THE EFFECTS OF BODY COMPOSITION ON SWEAT RATE AND CORE TEMPERATURE IN FEMALE RUNNERS

by

Halie Thomas

An Abstract
of a thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the Department of Kinesiology University of Central Missouri
ABSTRACT

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The purpose of this study is to examine the affects of percent body fat on sweat rate and core temperature in women ages 18-55 who are competitive runners. Specifically, this study will answer the question: how does body fat effect core temperature and sweat rate in female runners? It is hypothesized that as body fat increases, sweat rate and core temperature will also increase. The first session included body fat measurements and maximal aerobic testing. The second session included running in a heat controlled environment for 60 minutes at 70% of maximal aerobic test. The results of this study indicate that there is no significant relationship between body fat and sweat rate and no significant relationship between body fat and core temperature. The average sweat rate in this investigation was 0.782 L/hr. It is concluded that the human body can regulate core temperature regardless of weather conditions.
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Halie Thomas

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APPROVED:

Thesis Chair: Dr. Steve Burns
Thesis Committee Member: Dr. Scott Strohmeyer
Thesis Committee Member: Dr. Michael Godard

ACCEPTED:

Chair, Department of Kinesiology: Dr. Michael Godard

UNIVERSITY OF CENTRAL MISSOURI
WARRENSBURG, MISSOURI
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The core body temperature is controlled by thermoregulatory reflexes, within a narrow range of 36.5 to 37.5°C, which fluctuate throughout each day (Waterhouse, Aizawa, Nevill, Edwards, Weinert, Atkinson, Reilly, 2007). These thermoregulatory reflexes within blood vessels, brain, and intestines act to modify fluid input and fluid output. When there is an increase in core body temperature, thermoregulatory responses include sweating from eccrine glands and increased blood flow (Waterhouse et al, 2007). When core temperature falls below thresholds, sweating and vasodilatation cease. Sweating can be described as the body’s natural way of cooling to insure that the body does not overheat and cause heat induced illness. The hypothalamus is the body’s thermostat and responds to temperature receptors in different parts of the body to make adjustments to core body temperature within a range of 36.5 to 37.5°C. Humans can tolerate temperatures below 35°C or above 41°C, but only for brief periods of time (Wilmore, Costill, Kenney, 2008).

During exercise, the body can lose up to one to two liters of body fluids per hour (Donohue, 2000). In order to enhance hydration, a good practice to follow would be to consume foods like fruits, vegetables, and carbohydrates twenty-four hours prior to exercise. Two hours prior to exercise, one should drink 0.5 liters of fluid.

Prior to, during, and post exercise it is vital to stay hydrated so the body can continue to maintain or make adjustments to core temperature. It is vital to stay hydrated and maintain core temperature during competitive events, such as running. During a running event, dehydration and adjustment in core temperature can lead to performance decrement. Dehydration greater than 2% body weight can affect the ability to do work and lead to inadequate responses of the
cardiovascular, autonomic, and thermoregulation systems as well as performance effects. (Vanderlei, Moreno, Vanderlei, Pastre, deAbreu, Ferriera, 2013).

Most recently, competitive physical activities are largely seen around the world especially running; competitive races date all the way back to the era of the Greeks. Marathons were also one of the first Olympic events and continue to this day. Research has shown that, during exercise, core temperature can reach temperatures as high as 40°C- 42°C in active muscle (Wilmore et al, 2008). Cardiac death, mortality rate, and organ damage from heat illness have been shown to be directly related to increases in core body temperature (Coris, Ramirez, Van Durme, 2004). There is a paucity of published research relating to women; specifically women who are competing in endurance activities. It is important to find out trends in core temperature, sweat rate, skin temperature, body composition, and hydration status in women over the age of 18 who are regularly performing in competitive events that have been known to cause dehydration and result in other heat illnesses.

**Purpose**

The purpose of this study is to examine the association of percent body fat on core temperature and sweat rate in women who are competitive runners. Specifically, this study will answer the question: is percent body fat associated with core temperature and sweat rate in women? A study of ten exertional heatstroke cases reported that eight incidents occurred during group running at environmental temperatures of ≥25°C (Armstrong, Casa, Millard-Stafford, Moran, Pyne, Roberts, 2007). In both men and women, the number of exertional heatstroke cases increases with participation in strenuous sports (Armstrong et al, 2007). Women are at greater risk for symptomatic hyponatremia; when plasma sodium drops to ~130 mmol·L⁻¹ and below (Sawka, Burke, Eichner, Maughan, Montain, Stachenfeld, 2007).
Every day women are practicing and competing in competitive runs. In order to decrease the number of heat illness cases, it is important to provide information about sweat rate and core temperature to competitive runners. The results of this study will determine how percent body fat is associated with core temperature and sweat rate in competitive women runners. The findings of this study will additionally inform competitive women runners of the dangers of rising of core temperature and add to the current literature on how to prevent heat illness while competing.

Purpose of Study

The purpose of the current investigation answers the following question; is percent body fat associated with core temperature and sweat rate? The purpose of the current investigation is to determine how body fat percent is associated with sweat rate and core temperature specifically in women who compete competitively in running events.

Hypothesis: Subjects with higher percent body fat will have an increased sweat rate.

Hypothesis: As body fat percent increases, core temperature will increase.

Delimitations

This investigation was delimitated to;

1) Ten female competitive runners, age 18-55;
2) control of fluid intake during exercise testing;
3) the investigator conducting all exercise testing to ensure standardization in testing;
4) the use of DEXA scan to measure body composition;
5) data collection conducted in two testing session at the University of Central Missouri;

and

6) the use of portable urine refractometer to measure hydration status.

Limitations
This investigation was limited by:

1) daily activities of the subjects were not controlled; and

2) floor heat lamps limiting ability to control room temperature when compared to environmental chambers.

Assumptions

It was assumed that:

1) the CorTemp sensor pill was appropriate for the participants and is a valid and reliable measure of core temperature;

2) the DEXA scan for body composition is a valid and reliable measure of body fat percent;

3) the portable urine refractometer for pre-hydration status is valid and reliable;

4) the subjects followed the directions as they are intended; and

5) the subjects completed the exercise testing to the best of their ability.

Significance of the Study

The purpose of this study is to examine if body fat percent is related to sweat rate and core temperature. Specifically, this study will answer the question: is the percent body fat associated with core temperature and sweat rate? It was hypothesized that subjects with higher percent body fat will have an increased sweat rate and core temperature compared to subjects with a lower percent body fat. It is important to study the relationship of body fat percent and sweat rate and core temperature in competitive runners for numerous reasons. It is beneficial for runners to know how much fluid to consume before, during, and after exercise by determining their sweat rate to prevent dehydration. Also, it is useful to know if body fat percent has significance in change of core temperature as well as sweat rate. This investigation will touch on
how sport performance is impacted. Some critical findings tell us that performance is significantly affected in higher ambient temperatures. The results of this investigation will additionally help competitive runners keep or achieve performance goals by being aware of how core temperature and sweat rate can be affected by body fat percent.

Definition of terms

The following terms were defined to eliminate any misunderstandings:

*Euhydration* - Normal daily water variation.

*Hyperhydration* - State of increased water content; this can be known as ingesting extra water before exercising in the heat.

*Hypohydration* - A steady-state of decreased water content.

*Hyponatremia* - “water intoxication” first described among athletes in 1985. Symptoms range from headache, confusion, nausea and cramping to seizures, coma, pulmonary edema, and death.

*Rehydration* - Restoring fluid balance after a hypohydrated stated towards euhydration.

*Heat cramps* - Painful spasms of skeletal muscle of arms, legs, abdomen and trunk.

*Heat syncope* - Loss consciousness with prolonged standing or sudden rise from seated position in heat environments.

*Heat exhaustion* - Involuntary muscle cramping is the most common form of heat illness and is described as an insufficient amount of blood returning to the heat because blood volume is being directed to working muscles. May also include mild confusion, nausea, and profuse sweating, “chills of head and neck.”

*Heat stroke* - Defined as a condition where body temperature is elevated and may causes damage to tissues and affecting organs Features of heat stroke include elevation of core temperature, failure to sweat, and mental status impairment especially in long endurance races.
$E_{\text{req}}$ - The amount of evaporation needed to keep the body at a healthy temperature.

(R) - Radioactive heat exchanges.

(C) - Convective heat exchanges.

(H) - Metabolic heat production.

($E_{\text{max}}$) - The maximum rate of sweat evaporation in the environment.

*Menstrual cycle* - Cycle of uterine changes averaging 28 days and consisting of the menstrual flow phase, proliferative phase, and secretory phase.

*Endometrium* - Innermost glandular layer and functions as a lining for the uterus.

*Menstrual (flow) phase* - The first phase of the menstrual cycle lasting four to five days. During this time, the uterine lining or endometrium is shed and bleeding occurs.

*Proliferative phase* - Prepares the uterus for fertilization and the endometrium begins to thicken and ovarian follicles that house ova mature. This phase typically lasts about 10 days.

*Secretory phase* – This phase corresponds to the luteal phase of the ovarian cycle. The endometrium continues to thicken and nutrient supply increases. The uterus also prepares itself for pregnancy and the empty follicle now secretes progesterone and still continues to secrete estrogen. This phase typically lasts 10-14 days.
Chapter 2
Review of Literature

The purpose of this study is to examine the association of core temperature and sweat rate in women who are competitive runners. Additionally, to investigate the relationship between core temperature and sweat rate as well as sweat rate with body composition taken into account. This review is organized into five main sections: 1) Hydration, 2) Heat Illness, 3) Core Temperature and Sweat Responses, 4) Body Composition, 5) Menstrual Cycle, and 6) Heat and Running performance.

Introduction

Humans are homoeothermic, so core body temperature is physiologically regulated to keep a relatively constant temperature even when environmental temperatures change. During prolonged exercise and extreme heat or cold body temperatures deviate from a normal range (Wilmore et al, 2008). The body has thermoregulatory mechanisms to keep the body from overheating. Core temperature that elevates between 38 and 40°C during exercise usually causes fatigue. This range is known as a “critical” high body temperature and can impair muscle activation from high brain temperature that decreases the central drive for exercise (McArdle, Katch, Katch, 2010).

During exercise in hot weather, dissipating heat is vital and this occurs in four processes: radiation, conduction, convection, and evaporation (McArdle et al, 2010). Evaporation is the primary source of heat dissipation during exercise and accounts for 80% of the total heat loss (Wilmore et al, 2008). During heat, eccrine glands secrete large quantities of hypotonic saline solution (McArdle et al, 2010). When sweat evaporates from the skin there is a cooling effect. When the skin is cooled, it in turn cools the blood coming from interior tissues to the surface.
Evaporation of 1 L of sweat per hour results in 680 W of heat loss (Wilmore et al., 2008). Also, evaporation of 1 L of sweat removes about 580 kcal of heat energy (Maughan, 2010). However, high humidity limits the evaporation of sweat which results in loss of water and electrolytes (Maughan, 2010). When sweat drips off the body or stays on skin and clothing it is not contributing to the body cooling and represents wasteful loss of body water (Wilmore et al., 2008). Clothing adds some resistance to evaporation of sweat; clothing that fits loosely enhances evaporation and cooling of the body (Wilmore et al., 2008).

For individuals in a moderate ambient condition, body temperature is usually maintained at a relatively constant level. When ambient temperature rises heat loss by physical transfer becomes compromised (Maughan, 2010). Heat loss becomes more dependent on evaporation of sweat. While exercising in heated environments the body encounters cardiovascular demands; the muscles require delivery of oxygen to maintain energy metabolism and arterial blood diverts to periphery to transport metabolic heat for cooling at the skin surface and this blood cannot deliver oxygen to active muscle. Maintaining cutaneous and muscle blood flow during exercise under heat stress requires tissues to compromise blood supply. McArdle et al., 2010, explains that during heat stress, constriction of splanchnic vascular bed and renal tissues rapidly counteracts vasodilation of subcutaneous vessels responsible for elevated skin blood flow. Prolonged reduction in renal and visceral tissue blood flow can contribute to liver and renal complications. Also during exercise, less blood diverts to peripheral areas for dissipation. This could be explained as the body’s attempt to maintain cardiac output in the face of diminishing plasma volume which is caused by sweating. Circulatory regulation takes precedence over temperature regulation during heated exercise.
Hydration

Concerns of exercise may include sweat loss, where typically a moderate workout over one hour produces a sweat loss of 0.5 to 1.0 L in both men and women (McArdle et al, 2010). During high environmental temperatures and strenuous exercise, sweating rates can be as high as 1.4 – 2.0 L/h (Armstrong, 2000). The highest sweat rate reported was 3.7 L/h during the 1984 Summer Olympic Games (Armstrong, 2000). Exercise in the heat places unusual demands on the thermoregulatory centers of the body. Heat production during exercise is 15-20 times greater than at rest and there is a raise in core body temperature 1°C every five minutes if there are not any thermoregulatory adjustments (Coris et al, 2004). Dehydration is the process of losing water from a hyperhydrated state to a euhydrated state, or from euhydration to hypohydration (McArdle, Katch, Katch, 2001). Euhydration is known as normal daily water variation. Hyperhydration is a state of increased water content; this can be known as ingesting extra water before exercising in the heat (McArdle et al, 2010). Hyperhydration can offer thermoregulatory protection and delays hypohydration. Hypohydration is a state of decreased water content (McArdle et al, 2001). The term used for restoring fluid balance after a hypohydrated stated towards euhydration is known as rehydration. During this time, ingestion of fluid must exceed 25 to 50% of sweat loss during exercise (McArdle et al, 2010).

Hydration plays an essential role during exercise. Research suggests that proper hydration promotes better response to increased body temperature, ensures the maintenance of physiological functions and homeostatic functions which help maintain blood pressure and cardiac output (Vanderlei et al, 2013). Dehydration of 2-3% of body mass routinely occurs during high-intensity exercise (Coris et al, 2004). Children and older adults are susceptible to fluid loss because of decreased sweating ability, greater surface area to body mass ratio,
decreased thirst response, decreased mobility, and decreased vasodilatory response (Coris et al, 2004). When one is dehydrated by prolonged exercise, the ability to work is limited by inadequate responses of the cardiovascular, autonomic, and thermoregulation systems in the body.

Hydration can be achieved in several ways, such as water, isotonic solution, pasteurized milk, infusion of pure glucose, and solution of pure sodium chloride (Vanderlei et al, 2013). Drinking water, in comparison with no fluid, reduces the risk of an increase in core body temperature, prevented decreased stroke volume and cardiac output, and reduction of plasma volume with exercise (Coris et al, 2004). Studies have also revealed that slower core body temperature rise in heat related exercise when fluid intake was supervised and replaced sweat losses (Coris et al, 2004). Research has shown that a fluid deficit of 1-2% of body mass can impair subjective ratings of alertness, concentration, tiredness, and headache (Peacock, Stokes, Thompson, 2011).

Prior to exercise, one should hydrate by drinking beverages approximately 5-7 mL·kg⁻¹ per body weight (Sawka et al, 2007). This should be done at least four hours before exercise. If there is not enough urine produced or urine is highly concentrated then approximately 3-5 mL·kg⁻¹ should be consumed about two hours before exercise (Sawka et al, 2007). During exercise, the goal of consuming fluids is to prevent excessive dehydration and compromise exercise performance. Sawka et al, (2007) states that the amount of fluid replacement depends on the individual and their sweating rate, exercise duration, and opportunities to drink. Additionally, there should be extra care with exercise exceeding three hours. After exercise, the replacement of fluid and electrolyte deficit is needed which depends on the speed that rehydration must be accomplished. If there is optimal time, consumption of normal meals and beverages will restore
euhydration (Sawka et al, 2007). For rapid recovery, one should consume approximately 1.5 L of fluid for each kilogram of body weight lost. Beverages and food with sodium will help with rapid recovery because it stimulates thirst and fluid retention (Sawka et al, 2007).

Heat illness

Heat illness is a general term regarding pathologic events during a hot and humid environment (Yamazaki, 2012). Heat illness can be broken down into four categories in order of severity; heat cramps, heat exhaustion, heat syncope, and heat stroke (Yamazaki, 2012). Heat illness is also the third leading cause of death in United States high school athletes (Coris et al, 2004). When exercising in the heat, extreme demands sometimes are placed on the body’s thermoregulatory centers and the core body temperature can raise 1 °C every five minutes if there are no thermoregulatory adjustments (Coris et al, 2004).

Heat cramps can present painful spasms of skeletal muscle of arms, legs, abdomen and trunk (Coris et al, 2004). Heat cramps are typically seen with negative sodium balance and diuretic use. Treatment includes replacing fluid and sodium losses with oral or parenteral fluid (Coris et al, 2004). Heat syncope includes loss of consciousness with prolonged standing or sudden rise from seated position in heat environments. Treatment involves placing patient in supine position with lower extremities elevated. Treatment of syncope should also involve replacement of fluid deficit (Coris et al, 2004). Heat exhaustion with associated involuntary muscle cramping is the most common form of heat illness and is described as an insufficient amount of blood returning to the heart because blood volume is being directed to working muscles (Fahey, Insel, Roth, 2013). Heat exhaustion may also include the inability to continue exercise and may also include mild confusion, nausea, profuse sweating, and “chills of head and neck” (Fahey et al, 2013). The most serious of heat illness is heat stroke which is defined as a
condition where body temperature is elevated greater than 40.5°C and may cause damage to tissues and affecting organs (Coris et al, 2004). Features of heat stroke include elevation of core temperature, failure to sweat, and mental status impairment especially in long endurance races (Coris et al, 2004). A heatstroke victim should be cooled as fast as possible and transported to a hospital immediately (Fahey et al, 2013). Cooling techniques that can be utilized are water immersion, wet towel application, ice packs to neck, axillae, and groin (Coris et al, 2004).

Hydration before exercise and consumption of fluids during physical activity is vital to exercising in a heated environment.

*Core temperature and sweat responses*

Evaporation of sweat is important to control internal body temperature in a hot and humid environment (Kondo, Manabu, Aoki, Koga, Inoue, Crandall, 2001). Increases in sweating could be due to increase in sweat output per gland (SGO), density of activated sweat glands (ASG), or a combination of both (Kondo et al). The purpose of Kondo et al’s study was to investigate the contribution of ASG and SGO in elevating sweat rate during dynamic constant-workload exercise. Eight males were included in this study and sweat rate were taken on the left forearm. Skin temperature was taken at forearm, chest, palm, forehead, abdomen, thigh, lower leg, and foot. Internal temperature was measured via the esophagus. Subjects wearing shorts rested on a cycle ergometer in a climatic chamber for 40 minutes with ambient temperature of 25°C and relative humidity at 50%. This was followed by either a 30 minute cycle ergometry exercise at an average of 117 watts or immersion of lower legs in hot water bath for 60 minutes.

The findings of Kondo et al, 2001 indicated that sweat rate during exercise increased abruptly for eight minutes after the onset of sweating and then continued increasing at a lower rate. Activated sweat glands increased steeply eight minutes after onset of sweating and then
plateaued. Sweat output per gland increased linearly throughout the exercise protocol thus indicating both ASG and SGO contributed to sweat rate changes, however sweat rate changes are primarily dependent on increase in SGO. During the first 20 minute period changes in sweat rate, ASG and SGO were virtually identical between the 30 minute cycle or immersion of lower legs in hot water for 60 minutes.

Brotherhood, 2008 demonstrated how different environmental and physical factors effect core body and skin temperatures. Core body temperature is determined by internal metabolic processes, however, skin temperature is dictated by the thermal environment, but the combination of these influences sweat rate (Brotherhood). Heat transfer between the body and the environment occurs because of humidity and temperature gradients. Heat transfer down the gradients by convection, thermal radiation, or evaporation. Evaporation is the main components of heat stress relief (Brotherhood, 2008). The amount of evaporation (E_{req}) needed to keep the body at a healthy temperature, is determined by sum of radioactive (R) and convective (C) heat exchanges and metabolic heat production (H), E_{req}=H±R±C. The factors that dictate whether or not E_{req} can be met are the body’s ability to produce enough sweat, and the environments ability to allow enough evaporation. The maximum rate of sweat evaporation in the environment (E_{max}), is the other main component of heat stress. The factors affect E_{max} are air flow over the skin and absolute humidity. The maximum rate of sweat evaporation must exceed E_{req} to prevent heat storage in the body.

Wingo, Low, Keller, Brothers, Shibasaki, & Crandall, 2010 performed a study that involved men and women and tested the hypothesis that decreased skin blood flow and decreased local temperature each independently attenuate sweating. There were two protocols done with this study and subjects were asked to swallow a temperature sensing pill to measure core
temperature. Heart rate, by electrocardiogram and skin temperature by thermocouple were continuously monitored and recorded. Subjects were also asked to put on a tube-line water perfusion suite. Changing the temperature of the suit controlled the mean body temperature, core temperature, and skin temperature. There are different solutions used in the study to be injected into micro dialysis membranes on the forearm which are not covered by the suit. Examples of the samples include Ringer solution, norepinephrine, and sodium nitroprusside. This shows whole body stress by injection of the different solutions listed above. The findings in this study suggest that cooling is due to decreased skin blood flow or local temperature. The onset of sweating was not affected by decreased skin blood flow and was only slightly affected by decreased local temperature.

Since the current study concerns sweat specifically related to women, the differences between genders and sweating may be valuable. Hazelhurst and Claassen, (2006) investigated gender difference related to sweat responses when both trained men and women preparing for a 108 km race. The investigation included indoor cycling for a period of 90 minutes. It was assumed that participants were accustomed to heat and physically fit and 14 men and 12 women participated in the study. Prior to the study, subjects were to attend at least two spinning classes per week and at least three hours per week on a road bicycle. The actual study took place in a spin classroom with nine overhead fans placed in the room. Each subject was to adjust the resistance on the flywheel on a scale of 1 to 10 when commanded by the instructor.

Sweat loss was calculated from seminude body mass measure on electronic scale. Volume of sweat produced was estimated from the change in body mass measured directly pre and post exercise with the value corrected for the volume of fluid ingested during the class. The results indicated significant differences between the genders in mass, height, and body surface
area, body surface area to mass ratio, and body mass index. There was also a significant difference in gender sweat rate; men with $1.12\pm0.45 \text{ L·h}^{-1}$ and women significantly less with only $0.57\pm0.26$. Since exercise heat production is proportional to body mass, women in this study would generate less heat and be able to dissipate more than men for the same relative exercise intensity (Hazelhurst & Claassen, 2006).

Age can also affect sweat responses during heat exposure. Dufour and Candas (2007) compared how age affects the sensory and sweat aspects due to passive heat exposure. The authors of this study use males in three different age categories (20-30, 40-50, and 60+) doing the same exercises to compare how age or sensory can be different among the age groups. The results indicated that skin temperature had risen in older adults due to decreased amount of sweat in older adults. The younger adults were found to have a higher sweat rate, accompanied by lower temperature. The time of sweat onset appeared not to be affected by aging, noting that younger individuals showed a higher sweat rate increase during the first 40 minutes.

**Body Composition**

Many factors contribute to the body’s ability to maintain core temperature during exercise. In cold environments, body fat provides significant protection during cold air exposure (Glickman-Weiss, Nelson, Hearon, Prisby, Caine, 1999). Also during cold environments, greater subcutaneous fat exhibited by women may be advantageous (Prisby, Glickmann-Weiss, Nelson, Caine, 1999). For example, successful ocean swimmers typically possess a large amount of subcutaneous fat (McArdle et al, 2001). The additional fat increases insulation in the cold water when peripheral blood diverts from the body’s shell to the core. Because of this thermal insulation from fat, ocean swimmers can be in cool water with almost no fall in core temperature (McArdle et al, 2001).
However, excess body fat may not be as advantageous when exercising in the heat. McArdle et al, 2001 states that the specific heat of fat exceeds muscle tissue, so fat will increase the insulation quality of the body’s shell and retards heat conduction to the periphery. Obesity may also be related to altered physiological responses to exercise (Eijsvogels, Veltmeijer, Schreuder, Poelkens, Thijssen, Hopman, 2011). Eijsvogels et al, 2011 also states that because of the larger surface area and greater number of sweat glands, obese subjects have larger fluid losses as well as altered thermoregulatory responses.

**Menstrual Cycle**

Both thermoregulation and body hydration is effected by hormonal changes occurring during menses and are reviewed here. These altered states may also affect athletic performance. When reaching physical maturity, females continuously experience fluctuations in hormone release through cyclic changes until menopause (Marsh & Jenkins, 2002). The menstrual cycle is broken up into three major phases. The first phase is the menstrual phase lasting four to five days. During this time, the uterine lining or endometrium is shed and bleeding occurs (Wilmore et al, 2008). The second phase is known as the proliferative phase which prepares the uterus for fertilization and the endometrium begin to thicken and ovarian follicles that house ova mature (Wilmore et al, 2008). These follicles will secrete estrogen and this phase typically lasts 10 days (Wilmore et al, 2008). The first two phases, the menstrual and proliferative, correspond to the follicular phase of the ovarian cycle. The final phase of the menstrual cycle is the secretary phase which corresponds to the luteal phase of the ovarian cycle. The endometrium continues to thicken and nutrient supply increases. The uterus also prepares itself for pregnancy and the empty follicle now secretes progesterone and still continues to secrete estrogen (Wilmore et al, 2008). This phase lasts 10 to 14 days, which averages 28 days for the complete menstrual cycle.
During the different phases of the menstrual cycle, there may be alterations in athletic performance. There is variability in this and some women do not notice a change in performance whereas others see change during menstrual cycle and in pre-flow phases. Marsh & Jenkins, 2002 state that the fluctuation in hormonal release can cause physiological changes in core temperature and temperature for onset of sweating. The development of heat illness is also of concern particular to those in warmer climates as well as athletes (Marsh & Jenkins, 2002).

The threshold for the onset of sweating is increased during the luteal phase and could be associated with progesterone and estrogen elevated during this time (Marsh & Jenkins, 2002). Sweat rates have also been shown to be elevated during the luteal phase as well because progesterone acts on the anterior hypothalamus (Marsh & Jenkins, 2002). Because of the increase in firing rate of neurons within the hypothalamus due to progesterone, this additionally increases the core temperature found during the luteal phase (Marsh & Jenkins, 2002). During the luteal phase, it has been shown that there are differences up to 0.6°C both at rest and during exercise. Specifically, reports show significantly elevated resting rectal temperatures during the luteal phase in ambient and hot conditions (Marsh & Jenkins, 2002). Because core temperature is increased, it could be assumed that skin temperature would also be elevated however, there are varying results recorded; few have found no phase differences while others have found increased luteal temperatures at rest as well as during exercise (Marsh & Jenkins, 2002). The menstrual cycle does not appear to alter heart rate, VO2max, blood lactate concentration, or RPE (Marsh & Jenkins, 2002).

Heat and running performance

At rest, the variation of core temperature is 0.5°C. The resting metabolic rate is low and dissipation of heat is seen through primarily radiation, conduction, convection, and evaporation
(Maughan, 2010). As ambient temperatures rise, the effectiveness of heat by physical transfer is compromised, so heat loss becomes dependent on evaporation of water and sweat from skins surface (Maughan, 2010).

Endurance exercise such as running is affected by a unique blend of heat exposure, exercise intensity, and opportunity for consuming fluids during a heated environment (Armstrong, 2000). It is best to consider the influences of elevated body temperatures, hyperthermia, and dehydration as critical factors (Armstrong, 2000). Hyperthermia can be caused by exercise intensity, high air temperature, and high relative humidity. Hyperthermia can degrade physical performance in three ways. Hyperthermia can reduce muscular endurance, the ability to substance muscular contractions for minutes to hours, and alter performance in long distance events (Armstrong, 2000). Armstrong, 2000 also states that hyperthermia shifts metabolism from aerobic to anaerobic form. This means that the store of carbohydrates in skeletal muscle and liver will be consumed at a faster rate. This could explain why exercising in hot and humid environments are not maintained as long as in a cool environment. This response will affect events that rely heavily on carbohydrates like endurance road cycling and marathon running (Armstrong, 2000). Increased fatigue can be seen through dilation of blood vessels in skin and pooling of blood in limbs. This reduces the volume of blood that returns to the heart, reduces cardiac output, and increases circulatory strain (Armstrong, 2000).

Routine physical activity and mild to moderate work typically results in sweat losses of 0.8 – 1.4 L/h. Athletes routinely experience a 2-8% loss in body weight during competition and training (Armstrong, 2000). Sustained or repeated exercise lasting longer than 30 seconds deteriorates when moderate or severe dehydration exists (Armstrong, 2000). VO₂ max is reduced dramatically following moderate water losses in a heated environment. Additionally, it is
unlikely that small or moderate reductions in body weight due to dehydration will alter strength. Dehydration up to -5% can be tolerated without a loss of maximal strength (Armstrong, 2000). Maughan, 2010 states that environmental conditions do affect distance running performance and performance may be slowed in conditions of high heat and humidity.

In runners, 75-80% of metabolic energy turnover appears as heat, and for runners this can be determined by a number of factors (Maughan, 2010). Roughly, it is proportional to running speed and body mass (Maughan, 2010). Runners that are faster perform at a higher fraction of aerobic capacity, so high rates of heat production in combination with reduced opportunities for physical exchange in hot weather. This means that sweat production becomes primary source for heat loss in hot and humid conditions. High rates of sweat loss are typically encountered in hot and humid environments while exercising ad without replacement of sweat losses. This could result in a progressive reduction in blood volume and stroke volume and eventually blood flow to muscle (Maughan, 2010). Maughan, 2010 includes a cross-sectional analysis stating that there is a progressive slowing of marathon performance when wet bulb globe temperature increases from 5°C to 25°C. Analysis of female runners in three marathons (times available at 5 km intervals) showed that faster runners ran at an even pace while slower runners ran progressively more slowly throughout the race (Maughan, 2010). Maughan, 2010 also states that optimal ambient temperature for exercising is 10-12°C.

Eleven members of the Australian National Road Cycling Squad completed two 30 minutes cycling time trials at a high temperature at 32°C with 60% relative humidity and a neutral temperature at 23°C with 60% relative humidity (Tatterson, Hahn, Martin, Febbraio, 2000). Prior to each trial, nude weight as record, skin temperature, and heart rate monitors were positioned into place. Each subject was instructed to complete as much work as they could in the
30 minute period. Subjects were provided water throughout the trials with the total volume consumed recorded for each experiment. After the completion of each trial subjects removed probes, monitors, and clothing, towel dried and weight again. Sweat rate was estimated by change in body mass and adjusted for any fluid consumption. The results indicated that mean power output was decreased significantly (P<0.05) by 6.5% during high temperature compared with neutral temperature (Tatterson et al, 2000). Average sweat rate, heart rate, and perceived exertion were also significantly (P<0.05) greater in high temperature in comparison to neutral temperature (Tatterson et al, 2000). These results indicated that performance during a 30 minute time trial is reduced in high ambient temperatures (Tatterson et al, 2000).

**Summary**

Hydration plays an essential role during exercise, especially exercise in heat to maintain physiological functions (Vanderlei et al, 2013). Fluid loss can impair multiple functions of the body including alertness, concentration, tiredness, and headache. Also, during hot and humid environments, it is of importance to understand and recognize the signs of the different types of heat illness. Heat illness includes heat cramps, heat exhaustion, heat syncope, and heat stroke. Each type of heat illness is of concern due to extreme demands on the body’s thermoregulatory centers during heated environments. During hot and humid environments, heat loss becomes dependent on evaporation of water and sweat from the skins surface. Sweat loss and core temperature can also be affected during a heated environment and many factors play into core temperature such as: evaporation of sweat, sweat output per gland, density of activated sweat glands, age, gender, body composition, and menstrual cycle in women. Excess body fat may not be as advantageous during exercise in the heat compared to exercise in cold environments and water. Obesity leads to a greater fluid loss as well as altered thermoregulatory responses. The
menstrual cycle, during the luteal phase specifically, may lead to increases core and skin temperature during exercise. It is important to investigate the effects of sweat rate, core temperature, and its relation to percent body fat.
CHAPTER 3  
MEHTODOLOGY

The purpose of this study was to examine the association of body fat percent on core temperature and sweat rate in women competitive female runners. Specifically, this study answered the question: What is the relationship between percent body fat and sweat rate and core in female runners? There is paucity of published data on this topic specifically regarding women that are competitive runners. Additionally, information regarding body composition in a heated environment is also scarce. Participants of this study included females that compete in running. This chapter is organized into five sections: (1) Selection of Participants, (2) Instrumentation, (3) Design of the Study, (4) Procedures for Testing and Data collection and (5) Data Analysis.

Selection of Participants

The subjects selected for this study were females age 18-55. Participants in this study were competitive runners who participate in one or more competitions per year, there will be approximately 25 subjects determined by using Cohen’s f-squared power analysis using an effect size of 0.35. The procedure used to recruit subjects was in-person advertising to numerous classes in the Nutrition and Kinesiology Department at the University of Central Missouri.

Instrumentation

This investigation consisted of two sessions. During the first session subjects had body composition measured by means of DEXA scan and performed a maximal treadmill test to determine aerobic capacity. During the second session, subjects had height measured by stadiometer, body mass by Bod Pod electronic scale, and hydration status by portable urine refractometer with the urine specific gravity (USG). Urine specific gravity is the density (mass per volume) of a urine sample in comparison to pure water. Normal urine has a range from
1.013 to 1.029 in healthy adults (Armstrong, 2000). Dehydration is determined by a urine specific gravity greater than 1.030 (Armstrong, 2000). Subjects who were considered dehydrated by USG greater than 1.030 were excluded from the study. Subjects performed exercise on a Trackmaster TMX22 treadmill for one hour at 70% of aerobic capacity determined by maximal treadmill test. Core temperature was assessed by CorTemp sensor pills. Heart rate was monitored continuously by Polar heart rate monitors.

**Design of the Study**

This study utilized one group of women age 18-55 classified as a competitive runner varying in body composition in an intervention study. Women age 18-55 that have competed in at least one competitive race in the past year were included in this study. All subjects were living in a similar environmental condition and the study took place in spring. Since core temperatures are regulated at a higher degree during the luteal phase, the trial was limited to the follicular phase (the menstrual and proliferative phases of the menstrual cycle). Measurement of core temperature and heart rate were continuously measured over the course of exercise testing.

**Procedures for Testing and Data collection**

A university approved informed consent was completed by all subjects prior to participating in this study. On the first session preliminary body composition data, height, weight maximal aerobic test were performed and recorded. On the second exercise session, subjects reported to laboratory after having abstained from alcohol and strenuous exercise as well as during luteal phase of menstrual cycle. On the second session hydration status and preliminary nude weight were measurement in a private changing room equipped with an electronic scale. Subjects were then be escorted into a controlled heated environment where heat is increased by electronic floor heaters to approximately 24-28°C. CorTemp sensor pills were
ingested through the mouth approximately 45 minutes prior to second exercise session. While standing on the treadmill, resting assessments for core temperature and heart rate monitors were positioned and were recorded for a period of three minutes. Subsequent to resting data collection subjects ran on the treadmill for one hour at 70% of aerobic capacity. Core temperature, heart rate, RPE, ambient temperature and relative humidity were recorded every five minutes for the duration of the exercise study. Subjects were provided water as requested throughout the exercise session with the total volume consumed recorded for each subject. After exercise testing is completed, subjects dried skin and hair with a towel and nude weight was determined as well as post trial measurement of core temperature. Pre to post core temperature were calculated. An average core temperature and heart rate during exercise testing were calculated and recorded. Sweat rate was estimated by the change in body mass and adjusted for any fluid consumption.

Data Analysis

The purpose of this study was to examine the association of sweat rate with core temperature in women who are competitive runners. Additionally, to investigate the relationship between core temperature and sweat rate as well as sweat rate with body composition.

The first hypothesis states that subjects with higher percent body fat will have an increased sweat rate and core temperature. As body fat percent increases, sweat rate will also increase. The second hypothesis states that as body fat percent increases, core temperature will increase. Simple regression tests will be administered to determine if there is a relationship between core temperatures and sweat rate. Simple regression was used to determine if there is a relationship between body composition and sweat rates. A 0.05 probability level was used to determine significance.
CHAPTER 4
RESULTS

The purpose of this study was to examine the association of body fat percent on core temperature and sweat rate in women competitive female runners. Specifically, this study answered the question: What is the relationship between percent body fat and sweat rate and core in female runners? Participants of this study included females that compete in running. Twenty-five women aged 18-55 classified as competitive runners exercised for one hour at 70% of maximal aerobic capacity in a heated environment. Body composition and weight were taken prior to exercise. Core temperature, heart rate, and ambient temperature were recorded throughout exercise and weight was also recorded after exercise. This study was designed to determine if percent body fat is associated with an increased core temperature and sweat rate in female runners. Subject and investigation characteristics are described in detail (See Table 1).

Table 1

Subject Measures

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (cm)</td>
<td>166.7</td>
<td>7.057</td>
<td>33.02</td>
</tr>
<tr>
<td>Pre-exercise weight (kg)</td>
<td>63.289</td>
<td>10.399</td>
<td>47.174</td>
</tr>
<tr>
<td>Post-exercise weight (kg)</td>
<td>62.558</td>
<td>10.316</td>
<td>46.811</td>
</tr>
<tr>
<td>Body Fat (%)</td>
<td>28.87</td>
<td>7.957</td>
<td>36</td>
</tr>
<tr>
<td>VO₂ max (ml/kg/min)</td>
<td>44.804</td>
<td>5.529</td>
<td>19.4</td>
</tr>
<tr>
<td>Sweat Rate (L/hour)</td>
<td>0.782</td>
<td>0.236</td>
<td>1.041</td>
</tr>
<tr>
<td>Change in Core Temperature (°C)</td>
<td>1.639</td>
<td>0.624</td>
<td>2.31</td>
</tr>
<tr>
<td>Ambient Temperature</td>
<td>26.432</td>
<td>0.895</td>
<td>3.53</td>
</tr>
</tbody>
</table>
Hypothesis #1

Hypothesis one states that as body fat increases, sweat rate will also increase. When testing the association of body fat, to sweat rate, linear regression indicated no significant relationship $F(24)=3.35 \ p > 0.05$. Hypothesis one is represented below (See Figure 1).

*Figure 1. Relationship of Body Fat and Sweat Rate. This figure shows the relationship between percent body fat and sweat rate of the current investigation.*
Hypothesis #2

Hypothesis two states that as body fat increases, core temperature will also increase. When testing relationship of body fat to core temperature, linear regression indicated no significant relationship $F(24) = 3.154, p > 0.05$. Hypothesis two is represented below (See Figure 2). Additionally, linear regression was used to determine if significance of core temperature was related to sweat rate. No significant relationship was indicated $F(24) = 1.84, p > 0.05$.

![Relationship of Body Fat and Core Temperature](image)

*Figure 2. The Relationship of Body Fat and Core Temperature. This figure represents the data to determine the relationship between body fat and core temperature.*
The purpose of this study was to examine the association of percent body fat on core temperature and sweat rate in women who are competitive runners. Specifically, this investigation studied 25 women age 18-55 classified of competitive runners. The women participated in a two session investigation where body composition was measured and they ran at 70% of maximal aerobic capacity for one hour at an average ambient temperature of 26.43°C. Core temperature, heart rate, and ambient temperature were recorded throughout exercise and weight was also recorded after exercise. After the completion of exercise, sweat rate was calculated by the difference in pre- and post exercise body mass and corrected for fluid ingestion. There were two hypothesis for this study; 1) subjects with higher percent body fat will have an increased sweat rate and core temperature. As body fat percent increases, will rate will also increase, and 2) as body fat percent increases, core temperature will increase. The main findings of this study indicated no relationship between body fat percent and sweat rate. Additionally, findings also indicated no relationship between core temperature and sweat rate.

In this study, the average sweat rate for the women that participated was 0.782 L/hour. This average sweat rate is significantly less than what other published studies have reported (See Table 2).
Table 2

Sweat Rate

<table>
<thead>
<tr>
<th>Authors</th>
<th>N</th>
<th>SR:Male</th>
<th>SR:Female</th>
<th>Mode</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Henkin et al, 2010</td>
<td>30</td>
<td>1.5±0.2 L/hr</td>
<td>N/A</td>
<td>Cycle ergometer</td>
<td>32°C</td>
</tr>
<tr>
<td>Godek et al, 2005</td>
<td>15</td>
<td>1.77±0.4 L/hr</td>
<td>N/A</td>
<td>Outdoor run</td>
<td>26.1-33.9°C</td>
</tr>
<tr>
<td>Millard-Stafford et al, 1995</td>
<td>12</td>
<td>1.71 L/hr</td>
<td>1.25 L/hour</td>
<td>Outdoor run</td>
<td>23.1-28.9°C</td>
</tr>
<tr>
<td>Hazelhurst &amp; Claassen</td>
<td>26</td>
<td>1.12 L/hr</td>
<td>0.57 L/hour</td>
<td>Spin bicycle</td>
<td>N/A</td>
</tr>
<tr>
<td>Tatterson et al, 2000</td>
<td>11</td>
<td>NT: 1.88 L/hr</td>
<td>N/A</td>
<td>Cycle ergometer</td>
<td>NT: 23°C</td>
</tr>
<tr>
<td>Current Investigation</td>
<td>25</td>
<td>N/A</td>
<td>0.78 L/hr</td>
<td>Treadmill</td>
<td>26.4°C</td>
</tr>
</tbody>
</table>

Note: SR= sweat rate, N/A= not available, NT= neutral temperature, HT= high temperature, hr=hour

Numerous investigations have examined thermoregulation and sweat responses in men and women. Henkin et al studied endurance runners, endurance swimmers, and non-athletes that were all males. The runners in this study were competitive and ran an average of 57 miles/week (Henkin, Sehl, Meyer, 2010). There were two sessions for this investigation. The first session was maximal aerobic testing by means of cycle ergometer. The second session subjects cycled for 30 minutes. Subjects did not intake fluid during exercise and sweat rate was calculated by the difference of pre- and post-exercise body mass (Henkin et al, 2010). Runners in this study had an average sweat rate of 1.5 ±0.2 L/hour (Henkin et al, 2010). Another study looked at male football players and male cross country runners age 19-26 (Godek, Bartolozzi, Godek, 2005). All runners ran an average of 52 miles per week. The data in this study was collected over a period of eight days and the runners ran for a total of 60 minutes per day in a hot, humid environment. The average sweat rate for runners in this study was 1.77 L/hour which is similar to findings of 1.71 L/hour of males during a 40 km run in similar environment conditions (Millard-Stafford,
Sparling, Rosskopf, 1995). Millard-Stafford et al reported that the women in this study had a sweat rate of 1.25 L/hour. The mean sweat rates for the male runners were significantly higher (P<0.05) compared to the female runners (Millard-Stafford, 1995). The wet bulb globe temperature (WBGT) at the beginning of the 40-km race was 23.1±0.2°C and 28.9±0.8°C at the run finish. These are considered high temperatures as well as hazardous heat stress conditions (Millard-Stafford, 1995). Hazelhurst & Claassen aimed to determine gender differences in sweat response in trained men and women during indoor cycling for 90 minutes. Women in this study had average sweat rate of 0.57 L/hour and men had an average sweat rate of 1.12 L/hour. Eleven members of Australian National Road Cycling Squad completed two 30 minute cycling trials in environmental chamber at either 32°C or 23°C with relative humidity at 60% for each temperature (Tatterson, Hahn, Martin, Febbraio, 2000). The average sweat rate in this study was greater (P<0.05) in 32°C at 2.25±0.14 L/hour versus at 23°C at 1.88±0.10 L/hour. One can see that the average sweat rates for men and women are higher than the women of the current investigation. This could be due to lower ambient temperature in the current investigation, training level of subjects, indoor facility compared to outdoor, and acclimatization to heat. It is also important to know that individual sweat rates vary on factors such as ambient temperature, humidity, air movement, and exercise intensity insulating clothing or equipment, and body size (Godek et al, 2005). In the current investigation, the highest sweat loss was 1.325 L/hour and the lowest was 0.284 L/hour. These two subjects had a difference of 5.3% body fat and both subjects did not consume any water during exercise. Additionally, both subjects ran about 20 miles per week and had ran in over two races in the last year. The highest sweat loss is what one is expected to sweat in a hot environment, which is above the average for the current investigation.
On the other hand, the lowest sweat loss is below the current average and below what one would expect from reading previous literature.

In addition to sweat rate, various investigations have examined the effects of temperature on performance. During the current investigation there was a change in core temperature of an average of 1.639°C. The average RPE throughout the course of exercise was 12.8 and the average ambient temperature was 26.432°C. Treadmill speed was not recorded during exercised. Subjects stayed within ±5 beats of heart rate located at 70% of maximal aerobic testing during the first session. Future studies should aim investigations on performance related to exercise in heated environment. However, it is worthy to note that similar investigations have studied performance in the heat. One study looked at members of the Australian National Road Cycling Squad that cycled for 30 minutes at a high temperature of 32°C and relative humidity 60% and 30 minute cycling at neutral temperature of 23°C and relative humidity 60%. Mean power output was significantly decreased (P<0.05) by 6.5% during high temperature compared with neutral temperature. Mean skin temperature, heart rate, and sweat rate was also significantly higher (P<0.05) throughout exercise during high temperature. Perceived exertion was higher at 5, 10, and 25 minutes of exercise in high temperature.

In summary, the current investigation indicates that the human body can regulate core body temperature regardless of the weather conditions. So, in this study, females did not sweat as much as expected in hot conditions compared to similar investigations. However, McArdle et al, 2010 states that typically a workout over one hour can produces a sweat loss of 0.5 to 1.0 Liters. In addition, in hot environments sweat rates can be as high as 1.4 to 2.0 L/hour (Armstrong, 2000). Sex differences were also observed that men had higher sweat rates in similar studies (Henkin et al, 2010, Godek et al, 2005, Millard-Stafford, 1995). The conclusion of this study
was no significant correlation found between percent body fat and sweat and percent body fat and core temperature. Essentially, for female’s runners that are running competitively, body fat does not affect performance in a heat challenging event. Additionally, there was no relationship found between core temperature and sweat rate.

Recommendations

For future research investigating the relationship between percent body fat and sweat rate and core temperature, the following are recommendations.

1) A large sample size;

2) Researchers should consider using a non-trained population;

3) Researchers should investigate how fluid ingestion during exercise affects sweat rate;
REFERENCES


How many competitive races have you participated in the last year?
0
1
2
3
4 or more

Most recently, how many miles have you been running on average per week in the last 6 weeks?
0
2-5
5-10
15-20
20 or more

When was the last day of menstrual cycle?
APPENDIX B
HUMAN SUBJECTS CONSENT FORM

Identification of Researchers: This research is being done by Halie Thomas, a graduate student. This research is being done in the Kinesiology Department at University of Central Missouri.

Purpose of the Study: The purpose of the current investigation is to determine how body fat affects sweat rate and core temperature specifically in women who compete competitively in running events.

Request for Participation: I am inviting you to participate in a study on body composition and its effect on core temperature and sweat rate. It is up to you whether you would like to participate. If you decide not to participate, you will not be penalized in any way. You can also decide to stop at any time without penalty. You may withdraw your data at the end of the study.

Exclusions: You must be a woman, currently competing recreationally in running events, at least 18 years of age to participate in this study. Pregnant women will be excluded from the study.

Description of Research Method: This study involves exercise testing on a treadmill in a heat-controlled room for 60 minutes. Body composition will be measured by means of DEXA scan prior to exercise. Subjects will additionally perform a maximal treadmill test to determine aerobic capacity. Nude weight will be determined both before and after exercise to determine sweat rate. You will be provided complete privacy for weighing. Core temperature and heart rate will be measured and recorded continuously during this study by means of CorTemp sensor pills and heart rate monitors. The goal of this investigation is to determine whether body fat percentage has an effect on core temperature and sweat rate. You will have a chance to ask questions and individual results will be given and discussed. Total time commitment will be one visit no more than 90 minutes each visit. The consent form will be obtained prior to exercise testing to make sure participants understand the process and procedures.

Privacy: All of the information we collect will be confidential. Any publication of this research will be done using aggregate data without any personal data being shared publically. Data will be secured on a password protected computer or a locked file cabinet if in paper form.

Explanation of Risks: The risks associated with participating in this study are similar to the risks of everyday life or as a regular runner. Possible complications include: muscle fatigue. Any medical treatments provided if an injury occurs will be at the expense of the participant. Running may cause discomfort or hyperthermia not the experiment procedures. If symptoms of hyperthermia do occur, exercise testing will be stopped and the subject will immediately be moved to a cooler environment outside of the Human Performance Lab and rehydrate via water. Additionally, ice packs, and wet towels will be available for use at the neck, axillae, and groin of subjects.
**Explanation of Benefits:** You will benefit from participating in this study by getting firsthand experience in exercise physiology research. You may also benefit by accurate information regarding your own sweat rate as well as body composition.

**Questions:** If you have any questions about this study, please contact Halie Thomas at hthomas@ucmo.edu or by cell (816)-442-1407. If you have any questions about your rights as a research participant, please contact the Human Subjects Protection Program at (660) 543-4621.

If you would like to participate, please sign a copy of this letter and return it to me. The other copy is for you to keep.

I have read this letter and agree to participate.

Signature: ________________________________

Print: ________________________________

Date: ________________________________