold-water pouring and hot with no cooling (0.72±0.16°C; p=0.73). This infers that cold-water pouring was not an efficient method of per-cooling in hot and humid conditions for attenuating the rise in T_{rectal} during 45min of fixed intensity cycling.

The greatest change in T_{rectal} during the time-trial was reported in hot with no cooling (0.94±0.05°C) compared to control with no cooling (0.64±0.05°C; p =0.012), cold-water ingestion (0.43±0.12°C; p = 0.008) and cold-water pouring (0.88±0.22°C; p = 0.042). Change in T_{rectal} during the time-trial was also significantly greater with cold-water pouring (0.88±0.22°C) compared to cold-water ingestion (0.43±0.12°C; p= 0.023). This infers that cold-water ingestion was a more efficient method per-cooling in hot and humid conditions compared to cold-water ingestion for attenuating the rise in T_{rectal} during a 30min cycling time-trial.

Group Comparison

There was a significant difference in T_{rectal} change between groups during the preload f= (1,10) 5.056, p = 0.043). and time-trial (f= (1,10) 5.015, p = 0.046). Change in T_{rectal} was significant greater in hot and humid compared to hot and dry for both the preload (1.08±0.15 vs 0.92±0.12°C, p = 0.041) and time-trial (0.93±0.05 vs 0.75±0.16°C, p = 0.034). The infers that there was a greater heat gain/storage compared to heat loss in hot and humid conditions compared to hot and dry conditions.

Change in T_{rectal} was significantly greater in hot and dry conditions with cold-water pouring compared to hot and humid with cold-water pouring in both preload (0.74±0.2 vs0.58±0.08°C, p = 0.032) and time-trial (0.73±0.14 vs 0.43±0.12°C, p = 0.029).