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Effects of Breathing Cool Air during Cycling Exercise in the Heat

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Abstract

INTRODUCTION: The purpose of this study was to establish the ability of the Core Cooler device to prevent rises in physiological heat strain of trained male cyclists during cycling exercise in the heat. **METHODS**: 15 healthy male cyclists cycled at 50-70% VO_2max for 75 minutes in a heat chamber of 31°C & 55% RH while breathing through the Core Cooler device under three different conditions: 1:4 ratio without ice termed control (CN), 1:4 ratio with ice termed low intermittent (LI), and at 1:1 ratio with ice termed high intermittent (HI). Data collected every 15 minutes assessing intestinal temperature (T_{GI}), heart rate (HR), physiological strain index (PSI), blood pressure (BP), mean skin temperature (T_{SK}), and perception of thirst, thermal sensation, and rate of perceived exertion, inspired air temperature, ambient temperature and relative humidity in all trials. VO_2 workload and respiratory rates (RR) recorded three times at evenly spaced time points (12.30, 42.30, 1.12.30), during all trials respectively. Statistical significance was set at a p value of 0.05 and measured using repeated measures ANOVA and post hoc t-test. **RESULTS**: No statistically significant differences in diet, USG, temperature, %RH, VO2 workload, or RR were found between any trial. Inspired air temperature averaged significantly different between CNvsLI & CNvsHI ($p<0.01$, CN 30.92±0.35°C, LI 19.81±0.44°C, & HI 19.28±0.72°C), but not between LIvsHI ($p=1.000$). Physiological responses between trials found insignificant differences. T_{GI} produced significant interactions between trials ($p = 0.033$) averaging CN 37.86±0.02°C, LI 37.91±0.10°C, & HI 37.80±0.07°C, but post hoc analysis provided no difference between any time or trial ($p>0.05$). HR ($p=0.103$), systolic BP ($n=11$, $p = 0.102$), diastolic BP ($n=11$, $p = 0.190$), T_{SK} ($n=5$, $p=0.464$), thirst ($p=0.773$), thermal sensation ($p=0.709$), and RPE ($p=0.669$) were not significantly different between trials. **CONCLUSION**: Modifications to the Core Cooler device are needed providing greater

inhalation capabilities of cool air during exercise in the heat for significant attenuation of physiological heat strain. The Core Cooler in its current form will not provide an adequate prevention to heat illness, prolong endurance capabilities, or enhanced performance to a significant degree. This research was funded by Core Cooler Company, LLC.

Acknowledgements

Special thanks are extended to the staff of the University of Arkansas Graduate School for all their help throughout this process. It would be extremely difficult to complete everything without their guidance and passion to see young students develop into professional scientists.

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Introduction:

Heat illness is a medical emergency that is life threatening. Over the past 35 years the highest number of fatalities due to exertional heat stroke occurred within a 5 year period between 2005 and 2009 despite current knowledge and prevention practices (Casa, Armstrong, Kenny, O’Connor, and Huggins, 2012). The risk of heat illness during exercise in the heat is always present unless precautions and preventive measures are involved. Predisposing factors that increase ones risk of heat illness include obesity, dehydration, low fitness level, medication use, heat acclimatization, clothing, illness, age, and prior heat illness (Keller, 2011). During exercise in the heat, athletes are at a potential risk of self-induced heat illness from exceeding the limits of their thermoregulatory capabilities. Heat illness is often caused by extended bouts of intense exercise in the heat that leads to heat cramps, heat exhaustion, and in some cases exertional heat stroke.

Other populations such as the elderly are at an increased risk of heat illness because their bodies do not adapt to sudden changes in temperature as efficiently as younger populations. Specifically, elderly populations are more likely to take prescription medicines that impair the body's ability to regulate its temperature or that inhibit perspiration (Center for Disease Control & Prevention, 2012). Elderly populations are also more likely to have a chronic medical condition that changes the normal body responses to heat than younger populations (Center for Disease Control & Prevention, 2012). While specific groups are at increased risk, everyone has a potential risk of heat illness. Understanding the physiology behind human thermoregulation and heat illness remains crucial in setting preventive standards and protocols that will ultimately save lives.

Humans normally maintain a core temperature between 35-40°C (95-104°F) throughout daily life activities (Keller, 2011). The human body thermoregulates to maintain homeostasis by exchanging heat with the environment through evaporation, radiation, convection, and conduction (Folk, Riedesel, & Thrift, 1998). Removing heat from the body is controlled by central nervous system in the hypothalamus, spinal cord, and peripherally by centers in the skin and organs (STAND, POSITION 2007) & (Keller, 2011). When heat is produced during exercise, the body works to cool itself by increasing blood flow from the center of mass to the periphery while simultaneously increasing sweat production to increase heat loss through evaporation (Keller, 2011).

The main pathway to lose heat is through evaporation. When a person exercises in low humidity environments more than 80% of the heat produced is lost by evaporative heat loss, making it the primary mechanism of heat removal from the body (Gisolfi and Mora, 2000). This control works by evaporating sweat from the skin to cool the body although, in high humidity environments evaporative heat loss is limited by the inability to evaporate sweat from the skin (Lim, Byrne, and Lee, 2008). Other pathways of heat exchange do not contribute very much to heat loss during exercise and depending on the environment can cause someone to gain heat.

A brief review of conduction, radiation, and convection is necessary to understand how humans physiologically exchange heat with the environment. The direct transfer of heat when objects of different temperatures encounter each other has collectively been termed conduction. A good example of conduction can be seen in athletes who use an ice pack after exercise to recover faster. The heat transfer by conduction in this circumstance starts from the core extending to the peripheral muscles and skin, subsequently followed by another transfer of heat from the skin to an ice bag (Keller, 2011).

Radiation occurs between each other and with the air; warmer objects lose heat to cooler objects without ever touching. The loss of heat from the warmer object to the cooler object or environment occurs through electromagnetic waves (Keller, 2011). Radiation accounts for 50% of heat loss during rest and becomes a source of heat loss during exercise if the air temperature significantly drops below body temperature (Keller, 2011).

Convection occurs when a breeze of air or wind encounters an object or person. Depending on the temperature of both will determine the magnitude and direction of heat exchange. In one instance, if someone has a skin temperature that is warmer than the wind temperature, the wind will actually gain heat from the person. This process has been described as the warming of air next to the body, which is displaced, by cooler air. Another explanation is to visualize the sun warming the ground. The ground will warm the air above it. As this air warms, it will expand and become less dense causing it to rise. Heat will rise away from the ground. In the right environment, wind can accelerate convective heat loss by causing the expansion of warm air to occur sooner (Keller, 2011).

One of the relatively under-explored areas of heat loss is respiratory heat loss through breathing cold air. Although respiratory heat exchange is not known to be a major mechanism of heat exchange it is in a primary location to cool the lungs which come into contact with the majority of circulating blood in the body. Previous documentation shows that inspired air temperature that is above body temperature will add heat to the body through the lungs (Lind, 1955). With this observation in mind, it is reasonable to suggest that if inspired air temperature is lower than body temperature, heat exchange can occur through the lungs to help dissipate heat. The transfer of heat is not confined to any specific region of the respiratory tract and has been described as a longitudinally distributed process that occurs anywhere within the tracheobronchial tree if a thermal gradient exists (McFadden, Pichurko, Bowman, Ingenito, Burns, Dowling & Solway, 1985). Simply, if there is a difference in temperature between two objects a heat exchange will occur in which the warmer object (respiratory tract) loses heat and the cooler object (cold air) gains heat.

Although humans have numerous heat exchanging mechanisms, heat illness remains a risk because it is not always possible to dissipate the amount of heat produced. Not only does the body heat itself as a by-product of performing work, it can gain heat through the environment. Hot and humid environments will transfer heat to any cooler object or person. Specifically, humidity becomes a limiting factor to evaporative heat loss and evaporation is significantly restricted at environments of 60% relative humidity or higher (Keller, 2011). If the metabolic heat produced and environmental heat absorbed outweighs heat dissipation, the likely result produces symptoms of heat illness. Physiologically, the consequence of heat illness is the inability to remove the heat produced from decreased heat dissipation, cerebral blood flow, and muscular strength (Keller, 2011).

To understand how heat illness develops the physiological progression must be explained. As body temperature increases from exercise, we sweat to cool ourselves. By sweating humans will lose heat but also fluids and electrolytes. Over 2 million sweat glands on the human body take fluid from plasma, intracellular, and interstitial fluid to use for sweating (Gisolfi & Mora, 2000). As sweating occurs, blood becomes thicker from the loss of fluid and electrolytes leading to hyperosmality making the heart work harder to redistribute blood flow from the core to periphery. This in turn leads to the symptoms of heat illness such as feelings of light headedness, dizziness, poor balance, and sometimes unusual behavior, such as, cursing.

Heat illness presents itself in different forms. Less extreme forms of heat illness are seen at core temperatures under 40°C (104°F) with no central nervous system symptoms or issues. These forms of heat illness include cramps, syncope, and exhaustion (Becker & Stewart, 2011).

The body responds with these symptoms for specific protective reasons. Syncope or the loss of consciousness for example forces the person to the ground making it easier to redistribute blood flow thus helping recovery from reductions in blood pressure.

Extreme forms of heat illness include classic heat stroke and exertional heat stroke. Classic heat stroke develops slowly over a few days and predominantly occurs in older adults and those with chronic illness (Becker & Stewart, 2011). Cases of classic heat stroke are usually seen in the elderly during heat waves and mostly affect those of lower economic status. Older and poorer populations are reluctant to turn on air conditioning due to the cost or lack of access and often try to wait out the heat. This, in turn, leads to the slow development of classic heat stroke and can result in fatality. Exertional heat stroke (EHS) rapidly onsets and is defined by hyperthermia or a core temperature above 40°C (104°F) with central nervous system disturbances and multiple organ system failure if not treated (STAND, POSITION 2007). When core temperature reaches 40°C (104°F) cellular damage occurs starting a cascade of events that can lead to organ failure and death (Becker & Stewart, 2011). The events are seen in the form of heat cramps, heat exhaustion, and exertional heat stroke that ultimately leads to death if not treated immediately. Over time, researchers have investigated numerous preventive and treatment protocols for someone experiencing heat illness.

Prevention includes informing general populations and exploring ways to improve heat loss. The Centers of Disease Control and Prevention are proactive about informing general populations through posters and online websites making information such as “Tips for Preventing Heat-Related Illness” very easy to access. The CDC suggests the best defense is prevention. Recommended tips include staying hydrated, avoiding alcoholic or high-sugar beverages, wearing light and loose fitting clothing, and providing information on who has an increased risk of heat illness such as the elderly and obese populations. Increasing knowledge about what increases the risk of heat illness and EHS is beneficial. ACSM gives special communication reports on conditions such as obesity, low physical fitness, lack of heat acclimatization, dehydration, previous history of EHS, sleep deprivation, sweat gland dysfunction, sunburn, viral illness, diarrhea, or certain medical conditions as predisposing factors that increase the risk of heat illness and EHS. Recommendations to reduce the risk of heat illness include regular physical training, improving cardiorespiratory fitness, and acclimatization to the heat (STAND, POSITION 2007).

Along with preventive measures, guidelines and protocols are set in place. For example, severe cases of heat illness such as EHS are described as a life-threatening medical emergency that requires immediate whole body cooling for a satisfactory outcome (STAND, POSITION 2007). The gold standard in treating EHS is to cool the whole body by immersing in an ice bath (Casa, Armstrong, Kenny, O'Connor, and Huggins, 2012). This is done with cold-water immersion (CWI) or ice water immersion. When treatment is quickly engaged, the risk of death from exertional heat stroke is reduced drastically. Unfortunately, not everyone knows the best way treat a heat illness victim or may not know the signs and symptoms associated with heat illness leading to errors in care.

The largest limiting factor in surviving heat illness is from errors in care (Casa, Armstrong, Kenny, O'Connor, & Huggins, 2012). These errors include: misdiagnosis, receiving delayed treatment or no treatment, using an ineffective cooling modality, immediately transferring someone to a hospital instead of immediate treatment, and from returning to play/work too soon and without supervision often resulting in the unwanted outcome of death from EHS instead of survival (Casa, Armstrong, Kenny, O'Connor, & Huggins, 2012). Previous studies have shown that delayed access to rapid cooling modalities produce the leading cause of morbidity and mortality from EHS (Becker & Stewart, 2011). The difference between surviving and dying from EHS is about 30 minutes of delayed treatment, which has been considered the golden half-hour and led to the controversial cool first, transport second mentality (Casa, Armstrong, Kenny, O'Connor, and Huggins, 2012).

Aside from the recommended tips and protocols, researchers are still exploring new modalities in treating heat illness. Other treatment modalities such as a cool shower, rotation of cool wet towels, moving into air-conditioned rooms out of the sun, hand-cooling devices, and laying down provide less effective treatment. This research is vital because there are numerous situations where heat illness is occurring and there is no access to ice water immersion or CWI treatment. A new device known as the Core Cooler may provide another method for prevention of heat illness by using respiratory heat loss. Older research looking into respiratory heat loss through breathing cold air has shown to be a possible modality in preventing heat illness as well as improving performance and endurance in athletes.

Breathing cold air is suggested to have benefits preventing physiological heat strain but has also been associated with health risks in specific individuals. It has been suggested that breathing cold air could be responsible for mild local airway obstruction in the upper respiratory tract (Guleria, Talwar, Malhotra, & Pande, 1969). Additionally, breathing cold air during two hours of 15-minute rest/exercise intervals has been proposed to increase the number of inflammatory cells in lower airways, which may contribute to the development of asthma (Larsson, Tornling, Gavhed, Miller-Surr, & Palmberg, 1998). It is further reported that asthmatics develop bronchospasms from breathing cold air (Deal, McFadden, Ingram & Jaeger, 1978), (Deal, McFadden, Ingram, Strauss, & Jaeger, 1979), (Deal, McFadden, Ingram, & Jaeger,

1979) and individuals with certain medical conditions should avoid breathing cold air but no adverse effects from breathing air as cold as -30 to -40°C were found that would contraindicate vigorous exercise in normal subjects (Hartung, Myher & Nunneley, 1980). Furthermore, in 2011 Muller, Gao, Drew, Herr, Leuenberger & Sinoway reported that myocardial function was not impaired from breathing cold air and the redistribution of blood flow through the body was preserved. All of these data taken together suggest that unless someone has a medical condition that contraindicates breathing cold air or a history of asthma, it is safe and may be beneficial during exercise.

The idea of breathing cold air to improve exercise performance has previously been studied by Geladas & Banister in 1988 who looked at the effects of breathing cold air on core temperature in people exercising in the heat. The data reported suggest that exercise intensity and duration could be prolonged through cold air inhalation during exercise by attenuating rises in core temperature (Geladas & Banister, 1988). In contrast, Hartung et al, (1980) reported that only slight physiological changes were found and that the metabolic cost of exercise is not affected in a way that improves performance from observations of significantly reduced rectal temperatures while breathing cold air during vigorous cycling.

Geladas & Banister identified similar results in eight subjects cycling at 45-50% VO_2max workload until exhaustion, which was only about 26 minutes, in a room of 38°C & 95% relative humidity for two trials; one while continuously breathing cold air and one while breathing ambient air. Geladas & Banister found significantly reduced heart rate, respiratory frequency, rectal temperature, and a nine-fold greater respiratory heat loss while continuously breathing cold air during cycling exercise. With the data from previous research taken together, reports support the idea of breathing cold air during exercise to attenuate rises in core temperature and prolong one's ability to exercise in the heat.

The research by Geladas & Banister and Hartung et al, (1980) used an exercise time that was limited to less than 30 minutes. It is unclear if the same observations would be seen if exercise had continued for longer than 30 minutes, if cold air had not been inhaled continuously but intermittently, and if the temperature of the inhaled air was not as cold.

The purpose of this study was to investigate the effects of breathing cool air during exercise in the heat, to seek new ways to prevent heat illness and to establish the ability of the Core Cooler device to prevent an extreme rise in physiological heat stress of trained male cyclists during cycling exercise in the heat. Looking into the efficiency of respiratory heat loss during exercise in the heat may prove to show a significant pathway of heat loss that can prevent heat illness. It is hypothesized that breathing cool air of 18-21°C will reduce physiological heat stress but not significantly. The hypothesis is not thought to find significance due to the difference in cold air and ratio of use between this proposed study and previous studies that used much colder air at continuous respiration rates.

Methods:

This research used 15 healthy male cyclists' volunteers that were recruited via public media and university announcements through university provided email in accordance with all IRB protocols. Subjects averaged 25.67±4.12 years, 180.48±5.55cm in height, with VO_2max of 56.43±7.52ml/Kg/min, and 14.79±6.99 percent body fat as shown in Figure 1. If subjects agreed to participate in the IRB approved study, they scheduled times and dates to report to the Human Performance Laboratory four times for a total time commitment of about seven hours. The first visit familiarized participants about everything they would be required to do throughout the study and to determine if they met inclusion criteria. This visit was scheduled at least 2 days before their first exercise trial.

The first visit involved a medical history questionnaire that was explained and then completed by the subject. Following this was measurements of height, weight, body composition via DEXA scan, resting heart rate, and ended with aVO_2max test via metabolic cart on the VELOtron cycle ergometer. After the VO_2max test all results were reviewed to determine if the subject meet the requirements of participation.

Inclusion criteria for participants included being 18-39 years old, having a VO_2max of at least 40 mL/kg/min, no medical contraindications to exercise, no medical history of asthma or exercise induced asthma, and no contraindications to inhalation of cold air. Subjects were determined to be trained cyclists by having a high aerobic fitness of a VO_2max value of 40 mL/kg/min or higher. Subjects with aerobic values lower than 40 mL/kg/min were classified as untrained cyclists and excluded from the study. After determining eligibility to participate, any further explanations of perceptual questions (thirst, thermal sensation, and rate of perceived exertion), urine sample needed prior and post exercise trials for hydration status measure, diet recording, and intestinal temperature pill were explained. Any further questions were also answered and exercise trial dates and times were scheduled. The exercise trials were spaced out by one week to ensure no carry over effects or acclimation occurred. Data collection occurred in the winter and spring months where outdoor environmental temperatures were not likely to facilitate heat acclimatization during training.

The three exercise trials consisted of completing a 24-hour diet log prior to the visit and assessed after to ensure no differences between trials with respect to caloric or macronutrient intake. Five to six hours prior to scheduled exercise trials, participants ingested a pill that measures intestinal temperature (HQ, Inc). Gastrointestinal temperature measurement using the ingestible temperature thermistors has been shown to be safe, reliable, and valid for measurement of body temperature (Lim, Byrne, and Lee, 2008).

All participants reported to the Human Performance Lab Heat Chamber about 30 minutes prior to their scheduled time of exercise. They had body mass and hydration status assessed via body weight in kilograms and urine sample for urine specific gravity (USG). USG used to ensure subjects started the trials hydrated based on a USG below 1.020 urine concentration. Subjects were given a water cup that provided 1.5 ml/kg body weight of warm water to drink during the exercise trials. This cup was filled with warmed water at 40 degrees C to ensure it did not affect measurements of the intestinal temperature pill. Warm water was consumed every 15 minutes during exercise to ensure adequate hydration during the trials. Data collected every 15 minutes measuring environmental data, inspired air temperature from the Core Cooler, VO_2 workload, respiratory rates (RR), and perceptual data. Environmental data included measurements of ambient temperature taken from an Omega type T thermocouple heat sensor (PN: 5TC-PVC-T-24-180). Measurements of relative humidity were taken with VAISALA humidity transmitter (PN: HMT330). Inspired air temperature measured with an Omega type T thermocouple heat sensor (PN: 5TC-PVC-T-24-180) that inserted into the large straw like mouthpiece of the Core Cooler device. VO_2 workload (via metabolic cart) and RR were taken at three evenly spaced time points (12:30, 42:30, 1:12:30) during the 75 minute exercise trials to ensure subjects were working at 50-70% VO_2max via metabolic cart. Perceptual data included the thirst scale (Engell, Maller, Sawka, Francesconi, Drolet, Young, 1987), thermal sensation scale (Toner, Drolet, Pandolf, 1986) (Young, Sawka, Epstein, Decristofano, Pandolf, 1987), and ratings of perceived exertion scale (Borg, 1970).

The effects of breathing cool air was taken every 15 minutes on measurements of mean skin temperature (T_{SK}), heart rate (HR), blood pressure (BP), intestinal temperature (T_{GI}), and Physiological strain index (PSI). Subjects were instrumented with four Omega epoxy coated tip, type T thermocouple skin temperature probes (PN: 5TC-PVC-T-24-180) on the right calf, thigh, shoulder, and chest to measure T_{SK}. HR assessed with PolarT31 Coded Chest Transmitter and Elastic Strap (PN: 920135). An Orbit-K™ cuff, (Suntech PN: 98-0062-02) for BP with K-sound Microphone, (Suntech PN: 98-0006-00) on the left arm and three Heart Trace wet gel foam snap electrodes (PN: 8050) were attached on the center-left chest, lower right ribs, and lower left ribs just below the chest. T_{GI} was measured with CorTemp® Ingestible Core Body Temperature Sensor (PN: HT150002). PSI calculated from average HR and T_{SK} data using a formula provided by Moran, Shitzer, & Pandolf (1998). Lastly, subjects were briefed on their schedule and protocol for the trial and any questions about how to use the device or the protocol used for that day's trial were addressed prior to starting the 75 minutes of cycling exercise.

Subjects then performed cycling exercise for 75min. The exercise consisted of cycling on a VELOtron cycle ergometer at a workload in watts requiring on average 59.10±4.75%VO_2max in an environmentally controlled room of 31.21±0.64°C (88.18±0.14°F), relative humidity of 56.31±2.33%RH with an industrial size fan set to 3.5m/s. Having subjects cycle in a controlled environment limited evaporative heat loss ensuring the measurement of heat loss provided by the Core Cooler device. The workload of 59.10±4.75% VO_2max was set via the VO_2max test to elicit 50-70%VO_2 workload and adjusted by increasing or decreasing the resistance in watts throughout the trial to ensure adequate rises in T_{GI} during exercise. The workload implemented in the exercise trial was recorded then repeated in all following exercise trials. Repeating the same workload ensured no differences between trials with respect to workload and heat production.

The research utilized an experimental approach with a randomized experimental design. Subjects utilized the Core Cooler device during all three randomly assigned exercise trials. Breathing through the same device controlled for respiration, to ensure that the conditions between all trials were the same with the exception of the temperature of the inspired air. In one trial, subjects were required to use the device at a 1:4 ratio (1min using, 4min not using the device) without ice termed control (CN). Another trial required use of the device at the 1:4 ratio with ice termed low intermittent (LI). The other trial required use of the device with ice at a 1:1 ratio (2.5 min using, 2.5 min not using) termed high intermittent (HI). As the device was utilized, during LI and HI trials the ice within the device would melt and was thus replaced with crushed ice every 5 or 10 minutes depending on the amount of melting that occurred.

Preliminary testing comparing different forms of ice revealed the coldest inhalation producing ice. Testing occurred between the Core Cooler device filled with crushed ice, water filled then frozen into a solid block of ice, and cubed filled ice. Crushed ice presented the coldest inspiration of air possible between the three and used in this research. Subjects were instructed to always inhale through the device during use and were allowed to exhale either through the device or off the device depending on their personal preference with the understanding that they must breathe through the device the same way for the entire trial and every following trial. In order to reduce discomfort and improve feasibility of using the device during cycling; a stand/holder was made for the device so participants did not have to remove hands from handlebars to utilize the device. The stand/holder was a simple pipe attached to the front of the

VELOtron ergometer with zip-ties, which had a water bottle holder attached to it. The pipe could be bent and adjusted based on height and comfort of the subject. The bottle easily removed from the holder to refill with crushed ice and replaced during no use ratios of the device during LI and HI trials.

After the 75min of cycling exercise subjects then returned all lab equipment from instrumentation, had post body mass and hydration assessed, and were provided with a sports beverage for rehydration, intestinal core temperature pill, and diet log before leaving the Human Performance Lab. Upon completion of all four visits to the Human Performance Lab, subjects were paid 50 dollars, given VO_2max and body composition data with insights on using the data for training purposes. Data analysis was completed via SPSS using repeated measures ANOVA and post hoc paired t-tests with appropriate Bonferroni and Greenhouse-Giesser corrections to identify significant differences. Significance was set at a p value of 0.05.

Results:

Figure 1: Subject Characteristics

	N	Minimum	Maximum	Mean	Std. Deviation
Age	15	18	33	25.67	4.117
Height	15	170	190	180.48	5.550
VO_{2MAX}	15	45	67	56.43	7.523
BF	15	5	29	14.79	6.999
Valid N (list wise)	15				

Figure 1: Descriptive statistics of subjects. VO_{2MAX} is in mL/kg/min, and BF = % Body Fat.

Diet logs, Weight, Hydration, Environmental Conditions & Inspired Air: No differences between trials with respect to kCal (p= 0.127, CN 3044.50±687.70, LI 3047.42±1203.67, & HI 2785.99±1133.13), protein (p= 0.747, CN 110.64±31.00, LI 120.20±51.06, HI 117.29±68.52), carbohydrate (p= 0.396, CN 343.16±67.13, LI 357.64±134.13, HI 323.28±120.25), or fat (p= 0.335, CN 125.71±49.36, LI 117.48±80.33, HI 103.37±50.51) ensuring all subjects had equal energy balance prior to each exercise trial with respect to nutrition. Pre weight (p=0.451, CN 73.41±7.89kg, LI 73.60±7.91kg, & HI 73.33±7.84kg), pre USG (p=0.968, CN 1.010±0.006, LI 1.010±0.010, HI 1.010±0.010), and USG pre vs post (p=0.413, USG post CN 1.011±0.010, post LI 1.011±0.004, post HI 1.013±0.004) indicated no differences across trials and ensured that subjects were at normal weights and adequately hydrated prior to and during all trials. The temperature (p=0.155, average CN 31.18±0.11°C, LI 31.27±0.15°C, & HI 31.19±0.16°C) and relative humidity (p=0.163, average CN 56.18±0.50%RH, LI 55.71±0.49%RH, & HI 57.03±0.65%RH), were not significantly different across all trials. Wind speed was held constant across all trials at 3.5m/s. The inspired air temperature was significantly different between CN and LI (p<0.01), CN and HI (p<0.01), but was not significantly different between LI and HI (p=1.000). Mean inspired air temperatures during CN were 30.92°C±0.28°C (87.65°F±0.50°F), LI 19.81°C±0.82°C (67.66°F±0.47°F), and HI 19.28°C±0.88°C (66.71°F±0.58°F).

Figure 2 shows Inspired Air across trials from 15 to 75 minutes of exercise.

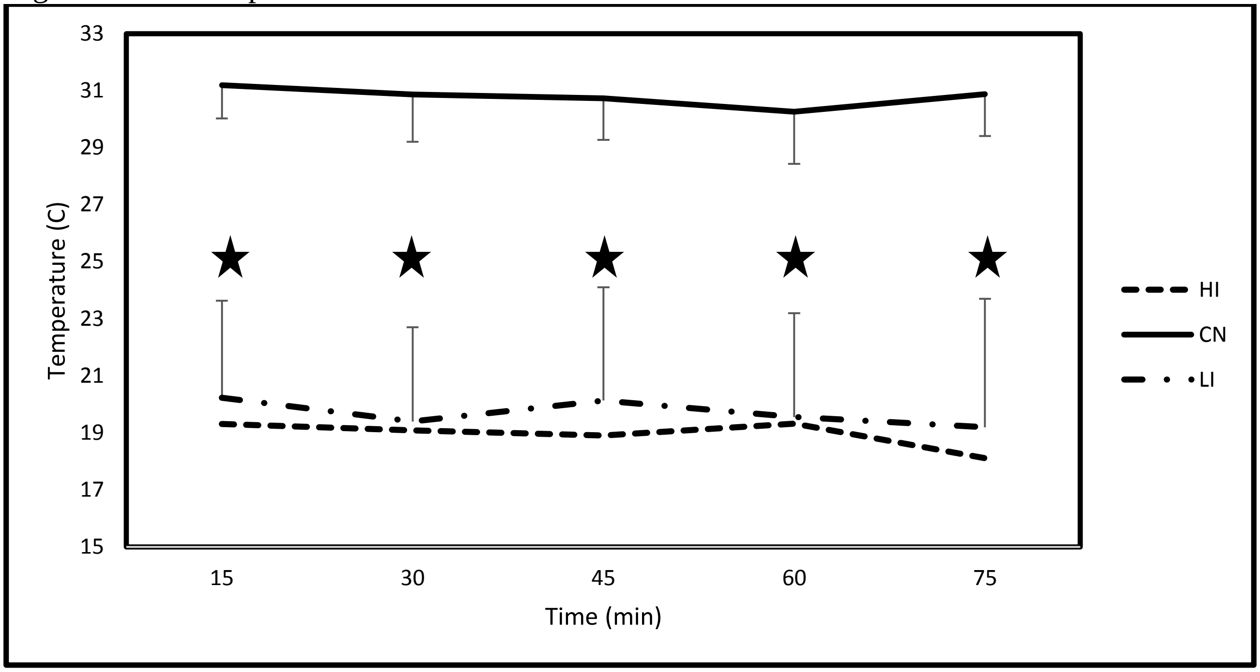

Figure 2: Inspired Air Temperature during cycling exercise was significantly different between CN and LI, CN and HI but not significantly different between LI and HI. CN = control, LI = Low Intermittent, & HI = High Intermittent

VO2 Workload: There was no difference across trials with respect to VO_2 workload during trials (p=0.578). On average subjects were working at a VO_2 of 33.15 ml/kg/min during CN or 58.97% of VO_2max, 33.56 ml/kg/min during LI or 59.67% of VO_2max, and 32.88 ml/kg/min during HI or 58.66% of VO_2max, during exercise trials. Respiratory Rates (RR) were not significantly different across trials (p=0.092). Insignificant findings shows RR during HI were 26.29±5.74 per min. RR during was CN 26.04±6.19 per min, and RR of LI was 24.75±6.63 per min.

Perceptual Data: Perceptual data of thirst (p=0.773), thermal sensation (p=0.709), and rating of perceived exertion (p=0.669) were compared across all trials showing a significant increase over time (p<0.001) for all perceptual data but no significant differences between trials were found. Average ratings of thirst were 4.00±1.68 for LI, 3.81±1.51 for HI and 3.92±1.51 for CN. At the end of exercise thirst averaged 4.8±1.89 during CN, 4.8±2.04 during LI, and

4.46±1.76 during HI. Thermal sensation ratings averaged 5.12±0.63 during HI, 5.35±0.60 during CN, and 5.35±0.70 during LI. At the end of exercise thermal sensation averaged 5.7±0.70 during CN, 5.56±0.90 during LI, and 5.46±0.76 during HI. RPE averaged 13±2 during CN, 13±2 during LI, and 13±1 during HI. At the end of exercise, RPE averaged 14±2 during CN, 14±2 during LI, and 14±2 during HI.

Mean Skin Temperature: Mean skin temperature showed no difference between time points (p=0.354) but a significant difference between trials (p=0.007) with HI reporting the lowest T_{SK} versus CN and LI. T_{SK} for CN averaged equal to T_{SK} for LI. No significant differences between time and trials were found (n=5, p=0.464). T_{SK} averaged 33.80°C±1.25°C during CN and 32.95°C±0.88°C during HI. T_{SK} during LI (33.65°C±1.22°C) was very similar to CN. At the end of exercise, T_{SK} averaged 33.76°C ±1.16°C during CN, 33.35°C ±1.09°C during LI, and 32.68°C ±0.61°C during HI.

Figure 3: T_{SK} across trials in degrees C.

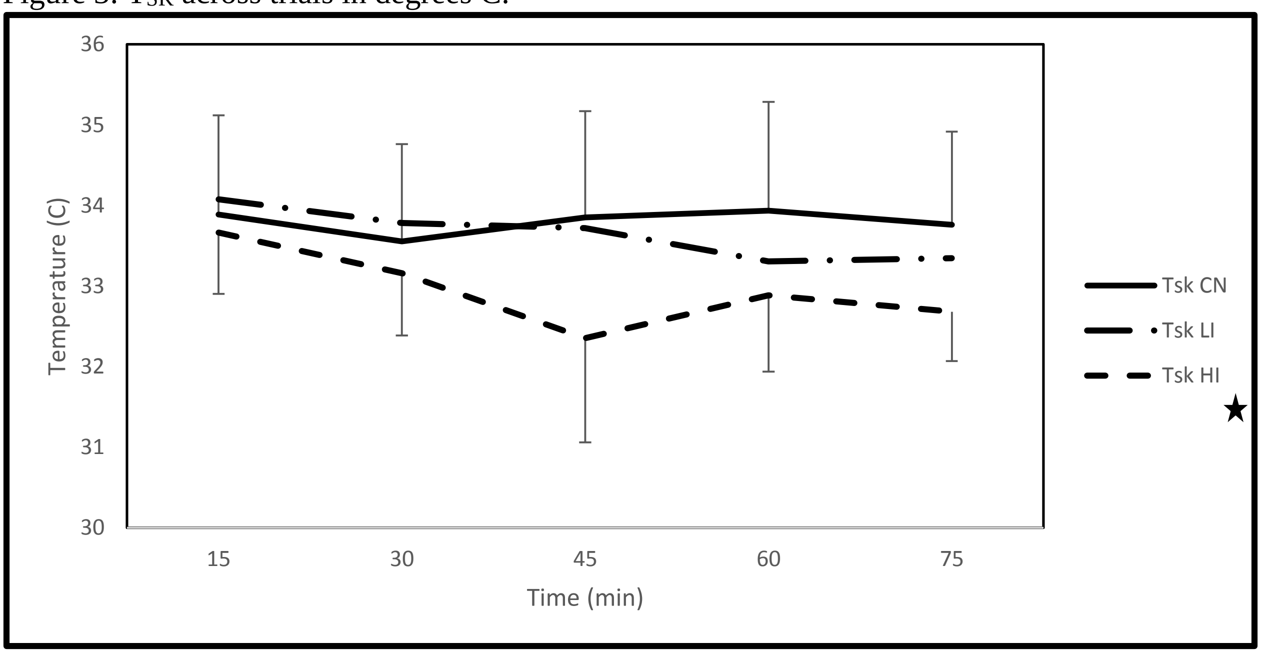

Figure 3: T_{SK} across all trials not significantly different. CN = control, LI = Low Intermittent, & HI = High Intermittent

Heart Rate: Heart rate significantly increased over time (p<0.01) from start of exercise to 30 minutes but then plateaued from 30 minutes until 60 minutes and significantly increased again from 60 minutes to the end of exercise at 75 minutes. There was no significant difference between trials (p=0.103) with respect to HR. HR averaged during CN at 158.20±11.51 bpm, 154.60±12.84 bpm during HI, and 153.40±12.55 bpm during LI. At the end of exercise, HR averaged 163.88±13.96 during CN, 157.95±12.39 during LI, and 159.67±12.09 during HI.

Figure 4: HR in beats per min (bpm) across all trials.

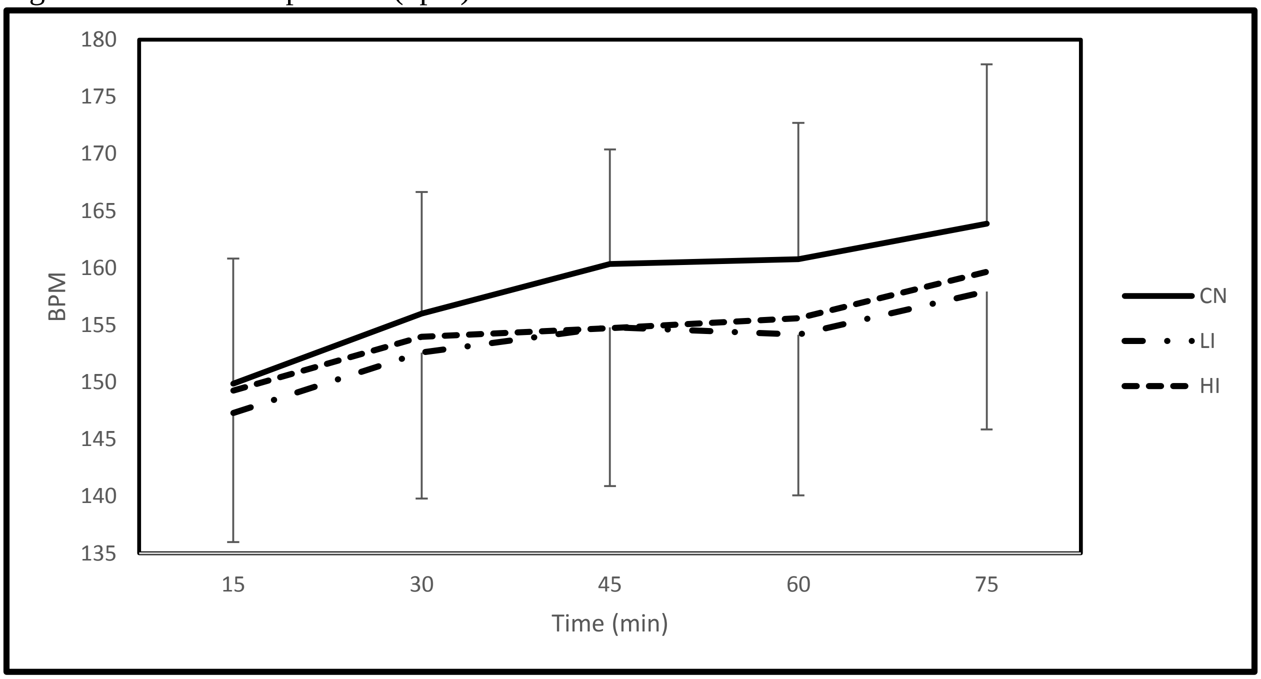

Figure 4: Heart Rate across trials was not significantly different. CN = control, LI = Low Intermittent, & HI = High Intermittent

Blood Pressure: Systolic BP significantly increased over time from start to 15 minutes then plateaued until the end of exercise (n=11, p<0.01) in all trials. Systolic BP was not significantly different between trials (n=11, p=0.507) or time by trial (n=11, p=0.102) and averages during CN were 181.10±17.38 and during HI were 187.50±25.01 with LI being 184.70±19.39. Diastolic BP significantly decreased (n=11, p=0.010) from start to 15 minutes then plateaued for the rest of the trials. There was no significant difference between trials (n=11, p=0.647) or time by trial (n=11, p=0.190) and averaged during CN of 63.83±13.94, LI averaged 68.58±17.65 and CN averaged 66.90±16.90. Neither systolic nor diastolic BP were significantly different between trials.

Figure 5: Systolic BP at top & Diastolic BP at bottom.

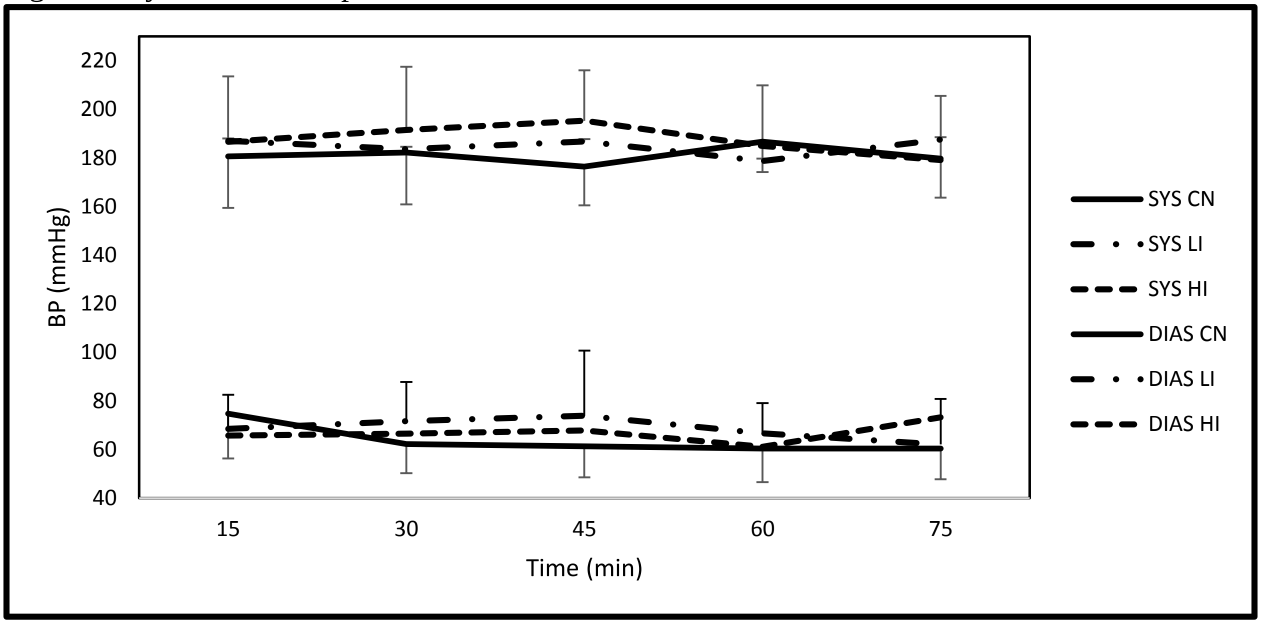

Figure 5: Top shows Systolic BP with no significant differences between trials. Bottom shows Diastolic BP with no significant differences between trials. CN = control, LI = Low Intermittent, & HI = High Intermittent

Gastrointestinal Temperature: Intestinal temperature significantly increased over the first three time points from start to 45 minutes but plateaued from 45 to 75 minutes in all trials ($p<0.01$). There was also a significant time by trial interaction ($p=0.033$) but post hoc analysis showed no significant differences between any time point and trial ($p>0.05$). At the end of exercise, HI produced an average T_{GI} of 37.95°C±0.45°C, CN T_{GI} elicited on average 38.14°C±0.37°C, and LI T_{GI} produced an average of 38.26°C±0.44°C. At the end of exercise, HI T_{GI} was 0.19°C±0.08°C lower than CN T_{GI}. HI T_{GI} was 0.31°C±0.02°C lower than LI T_{GI} and CN T_{GI} was 0.12°C±0.07°C lower than LI T_{GI}.

Figure 6: T_{GI} across trials.

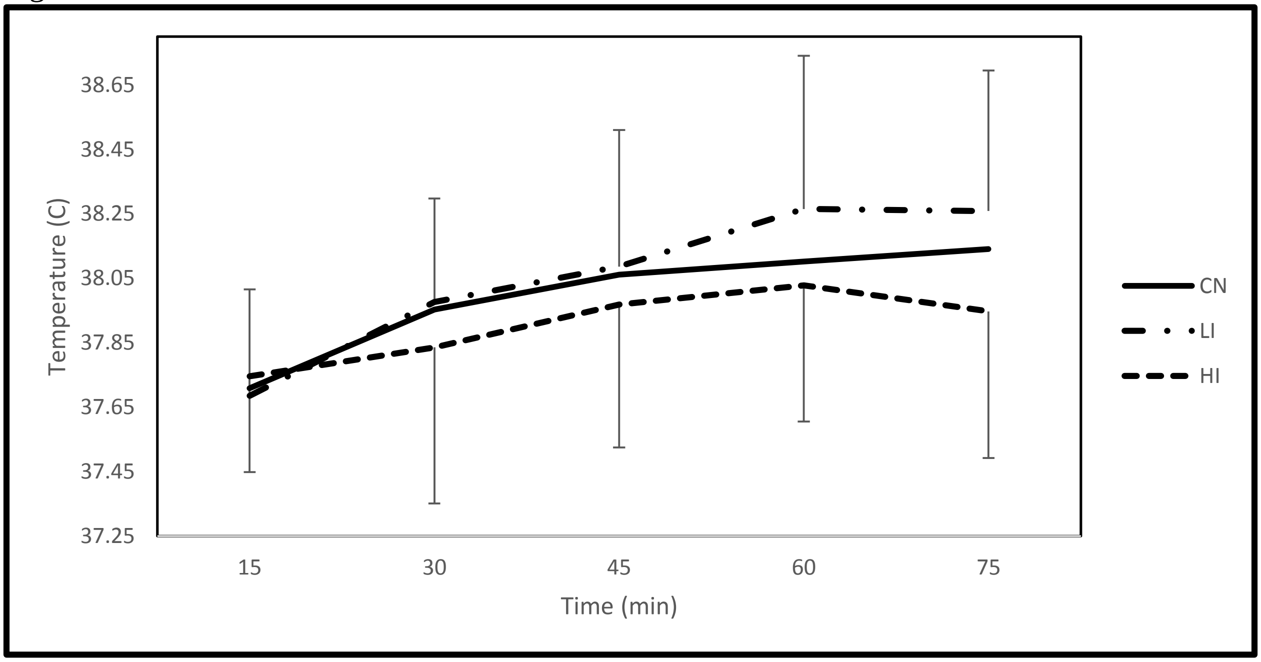

Figure 6: T_{GI} elicited no significant differences across trials. CN = control, LI = Low Intermittent, & HI = High Intermittent

Physiological Strain Index: PSI (p= 0.074) was insignificantly different across trials. PSI during CN trial was 6.00±1.40, during HI was 5.14±1.32, and LI was 5.94±1.41 but no significant differences between trials found.

Discussion:

We successfully controlled for diet, hydration, temperature, humidity, inspired air temperature, VO_2 Workload, and RR to ensure the accurate measurement of the effects of breathing cool air on perceptual ratings, $T_{SK,}$ HR, BP, T_{GI}, and PSI. In review, all aspects of the exercise trials were the same with the exception of the temperature of inspired air through the device during CN versus LI and HI and the ratio of use in the HI trial versus LI and CN. This research is the first to investigate prolonged exercise in the heat while intermittently breathing cool air at different ratios in trained cyclists. Previous studies examined acute cycling exercise to exhaustion in the heat while continuously breathing cold air.

Perceptual data: In this study, insignificant differences between trials show HI to provoke the lowest ratings of thirst, thermal sensation, and rating of perceived exertion in agreement with Geladas & Banister (1988). Perceptual ratings were lower during HI even though some subjects report feeling a limited ability to inhale as deeply as normal due to the device. Previous research by Hartung et al, (1980) did not report perceptual data and Geladas & Banister (1988) who also did not use perceptual scales report the majority of subjects stating that breathing cold air was beneficial and they would have exercised longer if asked. In the same study, two subjects who reported that they could continue to exercise were asked to do so, which they did for 15% longer during cold air inhalation.

Mean skin temperature: No statistically significant differences found between trials with respect to T_{SK}. Insignificant data shows CN produced the highest average T_{SK} while HI produced the lowest. T_{SK} for LI was very similar to CN. As T_{GI} rose during exercise in all trials, T_{SK} declined during HI and plateaued during LI and CN, this is in contrast to Geladas and Banister (1988) reports that skin temperature increases were almost parallel or equal to increases in rectal temperature. This study found T_{SK} to be lower than T_{GI} during CN, LI, and HI and rates of rise did not align either. The inconsistencies between studies may be due to the small number of data for T_{SK} from subjects, but it should be noted that Geladas and Banister (1988) only had eight subjects and Hartung et al, (1980) only had six. Further research is needed to clarify the differences between this study and previous research with respect to the effects of breathing cool air during exercise in the heat on physiological responses of T_{GI} and T_{SK}.

Heart Rate: During prolonged exercise, the changes in HR follow normal physiological responses. The initial increase in HR from start of exercise to a plateau around 30 minutes observed in all trials is accounted to the normal responses of reaching steady state exercise. As exercise continued, HR showed slight increases from 60 minutes until the end of exercise and is attributed to cardiovascular drift. No statistically significant differences found between trials with respect to HR. In this research, HR was lower in HI and LI trials and highest in the CN trial in agreement with reports by Geladas & Banister and Hartung et al, (1980) who found HR to be slightly higher during exercise with ambient gas breathing versus cold air breathing. The lower insignificant HR in cool air trials cannot be accounted to differences in use because subjects utilized the device at the same ratios in CN and LI. There may be reasonable argument that differences between CN and HI trials caused the difference in HR due to the lengthened ratio of use during HI but no differences in RR between trials were found. Slight physiological differences in HR are noted but do not lend support to suggestions by Geladas & Banister that breathing cold air aided a natural enhancement of HR and strengthened contractility of the myocardium. No support can be made because myocardium contractility was not measured and needs further research specifically focused at elucidating cold air respiration to correlations in contractility of the myocardium and enhanced heart rates.

Systolic & diastolic blood pressure: Normal blood pressure responses during exercise were observed in which elevated systolic BP remained on average between 175&200 mmHg and slightly elevated diastolic BP remained on average between 60&80 mmHg across all trials. Slight elevations of systolic BP observed in LI and HI trials versus CN and diastolic BP follows in parallel suggesting a slight interaction. Although a slight interaction may be present, future research is needed using colder inspired air and greater ratios of use to determine if any correlation between elevated BP responses and cold air breathing exists during exercise in the heat. As previously mentioned and in agreement with Hartung et al, (1980) breathing cold air is not advised in specific populations with medical contraindications but has no adverse effects in normal healthy populations.

Intestinal temperature: T_{GI} was insignificantly different across trials but was slightly lower during HI and slightly higher during LI. It is possible that differences in inspired air temperature and intermittent ratio of use between this research and previous research using colder continuous breathing accounts for the inability to find significant differences between trials with respect to T_{GI}. Specifically, the inspired air used by Hartung et al, (1980) and Geladas & Banister was -35°C (-31°F) cold enough to ice over the inspired air temperature sensor and 3.6°C (38.48°F) at continuous ratios, while inspired air during this research averaged higher temperatures at lower ratios of intermittent use. Therefore, it is suggested that breathing cool air intermittently attenuates rises in T_{GI} insignificantly and significantly reduced T_{GI} will be observed when continuous breathing of colder inspired air temperatures create greater thermal gradients for respiratory heat exchange to occur, in agreement with Geladas & Banister, Lind, and McFadden et al. To improve the thermal gradient and attenuation of T_{GI} increases, either cooler air must be breathed or a modification to the Core Cooler device allowing longer or deeper breathing be implemented. Some subjects did report feeling a limited ability to inhale as deeply as normal when utilizing the device supporting the recommendation for a modified mouthpiece.

Physiological strain index (PSI): A slight difference in PSI between trials is noted with the highest PSI during CN and lowest during HI, while PSI for LI was very similar to CN. It is possible that due to the longer ratio of use in the HI trial vs CN and LI created the insignificantly lower PSI, as well as, insignificantly lower T_{GI}, HR, and BP.

VO_2 Workload: CN produced the second highest percent of VO_2 workload, highest HR, T_{SK}, RPE, and lowest BP, across all trials. Subjects were working insignificantly hardest during LI with respect to percent of VO_2 workload yet had the lowest average HR and highest diastolic BP, thirst, and thermal sensation versus all other trials. HI produced the lowest percent of VO2 workload, T_{GI}, T_{SK}, thirst, thermal sensation, RPE, and the highest systolic BP. The observation of HI producing the lowest VO_2 workload across trials is in agreement with Geladas & Banister who attribute the suppression of mean body temperature increases to decreased VO_2 workloads in cold air trials.

In conclusion and agreement with Hartung et al, (1980) and in contrast to Geladas & Banister, physiological measurements during 75 minutes of cycling exercise in the heat while breathing cool air revealed no differences between CN, LI, or HI. Insignificant findings attributed to the difference in inspired air temperatures and ratio of use between this research and previous research by Hartung et al, (1980) and Geladas & Banister (1988) that did find significant differences in core temperature when continuously breathing cold air. In review of the data, CN produced the second highest percent of VO_2 workload, highest HR, T_{SK}, RPE, PSI and lowest BP, across all trials. Subjects were working slightly harder during LI with respect to percent of VO_2 workload yet had the lowest average HR and highest diastolic BP, thirst, and thermal sensation versus all other trials. HI produced the least stressful environment with the lowest percent of VO_2 workload, T_{GI}, T_{SK}, thirst, thermal sensation, RPE, PSI, and the highest systolic BP. With slight observations in consideration, it is reasonable to suggest that breathing cool air at high ratios during exercise in the heat slightly attenuates rises of physiological heat strain. As a result, modifications to the Core Cooler device are needed allowing for greater inhalation of cool air via a modified mouthpiece or the temperature of the inspired air must be enhanced to elicit colder respiration of air. Future studies are needed to further establish if a modified device providing greater inhalation capabilities allowing normal breathing of cool air during exercise in the heat would attenuate rises in physiological heat strain, prolonging the ability to perform and endure exercise in the heat. The Core Cooler in its current form will not provide an adequate prevention to heat illness, prolong endurance capabilities, or enhanced performance to a significant degree.

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Appendix

January 21, 2014

MEMORANDUM

TO:	Christian Ridings Stavros Kavouras Matt Tucker JD Adams Brendon McDermott Matthew Ganio James Grant Nicole Moyen Morgan DeMartini
FROM:	Ro Windwalker IRB Coordinator
RE:	PROJECT MODIFICATION
IRB Protocol #:	13-09-072
Protocol Title:	*The Use of the Core Cooler Cold-Air Inhalation Device in Attenuating Core Temperature Increases During Exercise in the Heat*
Review Type:	☐ EXEMPT ☐ EXPEDITED ☒ FULL IRB
Approved Project Period:	Start Date: 01/17/2014 Expiration Date: 09/12/2014

Your request to modify the referenced protocol has been approved by the IRB. **This protocol is currently approved for 30 total participants.** If you wish to make any further modifications in the approved protocol, including enrolling more than this number, you must seek approval *prior to* implementing those changes. All modifications should be requested in writing (email is acceptable) and must provide sufficient detail to assess the impact of the change.

Please note that this approval does not extend the Approved Project Period. Should you wish to extend your project beyond the current expiration date, you must submit a request for continuation using the UAF IRB form "Continuing Review for IRB Approved Projects." The request should be sent to the IRB Coordinator, 210 Administration.

For protocols requiring FULL IRB review, please submit your request at least one month prior to the current expiration date. (High-risk protocols may require even more time for approval.) For protocols requiring an EXPEDITED or EXEMPT review, submit your request at least two weeks prior to the current expiration date. Failure to obtain approval for a continuation *on or prior to* the currently approved expiration date will result in termination of the protocol and you will be required to submit a new protocol to the IRB before continuing the project. Data collected past the protocol expiration date may need to be eliminated from the dataset should you wish to publish. Only data collected under a currently approved protocol can be certified by the IRB for any purpose.

If you have questions or need any assistance from the IRB, please contact me at 210 Administration Building, 5-2208, or irb@uark.edu.