A STANDARD MEASUREMENT OF

INSULATIVE PROPERTIES OF

FOOTBALL SHOULDER PADS

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CHAPTER I

INTRODUCTION

Football is an intense cardiovascular and endurance sport in which athletes train year round to be prepared for regular-season play. The beginning of the American football season coincides each year with what is in many parts of the United States the hottest and most humid part of the year (Kulka, 2002). This hot environment can lead to many problems for the athlete. From 1979 to 1999, the Centers for Disease Control and Prevention reported that 8015 deaths among the general population were attributed to heat-related problems (Cooper, 2006). Although not all of the deaths were sport related, the deaths of many professional, college, and high school athletes has raised attention to heat illnesses in athletic competitions. Many different heat illnesses can occur, but between 1931 and 2009 one hundred and twenty-eight heat stroke deaths occurred in the game of football (Muller, 2010). It is important to note that these deaths are only from heat stroke and do not encompass death from other heat illnesses. More athletes playing football have died from heat illnesses than in any other sport (Muller, 2010).

An examination of heat related deaths in football should include evaluation of the uniform. The uniform may elevate heat levels and retain heat against the body. The hot climate coupled with extensive protective equipment exposes many athletes to heat stress (Kulka, 2002).

Heat stress affects the body's thermo regulations including sweat rate, electrolyte balance and bodyweight retention, all contributing factors to the probability of heat illnesses. The football ensemble is multi-layered and includes shoulder pads, leg pads, pants, jerseys, and undergarments. The type of shoulder pads worn vary by player position. The linemen wear a different shoulder pad than skill position players such as running backs and quarterbacks. It is not ideal for an athlete to wear uniforms that impede heat transfer to the environment in extremely warm weather conditions.

This project was focused on one component of the uniform—the shoulder pads. The purpose was to examine and compare the insulative variables of football shoulder pads. The findings help determine if the shoulder pads along with the uniform configuration tested are appropriate or safe to wear in hot environments by calculating the wearable time variables based on the temperature and relative humidity of a specific environment.

Purpose of this Study

The purpose of this study was to assess and compare six different football shoulder pads regarding heat and moisture transfer performance. The measurements for thermal and evaporative resistance were taken using a sweating thermal manikin. All measurements were analyzed for differences in insulative values to determine which shoulder pads were the safest for athletes to wear in hot environments. The hypotheses guiding this study are outlined below.

Ho1: There will be no significant difference in all insulation variables of the shoulder pads tested produced by different manufacturers.

Ho2: There will be no shoulder pads tested that are safe for individuals to wear in the tested temperatures.

This measurement of the insulation variables could help athletes and equipment managers determine what pads could be worn in various temperature settings.

Limitations

This study was limited to comparing and evaluating the effects of six different commercially available shoulder pads on one sweating manikin. The environments tested created another limitation due to the multitude of conditions possible during football competition. These tests were conducted in a simulated laboratory setting with no air movement and a static manikin.

LIST OF NOMENCLATURE

Absorption- when a substance penetrates the surface of an object and travels throughout the structure(Watkins, 1995).

Clo - a unit of thermal insulation that is widely used because it clearly conveys the warming power of an ensemble. This unit is intended to express the insulation provided by a total clothing ensemble, not a single item (Watkins, 1995). One clo corresponds to a person wearing a business suit.

Conduction– heat exchange that occurs between two objects that are touching (Armstrong, 2000 and (Watkins, 1995)

Convection – heat exchange that occurs between two objects that are touching (Armstrong, 2000).

Evaporation of sweat – when water changes from liquid to gas (Armstrong, 2000).

Evaporative Resistance- The moisture related (wet) resistance of thermal insulation.

Heat acclimatization – when a persons expose themselves to exercise-heat stress gradually, on consecutive days, to stimulate adaptive responses that improve exercise performance and heat tolerance, and reduce physiological strain and the incidence of some forms of heat illness (Armstrong, 2000).

Radiation – the transfer of energy waves that are emitted by one object and absorbed by another (Armstrong, 2000).

Sweat Rate - the rate of sweating a person incurs over their entire person for a given amount of time (Layman, 1970).

Thermal Insulation- resistance to the passage of heat (Layman, 1970).

Thermal Resistance (R_t or R_{ct}) - “Temperature difference between the two faces of a material divided by the resultant heat flux per unit area in the direction of the gradient. The dry heat flux may consist of one or more conductive, convective, and radiant components” (11092, 1993). Thermal resistance is the dry measure of thermal insulation.

Thermoregulation - ability of an organism to keep its’ body temperature within certain boundaries.

Uniform Configuration- for the purpose of this study, this is described as the girdle, football pants, under shirt, jersey and pant pads worn during the game of football. This does not include football shoulder pads.

Uniform Ensemble- For the purpose of this study, we describe a uniform ensemble as the girdle, football pants, under shirt, jersey, pant pads and shoulder pads worn during the game of football.

Water-vapor resistance (R_{et}) "the vapor pressure difference per unit times rate of water vapor steady-state flow through a unit area, normal to specific parallel surfaces. Water-vapor pressure difference between the two faces of a material divided by the resultant evaporative heat flux per unit area in the direction of the gradient. The evaporative heat flux may consist of both diffusive and convective components." (11092, 1993)

CHAPTER II

LITERATURE REVIEW

This chapter begins with an explanation of the concept of thermoregulation and the human body response to thermoregulation. The environmental risk factors of minor and serious heat illnesses, muscle heating and the effects of heat on football players, protective equipment focusing on shoulder pads temperature variations lead to a description of thermal measurements. The chapter ends with standards for the assessment of risk of thermal strain and the associated hypotheses of the study.

Thermoregulation

Environmental Thermoregulation

McIntyre (1973) wrote when evaluating a thermal environment, the physical variables of an individual's heat loss should be examined. In a human, heat loss occurs by radiation, convection, and evaporation. In radiation the heat loss is to surrounding surfaces, with convection heat is lost to the air, and evaporative heat loss comes from the skin and lungs when body moisture and sweat are absorbed into the environment. Radiation heat loss depends on the radiant temperature of surroundings (McIntyre, 1973). Convective heat loss depends on air temperature and air speed. Evaporative heat loss allows a greater amount of energy dissipation but is often difficult in hot environments.

For evaporative heat loss to occur, the body's sweat must reach the ambient air. This is often difficult in environments where the body's coverings block skin to air availability. Within the body, water is extruded by the capillaries and is pushed to the skin resulting in cooling of the body. The body's capillaries fill with blood and expand their surface area to dissipate heat. The body then sweats water that evaporates to keep the skin temperature normal (Phan, 2005). If no fluid is in the sweat glands, there is no fluid to get pushed to the skin's surface to help cool the body. The sweat extruded by the body evaporates, turning into water vapor (Phan, 2005). When this occurs, the body's energy is used as the liquid evaporates into vapor. This reduces heat by using the body as its source of power (Phan, 2005).

When performing strenuous activities in extreme heat, sweat output can often exceed water intake leaving the body in a state of water deficit known as hypohydration (Sawka, 2000). These individuals usually suffer from electrolyte losses and an increase in core body temperature. When individuals lose 1% of their body weight during exercise their core temperature is elevated causing exercise heat stress. As a result of hypohydration, heat storage is increased and ability to tolerate heat strain is decreased (Sawka, 2000).

When the temperature of the environment rises above skin temperature, an athlete begins to absorb heat from the environment. This results in heat loss that depends on evaporation (Brinkley, 2002). The environmental factors and ambient air temperature, relative humidity, and the amount of radiant heat from the sun or other sources influence the risk of heat illness (Brinkley, 2002).

Human Thermoregulation

A normal state of hydration is thought by Godek (2005) to be important for the prevention of heat-related illness. For individuals' organs to stay healthy, water and electrolyte balance are critical (Sawka, 2000). Within the body, there are many water compartments. Each of these water compartments contains electrolytes, which help move fluids between intracellular and extracellular components (Sawka, 2000). When excessive sweating occurs, this free fluid exchange causes water loss to all parts of the body (Sawka, 2000). Sawka (2000) suggests that during exercise in the heat, fluid consumption should be matched with sweat loss to help the body regulate its temperature. It is important for athletes to begin fluid intake during the early stages of exercise to maximize the bioavailability of the fluids. Athletes have a smaller percentage of body fat and a higher amount of skeletal muscle resulting in a larger amount of total body water than an individual who is not athletic (Sawka, 2000).

When the body overheats, external heat illnesses often occur. External heat illness is readily correlated with a rise in ambient air temperature and humidity. Intense environmental conditions place significant stress on a football player's body. When the body is stressed due to heat, the internal organs can suffer devastating effects including immobilizing the ability of nutrients and electrolytes to maintain appropriate equilibrium amounts in body fluids, and an increase in body temperature, pH and blood pressure. When the body does not respond appropriately, the athlete can develop a series of catastrophic medical conditions (Havenith, 2001) including heat illnesses.

Heat Illnesses

All forms of heat illness are related to an imbalance in water and sodium in the body (Carter, 2008). These imbalances occur when hydration is not proper or when heat transfer from the body is not efficient. When heat transfer is not efficient in keeping the body cool, the body must overcompensate by sweating excessively to keep itself cool. Due to the larger amounts of body fat, muscle mass, and higher core temperatures of larger individuals, they have an increased risk for heat illnesses to incur because they have a greater amount of body insulaiton.

Carter (2008) found that when extensive physical activities occur in extremely hot environments, there is an increased risk for heat illnesses. Electrolyte imbalance is common in hot weather and results in preventable heat injuries, heat illnesses, and many deaths in healthy young athletes (Carter, 2008). Heat illness may occur only when there is clear evidence of abnormal body heat retention causing an elevation in core body temperature (Nokes, 2008). In examining the different classifications of heat illnesses, there are minor heat illnesses and serious heat illnesses.

Hitchcock (2007) found that heat stress could occur at 26 degrees Celsius with 52% relative humidity. Coyle (2003) found that when football players were exercising in extreme heat, full uniform should not be worn in temperatures that exceed 83.1 degrees Fahrenheit or 28.34 degrees Celsius.

Minor Heat Illnesses

Minor heat illnesses include muscle cramps, muscle exhaustion and heat syncope. Muscle cramps are a very acute, painful, and involves involuntary muscle contraction. Cramps occur due to an imbalance in the body's fluids or electrolytes, or neuromuscular fatigue (Brinkley, 2002). Muscle exhaustion occurs when an individual has used muscles at extreme rates resulting in overuse of muscles. Another mild heat illness is heat syncope or dizziness that occurs when a person is exposed to extreme environmental conditions. For this to occur, the individual may experience peripheral vasodilatation (postural pooling of blood) diminished venous return (dehydration) reduction in cardiac output and cerebral ischemia (insufficient blood flow to the brain) (Brinkley, 2002).

Serious Heat Illnesses

Serious heat illnesses include heat stroke and external hypothermia (Carter, 2008). Heat stroke occurs when the core body temperature is elevated over 40 degrees Celsius and signs of organ system failure are evident. The first markers of heat stroke can be seen when an individual has changes in their central nervous system as well as neurologic changes. The temperature regulation system is overwhelmed due to excessive heat production or inhibited heat loss. When excessive heat production or inhibited heat loss occurs the thermoregulatory system can progress to complete system failure and be fatal unless promptly recognized and treated. Some signs of system failure include tachycardia (heart rate irregularities), hypotension (low blood pressure), sweating, hypertension (high blood pressure), altered mental status, vomiting, diarrhea, seizures, and coma (Brinkley, 2002).

Another serious heat illness that is a rare condition is called external hyponatermia. This occurs when low serum-sodium levels are present and when activity exceeds 4 hours. For external hyponatermia to occur, an athlete usually does not ingest enough water or low-solute beverages to compensate for sweat losses, or an athlete has sweat sodium losses that are not adequately replenished. When the body's fluid levels are inadequate, the intravascular and extracellular fluid has a lower solute load than the intracellular fluids, and water flows into the cells creating swelling that causes potently fatal neurologic and physiologic dysfunction. When athletes have external hyponatermia, they have a combination of disorientation, altered mental status, headache, vomiting, lethargy, and swelling of their extremities. This condition can result in death if not prevented by matching fluid intake with sweat and urine losses (Brinkley, 2002).

Muscle heating

To determine the magnitude of body temperature change at a certain heat storage rate, body heat capacity must be evaluated (Havenith, 2001). This body heat capacity can be determined by body mass and the specific body heat of the tissue. Body fat has a specific heat, up to 2.51 J/g, jolts per gram . Other body tissues like skin, muscle, and the skeleton heat on average to 3.65 J/g (Havenith, 2001).

When measuring the body heat that travels from the core to skin, one must examine the resistance formed by the body's shell. This outer shell is made of muscle, fat and skin. When muscles become vasoconstricted, they are included in the shell because the heat flow from core to skin is conductive heat transfer. This makes muscles an important instrument in the core-to skin heat transfer (Havenith, 2001).

Havenith (2001) found that there was a correlation between the shell insulation and the individual's subcutaneous fat thickness, creating an insulation of .0048 per millimeter of fat thickness. Havenith also found insulation of 0.0022 per millimeter of skin. In larger individuals, their amount of conductive heat transfer is lower causing them to store larger amounts of their body heat within their bodies. When the individual begins aerobic activity the working muscle activity increases causing reduced insulation. Core-to skin conductance and muscle blood flow can be increased because blood flow is correlated with radial heat flow and skin blood flow. This increase will affect the core-to skin conduction through heat transport. In addition, the fat layer thickness is a constant conductive heat resistance. To summarize, an individual with larger amounts of muscle tissue will incur greater core temperatures resulting in an increased overall body temperature.

Heat Related Risk Factors on a Football Player's Body

When an individual loses 1% of body weight during exercise, their core temperature is elevated. Football players routinely lose 3.5 to 5 kg, 1%, of weight during practice (Godek, 2005). Athletes who perform intense exercise in the heat usually have a sweat rate of 1.0-2.5 L/h (liters per hour), whereas a resident of a desert climate has a sweat rate of 0.30-1.2L/h (Sawka, 2000). The sweat rate is measured without the evaporation limiting protective equipment worn by football players. This extreme amount of sweat loss makes it nearly impossible for players' bodies to replenish water volume leaving the athletes dehydrated (Godek, 2005). This state of dehydration makes it harder for the body to efficiently thermo-regulate leading to an increased probability that any heat illnesses will occur.

A football player has nearly 3 million sweat glands (Phan, 2005). Although football players have a large number of sweat glands, their individual sweat rates differ depending on the ambient temperature, humidity, air movement, exercise intensity, insulating clothing or equipment and body size (Godek, 2005).

Godek (2005) found the sweat production of linemen to be higher than smaller skill players, meaning linemen also have a greater fluid replacement need. In addition to linemen having high fluid replacement needs, when they are wearing their football pads, their bodies sweat at an even higher rate. Wearing their football equipment, the athletes have been found to sweat during the first stretching stages of their competition (Godek, 2005). This increased sweat rate is due to the increased body heat capacity of athletes from their large amounts of muscle mass.

Heat-related risk factors

When exercising, the heat exchange between the body and the environment is modified by the clothing system worn depending upon the amount of body surface that is covered and the material make up of that clothing (McCullough, 2003). The body temperature of the athlete will be readily increased because of the air trapped between the material layers (McCullough, 2003).

In examining American football, it is important to realize that football is very metabolically demanding and the game is often played in high ambient temperatures. The high ambient temperatures lead to physiological consequences due to the extreme exertion necessary to efficiently play the game of football (Johnson, 2009). Football protective equipment that is made of plastic does not allow water vapor to pass through; therefore it inhibits evaporative, convective and radiant heat loss (Johnson, 2009 & Brinkley, 2002). The equipment holds the warm air inside the padding layers creating a higher core body temperature in the athlete. As a result of a higher body temperature, and the impenetrable plastic in the equipment, athletes are much more susceptible to heat illnesses (Brinkley, 2002).

Hitchcock (2007) found in a simulated football practice where body core temperatures were measured that the core body temperature of linemen was elevated during rest periods along with periods where exercise was occurring (Hitchcock, 2007). This study further validates the results McCullough (2003) reported when examining the body surface area in conjunction to the body temperature and thermoregulation. Due to these strenuous conditions, it is more likely that a football player incurs heat illness when wearing their different uniform configurations.

Protective Football Uniform Ensemble

The purpose of football equipment is to protect the wearer without the use of elements that may endanger their opponent (Mulvey, 1941). The football uniform ensemble for the purpose of this study, is described as an uniform ensemble as the girdle, football pants, under shirt, jersey, pant pads and shoulder pads worn during the game of football. Specifically pads should provide padding that could adequately protect the athlete without interfering with their movement or performance (Mitchell, 1989). In order to properly protect the athlete, and allow for the greatest amount of playing success, pads should be thin, compact, lightweight and comfortable. The pads must shield or deflect sharp blows and distribute the impact force over a large surface area and dissipate at least some of the energy of impact (Mitchell, 1991). When examining each piece of equipment, it is essential that every player be individually fitted for all equipment pieces to ensure safety and efficiency. Additionally, all equipment must be inspected for cracks, frayed strings and rivets (Gleck, 1980).

Equipment Standards

Each specific piece of football protective equipment has certain specifications they must meet. There are standards given by the National College Athletic Association (NCAA) and National Operating Committee on Standards for Athletic Equipment (NOCSAE) pieces except the shoulder pads. The shoulder pads standards are based more on the preference of the equipment managers and coaches.

Although there are not specific standards football shoulder pads must meet, Mark D. Monica, President/CEO of Impact Protective Equipment, LLC (2005) determined that increased protection from injuries, lighter weight, more movement and mobility, education to recognize risk of injury, and different equipment can all be important factors when determine the best equipment to have minimal injuries.

Shoulder Pad Design

The shoulder pads are designed in a way that can maximize protection of the wearer while minimizing restrictions on the movement (Mitchell H. , 1989). This construction is created to reduce and spread the load from colliding players (Mitchell 1987).Two basic types of shoulder pads exist: (1) Flat pads, used by players with limited contact, for example a quarterback or receiver, and (2) Cantilever pads which are worn by players in constant contact, such as a lineman (Gleck, 1980). The difference in these pads is important because each element inside the pads is constructed to protect the player from injury and to disburse pressure from impacts (Mulvey, 1941). The less protective flat pads, shown in Figure 1 (Dave's Sport shop, 2011), are worn by players with lower contact because they allow for more motion and movement (Gleck, 1980). The cantilever pads, shown in Figure 2 (Dave's Sport shop, 2011), have a larger blocking surface (Gleck, 1980). This larger blocking surface is important for linemen so they can protect the shoulder from impact. In order for the arch of the cantilever to protect properly, they must be fit properly to the wearer's chest and back (Watkins, 1995).

Figure 1

Figure 2

Shoulder pads are made of two arch portions (Neuhalfen, 1993) or u-shapes arch components that fit over the wearer's shoulders (Wingo, 1991). The arched portion is interconnected with the front and back shoulder pads by a curved protective portion (Mitchell 1987).The posterior portions are permanently hinged together over the spine and the chest portions are connected together by lacings or straps (Wingo, 1991).

Shoulder pads include a thick inner padding section, flexible straps located in-between the inner padding sections, a hard outer plastic layer, or exoskeleton, and combinations of web hinges and epaulets (Mitchell 1987).There is a space in-between the outer exoskeleton layer and inner foam layer that is meant to prevent the direct transmission of energy occurred on impact from the plate to the wearer. When the athlete is hit on his exoskeleton layer, the inner ply of padding is forced against the body causing the stiff outer plate to flex. This flexing brings the exoskeleton layer closer to the wearer's body resulting in both the exoskeleton and the inner padding being closer to the athlete's body resulting in a larger surface area to distribute the force of impacts. This plate flexing also absorbs and dissipates some of the impact energy resulting in a greater amount of protection for the athlete.

The pieces of the exoskeleton of the shoulder pads are placed together using a technique called shingling. This involves overlapping the protective materials in a way that is similar to shingles on the roof of a house (Watkins, 1995). These layers are created with the purpose to absorb the load in a manner to protect the body (Mitchell 1987) and still allow segments to bend with the body's movements (Watkins, 1995). Although the padding allows the body to move, there is no coverage gap in-between the shingled plates. When an impact occurs on a single plate, the shoulder pads distribute the load to each plate that is touched spreading the force almost as if a solid armor plate had been used. By using this shingled effect for protection, the shoulder and arm still have mobility and are protected extensively in the areas that are most likely to be hit (Watkins, 1995).

The Exoskeleton of Football Shoulder Pads

Different configurations and materials are used on the rigid exoskeleton of shoulder pads. To examine the exoskeleton material makeup it is important to understand the basics of plastics. In plastics, there are two primary classes of materials: thermo-set plastics and thermoplastics. Thermo-set plastics include urethanes, phenolycs, vinyl resins, and polyester gels. Thermo-set plastics are set by temperature during the formation of the final product. These plastics do not melt and cannot be reformed because they do not plasticize (Wang, 1987). In contrast, thermoplastics are reform-able and reshape-able. The exoskeleton is formed by heating the plastic and forming the desired initial shape. Polyethylene is thermo-formable plastic meaning it can be reheated by immersing it in water, then reshaping can occur. Polyethylene is the largest commercially available polymer (Ides, 1986) with the ability to retain the molded shape or be remolded. A material stiffener is often added to these plastics in order to help the plastic in shape retention and to resist remolding. These stiffeners are usually used when it is not desired to have the capability of reshaping plastic during subsequent heating and forming after the initial formation (Wang, 1987). Due to the lack of consistency and standards in the production of football shoulder pads, both types of plastics are used. The manufacturer determines what material they would like to use for their specific shoulder pads.

Each manufacturer has different specifications to the specific type and thickness of exoskeleton material used. Douglass® shoulder pads are constructed using high-density polyethylene that is produced in large sheets. These sheets have different levels of thickness based on the position they are being produced for. For linemen, shoulder pads are produced with polyethylene that is 140 hundreds of an inch thick. It has been found by the Douglas® (2010) manufacturers that this thickness and density is best for these athletes in terms of cost and durability. For skill players, shoulder pads are produced with polyethylene that is 125 hundreds of an inch thick.

After the molding process is complete, the eyelets for the lacing strings and the grommets for the t-hooks used to attach the shoulder pads are added. The eyelets and grommets are added after molding because they are made out of steel and would damage the epoxy molds (Wells, 2010). Each manufacturer has specific processes, materials, and material thicknesses that their exoskeleton material goes through before it reaches a finished stage to be joined with the inner padding layer to create shoulder pads.

The inner layer of shoulder pads is typically a foam body that is composed of a layer of open cell foam and two layers of closed cell foam (Rector, 1997) or three layers of open cell foams of different densities (Wingo, 1991).

Table 1 shows the differences in uniform configurations that are worn based on the weather conditions. Please note that there is no difference in the shoulder pads worn during hot environmental conditions and cold weather uniform configurations.

In examining the different uniform configurations, McCullough (2003) determined that a football uniform, even the configuration worn in warm weather, had a higher evaporative resistance than a sweat suit or jeans and a heavy long-sleeved shirt. It is known that the higher the evaporative resistance, the less permeable the clothing is to moisture transfer. The evaporative resistance of the materials used depends on the moisture permeability and wicking probabilities of football pads. This content of the fibers is not the main characteristic that determines the moisture resistance (McCullough, 2003).

Table 1

Uniform	Warm Weather Game Uniform	Temperate Game Uniform	Cold Weather Game Uniform	Practice Uniform with Hip Girdle	Practice Uniform with shorts only
Upper Body	Helmet + Chin Strap Shoulder Pads Sleeveless cut-off T-shirt Short-Sleeved Mesh Jersey (tucked into pants)	Helmet + Chin Strap Shoulder Pads Long-Sleeved knit shirt Short-Sleeved knit jersey (tucked into pants)	Helmet + Chin Strap Shoulder Pads Thick long-sleeved shirt Short-sleeved knit jersey (tucked into pants)	Helmet + Chin Strap Shoulder Pads Sleeveless cut-off t-shirt Short sleeved mesh jersey (cut off at waist and hanging loose)	Helmet + Chin Strap Shoulder Pads Sleeveless cut-off t-shirt Short-sleeved mesh jersey (cut off at waist and hanging loose)
Lower Body	Jock Strap Hip Girdle with hip, thigh, and tail bone pads Football pants with knee pads + belt Ankle-thigh length socks Turf Shoes	Gloves Jock Strap Hip girdle with hip, thigh, and tail bone pads Football pants with knee pads + belt Knee-length socks Turf Shoes	Gloves Jock Strap Hip girdle with hip, thigh, and tail bone pads Knit long underwear Football pants with knee pads + belt Knee-length socks Turf shoes	Jock Strap Hip girdle with hip, thigh, and tail bone pads Mesh Shorts Ankle-length socks Turf shoes	Jock Strap Mesh Shorts Ankle-length socks Turf Shoes

(McCullough, 2003)

Football Equipment's Role in Evaporation

When wearing shoulder pads, due to the protective plastic outer layer, the heat produced by the body is not released creating a very warm environment for the athlete. Matthews (1969) found that the football uniform imposes a heat-barrier loss that can impede evaporative heat loss by 60% to 70%. Beneath the plastic shoulder pads, blood returning to the body's core was only cooled at 1/5 the rate as other parts of the body not covered by shoulder pads. This increase in blood temperature causes the individual's body temperature to rise. In warm environments, this can be extremely dangerous for the athlete.

When the plastic shoulder pads are worn, they reduce the efficiency of the sweat evaporation (Matthews, 1969). In his study of sweat evaporation, Matthews (1969) found that only 30-40% of the body's sweat could be evaporated when the full football uniform is worn. When only shorts were worn, 60-75% of the body's sweat was able to evaporate (Matthews, 1969). The sweat evaporation is related to the impermeable nature of the plastic on the shoulder pads, which leave evaporation virtually impossible (Matthews, 1969). The large difference seen when shoulder pads are worn and not worn leads to the conclusion that the shoulder pads worn by football players cause a decrease in the body's heat loss, leaving the football players with an increased body temperature with limited ways for their body heat to escape.

Thermal Measurement

When determining if materials are safe to wear by thermal standards, it is important to have a unit of measure. In the early 1940's, when the clo-value was determined, a method was needed for determining an accurate measuring process (Holmer, 2004). To determine the clo reading, there are many factors. McCullough (2002) determined that the following variables are accounted for with a manikin test:

1. The amount of body surface area covered by textiles and the amount of exposed skin

2. The distribution of textile layers and air layers over the body surface
3. Looseness or tightness of fit
4. The increase in surface area for heat loss due to the textiles around the body
5. The effect of product design
6. The adjustment of garment features
7. Variation in the temperature on different parts of the body
8. The effect of body position

Before determining thermal measurement of materials, it is important to consider what measurements are needed. Many tests are concentrated on only dry heat loss or water vapor transmission (Celcar, 2008). The common estimation of the thermal properties of clothing is determined using a sweating manikin. Since the early 1940's new research has developed advanced forms of these manikins. These manikins simulate heat and moisture production similar to the way a human body does (Celcar, 2008). Walter™, a fabric-sweating manikin, housed at the Institute of Protective Apparel at Oklahoma State University simulates perspiration using a waterproof, but moisture-permeable, fabric. This fabric holds the water inside the body while allowing moisture to transfer through the skin (Celcar, 2008). Walter™ is heated through his trunk where water is circulated through his body distributing heat to his arms and legs. His core temperature is controlled at 37ºC (Celcar, 2008). Walter™'s skin can be unzipped and interchanged to simulate different perspiration rates (limited). A photograph of Walter™ without his skin can be seen in Appendix B.

Standards for the Assessment of Risk of Thermal Strain

The International Standards Organization (ISO) had developed a series of standards to determine safe functioning environments' for the human body. These standards determine in specific environmental conditions, the duration of time and amount of insulation that is safe for the body to withstand.

ISO 7933 is a standard that specifies a rational assessment of environments by calculating and interpreting the sweat rate of an individual. The measurement of the environment in terms of air temperature, mean radiant temperature, humidity and air velocity, and estimates of factors relating to clothing, metabolic rate and posture, are used to calculate the heat exchange between a standard person and the environment (Parsons, 1999). Please refer to table 2 for descriptions of terms used in the following formulas. Sweat rate is determined from the following equation:

$$E_{req} = M - W - C_{res} - E_{res} - C - R$$

and

$$S_{req} = E_{req}/r_{req}$$

Although the Metabolic and mechanical power are estimated, W is often taken as a zero value if detailed information about the task is not known (Parsons, 1999). K is regarded as having negligible effects. Parsons (1999) determined that the following equations are used to calculate the terms.

$$C_{res} = 0.0014\ M\ (35 - t_a),$$

$$E_{res} = 0.0173\ M\ (5.624 - P_a),$$

$$C = h_c\ F_{cl}\ (t_{sk} - t_a),$$

$$R = h_r\ F_{cl}\ (t_{sk} - t_r),$$

where

$$w = E/E_{max},$$

$$r = 1 - w^2/2,$$

$h_c = 2.38\ |t_{sk} - t_a|^{0.25}$ for natural convection,

$h_c = 3.5 + 5.2\ v_{ar}$ for $v_{ar} < 1\ ms^{-1}$

$h_c = 8.7\ v^{0.6}_{ar}$ for $v_{ar} \geq ms^{-1}$

$v_{ar} = v_a + 0.0052\ (M - 58)$,

$$h_r = \sigma E_{sk} \frac{A_r}{A_{Du}} \frac{[(t_{sk} + 273)^4 - (t_r + 273)^4]}{t_{sk} - t_r},$$

$F_{cl} = 1/[(h_c + h_r)\ I_{cl} + 1/f_{cl}]$,

$F_{cl} = 1\ \_\ 1.97\ I_{cl}$,

$E_{max} = (P_{sk,s} - P_a)/R_t$,

$R_t = 1\ /\ h_e F_{pcl}$,

$H_e = 16.7\ h_c$,

$F_{pel} = 1\ /\{1 + 2.22\ h_c\ [I_{cl} - (1 - 1/f_{cl})/(h_c + h_r)]\}$

$t_{sk} = 30.0 + 0.093\ t_a + 0.045\ t_r - 0.571\ v_a$

$+ 0.254\ p_a + 0.00128\ M - 3.57\ I_{cl}$

This regression equation for t_{sk} can be used for the following ranges for each individual parameter:

$t_a = 22.9 - 50.6°C$,

$tr = 24.1 - 49.5\ °C$

$p_a = 0.8 - 4.8$ kPa

$v_a = 0.2 - 0.9\ ms^{-1}$

$M = 46.4\text{-}272\ W/m^{-2}$,

$I_{cl} = 0.1 - 0.6$ *Clo,*

$t_{sk} = 32.7 - 38.4\ °C$,

The following table from Parsons (1999) gives descriptions of the terms used in ISO 79339

Table 2

Symbol	Term	Units
M	Metabolic power	$W\ m^{-2}$
W	Mechanical power	$W\ m^{-2}$

C_{res}	Respiratory heat loss by convection	W m^{-2}
E_{res}	Respiratory heat loss by evaporation	W m^{-2}
K	Heat exchange on the skin by conduction	W m^{-2}
C	Heat exchange on the skin by convection	W m^{-2}
R	Heat exchange on the skin by radiation	W m^{-2}
E	Heat flow by evaporation at skin surface	W m^{-2}
E_{res}	Required evaporation for thermal equilibrium	W m^{-2}
S_{Wreq}	Required sweat rate for thermal equilibrium	W m^{-2}
w	Skin wittedness	ND
w_{req}	Skin wittedness required	ND
r_{req}	Evaporative efficiency at required sweat rate	ND
t_a	Air temperature	°C
P_a	Partial vapor pressure	kPa
h_c	Convective heat transfer coefficient	W m^{-2} K^{-1}
F_{cl}	Reduction factor for sensible heat exchange due to wearing	ND
T_{sk}	Mean skin temperature	°C
h_r	Adiative heat transfer coefficient	W m^{-2} K^{-1}
t_r	Mean radiant temperature	°C
$P_{sk,s}$	Saturated vapour pressure at skin teperature	kPa
R_t	Total evaporative resistance of limiting layer of air and clothing	m^2 kPa W^{-1}
E_{max}	Maximum evaporative rate which can be ached with the skin completely wet	W m^{-2}
v_{ar}	Relative air velocity	ms^{-1}
v_a	Air velocity for a stationary object	ms^{-1}
σ	Stefan-Boltzman constant, 5.67 x 10^8	W m^{-2} K^{-4}
E_{sk}	Skin emissivity (0.97)	ND
A_r/A_{du}	Fraction of skin surface involved in heat exchange by radiation	ND
F_{cl}	Ratio of the subject's clothed to unclothed skin surface area	ND
F_{pcl}	Reduction factor for latent heat exchange	ND
h_e	Evaporative heat transfer coefficient	W m^{-2} kPa^{-1}
I_{cl}	Basic dry thermal insulation of clothing	Clo or m^2 °C W^{-1}

An approximation of 36ºC for T_{sk} has been made and may be more applicable to many situations. The required sweat rate of an individual with the maximum limit values for moisture levels of the skin and sweat rate achievable by a person are presented for both acclimatized and non-acclimatized persons at work and rest. In cases where thermal equilibrium cannot be achieved, there will be heat storage and the body core temperature will rise. Limited values are presented in terms of the maximum allowable water loss compatible with the maintenance of body equilibrium (Parsons, 1999).

The sweat rate is predicted is from the required sweat rate and limited values. If an adequate sweat rate can be achieved it will not cause unacceptable water loss therefore there will be no time limit due to heat exposure over an eight hour shift. If this is not the case, allowable exposure times are calculated using the following equation:

$$E_p = E_{req}/8 \text{ and } S_{Wp} < D_{max,}$$

If the conditions are not satisfied then:

$$\mathrm{DLE}_1 = 60\ Q_{MAX}/S_{Wp},$$

$$\mathrm{DLE}_2 = 60\ D_{MAX}/S_{Wp}$$

DLE (duration limited exposures) is the lower value of DLE_1 and DLE_2. If DLE is determined, the worker must rest until there is no longer a risk of heat stress. If DLE_2. is determined then no further exposure is allowed during the day (Parsons, 1999).

CHAPTER III

METHODOLOGY

Protecting the body of football players is essential for the livelihood of the individual football player. This study examined the degree of thermal and evaporative resistance from a variety of styles of different shoulder pads developed by different manufacturers. The insulation variables were taken using Walter™ a manikin that measures the insulation variables of clothing. All sets of shoulder pads were tested using the ASTM F-1291-05, Standard Test Method for Measuring the Thermal Insulation of Clothing Using a Heated Manikin, and ASTM 2370-05, Standard Test Method for Measuring the Evaporative Resistance of Clothing Using a Sweating Manikin. These tests measured the thermal insulation (R_{cl}) and evaporation resistance (R_{ecl}). This test established units of measure for the insulation provided by the different shoulder pads and uniform configurations. It was important to test both the dry thermal resistance and evaporative resistance to determine H1.

The following insulation values were determined using SI units:

R_a = thermal resistance (insulation) of the air layer on the surface of the nude manikin

R_t= total thermal resistance (insulation) of the clothing and surface air layer around the manikin.

R_{cl} = intrinsic thermal resistance (insulation) of the clothing.

R_{ea}= the evaporative resistance of the air layer on the surface of the nude manikin's sweating surface.

R_{et}= total evaporative resistance of the clothing ensemble and surface air layer.

R_{ecl}= intrinsic evaporative resistance of the clothing ensemble.

It is stated in ASTM 1291-05 and ASTM 2370-5 that the specification of values measured can be used to compare different clothing ensembles as long as each test is conducted using the same experimental procedures and test conditions. Therefore, each test was conducted using the same procedures and test conditions. The shoulder pads were the only piece of the ensemble that changed from one test to another. The results of these tests were converted to a single measurement in clo units.

After completing the insulative and evaporative tests the findings were evaluated using ISO 9733 to determine the time variables that the ensemble is safe to wear in different environments. Both the alarm (DLE_1) and danger (DLE_2) readings for this standard were calculated. Alarm readings indicate a need for extreme caution. Danger readings indicate a need to seek medical attention and immediately stop activities.

Testing Procedure

Dry thermal resistance (R_{et}) was measured using ASTM F-1291-05 Standard Test Method for Measuring the Thermal Insulation of Clothing using a Heated Manikin. For evaporative resistance (R_{ecl}), ASTM 2370-5 Standard Test Method for Measuring the Evaporative resistance of Clothing using a Sweating Manikin was used. For tests, a standing manikin, Walter™ was heated to a constant, average skin temperature of 37˚C ± 0.2˚C. The deviations form the mean skin temperature were ± .03 ˚C. The temperature uniformity of the nude manikin was evaluated before tests were conducted. This nude test determined the measure of insulation (R_a) provided by the air layer surrounding the manikin by conducting a test in the same environmental conditions uses for the clothing tests.

As the test was conducted, the mean skin temperature of the manikin was measured using point sensors placed on 15 different places on the manikin's body. The sensor placement can be seen in Appendix C and Appendix D. The manikin was located in a temperature-controlled chamber to ensure environmental consistency for all tests.

This chamber had an air temperature of 20˚C with an air velocity of 0.4± 0.1 m/s, and a relative humidity of 50% ± 5%. Knowing that the air temperature and the temperature Walter™ operates are different, we can determine that this was a non-isothermal test resembling conditions in a natural environment.

Tests were conducted on each shoulder pad apparatus and uniform configuration. The uniform configuration is composed of the layers worn by football players during competition (Nickles, 2011). Because this test is developed to measure the thermal resistance of shoulder pads worn it is necessary for the manikin to represent the competition uniform as closely as possible. Six different types of shoulder pads were used in this test. The shoulder pads selected were based on common knowledge about the most used shoulder pads in football. These shoulder pads and their manufacturers' data can be found in appendix D- appendix I.

For each test Walter™'s uniform configuration was: football pants made by Nike™ with a fiber content is 92% nylon and 8% spandex, a Nike™ pro combat shirt made of 84% polyester and 16% spandex, a football jersey made of 100 % nylon, a Schutt™ 5 pocket girdle made of 95% spandex and 5% nylon and football shoulder pads. Inside the girdle and pants, a Schutt™ 7 piece pad set that includes a pair of hip pads, a tailbone pad and two thigh pads made out of compression molded EVA, and a pair of molded knee pads made out of compression molded EVA with a 2.0mm polyethylene sheet inside. Eighteen total heated manikin tests wearing the uniform ensemble were conducted. Six shoulder pads, three tests each, on the uniform configuration base. The manikin was positioned with its arms at its side and its feet above the floor because any contact with the environment can influence heat transfer through conduction. After the manikin was dressed and the skin temperature reached a steady state, the manikin's skin temperature and air temperature were measured every 1-minute for a period of at least 180 minutes.

The results of the heated manikin tests were calculated where the area-weighted temperatures of all body segments are summed and averaged, the power levels to all body segments are summed, and the areas are summed before the total resistance is calculated.   The total insulation of the clothing system including the air layer resistance (R_t) using:

$$R_t = (T_s - T_a)\ A/H$$

Where:

R_t = total thermal resistance (insulation) of the clothing ensemble and surface air layer (°C·m^2/W),

A = area of the manikin's surface (m^2),

T_s = Temperature at the manikin's surface (°C),

T_a = temperature in the air flowing over clothing (°C),

H = power required to heat the manikin (W).

The average total insulation value (R_t) of the sample was determined, and the average values and standard deviation of the three replications were calculated. The average R_t units in SI units were converted to I_t in clo units by multiplying R_t by 6.45.

The average intrinsic value (R_{cl}) of the clothing alone was then taken by using the mean R_t value previously calculated.

$$R_{cl} = R_t - R_a/f_{cl}$$

Where:

R_{cl} = intrinsic clothing insulation (°C·m^2/W),

R_t = total thermal resistance (insulation) of the clothing ensemble and surface air layer (°C·m²/W),

R_a = thermal resistance on the air layer of the surface of the nude manikin (°C·m²/W),

f_{cl} = clothing area factor (dimensionless),

The average R_{cl} in SI units was converted to I_{cl} in clo units by multiplying R_{cl} by 6.45.

The evaporative resistance of the clothing was determined by taking the area-weighed temperatures of all the sweating body segments, summed and averaged, and the area summed before total resistance was calculated. The total evaporative resistance was calculated by:

$$R_{et} = [P_s - P_a)\ A]/[H_e - (T_s - T_a)A/R_t]$$

Where:

R_{et} = total evaporative resistance of the clothing ensemble and surface area layer (kPa·m²/W),

P_s= water vapor pressure at the manikin's sweating surface (kPa),

P_a = water vapor pressure in the air flowing over the clothing (kPa),

A = area of the manikin's surface that is sweating (m²),

H_e = power required for sweating areas (W),

T_s= temperature at the manikin surface (°C),

T_a = temperature in the air flowing over the clothing (°C),

R_t = total thermal resistance of the clothing ensemble and surface air layer (°C·m²/W).

The average total evaporative resistance (R_{es}) of the sample was taken by averaging the values from the three replications of the test. Once this was completed, The average intrinsic evaporative resistance of the ensemble alone was determined (R_{ect}) using the mean (R_{et}) value:

$$R_{ect} = R_{et} - R_{ea}/f_{cl}$$

Where:

R_{ecl} = intrinsic evaporative resistance of the clothing ensemble (kPa·m^2/W),

R_{et} = total evaporative resistance of the clothing ensemble and surface area layer (kPa·m^2/W),

R_{ea} = evaporative resistance of the air layer on the surface of the nude manikin's sweating surface (kPa·m^2/W),

f_{cl} = clothing area factor.

The power measurement was used to calculate these results.

It is important to note, that the thermal insulation (R_t) should be as small as possible for summer clothing to keep cool. The thermal insulation (R_t) should be as high for winter clothing to keep worm. The water vapor resistance (R_{et}) of clothing should be as low as possible for any type of clothing to make the clothing permeable.

Upon completion of all testing, an ANOVA analysis with a significance of .05 was planned to be conducted to determine if there is a significant difference in the R_t and R_{et} for the different shoulder pads. This would have drawn concussions to Ho1 because it determines if there was significant difference between any of the shoulder pads.

After testing on the thermal manikin was completed, results were analyzed using ISO 7933, Ergonomics of the thermal environment - Analytical Determination and Interpretation of Heat Stress using Calculation of the Predicted Heat Strain. This standard determines thermal stress using calculations of sweat rates. ISO 7933 specifies a method that analytically evaluates and interprets the thermal stress experiences by a subject in specific environmental conditions. The model predicts the influence of different physical parameters of the environment on the thermal stress experienced by the subject. In this way, it is possible to determine which parameter or group of parameters should be modified, and to what extent, in order to reduce the risk of physiological strains.

ISO 7933 has two objectives: 1. Evaluate the thermal stress in conditions likely to lead to excessive core temperature increase or water loss for the standard subject, and 2. To determine the exposure time with the physiological strain is acceptable (no physical damage is to be expected). In the context of this prediction mode, these prediction times are called "maximum allowable exposure times." ISO 7933 does not predict the physiological response of individual subjects, but only considers standard subjects in good health and fit for the work they perform. It is intended to evaluate working conditions.

The results of the ISO 7933 test were calculated using four different temperature and humidity readings. Because Hitchcock (2007) determined heat stress could occur at 26°C with 52% relative humidity, these variables were tested. Tests were also run with 30°C with 50% humidity, 34°C with 50% relative humidity, and 22°C with 50% relative humidity. Each test we had a relative air velocity of 0.5 m/s, body area coverage was estimated at 68.8%, a duration of time set at 210 minutes, and a W/h2 of 474. The duration of time tested was 210 minutes because a football game is roughly estimated at 3 hours with a 30-minute warm-up period. Meaning, an individual will wear the football uniform configuration for 3.5 hours or 210 minutes, of exercise activities. We determined that W/h2 should be set at 474 by calculating data from the American Journal of Medical Association (2002) that estimates a competitive football player to burn 730 calories an hour. By determining that 1 calorie = .001162 watts per hour for nutritional calories it was determined that the result must be multiplied by 1000 to determine the watts per hour (W/h) for energy. It was calculated that 730 calories would result in 848 watts per hour (W/h). The watts per hour were then converted into watts per square meter by dividing it by the surface of the manikin (m^2) resulting in 474 W/m2.

For each pair of shoulder pads, it was determined if they were safe for athletes to wear for the duration of a football game for athletes acclimated and not acclimated to the heat. These results were configured in a table showing the alarm and danger time readouts for the different conditions. These readings were analyzed to determine if the shoulder pads were safe to wear resulting in a conclusion to Ho2.

The temperature variable was estimated where a football player can wear the football uniform without sustaining any heat injury during a full game time (approximately 3.5hours). In our search for the optimum ambient temperature begin by testing the insulation variables for the clothing with the ISO 7933 Prediction of Thermal Comfort in Hot Temperatures. Because conclusions within the given range of temperatures for the ISO 7933 standard could not be drawn testing temperatures using the ISO 11079, Prediction of Thermal Comfort in Cold Temperature were continued.

Limitations

The study was limited because only six different types of shoulder pads were tested. Although there many more shoulder pads available on the market, these were thought to be the most readily used throughout the industry. It is possible for other shoulder pads available to consumers to have different thermal insulation and evaporative resistance. The environments tested in the ISO 7933 standard also limit this study. Other environments will result in different time readings. These environments were tested based on previous studies and environmental conditions. Throughout all calculations, it was assumed the energy use was spread uniformly through time. In a usual football game, players spend some minutes on the bench and some units playing. It was assumed the energy used was spread out uniformly through time where in actuality periods of rest may alter the energy consumption.

CHAPTER IV

RESULTS

This study examined the thermal insulation and evaporative resistance of football shoulder pads developed by different manufacturers. The thermal resistance (R_{et}) was determined using ASTM F-1291-05 Standard Test Method for Measuring the Thermal Insulation of Clothing using a Heated Manikin. For evaporative resistance (R_{ecl}), ASTM 2370-5 Standard Test Method for Measuring the Evaporative resistance of Clothing using a Sweating Manikin was used. For tests, a standing manikin, Walter™ was heated to a constant, average skin temperature of 37˚C ± 0.2˚C with deviations form the mean skin temperature of ± .03 ˚C. Walter™ was located in a controlled chamber with an air temperature of 20˚C, an air velocity of 0.4± 0.1 m/s, and a relative humidity of 50% ± 5%.

When testing the thermal insulation (R_{cl}) and evaporative resistance (R_{ecl}) fifteen sensors were placed on Walter™'s body. The exact sensor placement can be seen in Appendix A and Appendix B. A nude test was conducted to determine the measure of insulation (R_a) provided by the air layer surrounding the manikin by conducting a test in the same environmental conditions uses for the clothing tests.

Three tests were conducted on six different sets of shoulder pads. During each test Walter™ wore a compression shirt, shoulder pads, jersey, compression shorts, football pants, and pant pads. The shoulder pads were the only variable changed between tests.

The results of the heated manikin tests were calculated where the area-weighted temperatures of all body segments that were summed and averaged, the power levels to all body segments were summed, and the areas were summed before the total resistance is calculated. The total insulation of the clothing system including the air layer resistance (R_t) was calculated using: $R_t = (T_s – T_a) A/H$. The average (R_t) of the sample was determined, and the average values and standard deviation of the three replications were calculated. The average R_t units in SI units were converted to I_t in clo units by multiplying R_t by 6.45. The average intrinsic value (R_{cl}) of the clothing alone was then taken by using the mean R_t value previously calculated and $R_{cl} = R_t – R_a/f_{cl}$.

For the duration of all tests, the nude value of the manikin was placed at .103. In testing the first shoulder pads, Schutt™ Lineman, the average R_t resulted in 0.164333333 mean, with a 0.180111 standard deviation. The Clo variable was calculated at 1.060215. The mean R_{cl} for these shoulder pads was 0.074512787 with a standard deviation of 0.005124. The Clo variable for the R_{cl} was calculated at 0.480728. The second shoulder pad tested, Douglas® Lineman, resulted in an mean R_t of 0.180111 with a standard deviation of 0.012335. The clo value was calculated at 1.162006. The R_{cl} testing for these shoulder pads resulted in a mean reading of 0.093031327 with a standard deviation of 0.014393. The clo reading of the R_{cl} for the Douglas® Lineman shoulder pads was 0.600202. The third shoulder pad tested, Douglas® quarterback, resulted in a mean R_t of 0.172778 with a standard deviation of 0.000962. The clo variable was calculated to be 1.114695. The R_{cl} for the Douglas® quarterback shoulder pads had a mean reading of 0.084472 with a standard deviation of 0.001131. The clo variable was calculated at 0.544983. For the fourth test Riddell™ shoulder pads were tested. The mean R_t for these tests was 0.162666 with a standard deviation of 0.007024. The clo variable was calculated at 1.049460. The average R_{cl} for these shoulder pads was 0.072531 with a standard deviation of 0.008319. The clo variable was calculated at 0.467944. The fifth shoulder pads tested by Tag® had a mean R_t of 0.168333 with a standard deviation of 0.002729. The clo variable was calculated at 1.086022. For the Tag® shoulder pads the average R_{cl} was 0.079239 with a standard deviation of 0.003218. The clo variable was calculated at 0.511219. For the sixth pair of shoulder pads, Schutt™ Skill, the mean R_t was 0.182333 with a standard deviation of 0.000882. The clo variable was calculated at 1.176344. The mean R_{cl} was 0.095667 with a standard deviation of 0.001030. The clo variable was calculated at 0.617204. Table 3 shows these findings.

The evaporative resistance of the clothing was then determined by taking the area-weighed temperatures of all the sweating body segments, summed and averaged, and the area summed before total resistance was calculated. The total evaporative resistance was calculated by: $R_{et} = [P_s – P_a) A]/[H_e – (T_s – T_a) A/R_t]$. The average total evaporative resistance (R_{es}) of the sample was calculated by averaging the values from the three replications of the test. Once this was completed, The average intrinsic evaporative resistance of the ensemble alone (R_{ect}) was determined using them mean (R_{et}) value: $R_{ect} = R_{et} – R_{ea}/f_{cl}$.

For the duration of this test, the nude value of the manikin was placed at .103. In testing the first shoulder pads, Schutt™ Lineman, the average R_{et} was 25.06967, with a 1.823252 standard deviation. The average R_{ecl} for these shoulder pads was 14.22670356 with a standard deviation of 1.590596. The second shoulder pad tested, Douglas® Lineman, resulted in an average R_{et} of 26.24622333 with a standard deviation of 0.343469. The R_{ecl} for these shoulder pads resulted in a mean of 15.25064255 with a standard deviation of 0.323921. The third shoulder pad tested, Douglas® quarterback, resulted in a mean R_{et} of 25.437223 with a standard deviation of 14.213807. The R_{ecl} for the Douglas® quarterback shoulder pads had a mean reading of 14.213807 with a standard deviation of 1.341094. For the fourth test Riddell™ shoulder pads were tested. The mean R_{et} for these tests was 24.597333 with a standard deviation of 1.158314. The average R_{ecl} for these shoulder pads was 13.503501with a standard deviation of

Table 3

Average R_t, R_{el} and clo values for all tested Shoulder Pads after three replications.

	Schutt Linemen			Douglas Linemen			Douglas Quarterback			Riddell			Tag			Schutt Skill		
	Mean	STD	clo	Mean	STD	clo	Mean	STD	clo	Mean	STD	clo	Mean	STD	clo	Mean	STD	clo
R_t	0.164333333	0.180111	1.060215	0.180111	0.012335	1.162006	0.172778	0.000962	1.114695	0.162666	0.007024	1.049460	0.168333	0.002729	1.086022	0.182333	0.000882	1.176344
R_{el}	0.074512787	0.005124	0.480728	0.093031327	0.014393	0.600202	0.084472	0.001131	0.544983	0.072531	0.008319	0.467944	0.079239	0.003218	0.511219	0.095667	0.001030	0.617204

For all testings the nude value was .103

Table 4

Average R_{et} and R_{ecl} for all tested Shoulder Pads after three repetitic

	Schutt Linemen		Douglas Linemen		Douglas Quarterback		Riddell		Tag		Schutt Skill	
	Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD
R_{et}	25.06967	1.823252	26.246223	0.343469	25.437223	14.213807	24.597333	1.158314	23.699110	0.484023	23.699110	12.907565
R_{ecl}	14.226704	1.590596	15.250643	0.323921	14.213807	1.341094	13.503501	1.175116	12.907565	0.480800	12.907565	0.480800

For all testings the nude value was .103

Table 5

R_t Paired Sample T-Test Results

	Schutt Lineman	Douglss Lineman	Douglas QB	Riddell	Tag	Schutt Skill
Schutt Lineman						
Douglas Linaman	0.386					
Doublas QB	1	0.632				
Riddell	0.719	0.351	0.281			
Tag	0.531	0.163	0.469	0.188		
Schutt Skill	0.212	0.58	0.788	0.932	0.743	

Table 6

R_{et} Paired Sample T-Test Results

	Schutt Lineman	Douglas Lineman	Douglas QB	Riddell	Tag	Schutt Skill
Schutt Lineman						
Douglas Linaman	0.411					
Doublas QB	0.706	0.329				
Riddell	0.655	0.224	0.085			
Tag	0.66	0.929	0.6	0.685		
Schutt Skill	0.884	0.473	0.143	0.228	0.456	

1.175116. Tag®, the fifth shoulder pads tested had a mean R_{et} of 23.699110 with a standard deviation of 0.484023. For the Tag® shoulder pads the average R_{ecl} was 12.907565 with a standard deviation of 0.480800. For the sixth pair of shoulder pads, Schutt™ Skill, the mean R_{et} was 23.699110 with a standard deviation of 12.907565. The mean R_{ecl} was 12.907565 with a standard deviation of 0.480800. Table 4 shows these findings. Results for all tests completed can be found in Appendix J.

Upon completion of these tests it was determined that the results did not have enough power to complete an ANOVA analysis. Therefore a paired sampled t-test was performed to determine if significant differences in treatment levels for dry thermal resistance (R_t) and evaporative resistance (R_{et}) existed. The Alpha level was set at .05. These results can be seen in Table 5 and Table 6.

The results determined there was no significant difference found between the different configurations for dry thermal resistance. There was also no significant difference between any of the different configurations for evaporative resistance. Therefore, the results have failed to reject the null hypothesis, Ho1, stating: there would be no significant difference for insulation variables between the shoulder pads made by different manufactures.

Walter™'s findings were then input into the ISO 7933 Standard and calculated using four different temperature and humidity readings. Because Hitchcock (2007) determined heat stress could occur at 26°C with 52% relative humidity, we tested these variables. Additional tests were run with 30°C with 50% humidity, 34°C with 50% relative humidity, and 22°C with 50% relative humidity. Each test had a relative air velocity of 0.5 m/s, body area coverage was

Table 7

ISO 7933 Results for persons not acclimated to the heat

		Schutt Lineman	Douglas Lineman	Douglas Quarterback	Riddell	Tag	Schutt Skill
22°C with 50% relative humidity	Alarm	9.6	9.2	9.4	9.7	9.5	9.2
	Danger	11.5	11.1	11.3	11.6	11.4	11
26°C with 52% relative humidity	Alarm	9	8.7	8.8	9	8.9	8.6
	Danger	10.7	10.4	10.5	10.8	10.6	10.4
30°C with 50% relative humidity	Alarm	8.4	8.2	8.3	8.4	8.3	8.1
	Danger	10.1	9.8	9.9	10.1	10	9.8
34°C with 50% relative humidity	Alarm	7.8	7.7	7.8	7.9	7.8	7.7
	Danger	9.4	9.2	9.3	9.4	9.4	9.2

All data is collected in minutes

Table 8								
ISO 7933 Results for persons acclimated to the heat								
		Schutt Lineman	Douglas Lineman	Douglas Quarterback	Riddell	Tag	Schutt Skill
22°C with 50% relative humidity	Alarm	9.6	9.2	9.4	9.7	9.5	9.2
	Danger	11.5	11.1	11.3	11.6	11.4	11
26°C with 52% relative humidity	Alarm	9	8.7	8.8	9	8.9	8.6
	Danger	10.7	10.4	10.5	10.8	10.6	10.4
30°C with 50% relative humidity	Alarm	8.4	8.2	8.3	8.4	8.3	8.1
	Danger	10.1	9.8	9.9	10.1	10	9.8
34°C with 50% relative humidity	Alarm	7.8	7.7	7.8	7.9	7.8	7.7
	Danger	9.4	9.2	9.3	9.4	9.4	9.2
All data is collected in minutes							

estimated at 68.8%, a duration of time set at 210 minutes, and a W/h2 of 474.

The test results showed that none of the uniform ensembles tested were safe to wear for 210 minutes in the given temperature and humidity settings. Table 7 shows the duration of time each uniform ensemble should be worn in each temperature setting for individuals not acclimated to the heat. The alarm time and the danger time are shown. Table 8 shows the duration of time each uniform ensemble be worn in each temperature setting for individuals acclimated to the heat. The alarm time and the danger times are shown. These results show that there is not a difference in the alarm or danger times for individuals not acclimated to the heat and individuals acclimated to the heat. The results also show that no shoulder pads tested are safe for the duration of 210 minutes. For all uniform configurations tested the safe amount of time worn is less than 7.7 minutes. In conclusion the tests have failed to reject Ho2 stating: there will be no shoulder pads tested that are safe for individuals to wear in the tested temperatures.

Due to the excessive insulation and evaporative resistance, researchers were unable to determine the ambient air temperature that is safe for the uniform configuration to be worn for duration of 3.5 hours such as a full football game. However even when the ambient temperature was lowered close to freezing (0 ^{o}C), the safe time period that a football player has before signs of heat exhaustion are present was less than 20 min. Therefore, according to the ISO 11079 we determined that in temperatures below freezing the uniform configuration is still too insulative to be worn for an entire game. The same standard suggests the clothing ensemble worn when exercising at 474 w/h2 at 0 ^{o}C should have a dry thermal insulation of .02 m^2 C/W. Finally, according to ISO 11079 at ambient temperature 17 ^{o}C and 50% relative humidity a football player during game time can wear the tested uniform configurations without risking any heat related injury for approximately 5 hours (it is recommended that the minimum intrinsic insulation be .06 when recommended insulation is .08).

CHAPTER V

DISCUSSION & CONCLUSION

Discussion

This study determined that there was no significant difference found between the six styles of shoulder pads tested for thermal resistance. There was also no significant difference between the shoulder pads in relation to evaporative resistance. Therefore, the null hypothesis, Ho1, stating that there would be no significant difference for insulation variables between the shoulder pads made by different manufactures was supported.

The results also show that no shoulder pads tested are safe for an individual to wear for the duration of a football game, or 210 minutes. For all uniform configurations tested the safe amount of time worn was less than 7.7 minutes. In conclusion it has been determined that Ho2 stating: There will be no shoulder pads tested that are safe for individuals to wear in the tested temperatures was also supported.

Conclusion

There was no significant difference found in the insulation resistance of shoulder pads tested. Six different sets of shoulder pads were tested for their insulation and evaporative resistance. Conclusions were drawn from the results of the insulation and evaporative resistance tests to determine that there was no significant difference between the thermal and evaporative qualities of the different sets of shoulder pads. In examining the results, it can be seen that these tests are reliable based on the small standard deviations for each set of shoulder pad. This is important for future research to know these tests have very little variation.

The second hypothesis, there will be no shoulder pads tested that are safe for individuals to wear in the tested temperatures, was accepted. The results revealed that none of the football uniform ensembles are safe to wear for the duration of a football game at the temperature variables tested. It is important to note that these tests were conducted to determine conditions where there is no risk of heat illness. It is possible for an athlete to be able to compete while wearing the current football uniform ensembles in a variety of conditions and walk away with no immediate damage, but as stated in the literature review heat illnesses can cause damage with and without immediate side effects. This study validated Hitchcock's (2007) research that determined heat stress could occur at 26°C with 52% relative humidity. However, Hitchcock's findings did not encompass all temperature ranges that are unsafe. Although heat stress could occur at 26°C with 52% relative humidity, this study determined that heat stress could also occur at 0 degrees centigrade for athletes wearing the football uniform ensemble.

It is evident from these results that the equipment worn during football practices and games significantly contributes to many of the heat illnesses incurred by athletes playing football. Heat illnesses are the largest cause of injuries in the game. Because the research has confirmed that the uniform ensemble currently worn is not safe for the duration of a game in any of the temperature variables tested, new designs for football uniform ensembles with appropriate thermal and evaporative qualities need to be developed.

This research is relevant to the survival of individuals playing the game of football. It is important for them to know their equipment is safe from the inside out, not just the outside in. It is also important that coaches and athletic personnel related to the game be aware of the safety hazards related to the football uniform ensemble.

Limitations

The study is limited by focusing only on the thermal and evaporative resistance of six shoulder pads. The fact that only one thermal manikin was used to gather data in one environmental setting with no air movement is another limitation. The sport of football is an intense physical activity, however this study tested football uniform configurations on a thermal manikin that was held in a static state. This study was also limited to the environments tested in the ISO 7933 standard. Throughout all calculations, it was assumed that the energy use is spread uniformly through time, however in a usual football game, players spend some minutes on the bench and some units playing.

Recommendations for Further Research

Although this research does not encompass every pair of shoulder pads on the market, it is a beginning of the research that needs to be conducted regarding football shoulder pads, uniforms, and equipment. Tests on a heated manikin have not previously been done because the Institute of Protective Apparel Technology at Oklahoma State University is the only place in the United States that has a Walter™ manikin that tests the thermal and evaporative resistance. While these tests show no significant difference among the six shoulder pads tested for greater validity it is recommended that a greater quantity of tests be conducted using a wider span of football shoulder pad types on Walter™.

It is also recommended that material tests be conducted on the materials used on the exoskeleton and inner padding of the shoulder pads to evaluate the air and moisture permeability rate. It would be ideal for shoulder pads to be tested on human subjects, but due to the dangerously high thermal ratings found it can be concluded that human subject tests are not safe. It is recommended that the thermal qualities of the uniform configuration be evaluated independent from the shoulder pads to help specifically determine which factors involved in the uniform can be most easily improved to reduce the risk of heat illnesses.

It is highly recommended that a standard be put into place that regulates the thermal readings allowable in the insulation variables worn for the duration of a football game for football uniform ensembles. A maximum insulation reading should be implemented. Such a standard would help regulate the heat illnesses and protect the players from the hazards of the heat of their own equipment.

This study has determined that the insulation and evaporative resistance of football uniform ensembles is not safe to be worn for the duration of a football game in any of the tested temperatures. It has also been determined that there is no significant difference in the thermal and evaporative resistance in the six shoulder pads tested. This is important because football is regularly played in hot environments. It was previously known that heat illnesses are the most readily incurred injury by football players. From this study it was determined that the ensemble worn during football have levels that are too insulative to be worn in these hot temperatures. This can lead to heat illnesses. For the safety of all football players improvement needs to be made.

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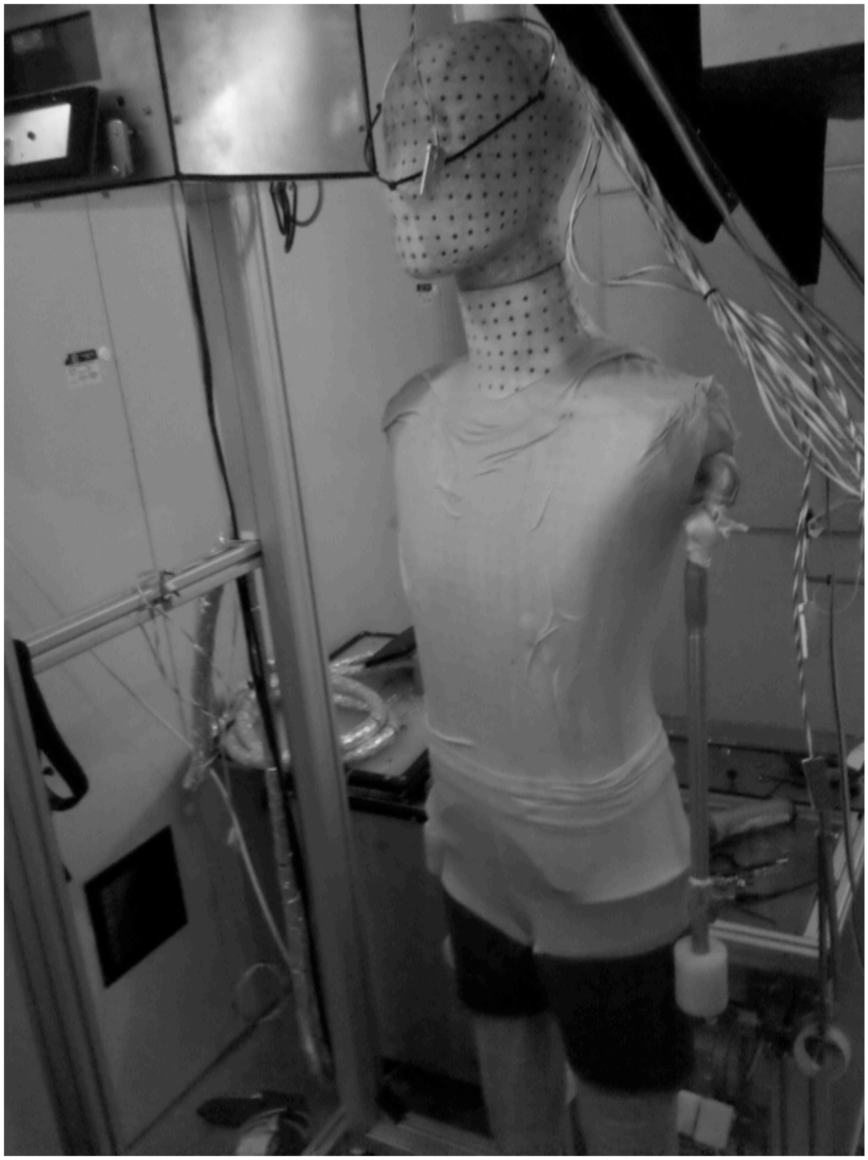
APPPENDICES

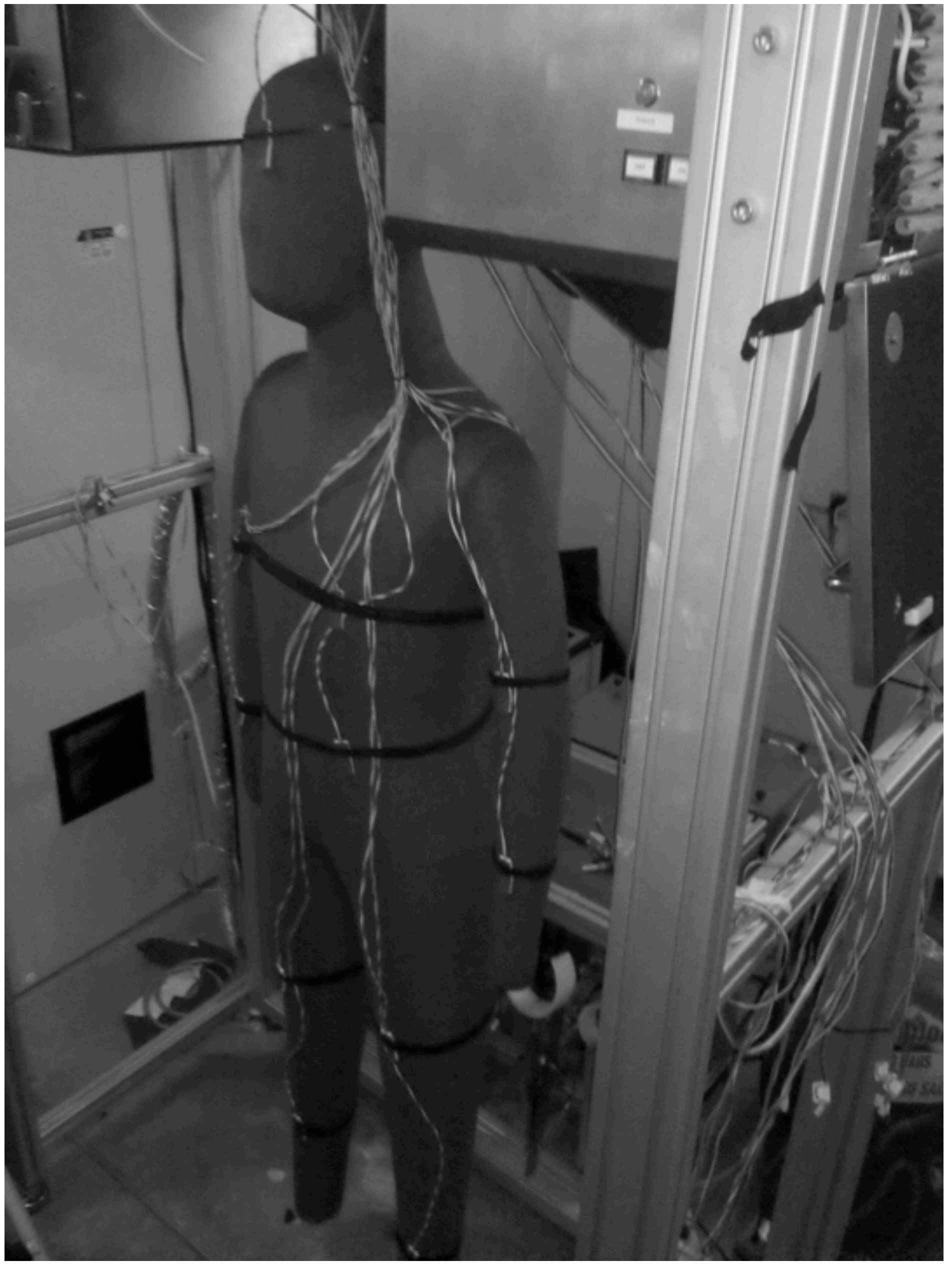
APPENDIX A

Walter, the heated Manikin, without skin.



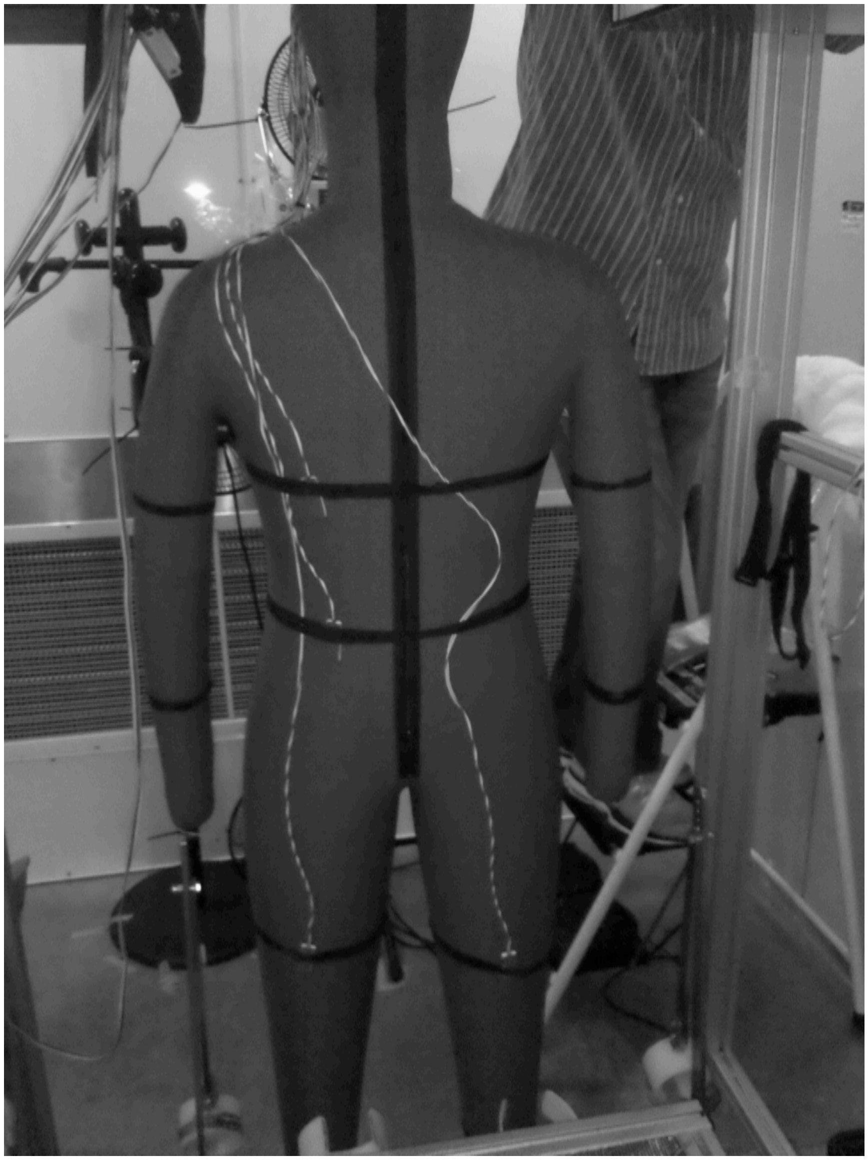
APPENDIX B

Walter’s Skin Temperature Placement (body front)



APPENDIX C

Walter's Skin Temperature Placement (Body back)



APPENDIX D

Douglas Lineman Shoulder Pads

Model: Douglas CP MR DZ Shoulder Pad - Men's

APPENDIX E

Riddell Shoulder Pads

Model: PM78 Power Series

APPENDIX F

Schutt Shoulder Pad

Model: Schutt Lightning Football Shoulder Pad

APPENDIX G

Douglas Quarterback Shoulder Pad

Model: CP 25 Series with a removable back plate

APPENDIX H

Tag Shoulder Pads

Model: TAG ALT710

APPENDIX I

Schutt Skill

Model: 800257 Schutt Varsity Flex Shoulder Pad

APPENDIX J

Rcl

		Rt	Std	Ra	Fcl*2	Fcl	Rcl
Shutt Lineman	Test 1	0.16	0.002646	0.103	2.273381	1.136691	0.069386
	Test 2	0.164333	0.005033	0.103	2.2936	1.1468	0.074518
	Test 3	0.168667	0.003215	0.103	2.31376	1.15688	0.079634
	Average	0.164333		0.103	2.29358	1.14679	0.074513
	Std for the	0.004334					0.005124
	Clo Unit for	1.060215					0.480728
Douglas Lineman		Rt	Std	Ra	Fcl*2	Fcl	Rcl
	Test 1	0.194333	0.006506	0.103	2.431929	1.215964	0.109627
	Test 2	0.172333	0.005132	0.103	2.330763	1.165381	0.08395
	Test 3	0.173667	0.005859	0.103	2.336939	1.168469	0.085517
	Average	0.180111		0.103	2.366543	1.183272	0.093031
	Std for the	0.012335					0.014393
	Clo Unit for	1.162006					0.600202
Douglas Quarterback		Rt	Std	Ra	Fcl*2	Fcl	Rcl
	Test 1	0.173333	0.002517	0.103	2.335393	1.167697	0.085125
	Test 2	0.171667	0.007024	0.103	2.327677	1.163838	0.083167
	Test 3	0.173333	0.001528	0.103	2.335393	1.167697	0.085125
	Average	0.172778		0.103	2.332821	1.166411	0.084472
	Std for the	0.000962					0.001131
	Clo Unit for	1.114695					0.544983
Ridell		Rt	Std	Ra	Fcl*2	Fcl	Rcl
	Test 1	0.169333	0.001155	0.103	2.316852	1.158426	0.080419
	Test 2	0.155333	0.003055	0.103	2.251528	1.125764	0.06384
	Test 3	0.163333	0.003055	0.103	2.28894	1.14447	0.073335
	Average	0.162666		0.103	2.285773	1.142887	0.072531
	Std for the	0.007024					0.008319
	Clo Unit for	1.04946					0.467944
Tag		Rt	Std	Ra	Fcl*2	Fcl	Rcl
	Test 1	0.165333	0.002517	0.103	2.298258	1.149129	0.0757
	Test 2	0.170667	0.004509	0.103	2.323041	1.161521	0.08199
	Test 3	0.169	0.003464	0.103	2.315306	1.157653	0.080027
	Average	0.168333		0.103	2.312202	1.156101	0.079239
	Std for the	0.002729					0.003218
	Clo Unit for	1.086022					0.511219
Shutt Skill		Rt	Std	Ra	Fcl*2	Fcl	Rcl
	Test 1	0.183	0.002	0.103	2.379994	1.189997	0.096445
	Test 2	0.182667	0.005508	0.103	2.378462	1.189231	0.096056
	Test 3	0.181333	0.008021	0.103	2.372323	1.186162	0.094498
	Average	0.182333		0.103	2.376926	1.188463	0.095667
	Std for the	0.000882					0.00103
	Clo Unit for	1.176344					0.617204

Recl

		Ret	Std	Rea	Fcl	Recl
Shutt Lineman	Test 1	24.061	0.228362	12.82533	1.136691	12.77796
	Test 2	22.93833	0.116899	12.82533	1.1468	11.75475
	Test 3	21.97133	0.209801	12.82533	1.15688	10.88519
	Average	22.99022		12.82533	1.14679	11.80597
	Std for the /	1.045801			0.010095	0.947421

		Ret	Std	Rea	Fcl	Recl
Douglas Lineman	Test 1	23.18267	0.270304	12.82533	1.215964	12.63521
	Test 2	26.82167	0.276778	12.82533	1.165381	15.81641
	Test 3	25.20467	0.193673	12.82533	1.168469	14.22849
	Average	25.06967		12.82533	1.183272	14.2267
	Std for the /	1.823252			0.028355	1.590596

		Ret	Std	Rea	Fcl	Recl
Douglas Quarterback	Test 1	25.93833	0.559515	12.82533	1.167697	14.95489
	Test 2	26.61667	1.0247	12.82533	1.163838	15.59682
	Test 3	26.18367	0.220128	12.82533	1.167697	15.20023
	Average	26.24622		12.82533	1.166411	15.25064
	Std for the /	0.343469			0.002227	0.323921

		Ret	Std	Rea	Fcl	Recl
Ridell	Test 1	23.95767	0.10992	12.82533	1.158426	12.88633
	Test 2	26.96067	0.319777	12.82533	1.125764	15.56811
	Test 3	25.39333	0.101791	12.82533	1.14447	14.18698
	Average	25.43722		12.82533	1.142887	14.21381
	Std for the /	1.501981			0.016388	1.341094

		Ret	Std	Rea	Fcl	Recl
Tag	Test 1	24.66867	0.272177	12.82533	1.149129	13.50775
	Test 2	25.71833	0.37702	12.82533	1.161521	14.67649
	Test 3	23.405	0.445128	12.82533	1.157653	12.32627
	Average	24.59733		12.82533	1.156101	13.5035
	Std for the /	1.158314			0.00634	1.175116

		Ret	Std	Rea	Fcl	Recl
Shutt Skill	Test 1	24.04333	0.014364	12.82533	1.189997	13.26571
	Test 2	23.14567	0.168586	12.82533	1.189231	12.36111
	Test 3	23.90833	0.104002	12.82533	1.186162	13.09587
	Average	23.69911		12.82533	1.188463	12.90756
	Std for the /	0.484023			0.00203	0.4808

VITA

Julie Diane Rader

Candidate for the Degree of

Master of Science

Thesis: A STANDARD MEASUREMENT OF INSULATIVE PROPERTIES OF FOOTBALL SHOULDER PADS

Major Field: Design Housing and Merchandising

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Education:

Completed the requirements for the Master of Science/Arts in your major at Oklahoma State University, Stillwater, Oklahoma in December 2011.

Completed the requirements for the Bachelor of Science in Design Housing and Merchandising at Oklahoma State University, Stillwater, OK in 2009.

Name: Julie D. Rader *Date of Degree: December, 2011*

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: A STANDARD MEASUREMENT OF INSULATIVE PROPERTIES OF FOOTBALL SHOULDER PADS

Pages in Study: 70 Candidate for the Degree of Master of Science

Major Field: Apparel Design and Production

Scope and Method of Study: The purpose of this study was to assess and compare six different football shoulder pads regarding heat and moisture transfer performance. The measurements for thermal and evaporative resistance were taken using a sweating thermal manikin. All measurements were analyzed for differences in insulative values to determine which shoulder pads were the safest for athletes to wear in hot environments.

Findings and Conclusions: This study determined that there was no significant difference found between the six styles of shoulder pads tested for thermal resistance. There was also no significant difference between the shoulder pads in relation to evaporative resistance. Therefore it was determined that there was no significant difference for insulation variables between the shoulder pads made by different manufactures.

The results also show that no shoulder pads tested are safe for an individual to wear for the duration of a football game, or 210 minutes. For all uniform configurations tested the safe amount of time worn was less than 7.7 minutes. In conclusion it has been determined that there were no shoulder pads tested that are safe for individuals to wear in the tested temperatures.

It is evident from these results that the equipment worn during football practices and games significantly contributes to many of the heat illnesses incurred by athletes playing football. Heat illnesses are the largest cause of injuries in the game. Because the research has confirmed that the uniform ensemble currently worn is not safe for the duration of a game in any of the temperature variables tested, new designs for football uniform ensembles with appropriate thermal and evaporative qualities need to be developed.

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