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Effects of Obesity on Thermoregulation and Cardiovascular Function During Exercise in Females

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of the requirements for the degree of
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By

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ABSTRACT

Previous research has shown that obese individuals are at greater risk for heat illnesses because of impaired thermoregulation. However, laboratory studies investigating cardiovascular and thermoregulatory function in obese individuals are difficult to interpret because of low sample sizes and methodological concerns. The purpose of this study was to determine if there are differences in thermoregulatory and cardiovascular function between obese and non-obese females. Twenty-four females, 13 obese (43.3 ± 4 .3 % fat, 77.2 ± 13.7 kg) and 11 non-obese (27.8 ± 6.0 % fat, 55.7±6.7 kg), cycled for 60 min in a warm environment (~40°C, 30% humidity) at a work load that elicited either 300 W of metabolic heat production (fixed heat production; FHP) or 175 W/m^2 of skin surface area (body surface area; BSA). In the FHP trial, when heat production was similar between obese (290 ± 16 W) and non-obese (299±18 W) individuals ($P > 0.05$), no differences in rectal temperature (T_{re}), mean skin temperature (T_{sk}), VO_2 (l/min), or sweat rate (l/hr) occurred (all $P > 0.05$). As expected because of greater skin surface area, the obese individuals in the BSA trial had a greater heat production (316±33 W) compared to the non-obese individuals (284 ± 23W) which was a result of higher VO_2 during exercise (1.14 ± 0.10 vs. 1.01 ± 0.09 l/min; $P > 0.05$). The rise in T_{re} and T_{sk}, over time in the BSA trial was not dependent on subject grouping (i.e., non-significant interaction $P > 0.05$). In conclusion, when obese and non-obese individuals exercise at a fixed metabolic heat production or a heat production relative to body surface area there are no thermoregulatory differences between groups. The overall relatively minor increases in T_{re} (0.55 ± 0.28 and 0.61 ± 0.34°C for FHP and BSA trials, respectively), may partially explain why differences were not observed in this setting.

This thesis is approved for recommendation
to the Graduate Council

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FIGURE CAPTIONS

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Chapter 1: Introduction

Obesity is often listed as a contributing factor to increased core temperature (i.e., hyperthermia) during exercise, and epidemiological data supports the hypothesis that obese individuals are at a greater risk for heat illnesses such as heat exhaustion and exertional heat stroke (Bartley, 1977). During exposure to the heat, thermoregulatory homeostasis is maintained by balancing heat gain and heat loss. Heat gain occurs primarily from the increase in metabolic heat production during exercise but also can occur from the environment if ambient temperatures are high enough (i.e., greater than skin temperature). Heat loss during exercise is primarily achieved by increasing skin blood flow and increasing sweating.

If heat production/gain is similar between individuals, impaired thermoregulation will be due to differences in heat loss (e.g., differences in skin blood and/or differences in sweating). As core temperature increases, there is a "set point" in which skin blood flow begins to increase. It continues to increase until it reaches an apparent upper limit (Brengelmann et al. 1977). Importantly the core temperature in which skin blood flow begins to increase and maximal skin blood flow level are dictated by various factors. For example, after heat acclimation, skin blood flow begins to increase at a lower core temperature set point and reaches a greater maximal level; these changes aid in the removal of heat and thus thermoregulation (Wenger CB, 1988). At 30, 50, and 70% VO_{2max} skin blood flow in obese individuals begins to increase at a greater core temperature (i.e., delayed onset of increased skin blood flow) and absolute skin blood flow is lower compared to non-obese individuals (Vroman et al. 1983). This provides some evidence for why obese individuals may have a greater core temperature response to exercise. However differences in metabolic heat production between individuals during exercise make these findings difficult to interpret (see below).

As core and skin temperature increases, sweat rate increases to aid in decreasing core temperature. Whole-body sweat rate is greater in obese individuals compared to non-obese individuals (Bar-Or, 1969). This is likely due to a greater sweat output per gland because obese and non-obese individuals do not have a different number of sweat glands (Bar-Or O, 1968). Greater sweat output per gland can be due to either greater metabolic heat production or when heat generation is kept constant, the central nervous system drive for sweating may be greater in obese versus non-obese individuals (Eijsvogels 2011).

In obese individuals, it is observed that several physiological changes may increase heat production or impede heat loss. Prior research comparing thermoregulatory function between obese and non-obese individuals had individuals exercise at the same relative intensity [i.e., percent maximal oxygen uptake (% VO_{2max})]. Obese and non-obese individuals often have a different VO_{2max}, thus at the same relative intensity absolute work load and in turn metabolic heat production will differ between obese and non-obese individuals. Heat production must be matched in order to properly examine thermoregulatory function. Not matching heat production between subjects has led some researchers to inappropriately conclude that obese individuals have impaired thermoregulation (Vroman et al. 1983).

Along with physiological differences, differences in physical characteristics may explain thermoregulatory differences between obese and non-obese individuals. A larger surface area-to-mass ratio is beneficial for thermoregulation during exercise in a warm and dry climate because relative to body size, one would have greater heat loss avenues through the skin (Shvartz et al 1973). For example differences between core temperature in males and females during exercise are attributable to differences in the surface area-to-mass ratio (Shapiro et al. 1980). Obese individuals may be at a greater thermoregulatory disadvantage because they have a lower

surface area-to-mass ratio (Epstein et al. 1983). As one becomes obese, there is an increase in body mass without a proportional increase in surface area, resulting in a lower surface area-to-body mass ratio. Because cutaneous heat loss is relatively proportional to skin surface area, obese individuals may lose their metabolic heat more slowly than non-obese individuals (Verbraecken et al. 2006). In order to effectively examine impairments in thermoregulatory due to physical differences between individuals, heat production during exercise should be proportional to their surface area. Thus any differences in core temperature would be due to differences in heat loss mechanisms (i.e., skin blood flow and sweating) and not physical characteristics (i.e., surface area-to-mass ratio).

In the present study, thermoregulatory function will be examined while females exercise at an intensity that elicits the same heat production (fixed heat production trial; FHP) and at an intensity in which heat production is proportional to skin surface area (body surface area trial; BSA).

Chapter 2: Literature Review

One third of Americans are obese (Finkelstein, Trogdon, Cohen & Dietz, 2009), and in order to lose weight, the American College of Sports Medicine recommends >250 minutes of exercise per week (Donnelly, Blair & Jakicic, 2009). Performing moderate intensity exercise increases body temperature (Gisolfi, Lamb & Nadel, 1993). This increase in temperature creates physiological and psychological fatigue that may decrease one's ability to meet exercise recommendations and greater goal to lose weight.

Obesity is often mentioned as a contributing factor to increased core temperature (i.e., hyperthermia) (Gisolfi, Lamb & Nadel, 1993), and epidemiological data has shown that obese individuals are at a greater risk for heat illnesses (Casa, 1999). However, findings from laboratory studies investigating whether obesity compromises thermoregulatory control are mixed (Bar-Or, 1969; Robinson, 1942).

Thermoregulation during exercise

Homeostasis is maintained within a variety of environments through constant internal and external changes. Thermoregulation is the ability of an organism to keep its body temperature within certain defined boundaries, even when the surrounding temperature is very different. During exposure to the heat, thermoregulatory homeostasis is maintained by balancing heat gain (from internal heat production and environmental heat gain) and heat dissipation. When core body temperature increases just 1˚C, physiological and psychological processes can be severely impaired (Bouchama & Knochel, 2002). The principal component for heat production at rest is the body's basal metabolic rate which can generate ~70 kcal/hour. Under normothermic conditions, this heat generation can be balanced by heat dissipation, thus no change in core temperature occurs (Knochel, 1989).

During exercise, muscle contractions produce heat and core temperature increases. Without adequate thermoregulatory control, core temperature can reach dangerous hyperthermic levels. Increases in skin blood flow and sweating are the primary physiological mechanisms by which heat is removed from the body during exercise. As core temperature increases, there is a "set point" in which skin blood flow begins to increase. It continues to increase until it reaches an apparent upper limit (Brengelmann et al. 1977). The core temperature in which skin blood flow begins to increase and maximal skin blood flow level are dictated by various factors. For example, after heat acclimation, the threshold for the onset of increased skin blood flow is at a lower core temperature and reaches a greater maximal level; these changes aid in the removal of heat and thus thermoregulation (Wenger CB, 1988). During exercise, evaporation of sweat accounts for upwards of 75% of heat loss (Gleeson et al. 1998). Similar to skin blood flow, there is a core temperature set point in which sweating begins along with a maximal sweat rate, both of which are dictated by a variety of physiological factors (Wenger CB, 1988). Steady-state core temperature is reached when the body's heat generation is matched by dissipation (Montain et al. 1998). Though greater strain is put on the thermoregulatory system as environmental temperature increases, healthy individuals are able to maintain a steady-state core temperature in a variety of environments.

Effects of obesity on thermoregulation

Core temperature differences between individuals are due to either differences in heat production and/or heat loss. In obese individuals, it is observed that several physiological changes may increase heat production or impede heat loss. Traditional research examining thermoregulatory function between obese and non-obese individuals has individuals exercise at the same relative intensity [i.e., percent maximal oxygen uptake (% VO_{2max})]. Obese and non-

obese individuals often have a different VO_{2max}. Thus at the same relative intensity, absolute work load and in turn heat production differs between obese and non-obese individuals. Heat production must be matched in order to properly examine thermoregulatory function. Not matching heat production between subjects has led some researchers to inappropriately conclude that obese individuals have impaired thermoregulation (Vroman et al. 1983).

After matching heat production, differences in core temperature between individuals are due to differences in heat loss. Heat loss during exercise is primarily achieved by increasing skin blood flow and increasing sweating (see above). Thus impaired thermoregulation between populations will be due largely to differences in skin blood and/or differences in sweating. Vroman et al. (1983) observed that non-obese individuals have higher absolute skin blood flow compared to obese individuals at relative intensities of 30, 50, and 70% VO_{2max}. Vroman et al. (1983) showed that increases in sweating begin at a higher core temperature during exercise in obese individuals. This higher set point puts obese individuals at a thermoregulatory disadvantage and provides some evidence for why they may have a greater core temperature response to exercise. However differences in metabolic heat production between individuals make these findings difficult to interpret (see above).

As core and skin temperature increases, sweat rate increases to aid in decreasing core temperature. Obese individuals sweat more than non-obese individuals (Bar-Or, 1969); however this observation may be simply due to the use of inappropriate research designs (see above). Obese and non-obese individuals do not have a different number of sweat glands because after maturation, the number of sweat glands does not change (Bar-Or, 1969). However obese individuals have greater skin surface area, so the density of sweat glands (i.e., relative number in a given area) is lower in obese individuals (Bar-Or O, 1968). Thus greater sweat rate in obese

individuals is likely due to greater sweat output per gland. In support of this, Eijsvogels et al. (2011) reported that sweat rate remained higher in obese individuals even after taking skin surface area into account. Differences in sweat rate between obese and non-obese individuals may be due to a greater drive for sweating from the central nervous system in obese individuals.

Along with physiological differences, differences in physical characteristics may explain thermoregulatory differences between obese and non-obese individuals. Paralleled with obesity is increased body fatness. Adipose tissue, because of its reduced thermal conductivity (Cooper et al. 1971) and increased insulator capacity, provides an insulating barrier to the conductive heat flow. At rest, the degree of thermal insulation from adipose tissue has been shown to be positively related to the degree of obesity (Jequier et al 1974). Savastano et al. (2009) observed that increased adiposity can have blunted core-to-skin heat loss and that heat dissipation from the abdominal area is impaired in obese individuals when at rest in normothermic conditions. It is unknown if increased adipose insulation effects core temperature responses during exercise in the heat.

A larger surface area-to-mass ratio is beneficial for thermoregulation during exercise in a warm and dry climate because relative to body size, one would have greater heat loss avenues through the skin (Shvartz et al 1973). For example, it has been previously shown that differences between core temperature in males and females are attributable to differences in surface area-to-mass ratios (Shapiro et al. 1980). It follows that obese individuals may be at a greater thermoregulatory disadvantage because they have a lower surface area-to-mass ratio (Epstein et al. 1983). As one becomes obese, the increase in body mass occurs at a greater relative rate then the increase in surface area, resulting in a lower surface area-to-body mass ratio. Because cutaneous heat loss is relatively proportional to skin surface area, obese individuals may lose

their metabolic heat more slowly than non-obese individuals (Verbraecken et al. 2006). In order to effectively examine impairments in thermoregulatory due to physical differences between individuals, heat production during exercise should be proportional to their surface area. Thus any differences in core temperature would be due to differences in heat loss mechanisms (i.e., skin blood flow and sweating) and not physical characteristics (i.e., surface area-to-mass ratio).

Effects of obesity on cardiovascular function

Cardiovascular adaptations associated with obesity include increased cardiac output and stroke volume at rest and during exercise (Collis et al. 2001; Messerli et al. 1982). These changes are likely due to increased blood volume (Messerli et al. 1982) and fat free mass (Collis et al. 2001) associated with obesity. Characterizing the hemodynamic responses during exercise are important for understanding how the cardiovascular system responds to stress while compensating for the structural and metabolic changes associated with excess body mass.

It is possible that some of the cardiovascular responses in obese individuals are due to differences in VO_{2max}. Obese individuals have a greater absolute VO_{2max} than non-obese individuals, but when taking body mass into account, relative VO_{2max} is lower in obese versus non-obese individuals. Greater absolute VO_{2max} is positively correlated with left ventricular chamber size and mass at rest (Barbier et al. 2006) and enhanced diastolic function during exercise (Stickland et al. 2006).

In summary, obesity is a chronic and costly disease that affects millions of Americans (Finkelstein, Trogdon, Cohen & Dietz, 2009). Exercise is a recommended treatment for weight loss, described by the Exercise is Medicine® campaign created by the American College of Sports Medicine (Thompson, Gordon, Pescatello, 2009). Though the benefits of exercise are well understood, obese individuals are not meeting current recommendations (Hamer & O'Donovan,

2009). It is hypothesized that thermoregulatory dysfunction in obese individuals creates a significant barrier to fulfilling exercise recommendations and may put them at a greater risk for heat illness.

Thermoregulatory function in obese individuals has not been adequately described and the few studies who have attempted to examine this topic have mixed results. Previous studies have failed to equate heat generation between non-obese and obese subjects, so it is difficult to determine whether obese individuals have physiological impairments to heat stress. In the present study, thermoregulatory function was examined while females exercise at an intensity that elicits the same heat production (fixed heat production trial; FHP) and at an intensity in which heat production is proportional to skin surface area (body surface area trial; BSA).

Chapter 3: Procedures

Subjects

Eleven obese (body fat = mean 43.3±4.3%, range 38.6-52.8%) and 13 non-obese (body fat = mean 27.8±6.0%, range 17.8-36.6%) females (n=24) were tested in the early follicular phase of their menstrual cycle (days 1-7) when endogenous progesterone and estrogen levels are low. Classification of obese versus non-obese subjects were based off of published guidelines (Gallagher, Heymsfield & Heo, 2000) after body composition was measured using Dual-energy X-ray absorptiometry (General Electric®, Lunar Prodigy Promo). Subjects were sedentary as self-reported with the International Physical Activity Questionnaire (IPAQ; Table 1) (Craig CL, 2003). Subjects filled out an informed consent prior testing. This study was approved by the University's Institutional Review Board.

Prior to each visit, subjects were instructed to refrain from the consumption of alcohol, caffiene, and over the counter drugs for the 24 hours prior to testing and refrain from the ingestion of food other than water for the 2 hours prior to arrival. Euhydration was encouraged by having subjects consume an additional 500 mL of water the night before testing and 2-3 hours prior to arrival. Subject compliance to pre-test instructions was verified with a 24-hr questionnarie filled out prior to each trial.

Familiarization Visit

At least 72 hours prior to the first experimental trial, subjects completed a familiarization visit. Body mass (Health O Meter Professional®, 349 KLX), height, and body composition (Dual energy X-Ray absorptiometry, General Electric®, Lunar Prodigy Promo) were measured and body surface area (BSA) was calculated according to DuBois and DuBois (1916):

$$BSA = (W^{0.425} \times H^{0.725}) \times 0.007184$$

where W is weight in kilograms and H is height in centimeters.

Subjects then performed an exercise test to determine maximal oxygen consumption (VO_{2max}). Subjects exercised on an electronically braked ergometer (Racermate Veletron, Seattle, WA) while breathing through a mouthpiece connected to a metabolic cart (Parvo Medics' TrueOne® 2400, Sandy, UT). Exercise started at 40 W and increased 25 W every 2 minutes until volitional exhaustion. Every 2 minutes and at exhaustion, heart rate (HR; Polar Electro® T31) and rating of perceived exertion (RPE; Borg 1970) was measured. At exhaustion a small blood sample (< 1 ml) was collected via a finger-stick to assess blood lactate levels (Accutrend® Lactate, Cobas Lactate Strips; Hawthorne, NY).

Experimental Trials

Upon arrivial, urine specific gravity via a refractometer (Sper Scientific®, 300005; Scottsdale, AZ) was measured from a voided urine sample. Nude body weight was measured and subjects then inserted a rectal thermocouple (T_{re}; Physiotemp Instruments Inc., RET 1, Clifton, NJ) 10 cm past the anal sphinctor. Skin temperature thermocouples (Omega Engineering, Stamford, CT) were attached on the right side of the body and mean skin temperature (T_{sk}) was measured using the formula of Ramanthan (1963):

$$T_{sk} = 0.3 (T_1 + T_2) + 0.2 (T_3 + T_4)$$

where T_1 is the lateral subdeltoid; T_2 is the pectoral; T_3 is the lateral calf; T_4 is the quadriceps. Factory calibration of the thermocouples was verified throughout testing (Omega Engineering INC., Stamford, Connecticut).

The subject then entered a controlled environmental room (40°C, 30% RH) and sat on the ergometer for 10 min. The subjects then exercised at either 1) a fixed heat production (FHP) of 300 W or 2) a target metabolic expenditure of 175 W/m^2 of skin surface area. Trials were seperated by a minium of 72 hours and were performed in a randomized, counter-balanced fashion. A fan (Holmes®, Power 20 fan) producing an air speed of 3.5 m/s was directed at the subject throughout exercise, and subjects wore the same clothing for each trial.

During exercise, HR and T_{re} were recorded every 5 min. Rating of perceived exertion (RPE) was measured every 10 min. Thermal sensation (Young 1987) and thirst sensation were measured just prior to and every 10 min during exercise. At 10, 30 and 55 min of exercise, blood pressure was measured via automated syphgmammometer (Tango+, Sun Tech Medical, Morrisville, NC) on the right arm. In order to maintain euhydration throughout the trials four equal boluses (3 ml/kg body mass each) of body temperature water (~37°C) were provided just before and after 15, 30, 45 min of exercise. VO_2 was measured after 3 min of exercise and at least every 10 min therafter in order to verify the target metabolic heat production required for the trial was being produced. Metabolic heat production was calculated by subtracting external work performed (Watts) from metabolic energy expenditure. Rate of metabolic energy expenditure (M) was calculated from VO_2 and respiratory exchange ration (RER) during exercise using the following formula (Nishi Y. 1981):

$$\dot{M} = \sum \left(\dot{V}O_2 \left[\frac{RER - 0.7}{0.3} e_c + \frac{1 - RER}{0.3} e_f \right] \right), \qquad [3]$$

where e_c is the caloric equivalent per liter of oxygen for the oxidation of carbohydrates (21.13 kJ), and e_f is the caloric equivalent per liter of oxygen of fat (19.62 kJ).

After exercise, voided urine volume and specific gravity was measured. After deinstrumentation, a dry post-exercise nude body weight was measured. Whole body sweat rate, corrected for fluid ingestion, urine volume post-exercise, and respiratory water losses (Mitchell JW, 1972), was calculated using pre- and post-exercise nude body mass.

Statistical Analyses

Statistical analyses was performed using SPSS v.12 for Windows (IBM SPSS Software., Armonk, New York). Data are reported as mean ± standard deviation (SD). An alpha level of 0.05 was used for all significance tests. To examine the effects of body composition on thermoregulation during exercise, a two way (group vs. time) repeated measures of analysis of variance (ANOVA) was used to test the significance of mean differences. Differences between obese and non-obese individuals were examined by comparing the two experimental trials seperately (i.e., fixed heat production trial and heat production relative to body surface area) Greenhouse-Geisser corrections were made when the assumption of sphericitiy was violated. Follow-up repeated measures t-tests and the Bonferroni alpha correction were used when appropriate.

Chapter 4: Results

Demographics

There were no differences in age, height, VO_{2max} when expressed in L/min or ml/kg/fat-free mass, and IPAQ scores (all $P > 0.05$). As expected, body fat percentage, body mass, and body surface area were greater in the obese versus non-obese individuals ($P < 0.001$; Table 1). VO_{2max} (ml/kg/min) was lower in obese versus non-obese individuals ($P < 0.05$). Maximum HR, lactate, and RPE during the VO_{2max} test were 182 ± 13 bpm, 8.3 ± 1.5 mmol/L, 19 ± 1, respectively.

When comparing metabolic heat production between all trials, there was a significant interaction between group and trial ($P = 0.002$; Figure 1). Follow-up testing revealed no difference in heat production in the FHP trial between groups ($P = 0.192$), but there was a difference between groups in the BSA trial ($P = 0.01$; Figure 1). In the obese group, there was a difference in metabolic heat production in the FHP trial versus BSA trial ($P = 0.018$; Figure 1). In the non-obese group, there was no difference in metabolic heat production in the FHP trial versus BSA trial ($P = 0.069$; Figure 1).

Fixed Heat Production Trial

By design, metabolic heat production, ambient temperature, and relative humidity in the FHP did not differ between obese and non-obese individuals ($P > 0.05$, Table 2A). This resulted in a similar external ergometer load, VO_2, HR, MAP, and sweat rate ($P > 0.05$; Table 2A) between groups. Water consumption during exercise was relative to body mass, thus obese subjects consumed more fluid than non-obese (231.4 ± 39.7 vs. 166.9 ± 20.2 ml, respectively; $P < 0.001$). At the end of exercise % hydration was not different between groups ($P > 0.05$; Table

2A). Post-exercise voided urine volume was 141.4 ± 72.2 ml for obese and 36.5 ± 73.4 ml for non-obese ($P > 0.05$)

HR did not differ between groups ($P = 0.59$), but increased over time ($P < 0.001$; Figure 2A). Specifically, after increasing from rest, HR continued to increase for the first ten minutes of exercise ($P < 0.001$), but then stabilized for the remainder of the trial. MAP at 10, 30 and 55 min of exercise for the obese group was 83 ± 10, 81 ± 10, and 79 ± 11.00 mmHg, respectively. MAP over the same time points for the non-obese group was 88 ± 11, 87 ± 12, and 81 ± 4 mmHg. MAP did not differ between groups ($P = 0.13$) and showed no differences over time by either group ($P > 0.05$).

T_{sk} did not change over time or differ between groups ($P > 0.05$; Figure 3A). The increase in T_{re} over time was not dependent on subject grouping (i.e,. non-significant interaction: $P = 0.56$; Figure 4A). So, independent of group, T_{re} temperature increased from 10 min until the end exercise ($P < 0.05$), with one exception; there was a plateau from 40 to 45 minutes of exercise ($P = 1.00$). Change in T_{re} relative to rest (min 0 of exercise; ΔT_{re}) was not dependent on subject grouping (i.e,. non-significant interaction: $P = 0.90$; Figure 5). Independent of groups, ΔT_{re} temperature increased from 10 min until the end exercise ($P < 0.05$), with three exceptions; there were plateaus from 35 to 40, 40 to 45 minutes and 55 to 60 minutes of exercise (all $P = 1.00$). Overall ΔT_{re} from the beginning to end of exercise was not different between obese and non-obese in FHP ($P > 0.05$; Figure 6).

RPE increased over time ($P < 0.001$) (~11±1 for 10 min vs. 14±1 for 60 min), but the increase did not differ between groups ($P > 0.05$; Table 3). Thirst sensation did not differ between groups ($P > 0.05$; Table 3). There was, however, an increase over time ($P < 0.001$) (2±1 at 0 min vs. 3±1 at 60 min). Thermal sensation did not differ between groups ($P > 0.005$; Figure

9A; Table 3). There was, however, an increase over time ($P < 0.001$) (5±1 at 0 min vs 6±1 at 60 min).

Body Surface Area Trial

Since BSA differed between groups, metabolic heat production was different between groups during the BSA trials (Table 2B and Figure 1; P=0.01). Therefore VO_2 differed between groups ($P = 0.005$) but not cycling watts, ambient temperature, relative humidity, sweat rate ($P > 0.05$; Table 2B). Water consumption during exercise was relative to body mass, thus obese subjects consumed more fluid than non-obese (231.4 ± 39.7 vs 166.9 ± 20.2 ml, respectively; $P < 0.001$). At the end of exercise % hydration was not different between groups ($P > 0.05$; Table 2B). Post-exercise voided urine volume was 82.3 ± 82.4 ml for obese and 51.2 ± 87.5 ml for non-obese ($P > 0.05$).

HR did not differ between groups ($P = 0.106$; Figure 2B), but increased over time ($P < 0.001$). Specifically, HR increasing from rest to 5 min of exercise ($P < 0.001$), but did not change for the remainder of the trial. MAP over time for the obese group was 84 ± 6, 80 ± 4, and 81 ± 10 mmHg. MAP over time for the non-obese group was 85 ± 10, 86 ± 13, and 74 ± 25 mmHg. MAP did not differ between groups ($P = 0.33$) and showed no differences over time by either group ($P > 0.05$).

Over time, T_{sk} was dependent on subject grouping (i.e., significant interaction: $P = 0.01$; Figure 3B). This was due to obese individuals starting with a lower T_{sk} ($P = 0.02$), and at min 5 of exercise, obese individuals had a significant increase in T_{sk} relative to rest ($P < 0.001$). The increase in T_{re} over time was not dependent on subject grouping (i.e., non-significant interaction: $P = 0.409$; Figure 4B). Independent of groups, T_{re} temperature did not increase until min 25 of

exercise ($P < 0.001$), subsequent subtle increases in T_{re} every 5 min were not significantly different than the prior measure ($P > 0.05$). Change in T_{re} relative to rest (min 0 of exercise) was not dependent on subject grouping (i.e,. non-significant interaction: $P = 0.41$; Figure 5B). Independent of groups, ΔT_{re} temperature stabilized at the onset of exercise until there was an increase at 20 min ($P > 0.001$) and then plateaued until the end exercise ($P > 0.05$). Overall, there were no differences in ΔT_{re} between obese and non-obese in BSA trial ($P > 0.05$; Figure 6).

RPE increased over time ($P < 0.01$; Figure 7B; Table 3) (11±1 at 10 min vs. 15±1 at 60 min), but the increase did not differ between groups ($P > 0.05$). Thirst sensation did not differ between groups ($P > 0.05$; Figure 8B; Table 3). There was, however, a difference over time ($P < 0.001$) (3±1 at 0 min vs. 4±1 at 60 min) . Thermal sensation did not differ between groups ($P > 0.05$). There was, however, a difference over time ($P < 0.001$; Figure 9B; Table 3) (5±1 at 0 min vs. 6±1 at 60 min).

Table 1. Demographics for obese and non-obese participants

	Age (years)	Height (cm)	Mass (kg)	% Fat	BSA (m^2)	VO_{2max} (l/min)	VO_{2max} (ml/kg/FFM)	VO_{2max} (ml/kg/min)	IPAQ
Obese	26±7	168.3±5.6	77.2±13.7*	43.3±4.3*	1.90±0.10*	2.10±0.40	47.9±7.9	27.2±5.8*	3283±4110
Non-Obese	27±6	164.7±7.0	55.7±6.7	27.8±6.0	1.60±0.10	1.95±0.30	48.5±5.2	35.1±4.4	2501±1679

Mean ± SD. Body surface area (BSA) estimated using the equation of DuBois and DuBois (1916); VO_{2max}: maximal oxygen uptake; FFM: fat free mass; IPAQ: International Physical Activity Questionnaire. *Significant difference between obese and non-obese ($P \leq 0.001$)

Table 2A. Mean ± SD metabolic heat production, external workload, heart rate (HR), mean arterial pressure, oxygen consumption (VO_2), ambient temperature, relative humidity, sweat rate, and percent hydration for obese and non-obese participants in the Fixed Heat Production Trial (FHP) trial.

Fixed Heat Production Trial									
	Metabolic Heat Production (W)	**External Ergometer Load (W)**	**Exercising HR (bpm)**	**MAP (mmHg)**	**VO_2 (l/min)**	**Ambient Temp (°C)**	**Relative Humidity (%)**	**Sweat Rate (l/hr)**	**%Hydration**
Obese	290±16	57±9	141±16	81±8	1.06±0.04	40.2±0.4	34±2	0.87±0.28	0.00±0.4
Non-Obese	299±18	63±5	146±19	82±5	1.07±0.06	40.1±0.7	33±3	0.70±0.15	0.13±0.3

Mean ± SD. W: Watt; MAP: Mean Arterial Pressure; bpm: beats per minute. There were no significant differences between obese and non-obese ($P > 0.05$).

Table 2B. Mean ± SD metabolic heat production, external workload, heart rate (HR), mean arterial pressure, oxygen consumption (VO_2), ambient temperature, relative humidity, sweat rate, and percent hydration for obese and non-obese participants in the BSA trial.

Body Surface Area Trial										
	Metabolic Heat Production (W)	**External Ergometer Load (W)**	**Relative Metabolic Heat Production (W)**	**Exercising HR (bpm)**	**MAP (mmHg)**	**VO_2 (l/min)**	**Ambient Temp (°C)**	**Relative Humidity (%)**	**Sweat Rate (l/hr)**	**%Hydration**
Obese	316±33*	64±1	169±8	147±14	82±5	1.14±.10*	40±1.0	34±3	0.76±.17	-0.10±.22
Non-Obese	284±23	58±9	177±5	136±16	82±14	1.01±.09	40±.5	33±3	0.66±.14	0.10±.09

Mean ± SD. W: Watt; MAP: mean arterial pressure; bpm: beats per minute. *Significant difference between obese and non-obese ($P < 0.05$).

Table 3. Mean ± SD rating of perceived exertion (RPE), Thirst, and Thermal sensation for obese and non-obese groups while cycling at a fixed heat production or heat production relative to body surface area.

	Fixed Heat Production Trial			Body Surface Area Trial		
	Thirst	**Thermal**	**RPE**	**Thirst**	**Thermal**	**RPE**
Obese	3±1	6±0	13±2	3±1	6±0	13±2
Non-Obese	3±1	6±1	13±2	3±1	6±1	13±1

Mean ± SD. No significant differences between obese and non-obese individuals within each trial ($P > 0.05$).

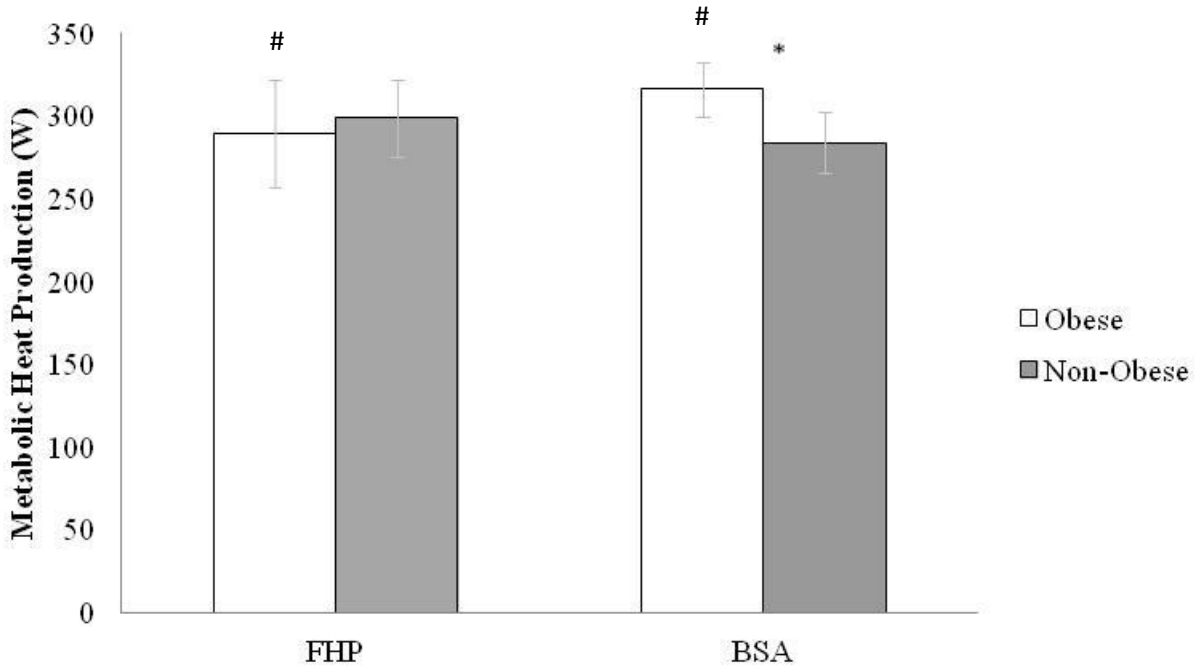
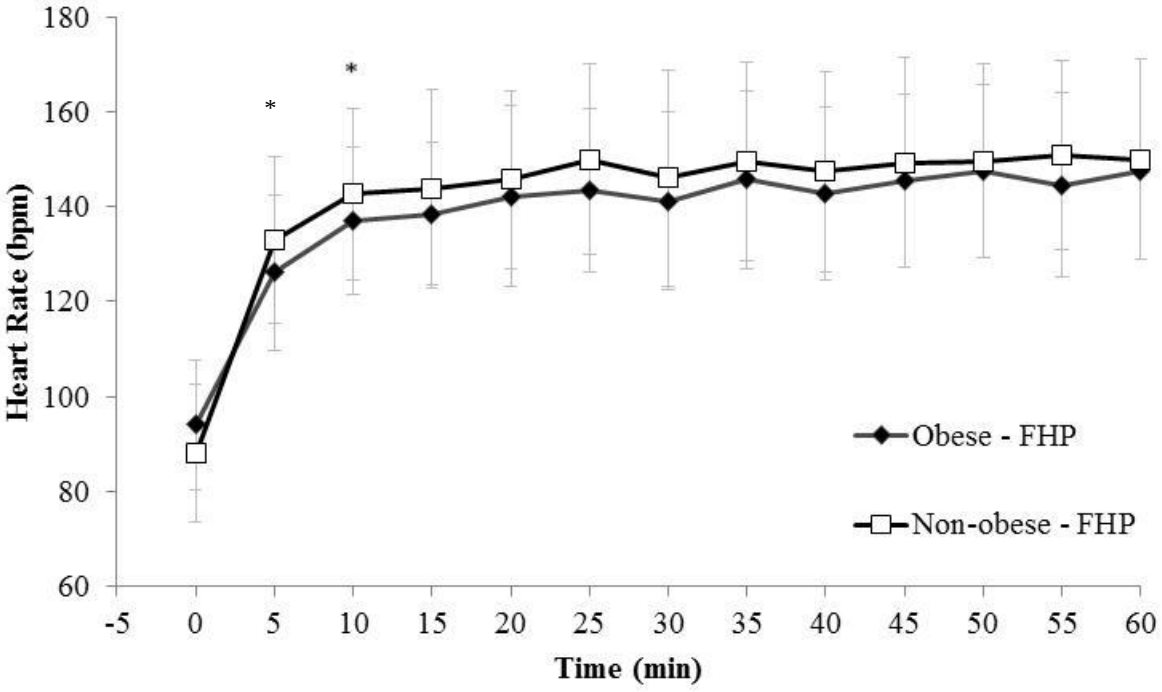

Metabolic Heat Production (W)
350
300
250
200
150
100
50
0
#
#
*
FHP
BSA
Obese
Non-Obese

Figure 1

A


180
160
140
120
100
80
60
Heart Rate (bpm)
*
*
Obese - FHP
Non-obese - FHP
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
Time (min)

B

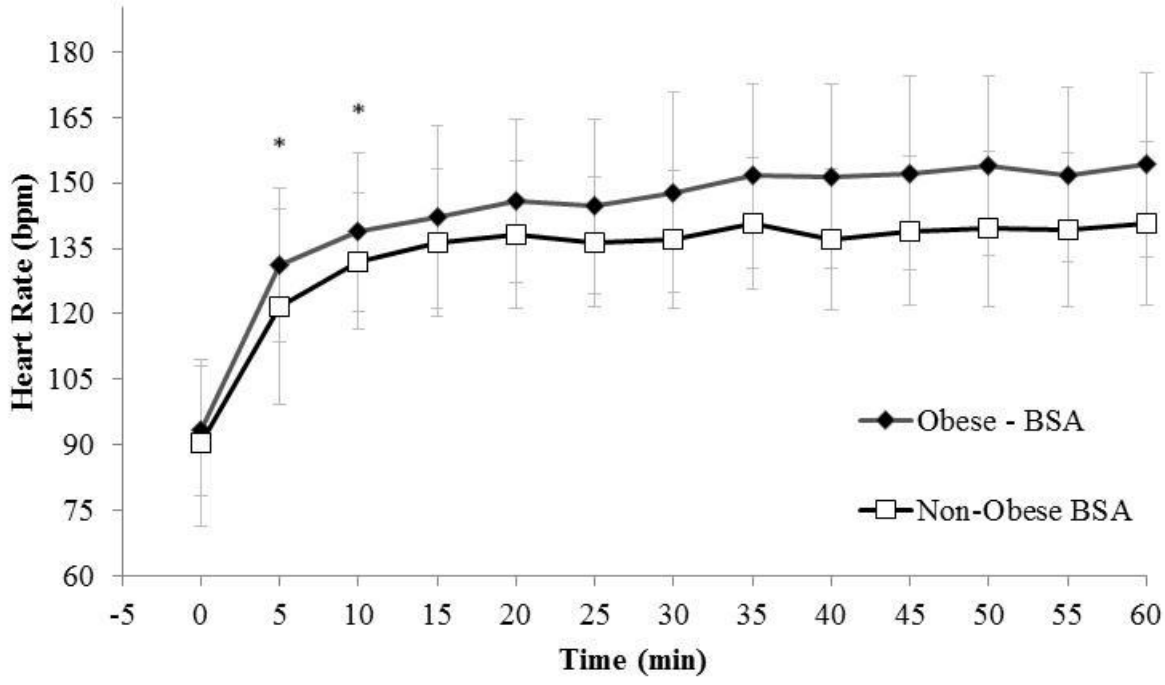
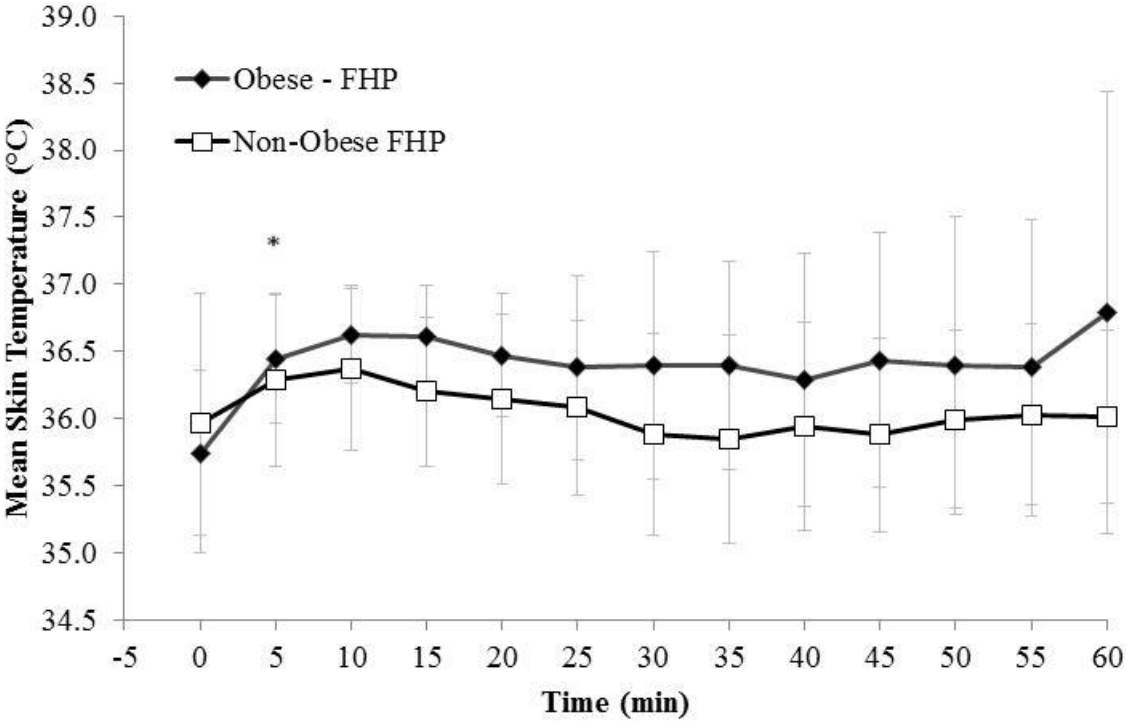

180
165
150
135
120
105
90
75
60
Heart Rate (bpm)
*
*
Obese - BSA
Non-Obese BSA
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
Time (min)

Figure 2

A


Obese - FHP
Non-Obese FHP
Mean Skin Temperature (°C)
Time (min)
*

B

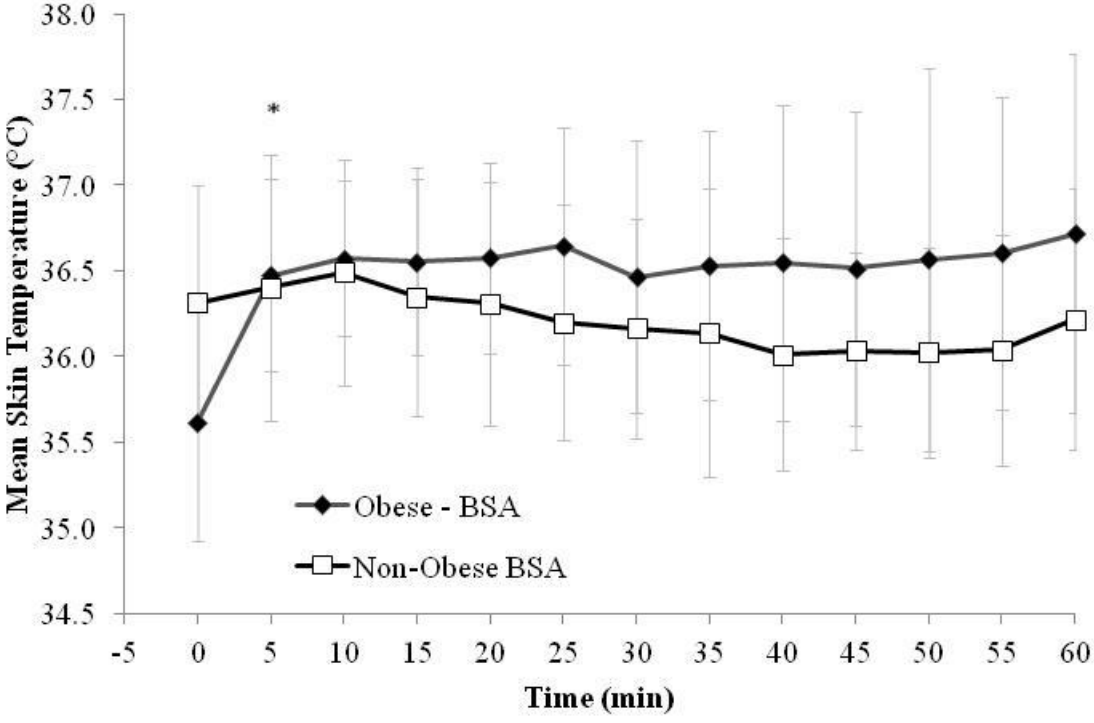
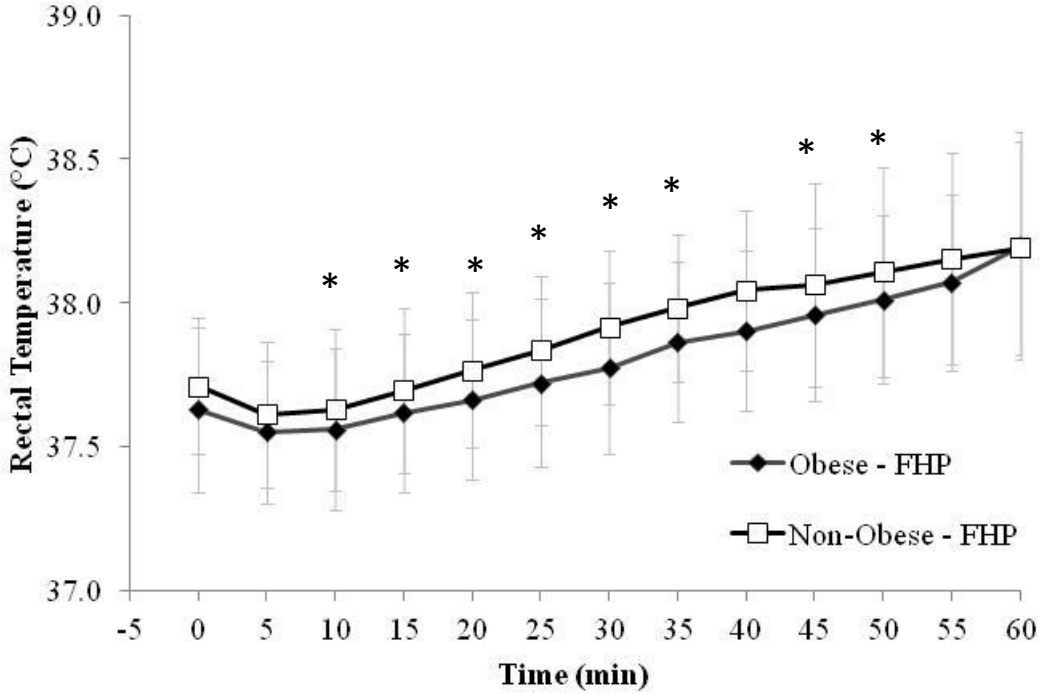

Obese - BSA
Non-Obese BSA
Mean Skin Temperature (°C)
Time (min)
*

Figure 3

A


39.0
38.5
38.0
37.5
37.0
Rectal Temperature (°C)
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
Time (min)
Obese - FHP
Non-Obese - FHP
*
*
*
*
*
*
*
*

B

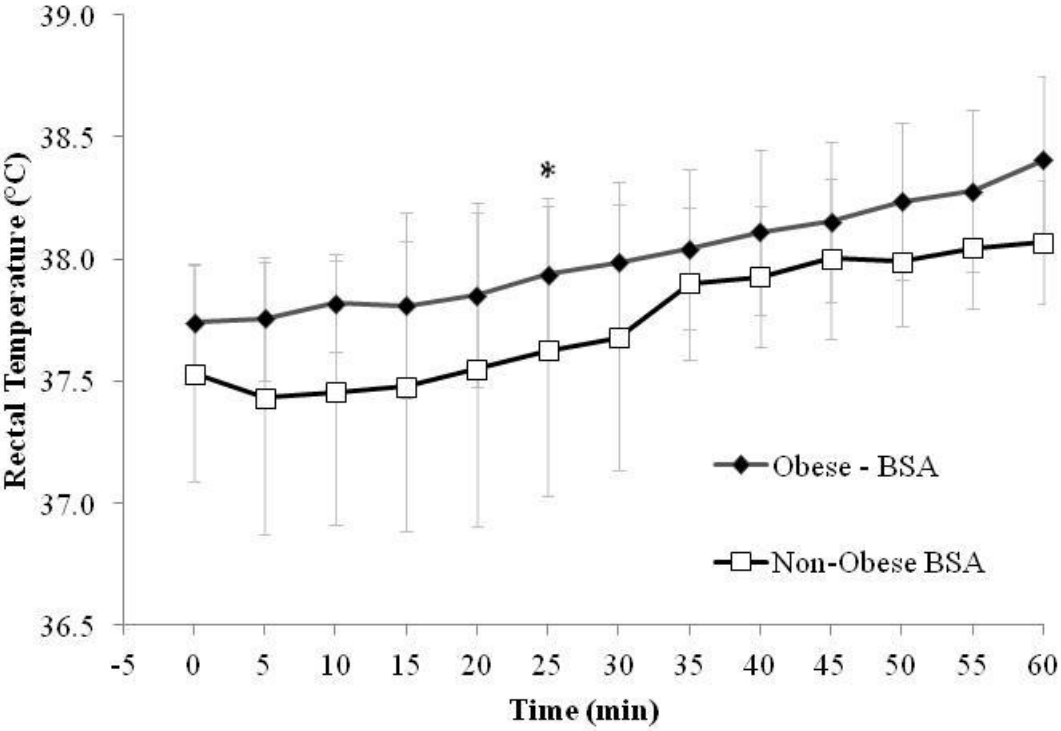
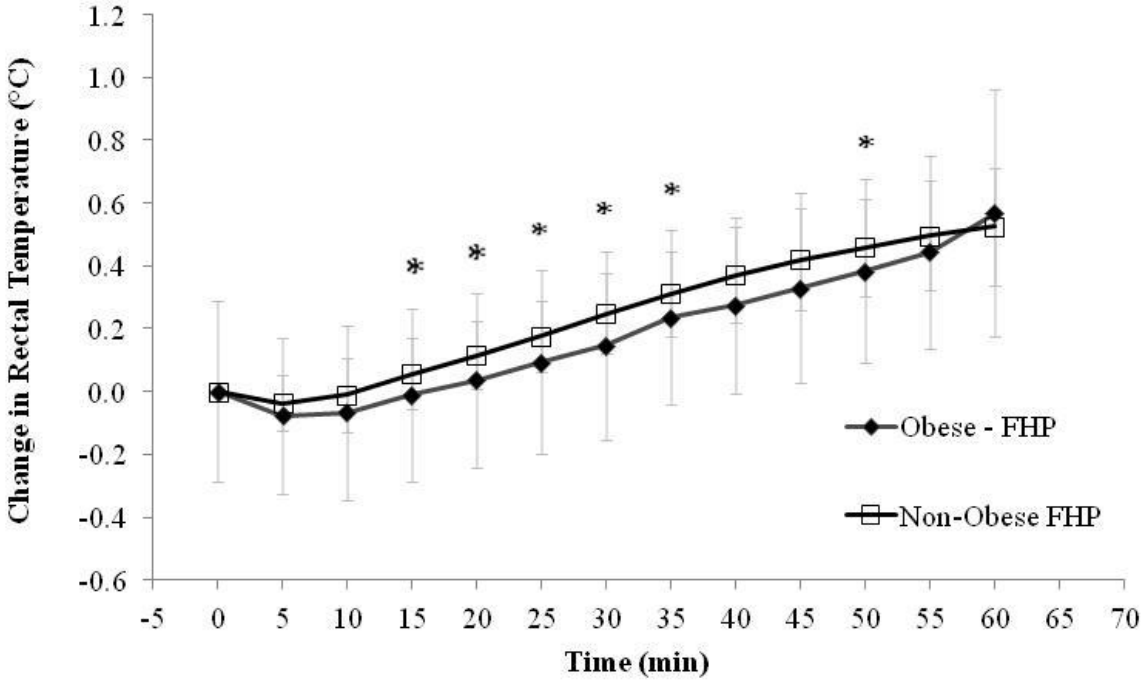

39.0
38.5
38.0
37.5
37.0
36.5
Rectal Temperature (°C)
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
Time (min)
Obese - BSA
Non-Obese BSA
*

Figure 4

A


Change in Rectal Temperature (°C)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-5 0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
Time (min)
Obese - FHP
Non-Obese FHP
*
*
*
*
*
*

B

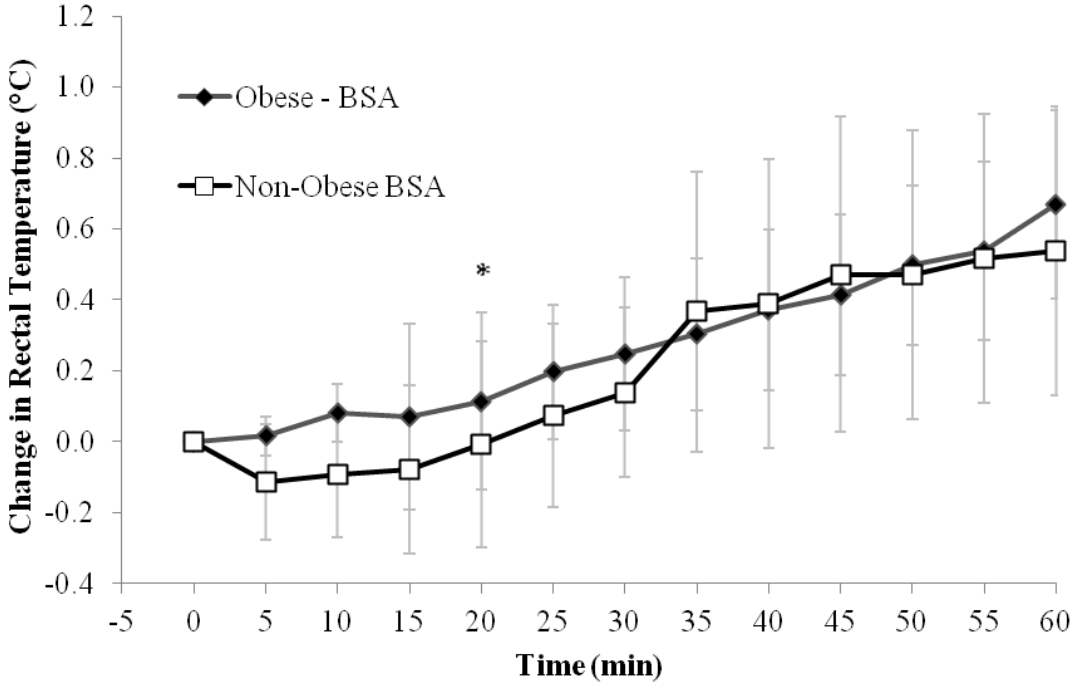

Change in Rectal Temperature (°C)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-5 0 5 10 15 20 25 30 35 40 45 50 55 60
Time (min)
Obese - BSA
Non-Obese BSA
*

Figure 5

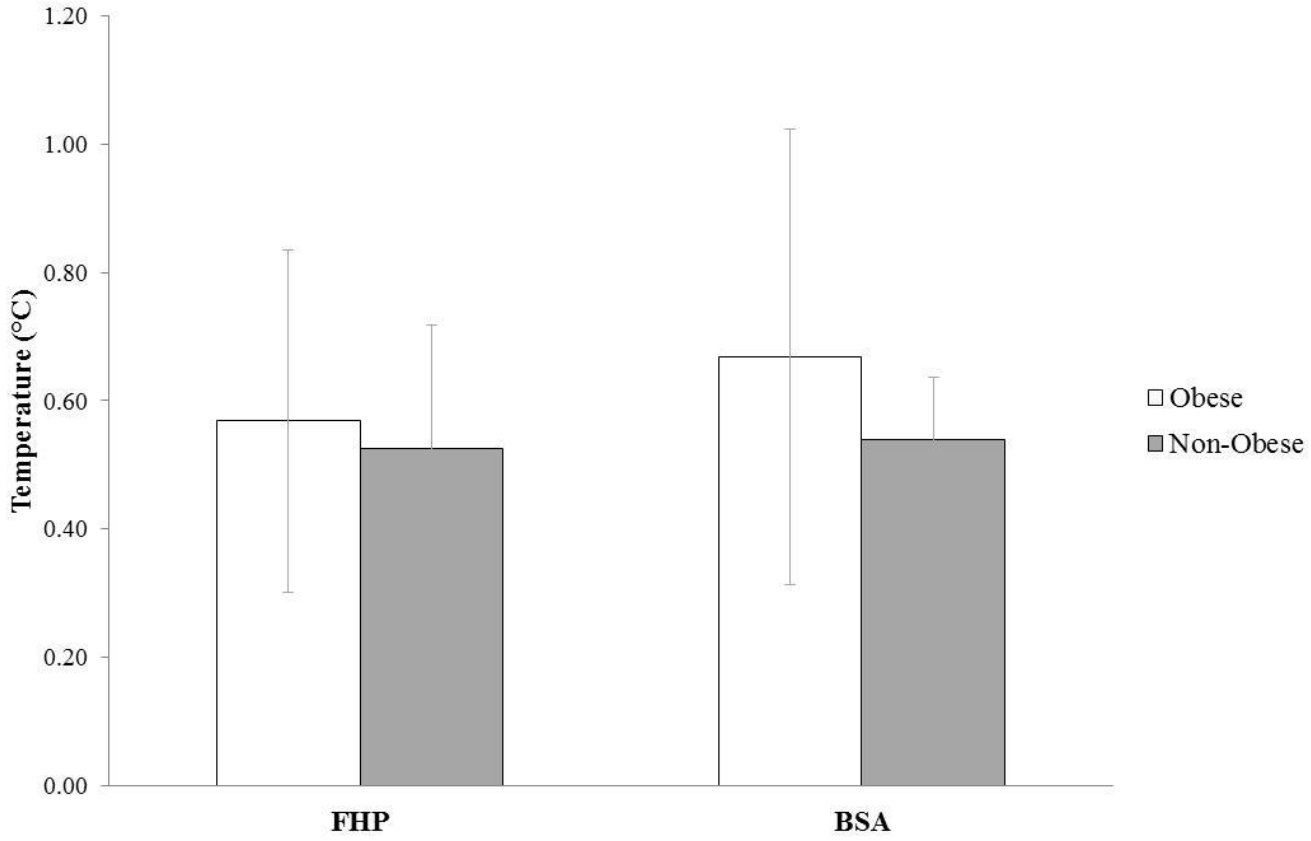

1.20
1.00
0.80
0.60
0.40
0.20
0.00
Temperature (°C)
FHP
BSA
Obese
Non-Obese

Figure 6

Chapter 5: Discussion

The aim of the present study was to examine possible differences in thermoregulation between obese and non-obese females. It has been claimed (Bartley, 1977) that with increased body size (i.e., obesity), there is a physiological impairment in thermoregulation. Though epidemiological data supports this (Bartley, 1977), laboratory studies are inconclusive. This is likely due to laboratory studies having participants exercise at intensities relative to VO_{2max} (Vroman et al. 1983). Individual differences in VO_{2max} will result in individuals exercising at different workloads, and thus different rates of metabolic heat production, for a given % of VO_{2max}. When metabolic heat production is kept constant throughout exercise (i.e., fixed heat production or FHP), differences in body temperature reflect differences in thermoregulation. However, because heat loss mechanisms are influenced by the amount of body surface area for heat exchange (Epstein, 1983), it is possible that differences in body temperature are due to differences in body surface area between obese and non-obese individuals. Taking these considerations into account, we examined the thermoregulatory function of obese individuals (compared to non-obese controls) when exercising at a fixed heat production (300 W; FHP) and when metabolic heat produced was relative to body surface area (175 W/m^2; BSA).

The ambient conditions, exercise duration and intensity were chosen because the specified time and intensity (~50% VO_{2max}) would be similar to what an obese individual may perform to meet the recommendations set forth by the American College of Sports Medicine for weight loss (>250 minutes per week at ~50% heart rate reserve) (Donnelly, 2009). The findings of this study may differ when examining obese and non-obese individuals that are athletes and/or are exercising at a high intensity (Jay et al. 2012). In the present conditions tested, there were no differences in T_{re} between obese and non-obese when exercising at a fixed metabolic heat

production or at a heat production relative to body surface area. This means that in this setting obese individuals do not have impaired thermoregulation. It should be pointed out that there were mild overall increases in T_{re} throughout both trials (~0.58°C for both obese and non-obese groups; Figure 6). This was due in part by the moderate intensity throughout the protocol. Vroman et al. (1983) also found no differences in obese and non-obese core temperatures after non-obese and obese males exercised at 50% $VO_{2\,max}$ in 38°C with slightly larger increases in T_{re} ~0.8°C. However, Bar-Or et al. (1969) observed moderate to large changes in core temperature (~1.2°C) when lean and obese females walked on the treadmill for three 20 minute bouts while in the heat. Differences between obese and non-obese T_{re} were ~39.1 vs. 38.9°C, respectively, with obese starting at a higher core temperature. Therefore it appears when obese individuals have greater heat strain (i.e., a large increase in core temperature); their ability to thermoregulate may be impaired. However, the findings of previous studies are complicated by the fact subjects exercised at varying metabolic heat production (see below).

The purpose of matching heat production relative to body surface area was to investigate the thermoregulatory properties of surface area-to-mass ratio (Epstein, 1983). As one becomes obese, the increase in body mass occurs at a greater relative rate then the increase in surface area, resulting in a lower surface area-to-body mass ratio. Since cutaneous heat loss is relatively proportional to skin surface area, obese individuals may lose their metabolic heat through more avenues of skin surface area than non-obese individuals (Verbraecken, 2006). Despite this apparent "advantage", there were no differences between T_{re} and T_{sk} when individuals exercised at a metabolic heat production relative to body surface area (Figures 3 and 4).

One explanation for previous observations that obese individuals have impaired thermoregulation (Bar-Or, 1969) is due to dehydration-induced thermoregulation. Dehydration is

well-known to increase core temperature during exercise (Montain, 1998). It has also been shown that obese individuals have a higher sweat rate than non-obese individuals (Bar-Or, 1969). Thus, it follows that obese individuals may become more dehydrated during exercise. This provides a possible explanation for why some have found obese individuals have increased core temperature during exercise when failing to control for hydration status. In present study we were able to control for hydration status prior to and throughout exercise (Table 2). It is possible that a lack of differences in core temperature between obese and non-obese individuals is due to the maintenance of euhydration throughout exercise.

Obese and non-obese individuals have different VO_{2max} values (ml/kg/min) due to differences in body mass. Similarly, in the present study, VO_{2max} values were different between obese and non-obese (Table 1). Thus differences in T_{re} may have been observed if our research design had participants exercise at a given $\%VO_{2max}$ as done previously (Vroman, 1983). When individuals have different VO_{2max} values, prescribing exercise intensity as % of VO_{2max} will have individuals exercising at different VO_2 values and thus difference metabolic heat productions (Vroman, 1983).

Adipose tissue, because of its reduced thermal conductivity (Cooper et al. 1971) and increased insulator capacity, provides an insulating barrier to the conductive heat flow. At rest, the degree of thermal insulation from adipose tissue has been shown to be positively related to the degree of obesity (Jequier et al 1974). Savastano et al. (2009) observed that increased adiposity can have blunted core-to-skin heat loss and that heat dissipation from the abdominal area is impaired in obese individuals when at rest in normothermic conditions. However, despite the general observation that obese females have more subcutaneous adipose tissue opposed to

viscerally-deposited fat in obese males, it appears this hypothesized increase in thermal insulation is not detrimental to thermoregulation during exercise in the heat.

Cardiovascular adaptations associated with obesity include increased cardiac output and stroke volume at rest and during exercise (Collis et al. 2001; Messerli et al. 1982). These changes are likely due to increased blood volume (Messerli et al. 1982) and fat free mass (Collis et al. 2001) associated with obesity. However, when oxygen uptake was held constant in the FHP trial, there were no differences in exercising HR and MAP between groups. Similarly, there were no differences between obese and non-obese groups in thermal and thirst sensation, as well as rating of perceived exertion.

Limitations

To see if there are thermoregulatory impairments in the obese population, further research is needed in which exercise intensity and thus metabolic heat production is greater. This will drive core temperature higher and perhaps reveal that when the thermoregulatory system is stressed, differences exist between obese and non-obese individuals. The present study observed only differences in the female obese and non-obese population. Therefore, mixed sex research design or male only research design is needed to observe if there are thermoregulatory differences between obese and non-obese individuals of both sexes.

Furthermore, it has been observed that the elderly (Hirata et al. 2012) and youth (Nelson et al. 2011) are at thermoregulatory disadvantages. Observing thermoregulatory responses whilst being controlled for metabolic heat production in clinical populations such as elderly and youth will further advance the knowledge of potential impairments in thermoregulation between individuals.

Conclusions

In conclusion, changes in core temperature, skin temperature, and sweating rate during exercise in a warm environment are determined by metabolic heat production, body surface area, and body mass. However, when metabolic heat production is matched, differences in T_{re} are not observed. Similarly, when metabolic heat production is matched according to BSA, there are no differences in T_{re}. This shows that during mild exercise in the heat when maintaining hydration status, young obese females do not have impairments in thermoregulation.

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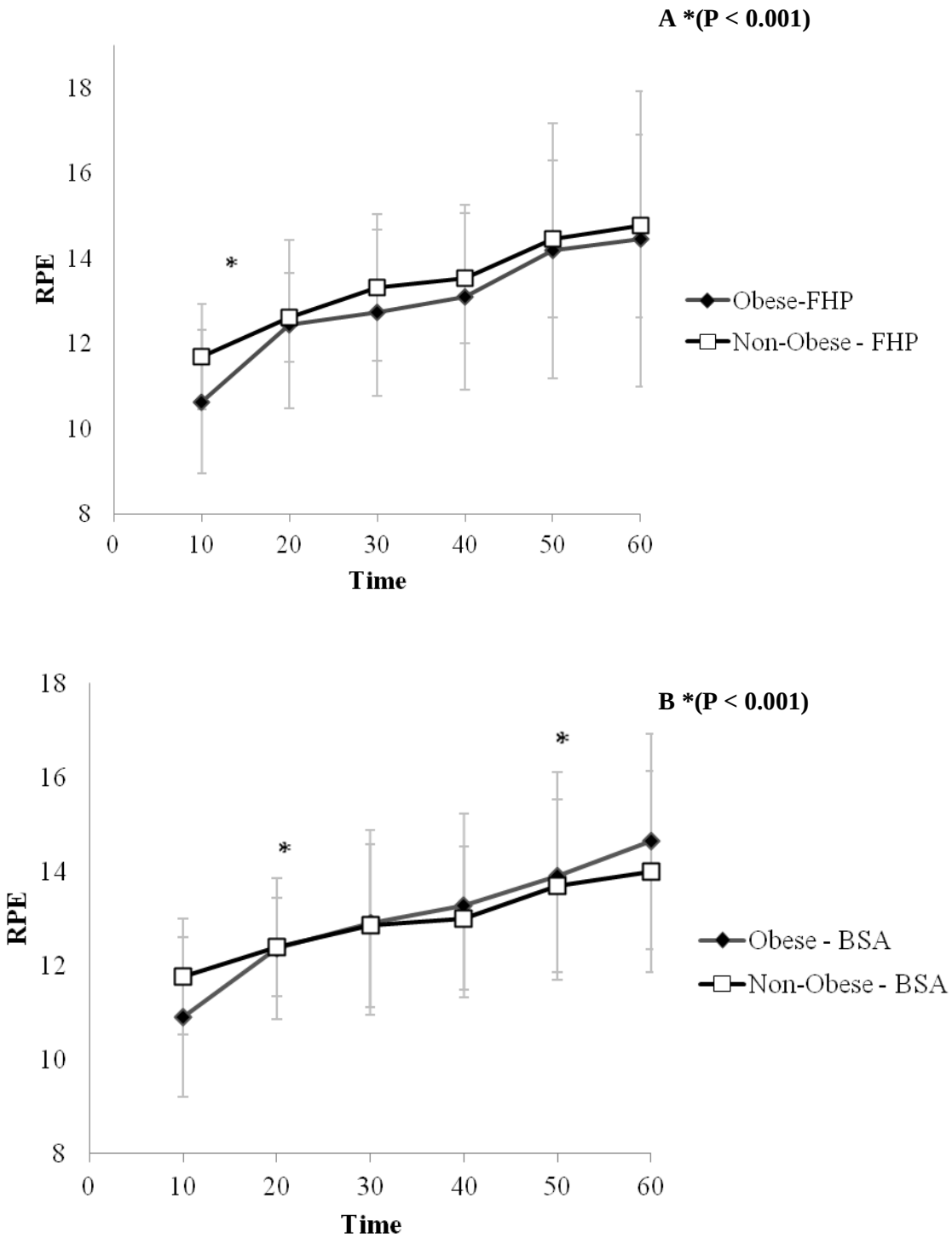


Figure 7 - Mean ± SD Rate rate of perceived exertion taken every 10 minutes of exercise during 60 min of exercise when for obese and non-obese individuals cycled when cycling at a fixed metabolic heat production (FHP) of 300 W (Panel A) or when cycling at a heat production relative to body surface area (175 W/m2; Panel B).

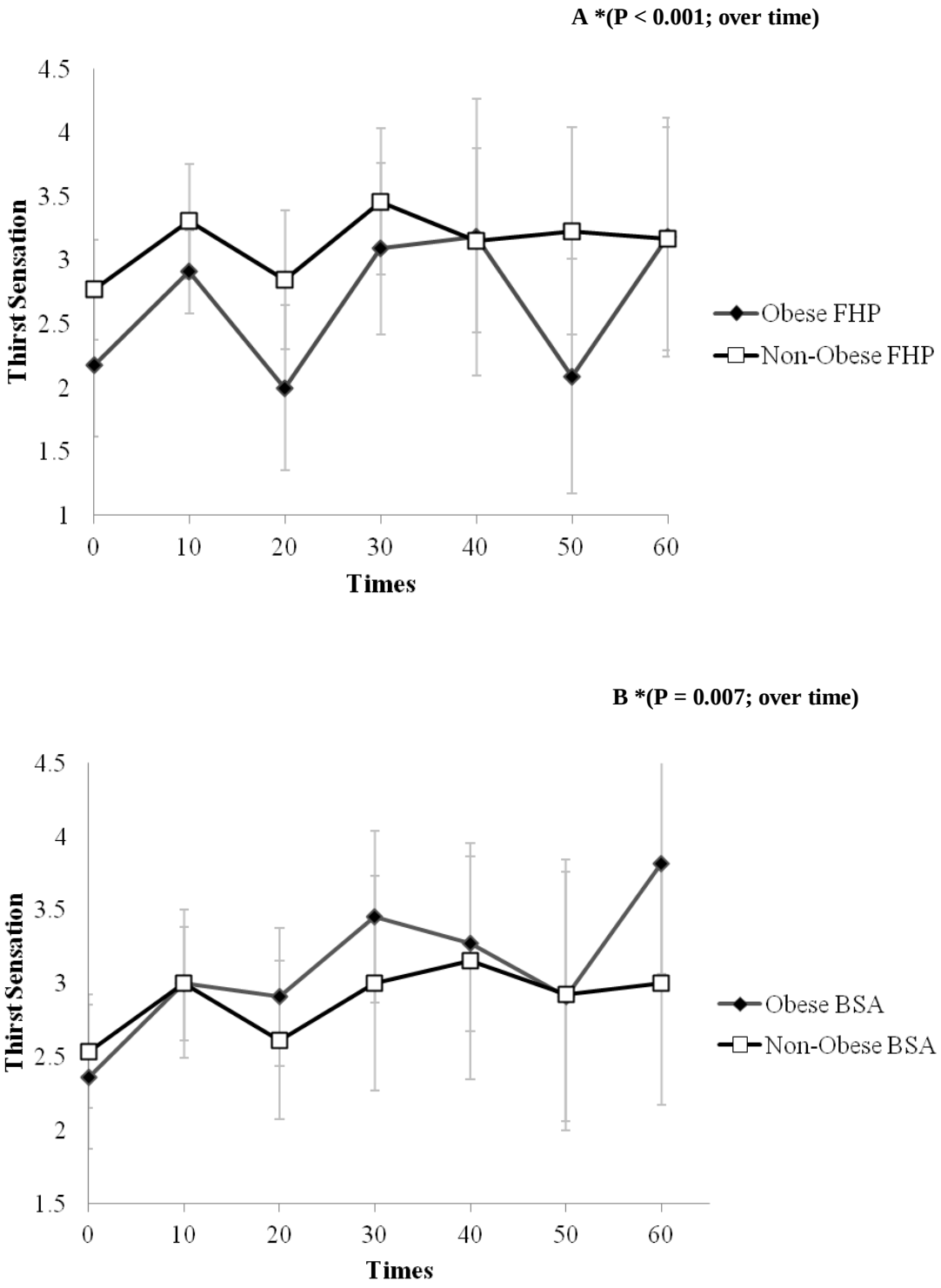


Figure 8: Mean ± SD thirst sensation taken before and every 10 minutes of exercise during 60 min of exercise for obese and non-obese individuals when cycling at a fixed metabolic heat production (FHP) of 300 W (Panel A) or when cycling at a heat production relative to body surface area (175 W/m2; Panel B).

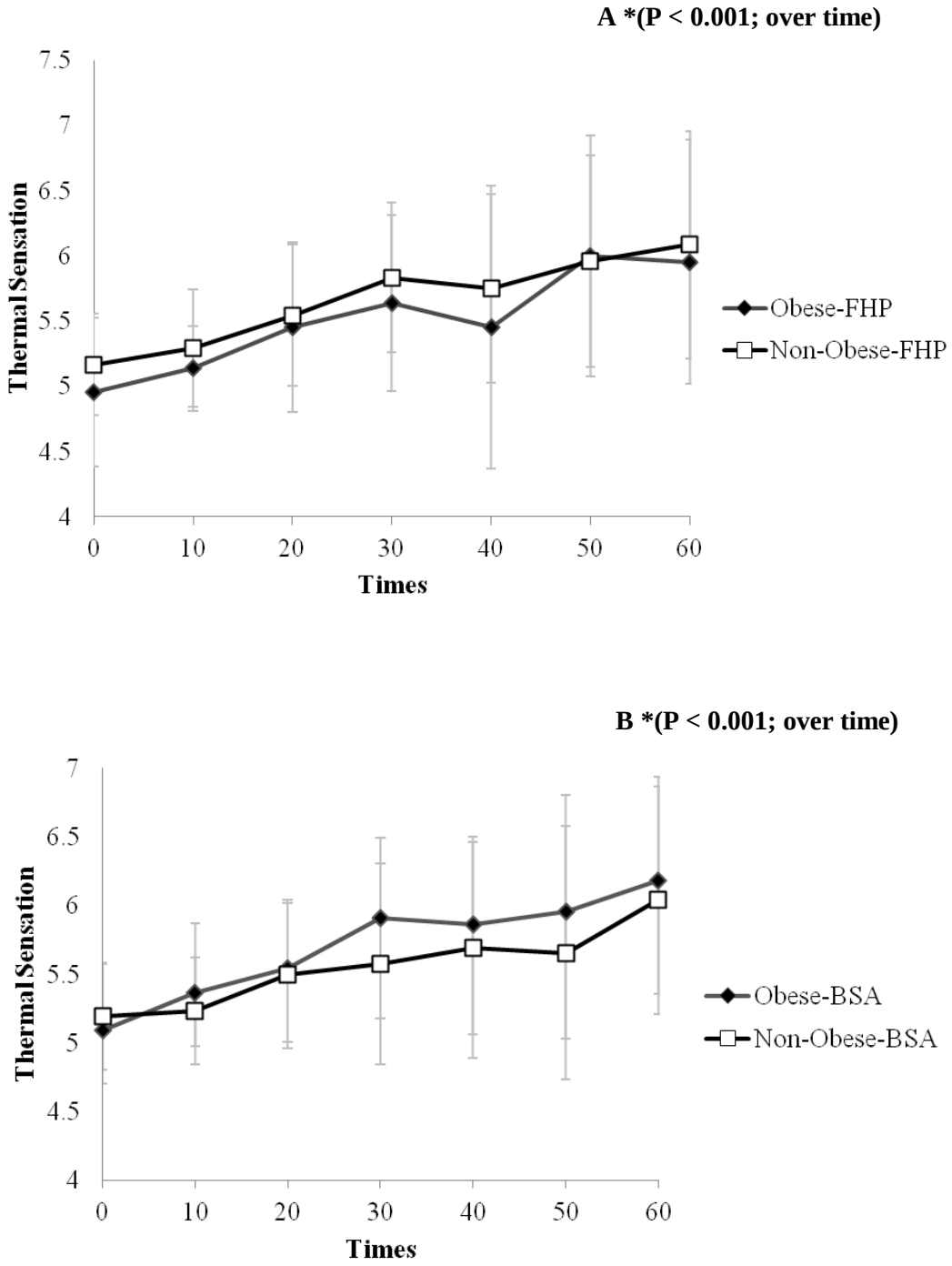


Figure 9: Mean ± SD thermal sensation taken before and every 10 minutes of exercise during 60 min of exercise for obese and non-obese individuals when cycling at a fixed metabolic heat production (FHP) of 300 W (Panel A) or when cycling at a heat production relative to body surface area (175 W/m2; Panel B)

Appendix B: Data Sheet for Familiarization Visit

Date: _____
File ID: _____
Time of Arrival: _____
Age: _____
DOB: _____
24 Hour History
Explain RPE, Thirst, Thermal Sensation

Body Mass: _____ kg (Clothed)
Height: _____cm (Clothed)
BMI_____ kg/m^2
Age-predicted max HR: _____

Can Be Done Prior to Fam. Visit
Informed Consent: _____ (Give Copy)
Medical History: _____
IPAQ: _____
Menstrual: _____

Dr. Ganio_____

DEXA _____ % Body Fat
Arm Circumference _____ cm
Blood Pressure after DEXA while supine _____mmHg
USG _____
Attach HR Monitor RHR: _____ bpm

Body Surface Area: _____ m^2

$$BSA = (W^{0.425} \times H^{0.725}) \times 0.007184$$

VO_2 Max Test

1. Begin exercise bout at 40 W
2. Increase 25 W every 2 minutes until volitional exhaustion
    a. Record HR and RPE every 2 minutes
3. Once exhaustion is achieved, collect blood sample

Time	Watts	HR	RPE
0-2 min			
2-4 min			
4-6 min			
6-8 min			
8-10 min			
10-12 min			
12-14 min			
14-16 min			
16-18 min			
18-20 min			

Test Time: _____
HR: _____
RPE: _____
Wattage: _____
VO_2 Max (ml/kg/min): _____
VO_2 Max (L/min): _____
RER: _____
Lactate: _____

Appendix C:
Data sheet for Thermal Exercise Test

Trial Preparation

1. Turn on water heater
2. Turn on metabolic cart
3. Prep thermocouples
4. Assemble mouthpiece(s)
5. Heat water bottle
6. Heat chamber

Date: _____
File ID: _____
Trial: 300W 175W/m^2 Time of arrival: _____
Voided USG: _____ (<1.028) Est. Starting Wattage: _____W
Pre Nude Body Weight: _____kg
Rectal Temperature: _____
Attach skin probes
Cardiac Output Bag Volume: _____ L
Attach HR Monitor: _____ bpm
Instrumented Body Mass: _____ kg

$\%CO_2$ for 1st measurement: _____

Volume of Water (3 ml/kg): _____per bolus ~37 C°

Time	HR	T_{sk}	T_{re}	RPE	Thirst	Thermal	BP	Q	Ambient Temp	RH%	VO_2 (L/min)	RER	Met Heat Prod.	Fluid Provided
Time Entering Chamber _____														
5 min Rest Actual:														
Initiate Exercise														0 min bolus _____ °C Has 15 min to finish Time:
5 min														
10 min														
15 min														15 min bolus _____ °C Has 15 min to finish Time:
20 min														
25 min														
30 min														30 min bolus _____ °C Has 15 min to finish Time:
35 min														
40 min														
45 min														45 min bolus _____ °C Has 15 min to finish Time:
50 min														
55 min														
60 min														

Did participant make it full 60 min? YES NO
Did participant drink all fluid? YES NO
Post-Instrumented Body Mass: _____kg
Post Urine Sample Volume: _____ml
Post Nude Body Weight : _____kg

If not, exercise time at stop of exercise:_____min
If no, how much fluid was left: _____ ml
USG: _____

Exercise Time	Wattage	Wattage Change

Appendix D: INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

1. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling?

   _____ **days per week**

   ☐ No vigorous physical activities → ***Skip to question 3***

2. How much time did you usually spend doing **vigorous** physical activities on one of those days?

   _____ **hours per day**
   _____ **minutes per day**

   ☐ Don't know/Not sure

Think about all the **moderate** activities that you did in the **last 7 days**. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

3. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

   _____ **days per week**

   ☐ No moderate physical activities → ***Skip to question 5***

4. How much time did you usually spend doing **moderate** physical activities on one of those days?

_____ **hours per day**
_____ **minutes per day**

☐ Don't know/Not sure

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you might do solely for recreation, sport, exercise, or leisure.

5. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time?

_____ **days per week**

☐ No walking → ***Skip to question 7***

6. How much time did you usually spend **walking** on one of those days?

_____ **hours per day**
_____ **minutes per day**

☐ Don't know/Not sure

The last question is about the time you spent **sitting** on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the **last 7 days**, how much time did you spend **sitting** on a **week day**?

_____ **hours per day**
_____ **minutes per day**

☐ Don't know/Not sure

This is the end of the questionnaire, thank you for participating.

Appendix E: Body Size on Cardiovascular and Thermoregulatory Responses Consent to Participate in a Research Study

Principal Researcher: Jon David Adams
Faculty Advisor: Dr. Matthew S. Ganio

INVITATION TO PARTICIPATE

You are invited to participate in a research study about how exercise in the heat effects your body temperature. You are being asked to participate in this study because you are a healthy female between the ages of 18 and 39.

WHAT YOU SHOULD KNOW ABOUT THE RESEARCH STUDY

Who is the Principal Researcher?
Jon David Adams; 479-575-7281

Who is the Faculty Advisor?
Matthew S. Ganio, Ph.D.; msganio@uark.edu; 479-575-5309

What is the purpose of this research study?

The purpose of this study is to examine the cardiovascular and thermoregulatory function of individuals with varying body sizes.

Who will participate in this study?

There will be no more than 30 females participating. The individuals will be between 18 and 39 years of age. They will be a mix of University of Arkansas students and non-students.

What am I being asked to do?

You will be asked to report to the Human Performance Laboratory on 3 occasions. Each visit will take approximately 2 hours. The 1st visit can occur at any time. The 2nd and 3rd visit will occur during the early follicular phase of your menstrual cycle. This will be identified by a questionnaire on your first visit.

Twenty four hours prior to each visit, we ask that you refrain from the consumption of alcohol, caffeine, and over-the-counter drugs. Prior to each visit, please consume an additional ~16 oz. (2 cups) of water the night before your arrival and 2-3 hours prior to arrival.

Familiarization visit (visit 1: ~2 hrs)

You will first fill out questionnaires regarding your medical and menstrual history, physical activity level, and what you have done over the last 24 hours. We will then measure your height and weight followed by a measurement of your body composition with a dual energy x-ray absorptiometry machine (DEXA). This involves you laying quietly for ~10 min while the machine moves over you. The amount of radiation used by the DEXA machine is about one tenth of the amount you would receive from a chest x-ray (see below for details).

You will then perform an exercise test to determine your aerobic fitness. This will occur on stationary bicycle. You will have nose clips on while breathing in room air and exhaling into a mouthpiece connected to a machine. This machine measures the amount of oxygen your body is using. The exercise will start at a low intensity and progressively get more difficult. It will continue until you are no longer able to pedal. This test takes ~10-15 min with the last ~3-6 minutes being difficult. Every 2 minutes and at the end, we will measure heart rate (HR) and ask you what your level of exertion is using a scale that you point at. At the end of the test, we measure blood lactate levels by sticking the end of your finger with a small needle and collecting a small amount of blood (1/5 of a teaspoon).

After ~10 min of rest and while lightly exercising you will practice a procedure in which we estimate the amount of blood your heart is beating through it (i.e., "cardiac output"). You will have nose clips on and breathe through a mouthpiece. For 15 seconds you will breathe in room air that has extra carbon dioxide added. The level of carbon dioxide is low and most people cannot even tell it is there.

Experimental Trials (visit 2 & 3: ~2 hrs each)

Upon arrival for an experimental trial, you will void your bladder while providing a small urine sample. We will measure the concentration of the urine to make sure you are well hydrated. We will then provide you a private bathroom in which you will undress and measure your body weight. You will then insert a sterilized, thin, flexible, rectal thermometer 4 inches past the anal sphinctor. We will then tape 4 temperature measuring wires to the following locations: lateral subdeltoid, pectoral, lateral calf, and quadriceps. You will then enter a controlled environmental room set at 104°F and 30% relative humidity and sit on the stationary bicycle for 15 min. You will then exercise for 60 min at either 1) ~1.5 l/min (equivalent to ~50% maximal effort) or 2) an intensity equal anywhere between 30 and 60% maximal effort (the exact intensity depends on your body size). The trial (i.e., exercise intensity) presented on the first experimental day will be assigned randomly. After a minimum of 72 hours, you will undergo the 2nd experimental trial. The only difference between trials is the exercise intensity performed (described above). A fan producing an air speed of 3.5 m/s will be directed at you throughout exercise.

Before, during and throughout exercise we will measure body temperature and HR and ask your effort level, how thirst you are and how hot or cold your feel. The measurement of cardiac output (using the methods described above) and blood pressure (with an arm cuff) will be measured throughout exercise. Four equal volumes of water (each 0.1 fluid oz per 2.2 pounds of body weight at ~99°F) will be provided just before and after 15, 30, 45 min of exercise. Oxygen consumption will be measured during exercise by having your breathe through the mouthpiece while wearing nose clips.

After exercise, you will return to the private bathroom, remove the rectal thermistor, provide a urine sample, undress and measure your body weight. The volume and concentration of your urine will be measured from the sample.

What are the possible risks or discomforts?
There are no apparent psychological, social, legal, or economic risks to the participants.

DEXA – Exposure to a small amount of ionizing radiation. The amount received during a DEXA test is about the same as four (4) days of normal background radiation in Northwest Arkansas. If you have an intact uterus and ovaries and there is a chance you may be pregnant (unprotected intercourse within the last 60 days), you may not participate in this testing at this time. Radiation may be harmful to a fetus.

Exercise – The discomforts (i.e., muscular and systemic) due to exercise will be no greater than when individuals exercise in daily living. The aerobic test presents a physical risk because it is a brief strenuous exercise (~6 min). Strenuous exercise may cause circulatory problems in some individuals. These are infrequent (and are unlikely to occur in healthy individuals) but include abnormal blood pressure, fainting, heartbeat disorders, and in extremely rare instances a heart attack (1 in 15,000). In the unlikely event of an emergency during the test or subsequent exercise, laboratory personnel trained in CPR and the use of an AED will be present during all test sessions.

Exercise in the heat - Elevated body temperature is a normal response to exercise in the heat. Extreme body temperatures (>106°F) may result in heat illnesses such as heat exhaustion and heat stroke. We do not anticipate your body temperature to get close to this level. This risk will be minimized by monitoring your body temperature and immediately stopping exercise if you reach a dangerous level. The most valid and practical manner to measure body temperature is with the rectal thermometer. You may have minor, temporary discomfort when inserting the rectal thermistor. Heat illness in people has not been reported in

carefully controlled laboratory studies such as this one. In addition to monitoring body temperature, we will educate you about the symptoms and signs of heat illness (headache, nausea, mental disorientation, lack of coordination, or dizziness) and instruct you to stop exercise if these symptoms or signs develop.

Finger stick - There is a small chance of bruising from the finger-stick blood sample acquired after the aerobic test.

Procedure to measure cardiac output – You may experience <10 seconds of feeling light-headed. There are no known residual effects (acute or chronic) that result from this technique. It is commonly used in exercise science research. The risk of being light-headed will be minimized by having you practice the maneuver during the familiarization visit and having you sitting (on the stationary bicycle) while performing the maneuver. The faculty advisor for this research has used this procedure on hundreds of participants with no one fainting or getting injured.

What are the possible benefits of this study?

Individually you will benefit by the physical conditioning received during exercise. You will be eligible to receive, at random, one of two $50 gift cards.

As a society, this research will benefit clinicians and practitioners by clarifying the effect of exercise in the heat on body temperature.

How long will the study last?

You will be asked to report to the Human Performance Laboratory on 3 occasions. Each visit will take approximately 2 hours. The 1st visit can occur at any time. The 2nd and 3rd visit will occur during the early follicular phase of your menstrual cycle. Depending on your availability you may be enrolled in this study for ~2-3 months.

Will I receive compensation for my time and inconvenience if I choose to participate in this study?

You will be eligible to receive, at random, one of two $50 gift cards.

Will I have to pay for anything?

No. There are no costs associated with you being a participant.

What are the options if I do not want to be in the study?

If you do not want to be in this study, you may refuse to participate. Also, you may refuse to participate at any time during the study. Your job, class grades, relationship with the University, etc. will not be affected in any way if you refuse to participate.

How will my confidentiality be protected?

All information will be kept confidential to the extent allowed by applicable State and Federal law.

You will be assigned a code number. This code will be used during data entry and all computer programs used for analysis. All data will be locked and stored in the Human Performance Laboratory. The results of all tests will be strictly confidential. Your results will not be shared with anyone except the investigators present at the time of the experiments. You will not be identified in any publication or presentation of this study.

Will I know the results of the study?

At the conclusion of the study you will have the right to request feedback about the results. You may contact the faculty advisor, Matthew S. Ganio, Ph.D. (msganio@uark.edu) or Principal Researcher, Jon David Adams (jxa014@uark.edu). You will receive a copy of this form for your files.

What do I do if I have questions about the research study?

You have the right to contact the Principal Researcher or Faculty Advisor as listed below for any concerns that you may have.

Jon David Adams; 479-575-7281
Matthew S. Ganio, Ph.D.; msganio@uark.edu; 479-575-5309

You may also contact the University of Arkansas Research Compliance office listed below if you have questions about your rights as a participant, or to discuss any concerns about, or problems with the research.

Ro Windwalker, CIP
Institutional Review Board Coordinator
Research Compliance
University of Arkansas
120 Ozark Hall
Fayetteville, AR 72701-1201
479-575-2208
irb@uark.edu

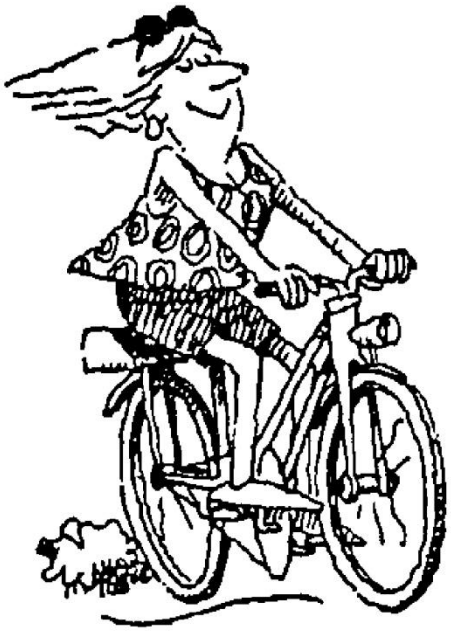
I have read the above statement and have been able to ask questions and express concerns, which have been satisfactorily responded to by the investigator. I understand the purpose of the study as well as the potential benefits and risks that are involved. I understand that participation is voluntary. I understand that significant new findings developed during this research will be shared with the participant. I understand that no rights have been waived by signing the consent form. I have been given a copy of the consent form.

_____

Appendix F: Flyer for posting

The Human Performance Laboratory,
University of Arkansas
is seeking

Females to Participate in an Exercise Study



<u>If you are 18 – 39 years old and have no medical illnesses please inquire</u>.

This study will involve 3 visits, 2 visits involve exercising in a warm room (total time commitment ~6 hrs).

Participants will receive $50

<u>Contact:</u>
JD Adams at (479) 575-7281,
Jxa014@uark.edu

The principal investigator is Matthew Ganio, Ph.D. This study has been approved by the University of Arkansas, Institutional Review Board for Human Studies, Fayetteville, AR.

Appendix G: Flyer for electronic communication

Participants wanted for a research study to evaluate the effects of exercise on body temperature.

Seeking: 30 females; should be 18-39 years old; no chronic illness or injury; should be able to tolerate cycling in a warm room for 60 minutes.

You will receive: you will receive $50.

This study will involve: 3 visits to the Human Performance Laboratory (approximately 2 hrs per visit); light/moderate cycling (60 minutes) on two occasions; heart rate and blood pressure monitoring

For details, telephone JD Adams at (479) 575-7281 or Jxa014@uark.edu

The principal investigator is Matthew Ganio, Ph.D. This study has been approved by the University of Arkansas, Institutional Review Board for Human Studies, Fayetteville, AR.

Appendix H: Medical History Questionnaire

HUMAN PERFORMANCE LABORATORY MEDICAL HISTORY QUESTIONNAIRE

PLEASE ANSWER ALL OF THE FOLLOWING QUESTIONS AND PROVIDE DETAILS FOR ALL "YES" ANSWERS IN THE SPACES AT THE BOTTOM OF THE FORM.

YES	NO		
☐	☐	1.	Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
☐	☐	2.	Has your doctor ever denied or restricted your participation in sports or exercise for any reason?
☐	☐	3.	Do you ever feel discomfort, pressure, or pain in your chest when you do physical activity?
☐	☐	4.	In the past month, have you had chest pain when you were not doing physical activity?
☐	☐	5.	Do you lose your balance because of dizziness or do you ever lose consciousness?
☐	☐	6.	Does your heart race or skip beats during exercise?
☐	☐	7.	Has a doctor ever ordered a test for you heart? (i.e. EKG, echocardiogram)
☐	☐	8.	Has anyone in your family died for no apparent reason or died from heart problems or sudden death before the age of 50?
☐	☐	9.	Have you ever had to spend the night in a hospital?
☐	☐	10.	Have you ever had surgery?

11. Please check the box next to any of the following illnesses with which you have ever been diagnosed or for which you have been treated.

☐ High blood pressure	☐ Elevated cholesterol	☐ Diabetes
☐ Asthma	☐ Epilepsy (seizures)	☐ Kidney problems
☐ Bladder Problems	☐ Anemia	☐ Heart problems
☐ Coronary artery disease	☐ Lung problems	☐ Chronic headaches

YES	NO		
☐	☐	12.	Have you ever gotten sick because of exercising in the heat? (i.e. cramps, heat exhaustion, heat stroke)
☐	☐	13.	Have you had any other significant illnesses not listed above?
☐	☐	14.	Do you currently have any illness?
☐	☐	15.	Do you know of any other reason why you should not do physical activity?

16. Please list all medications you are currently taking. Make sure to include over-the-counter medications and birth control pills.

Drugs/Supplements/Vitamins	Dose	Frequency (i.e. daily, 2x/day, etc.)

DETAILS: _____

17. Please list all allergies you have.

Substance	Reaction

18. Have you smoked?

	If yes, #/day	Age Started	If you've quit, what age?
Cigarettes			
Cigars			
Pipes			

19. Do you drink alcoholic beverages? If yes, how much? How often?

20. Do you have a family history of any of the following problems? If yes, note who in the space provided.

- ☐ High blood pressure
- ☐ High cholesterol
- ☐ Diabetes
- ☐ Heart disease
- ☐ Kidney disease
- ☐ Thyroid disease

21. Please check the box next to any of the following body parts you have injured in the past and provide details.

- ☐ Head
- ☐ Neck
- ☐ Upper back
- ☐ Lower back
- ☐ Chest
- ☐ Hip
- ☐ Thigh
- ☐ Knee
- ☐ Ankle
- ☐ Foot
- ☐ Calf/shin
- ☐ Shoulder
- ☐ Upper arm
- ☐ Elbow
- ☐ Hand/fingers

22. Have you ever had a stress fracture? ☐
23. Have you ever had a disc injury in your back? ☐
24. Has a doctor ever restricted your exercise because of an injury? ☐
25. Do you currently have any injuries that are bothering you? ☐

26. Do you consider your occupation as?

- ☐ Sedentary (no exercise)
- ☐ Inactive-occasional light activity (walking)
- ☐ Active-regular light activity and/or occasional vigorous activity (heavy lifting, running, etc.)
- ☐ Heavy Work-regular vigorous activity

27. List your regular physical activities

Activity	How often do you do it?	How long do you do it?	How long ago did you start?

ADDITIONAL DETAILS:

Appendix I: Menstrual History Questionnaire

Subject# _____ Date _____

We are interested in your personal history. Since some of these questions concern events that may have occurred more than a 5 years ago, it is possible that your memory of these events is inaccurate. For this reason, next to many of the questions we ask that you rate how certain you are of your memory: Absolutely accurate = 1, generally accurate = 2, probably inaccurate = 3, completely unsure = 4

Question	Answer	Degree of certainty
Exact age of first menstruation		
Number of periods missed in 2011		
…2010		
... 2009		
... 2008		
... 2007		
... 2006		
... 2005		

Regularity of menstrual cycles:
Do you have menstrual periods now? (Check one)
Yes, regularly every month
Yes, but I skip a month once in a while
Yes, but not very often (for example, once in six months)
No, I have not had a period in at least six months
No, I am post-menopausal, have had a hysterectomy, or am pregnant

Estrogen use:
Do you currently use a method of birth control that modifies hormone levels (examples includes oral contraceptive pills, patch, subcutaneous implantation?

At what age did you begin using this method?
Estimate total number of months that you have used birth control (e.g. 6 months one year plus 3 months in another and 12 months in a third year would equal 12 months):

Name the type (i.e. brand) of birth control pill that you use:

Is this a constant dose, bi-phasic, or tri-phasic pill?

Do you use any other estrogen or progesterone supplements (describe)?

Current menstrual status:
If using birth control pills, what day of your pill-pack is today?

If not using birth control pills, when did your last period start?

If not using birth control pills, how long is your average period and your average cycle (i.e. 7 days/ 28 days)?

Appendix J: Rating of Perceived Exertion Scale

6
7 Very, Very Light
8
9 Very Light
10
11 Fairly Light
12
13 Somewhat Hard
14
15 Hard
16
17 Very Hard
18
19 Very, Very Hard
2

Appendix K: Thirst Sensation Scale

1 Not Thirsty At All
2
3 A Little Thirsty
4
5 Moderately Thirsty
6
7 Very Thirsty
8
9 Very, Very Thirsty

Appendix L: Thermal Sensation Scale

0.0	**Unbearably Cold**
0.5	
1.0	**Very Cold**
1.5	
2.0	**Cold**
2.5	
3.0	**Cool**
3.5	
4.0	**Comfortable**
4.5	
5.0	**Warm**
5.5	
6.0	**Hot**
6.5	
7.0	**Very Hot**
7.5	
8.0	**Unbearably Hot**