The Effect of an Evaporative Cooling Vest During 40km Time Trial Performance in the Heat.

Joseph Procter

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Being a report submitted in partial fulfilment of the requirements of the University of Hertfordshire

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School of Life & Medical Sciences University of Hertfordshire

I declare that:

(a) all the work described in this report has been carried out by me – and all the results (including any survey findings, etc.) given herein were first obtained by me – except where I may have given due acknowledgement to others;

(b) all the prose in this report has been written by me in my own words, except where I may have given due acknowledgement to others and used quotation marks, and except also for occasional brief phrases of no special significance which may be taken from other people's work without such acknowledgement and use of quotation marks;

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I understand that if I have not complied with the above statements, I may be deemed to have failed the project assessment, and/or I may have some other penalty imposed upon me by the Board of Examiners.

Signed …………………………… Date …………………………...

Name ……Joseph Procter……

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Contents

Abstract

Purpose: Cooling during exercise in hot environments has been demonstrated to reduce thermal strain and improve exercise performance. Therefore, the principal aim of the study was to examine the effect of wearing an evaporative cooling vest on 40km time trial performance in a hot environment.

Method: Eight trained male cyclists (Mean ± SD: age 41 ± 13 height 174.4 ± 4.71cm body mass 68.6 ± 5.04kg VO_{2peak} 57.79 ± 8.16ml.kg^{-1}.min^{-1}) completed a preliminary VO_{2peak} test and two 40km time trials with (ECV) and without (CON) an evaporative cooling vest in the heat. Thermoregulatory and subjective responses were measured throughout the self-paced time trial. Skin temperature and core temperature were measured along with heart rate, power output blood lactate, and subjective measures of rate of perceived exertion (RPE) and thermal sensation during exercise. Furthermore, measures of blood lactate, haematocrit and haemoglobin were completed pre-and post-exercise.

Results: Time trial performance was improved in the ECV trial compared to the CON trial. Mean body temperature was significantly lower during the ECV trial (36.13 ± 0.40°C) than the CON trial (37.14 ± 0.58°C) ($p<0.05$). Power output and blood lactate was significantly higher in the ECV trial alongside RPE being significantly lower.

Conclusion: The application of a cooling vest during exercise in the heat significantly improves exercise performance and reduces thermal strain.

Key Words: Thermoregulation, Cooling, Thermal Strain, Time Trial, Cycling

Introduction

Exercise in the heat has been demonstrated to impair endurance performance and cause substantial detrimental effects to the health of an athlete (Tatterson, Hahn, & Martin, 2000). The application of various cooling methods prior to exercise to decrease core body temperature, has been well investigated and employed during cycling in the heat (Gonzalez-Alonso, Teller, Andersen, Jensen, Hyldig & Nielsen, 1999; Ishan, Landers, Brearley & Peeling, 2010, Ross *et al.,* 2011). However, the benefits obtained from pre-cooling may be lost 20-25 minutes during exercise performance (Kay, Taaffe & Marino, 1999; Bolster et al., 1999, Quod et al., 2008). Thus, the utilisation of cooling during exercise has been explored through neck cooling, cold water ingestion, and cooling vests. However, there is little research into cooling methods during cycling. Therefore, the aim of this review is to analyse current literature surrounding cooling methods during cycling in the heat.

Literature Selection

Searches were conducted through PubMed, Google Scholar, Science Direct, and Mendeley using eight keywords (cooling, thermoregulation, exercise in heat, cooling vest, neck cooling, cold water ingestion, percooling, and during exercise). Results were limited to human participants and articles published in English. Literature searches were conducted between September 2016 and April 2017.

The Effects of Exercising in the Heat

Hargreaves (2008) suggests alterations in energy metabolism, cardiovascular function, and central nervous system function are the main contributing factors affecting performance in the heat. Thus, time to exhaustion (TTE) is significantly impaired during time trial performance in the heat (Ely *et al*., 2010; Peiffer & Abbiss, 2011; Chapman *et al., 2011*). Muscle glycogen depletion is significantly higher when exercising in the heat due to an increase in carbohydrate oxidation and lactate accumulation. The augmentation of glycogen utilisation during exercise in the heat may decrease TTE due to the lack of a sufficient metabolic energy source (Parkin, Carey, Zhao & Febbraio, 1999).

Body and Skin Temperature

Thermoregulation of the body regulates internal temperatures using sensory feedback from thermoreceptors in the central nervous system sent to the hypothalamus. Changes in core temperature activate neural autonomic outflow, resulting in a response from vasomotor and cardiovascular systems in the body to maintain core temperature homeostasis (Jansky & Vybiral, 2004). When exercising in the heat for a prolonged period, reductions in cardiac output and arterial pressure occur. As a result, there is an elevation in vascular resistance and noradrenaline levels (Gonzalez-Alonso *et al*, 1999). As core temperature increases, vasodilation occurs to effectively modulate skin blood flow to thermoregulate (Wendt, Van Loon, Wouter, & Lichtenbelt, 2007). However, the locomotor muscles maintain a high demand for O_2 and therefore, cutaneous blood flow is redirected away from inactive tissue and redistributed to maintain an efficient oxidative capacity of the working skeletal muscle. The circulation of cutaneous blood faces a conflicting demand from the thermoregulation centre and the skeletal muscles, compromising skin blood flow and leading to a higher core body temperature (Kellogg *et al,.*1991).

As exercise continues, skin temperature reaches an upper limit temperature of 38°C, due to exercise limiting the active vasodilator system (Kellogg *et al.* 1993; Gonzalez-Alonso *et al*. 1999). Dehydration resulting from sweat evaporation inhibits the efficient delivery of oxygen to the exercising muscle (Hargreaves *et al.* 1996). As a result, dehydration can lead to early fatigue due to the reduction of blood flow to the locomotor muscle blood (Gonzalez-Alonso, Crandall, Johnson., 2007). This is supported by Wingo *et al.,* (2005), in which constant-load exercise in the heat is associated with a decrease in maximal oxygen uptake and an increase in the percentage of maximal oxygen uptake utilised. Arngrimsson et al*.,* (2004) suggests that the increase in heart rate during exercise in the heat is related to a greater $\%VO_{2max}$ utilisation. This is due to the reduction in VO_{2max} as a result of the increase in the decline in stroke volume, mean arterial pressure and cardiac output caused by exercising in the heat (Gonzalez-Alonso & Calbet, 2003).

Power Output

Literature suggests that exercise performance is inhibited and an increase in fatigue occurs when the core temperature of the body reaches 40.1°C-40.3°C (Cheung, 2007). Nybo and Nielsen (2001) hypothesised that fatigue caused by reaching the critical limit may occur due to its effect on the central nervous system. This study found that hyperthermia caused a reduction in force during sustained maximal voluntary contractions. A reduction in force was not found during short maximal voluntary contractions. Therefore, hyperthermia may affect the ability to maintain prolonged muscular contractions (Todd, Butler, Taylor & Gandevia, 2005). Evidence demonstrates that a reduction in power output during self-paced time trial cycling performance decreases when ambient temperature is elevated (Tucker, Marle, Lambert & Noakes, 2006).

Cooling Methods During Exercise

When environmental temperature is lower than skin temperature, a thermal gradient is created. Thus, blood flow is redistributed from the core to the skin, allowing heat loss to occur through radiation, convection, and the evaporation of sweat (Cheuvront & Haymes, 2001). However, during exercise in heated conditions, an imbalance between heat production and heat loss occurs, and has a detrimental effect on exercise performance (Duffield, 2008). Methods of cooling the body during exercise have been demonstrated to prevent heat storage, aiming to attenuate the increase of core temperature, which may delay the onset of fatigue through hyperthermic responses (Marino, 2002). Wimer, Lamb, Sherman and Swanson (1997) demonstrated a significant decrease in skin and core temperature following the ingestion of cold water at a temperature of 0.5°C. The decrease in body temperature is supported by Mundel, King, Collacott and Jones (2006), reporting the consumption of a cool beverage at a temperature of 4°C improved endurance capacity in 6 healthy males. The improved endurance capacity was achieved by attenuating hyperthermia and inducing a heat debt, allowing core temperature to start increasing from a lower temperature. However, a limiting factor to water ingestion during exercise is the risk of gastrointestinal discomfort. The consumption of a cool liquid during exercise may cause stomach cramping and pain (Waterman & Kapur, 2012). Another limitation during exercise is the inability to preserve the cool temperature of the beverage. Therefore, utilising alternative cooling methods such as multi-location cooling packs or cooling vests may be beneficial.

Cooling Pack Application

The use of cooling packs has been demonstrated to improve exercise performance and decrease thermal strain. A study by Tyler, Wild and Sunderland, (2010) concluded that neck cooling improved exercise performance by 6% during a 15-minute self-paced time trial in the heat. An increase in exercise performance was achieved by dampening the perception of thermal strain and preventing the activation of inhibitory signals which terminate exercise. However, the study concluded that once a thermal strain threshold is surpassed, cooling of the neck has no significant performance enhancing effect. It has been suggested that performance in a hot environment is limited by the attainment of an increased core temperature (Nielsen, Hales, Strange, Christensen, Warberg & Saltin*.,* 1993). The study by Tyler, Wild and Sunderland, (2010) found no significant decrease in core temperature, which is found in similar studies using neck cooling (Bulbulian, Shapiro, Murphy & Levenhagen*.,*1999; Hamada, Torii, Szygula & Adachi, 2006). This suggests that neck cooling is only beneficial during exercise of short duration, and the increase in core temperature needs to be attenuated for cooling to be beneficial to performance.

Cooling Vest Utilisation

Numerous studies have investigated the positive effects of a cooling vest prior to cycling in the heat (Webster, 2005; Jorgenen et al., 2007; Wegmann et al., 2012). However, there is limited research into the application of a cooling vest during cycling in the temperate conditions.

Prolonged exercise induces a limit on the vasodilatory capacity of the skin. Once internal temperatures reach 38°C, the distribution of blood flow to the skin is attenuated (Kenney & Johnson, 1992). The use of a cooling vest to decrease core temperature may prevent this reduction of skin blood flow and aid thermoregulation. However, it is difficult to optimise cooling garments in a temperate sporting environment (Marino, 2002). This is due to the necessary equipment to keep a vest at the required temperature to be effective on exercise performance. The practical application of the cooling garment is also limited by the weight of the vest which may inhibit cycling performance (Petitt et al., 2004; Webster et al., 2005). Hasegawa et al., (2005) reported an ice cooling vest added 3.3kg to the cyclists which resulted in difficulty maintaining an intensity of 60% $VO_{2max.}$ Due to the practical application issues, advanced and lightweight technology was required to have a positive effect on thermoregulation and performance (Eijsvogels, Bongers, Veltmeijer, Moen & Hopman, 2014).

The *Hyperkewl*™ is a lightweight cooling vest with evaporative technology designed to thermoregulate the athlete during exercise without adding unnecessary weight. Eijsvogels et al., (2014) conducted a study investigating the effect of *Hyperkewl*™ on 5km running performance in 25°C heat. Thermal comfort rating was improved and skin temperature decreased. However, time to completion and core temperature was not significantly different between the two trials. The findings suggest that the Hyperkewl™ does not improve performance. In contrast, Luomala et al., (2012) concluded that the use of a cooling vest significantly increased TTE during cycling in 30°C heat. The increase in TTE supports a study by Hasegawa et al., (2005) which examined cooling vest application in untrained males cycling at 60% $VO2_{max}$ at a mean temperature of 32°C. Results indicated a positive effect on performance by an increased TTE and decreased body temperatures. The increase in performance suggests that the use of a cooling vest may be beneficial at temperatures greater than 25°C. However, Merla et al., (2005) demonstrated that highly trained males have a greater thermoregulation response as opposed to untrained males due to a superior vasodilation capability. Therefore, the use of trained males as opposed to Hasegawa et al., (2005), may be beneficial when using an evaporative cooling vest due to the increased capacity of thermoregulation through evaporation.

Subjective Measures

Literature suggests that the neural control systems in the brain and spinal cord determine the volume of motor units which are activated during exercise to ensure homeostasis is maintained in the body (Noakes, 2007). The central governor model predicts that the brain generates the perception of fatigue to ensure the increase in bodily discomfort results in the termination of exercise to prevent homeostasis from failing. Sensory information relayed to the brain determines appropriate exercise behaviours to ensure bodily homeostasis in response to exercise-induced fatigue. Exercise is regulated based on physiological and psychological afferent feedback such as an increase in temperature (Desai & Bottoms, 2017). Marino, Mbambo and Kortekass (2000) report that participants altered pacing strategies to attenuate the rise in core temperature and prevent the accumulation of fatigue. This supports the central governor theory as it suggests that a subconscious centre may have been regulating exercise to maintain bodily homeostasis and prevent cellular injury (Marino, 2002).

Research indicates that cooling of the body can supress inhibitory neuronal signals from the central governor, by reducing heat stress on the body and delaying the onset of fatigue (Duffield, 2008). This is supported by Luomala et al., (2012) who reported a reduction in RPE, thermal comfort and thermal sensation following the application of a cooling vest during cycling in the heat. The increase in thermal comfort may have allowed for a greater exercise capacity, thus improving cycling performance. In contrast, Eijsvogels et al., (2014) discovered that the use of a cooling vest had no overall effect on RPE irrespective of a greater thermal comfort. This study also reported no significant benefit from cooling on performance, which may support the hypothesis that exercise is regulated by the brain acting as a master governor.

Gender

The use of male participants is favourable as the core body temperature of women fluctuates by 0.3-0.5°C determined by the phase of the menstrual cycle (Stepehnson & Kolka, 1993). The rise in temperature is due to an increase in the hypothalamic set point caused by an increased secretion of progesterone in the luteal phase of the menstrual cycle (Jonge, 2003). Pivarnik et al, (1992) reported that temperature regulation, cardiovascular strain and perceptual responses to exercise were affected during the luteal phase of the menstrual cycle. The effect on thermoregulation is supported by Fukouka et al, (2002) who found an increase in core temperature in the Luteal phase. Jonge (2003) also states prolonged exercise in hot conditions causes a decrease in TTE during the mid-luteal phase due to an increased body temperature and cardiovascular strain.

Previous research has identified the beneficial application of a cooling vest during exercise performance. Further investigation into the utilisation of a lightweight cooling vest during time trial cycling in the heat is warranted to determine the effectiveness of the cooling intervention on performance.

Experimental Aims and Hypotheses

Aims

- Investigate the effect of wearing a light weight evaporative cooling vest during 40km time trial cycling performance in the heat.
- Examine the physiological changes that occur whilst cooling during exercise in the heat.
- Understand the effect of cooling during exercise in the heat on the rate of perceived exertion.

Objectives

- Measure the differences in time trial performance between cooling and control trials.
- Monitor the change in skin and body temperature and compare the differences between cooling and control trials.
- Monitor changes in rate of perceived exertion and compare the cooling trial to the control trial.

Hypotheses

- *Experimental Hypothesis (H1):* The utilisation of the evaporative cooling vest will significantly improve 40km time trial performance in the heat.
- *Experimental Hypothesis (H2):* Cooling during exercise will reduce thermal strain and RPE during the 40km time trial in the heat.
- *Null Hypothesis (N1):* No improvements will be observed in 40km time trial performance with the application of the evaporative cooling vest.
- *Null Hypothesis (N2):* No significant differences in RPE will occur following cooling during 40km time trial performance in the heat.

Method

Participant Information

Eight trained male cyclists (Mean ± SD: age 41 ± 13 height 174.4 ± 4.71 cm body mass 68.6 ± 5.04 kg VO_{2peak} 57.79 ± 8.16 $ml.kg^{-1}.min^{-1}$) of national competitive standard volunteered to participate in this study. In this randomised repeated measures study, participants attended the laboratory three times. The first session was an incremental cycling test to exhaustion to determine $VO_{2peak.}$ The second and third sessions were the main experimental trials with and without the cooling intervention. All trials were performed between 10am and 3pm to avoid diurnal variation and separated by a minimum 7-day washout period. Ethical approval was granted by the institutional review board at the University of Hertfordshire. Written informed consent was obtained once participants had read the research information sheet and signed a health screen.

Preliminary VO_{2peak} Test

The incremental exhaustive test was completed on an exercise bike (Lode, Groiningen, Netherlands) which began at a starting intensity of 100W. The wattage increased by 20W every minute and gas analysis was recorded throughout (Metalyser, 3BR2, Cortex Biophysik GmbH, Leipzig, Germany) to determine VO_{2peak}. The participants were instructed to maintain an exercise intensity greater than 60rpm and the test was terminated once the intensity dropped below this level or at volitional fatigue.

40 km time trial pre-and post-exercise protocol

Main experimental trails were completed at a mean dry-bulb environmental temperature and humidity of 30.6 ± 2.77°C and 45.07 ± 26.8% respectively, and were measured continuously throughout each test. A metal stationary fan set to a low speed was directed 1.5m away from participants during exercise trials. Participants were instructed to avoid strenuous exercise, caffeine and alcohol 24 hours prior to testing and were instructed to avoid all liquids within 2 hours of testing. Participants age, body mass (Seca 704r, Birmingham, UK) and height (Seca Leicester Stadiometer, Seca, Birmingham, UK) were recorded before testing. A 10μL blood sample was then collected into a capillary tube and blood lactate (LAC) was analysed in a Biosen C-line glucose and lactate analyser (EFK Diagnostics, Cardiff, UK). A further 10μL was collected and haemoglobin was analysed in a Hemocue Hb 201+ (Hemocue AB, Angelholm, Sweden) immediately after collection. 75μL of blood was collected into a heparinized capillary tube and centrifuged in a Haematospin 1300 (Hawksley, Sussex, UK) for three minutes at 10,000rpm to analyse blood haematocrit concentration.

Heart rate (HR) was monitored using a chest strap (Polar, Kempele, Finland). Power output (PO) and time trial distance was recorded using a computrainer (Racermate, Seattle, USA). The participants inserted a rectal thermometer and 4 skin thermistors were attached to the right side of the chest in the midclavicular line level with the axilla, the lateral aspect of the right arm slightly below level of axilla, lateral aspect of the right calf mid-way between the knee and ankle, and the medial aspect of the thigh midway between the knee and the hip joint using black electrical tape. This enabled calculation for mean skin temperature (T_{sk}) using Ramanathan's equation (Ramanathan, 1964) and mean body temperature (T_b) using Burtons equation (Burton, 1935). Following the completion of the time trial, pre-exercise blood measures were repeated and the participant's mass was recorded.

Hyperkewl™ Evaporative Cooling Vest

The Hyperkewl™ evaporative cooling vest was submerged in cold water (8 ± 3°C) for two minutes. The vest was gently hand squeezed for 30-seconds post submersion. In the cooling trial, the vest was applied to the participants immediately before the start of the 40km TT.

40 km time trial protocol

Following a 10-minute warm up, participants were instructed to complete a self-paced 40km time trial on a road bike with or without a Hyperkewl™ evaporative cooling vest. No verbal encouragement was given to the participants during the time trial and participants were informed of the distance every 10 km. Fingerprick blood lactate was recorded every 10 minutes until completion of the 40km course. Measures of rate of perceived exertion (RPE), thermal sensation (TH_s), skin and core temperature and heart rate were recorded every 5 minutes. Power output was recorded continuously with an average recorded following completion.

Statistical Analysis

Statistical analysis was completed using the Statistical Package for the Social Sciences (SPSS) version 23 (IBM, New York, USA). Data is presented as mean ± the standard deviation. Data was checked for normality using a Shapiro-Wilk test ($p>0.05$). Differences between exercise trial and T_{sk}, T_b, RPE, HR, TH_s, and LAC up to 60 minutes into exercise were analysed using a two-way analysis of variance (ANOVA) with repeated measures and post-hoc Bonferroni adjustments. A paired t-test assessed significant differences between time to completion (TTC), pre-to post-exercise blood lactate, mean power output, and plasma blood volume change. Statistical significance was accepted at p≤0.05.

Results

The exercise time to completion significantly improved (p=0.04) in the ECV trial compared to the CON trial (70:05 ± 9.54 min compared to 74:16 ± 12.30 min). The relative improvement in exercise time was 5.56 ± 28.57%.

Physiological Measures

A main effect for T_b was found for intervention ($F_{1,4}$=8.057; P=0.04) and time ($F_{11,44}$=11.379; P<0.001). T_b was significantly lower during the ECV trial (36.13 ± 0.40°C) than during the CON trial (37.14 ± 0.58°C) (Figure 1).

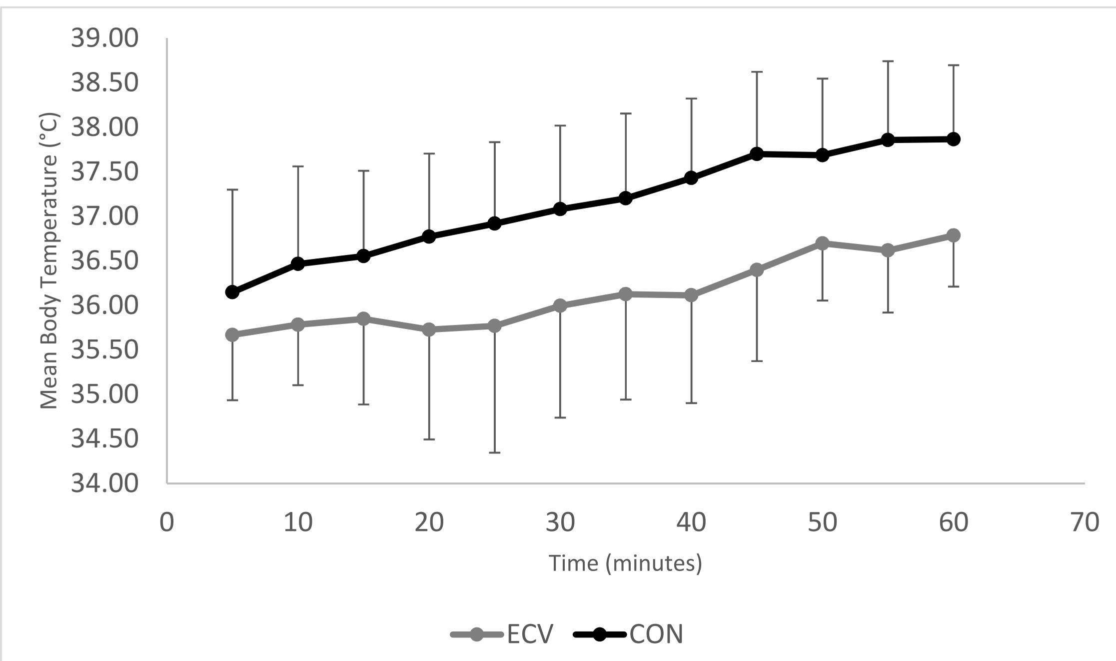

Figure 1. *Significant main effect between ECV and CON trials for T_b.*

A main effect of T_{sk} during exercise was found for time ($F=_{11,33}= 9.396$; $p= <0.001$) and no main effect was observed for intervention.

A main effect for LAC during exercise was found for intervention ($F_{1,4}=10.949$; $p=0.03$) and time ($F_{5,20}=5.764$; $p=0.002$). Mean blood lactate during ECV trial was significantly higher (4.68 ± 2.19 mmol.L^{-}1) than during the CON trial (3.82 ± 1.85 mmol.L^{-}1).

There was a main effect for pre-to post-exercise blood lactate found for time ($F_{1,4}=20.785$; $p=0.006$) and intervention ($F_{1,4}= 11.923$; $p=0.02$) with pre-to post-exercise LAC significantly increasing 127.835 ± 148.50% (1.75 ± 0.43 mmol.L^{-}1 to 7.95 ± 2.91 mmol.L^{-}1) in the ECV trial and 119.57 ± 123.72% (1.5 ± 0.41 mmol.L^{-a}1 to 5.96 ± 1.74 mmol.L^{-}1) in the CON trial.

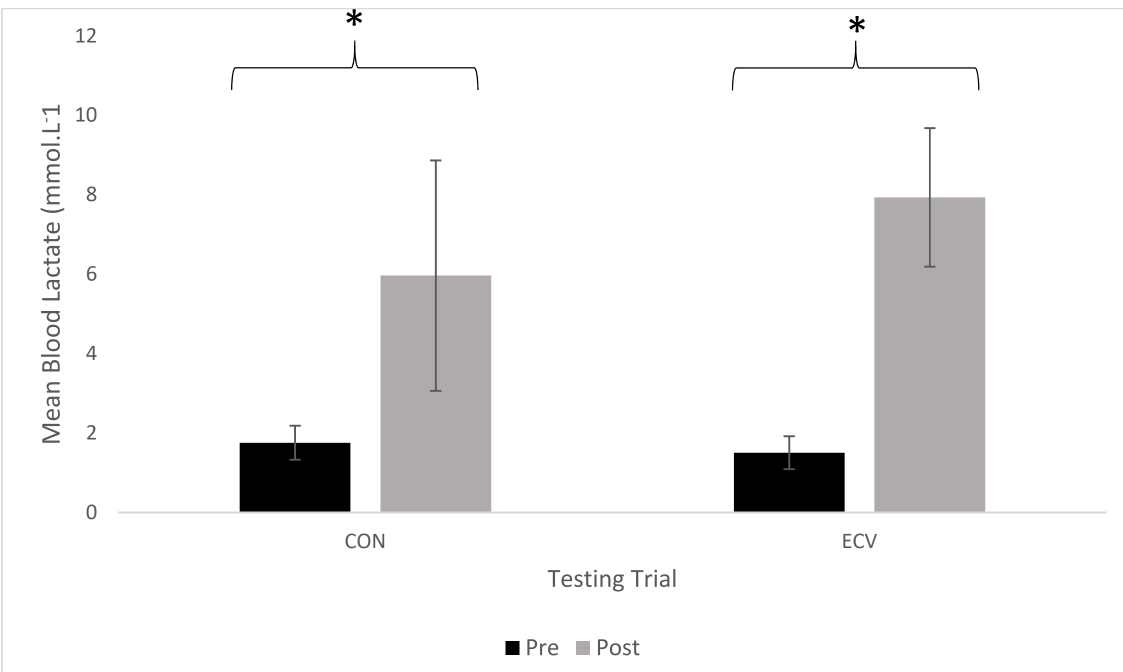

Figure 2. *Mean pre-to post-exercise LAC. * denotes statistical significance.*

Mean power output was significantly greater ($p=0.04$) in the ECV trial than in the CON trial (224 ± 59.94 W and 206.80 ± 52.98 W). A relative difference of 7.99 ± 12.33%. A main effect for HR during exercise was found for time ($F_{11,33}$= 6.290; p=<0.001). No significant main effect for HR was found for intervention (p=0.637).

Subjective Measures

A main effect for RPE during exercise was found for intervention ($F_{1,4}$=10.272; p=0.033) and time ($F_{11,44}$=19.652; p<0.001) (Figure 3). Mean RPE was significantly lower during the ECV trial (14.26 ± 2.43) than during the CON trial (15.41 ± 1.92).

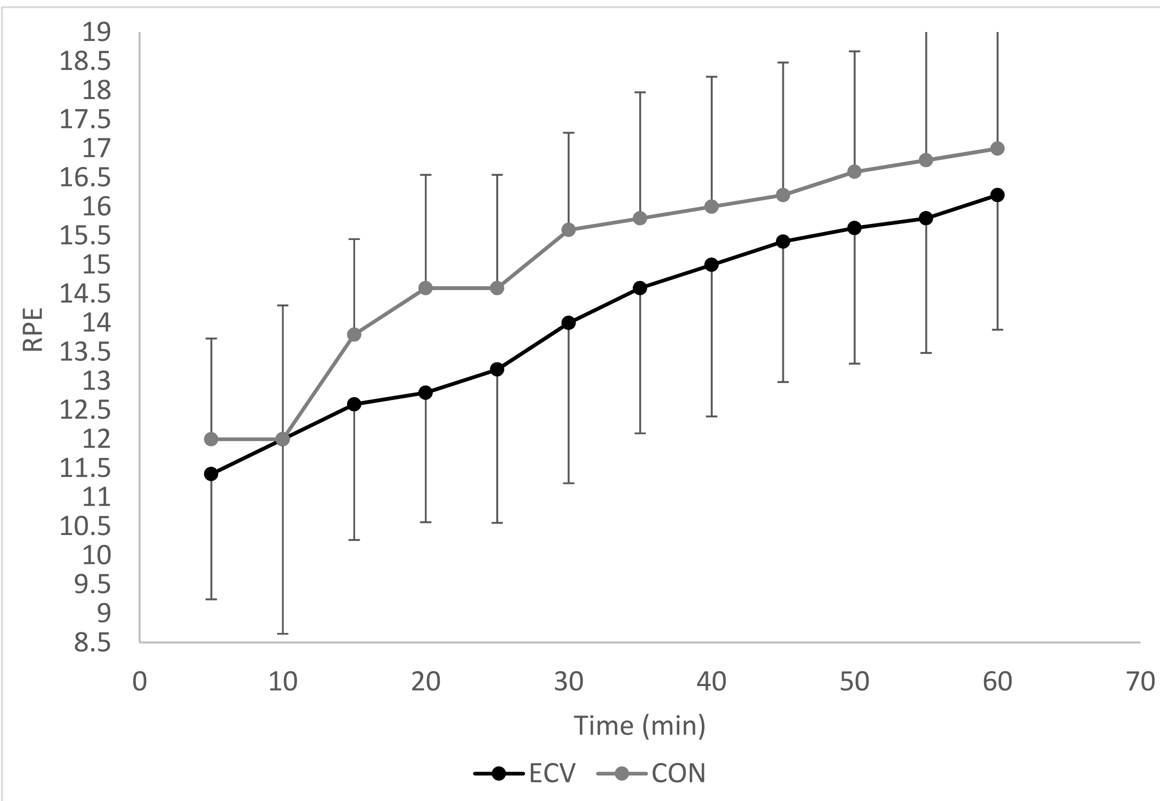

Figure 3. *Significant Differences in RPE during exercise between ECV and CON trials.*

A main effect for TH_S was found for time ($F_{11,44}$=34.119; p=<0.001). There were no differences between TH_S and exercise trial (p=0.104). There was no significant difference in pre-to post-exercise plasma blood volume.

Discussion

The aim of the present study was to investigate the effect of wearing a lightweight evaporative cooling vest during 40km time trial performance in the heat and its effect on thermal strain and RPE. This is the first study that has examined the effect of wearing a cooling vest during 40km time trial cycling performance in the heat. The main findings were; an improvement in time trial performance, reduced body temperature and RPE during the ECV trial in comparison to the CON trial and power output and LAC were greater during the ECV trial than the CON trial.

The present study concluded that time trial performance significantly improved upon utilisation of the evaporative cooling vest. This contradicts a study by Eijsvogels et al., (2014), which found no significant improvement in performance using the *Hyperkewl*™ vest during a 5km treadmill time trial in a mean environmental temperature of 25°C, which is classified as a moderate environmental temperature (Roberts, 2006). This contrasts with the present study in which mean environmental temperature was 30.6°C, in which Roberts, (2006) classifies as a high environmental temperature. Cooling during exercise performed in compensable heat stress conditions has been suggested to have a smaller effect on exercise performance than in cooling during uncompensable heat stress conditions (Tyler, Sunderland & Cheung, 2014). The maximum core temperature following the 5km time trial in the heat was 39.1°C, in comparison to the current study which reached 39.75°C. This suggests that there was a greater capacity for convection between the participant's body and the cooling vest in the current study as opposed to the study by Eijsvogels et al*.,* (2014). The present study is supported by current research into the effect of pre-cooling (Bogerd, Perret, Bogerd, Rossi & Daanen, 2010; Johnson, Sparer, Sleivert & Pethick, 2008) and per-cooling (Luomala et al*., 2012*) on cycling performance, reporting increases in exercise performance following cooling in environmental temperatures greater than 30°C. The improved exercise performance following cooling during high environmental temperatures may indicate that a greater thermal gradient was created between the cooling vest and the environment in the present study. This may allow for a greater heat exchange gradient and therefore, an increase in evaporation and cooling (Sawka, Wenger, Young & Pandolf, 1993).

Excessively elevated body temperature produced from an increase in heat production and a decrease in heat loss has been demonstrated to impair exercise performance (Duffield, 2008). The present study observed a significant decrease in mean body temperature during 40km time trial performance whilst wearing an evaporative cooling vest. Hasegawa et al*.,* (2005) supports the present study and found a decrease in body temperature with the application of an ice cooling jacket during cycling to exhaustion in the heat. Endurance performance can be impaired during exercise in the heat, with time to exhaustion being heavily influenced by body temperature (Booth, Marino & Ward, 1997). The attainment of a critical body temperature has been suggested to be a main limiting factor to endurance performance in the heat (Gonzalez-Alonso et al*.,* 1999). There is a considerable attrition from exercise as core temperature reaches 39°C (Nielsen & Nybo, 2003). A high muscle temperature can result in alterations in actin-myosin interactions and mitochondrial respiration which can accelerate fatigue (Hargreaves & Febbraio, 1998).

The results from the current study suggest that the cooling vest attenuated the increase in core temperature, thus allowing for a greater capacity for heat storage during exercise. Thus, the cooling intervention may have allowed for the athletes to exercise at a higher absolute intensity which may have improved time trial performance (Quod, Martin & Laursen, 2005).

The aforementioned increase in absolute working intensity is supported by an increase in power output found during cooling in the present study. A significant increase in power output was found in the ECV trial in comparison to the CON trial. Muscle power has been demonstrated to be reduced by elevations in core temperature via metabolic heat production (Cheung, 2007). This finding is supported by current research into the effect of heat on muscular contraction. Nybo and Nielsen (2001) demonstrated that force production was lower during a sustained isometric maximal voluntary contraction following exercise in a hot environment in comparison to a temperate environment.

Neural feedback from skeletal muscles has been suggested to be critical to endurance exercise as it may influence ventilatory and circulatory responses crucial to oxygen delivery (Nybo, Rasmussen & Sawka, 2014). It is possible that hyperthermia induced fatigue may occur from dynamic inhibitory processes in the brain responsible for motor activation (Nybo, Rasmussen & Sawka, 2014). Therefore, the attenuation of a high T_b through cooling may prevent the inhibitory processes regulated by the CNS (Siegel & Laursen, 2012). However, Sunderland, Stevens, Everson & Tyler, (2015) postulate that the increase in power output may occur from a placebo effect due to the inability to blind the participants. Nevertheless, impairment in the perfusion of skeletal muscle will limit oxygen delivery and alter muscle metabolism, affecting afferent feedback and may exacerbate the perception of fatigue during self-paced exercise (Nybo, Rasmussen & Sawka, 2014). However, Noakes (2011) suggests, through the central governor model (CGM), that feedback from the periphery influences the size of the central drive which determines the extent of skeletal muscle recruitment. During exercise, feedback from organs inform the central command in the brain the rate of heat accumulation. Consequently, this regulates exercise behaviour by altering the number of recruited motor units in the exercising muscles. Tucker (2006) argues that self-paced exercise and work rate is reduced in anticipation of excessive heat accumulation prior to exercise, preventing catastrophic heat accumulation from occurring. Therefore, reductions in exercise intensity may occur to delay the onset of fatigue during self-paced performance. The results from the present study indicate that the application of the cooling vest may have modified the anticipatory mechanism of the brain. Consequently, an increased power output was observed with a reduction in perceived exertion. The increase in power output in the ECV trial resulted in a significantly greater increase in blood lactate in comparison to the CON trial. This is supported in a study Temfemfo, Carling and Ahmaidi, (2011), which observed a significant progressive increase in power output during repeated cycling sprints, which was accompanied by an increase in blood lactate accumulation.

The suggested reduction in perceived exertion and increase in power output is supported in the present study by the significantly lower RPE in the ECV trial than in the CON trial. This finding is supported by Sunderland, Stevens, Everson and Tyler, (2015) who observed significant decreases in RPE following cooling during exercise.

The current study also found no significant difference in TH_S between the two exercise trials. Sunderland, Stevens, Everson and Tyler, (2015) argue that the decrease in RPE and the lack of significant difference in thermal sensation may because by dampening of the sensory cues which act to form the perceptual rating of fatigue, as an increase in work completed was observed in conjunction with lower RPE scores. However, Noakes (2011) argues that RPE is a measure of the duration of exercise completed or of the duration that remains, as opposed to intensity. Per the CGM, the brain determines the potential rate of heat accumulation during varying environmental temperatures. Subsequently, the brain plans the exercise duration that could be safely sustained without incurring detrimental heat stress to the body. Therefore, this suggests that the anticipation from the brain may have limited performance in the CON trial and altered the perception of fatigue in the present study.

A significant main effect for T_{sk} was found for time. However, no significant difference in T_{sk} was observed between the ECV and the CON trials. This contradicts Eijsvogels et al., (2014), who demonstrated a decrease in skin temperature using the *Hyperkewl*™ evaporative cooling vest. The average completion time of this study was 20 minutes 30 seconds in comparison to the present study in which average completion time was 72 minutes 15 seconds. During exercise in the heat, cardiac output increases due to an increased demand for blood flow from the skin and from the active muscle (Gonzalez-Alonso, Crandall & Johnson, 2008). The demand for blood flow is so high that a cardiac pumping capacity limit is reached, failing to meet the demand from both the skin and muscle. Consequently, a compromise in skin blood flow occurs as blood is redistributed towards the active muscles through modifications in the vasoconstrictor and vasodilator systems (Johnson, 1992). It is possible that in the study by Eijsvogels et al., (2014) that skin blood flow was less likely compromised in comparison to the current study due to the much shorter exercise duration.

Dehydration has been demonstrated to reduce skin blood flow through reductions in cardiac output and stroke volume (Gonzalez-Alonso et al., 2000). The onset of dehydration was almost inevitable in the present study due to the complete restriction of fluids two hours prior to testing, in combination with a mean sweat loss of 1.7L across both trials. This is supported by the insignificant difference in plasma blood volume change between the ECV and CON trials. Consequently, this suggests that dehydration may have been present in both exercise trials which may have caused a restriction in skin blood flow, thus resulting in an insignificant difference between the two trials. The potential effect of dehydration across both trials may have caused an increase in sympathetic activity, resulting in a significant increase in heart rate during the trials (Castro-Sepulveda et al., 2014). Dehydration in combination with continuous exercise in a hot environment elicited heart rates that are near maximal for all participants in both trials, which may explain the lack of difference in heart rate regardless of cooling.

Practical implications

The application the *Hyperkewl*™ vest may be beneficial during triathlon events due to the simple protocol to activate its cooling mechanism. Theoretically, an athlete can activate the cooling vest during the swimming event which will provide cooling during the subsequent cycling event. The lightweight nature of the vest prevents any performance inhibiting effects which has been seen in previous cooling vest studies. Reactivation of the cooling vest can be achieved through soaking at any of the hydration stations during the race.

Conclusion

The results of the current study suggest wearing an evaporative cooling vest during a 40km time trial can decrease the rate of perceived exertion and attenuate the increase in body temperature produced from metabolic heat production. This is supported by a 5.56% improvement in time trial performance during the ECV trial compared to the CON trial. It is therefore possible to formally accept experimental hypotheses H1 and H2 and reject the null hypotheses N1 and N2. However, the effectiveness of the vest may have been limited by the onset of dehydration. Therefore, future research should aim to investigate the effect of a cooling vest on performance in the heat whilst allowing for fluid intake ad libitum during the exercise trials.

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