

CLOTHING FABRIC EFFECTS ON PHYSIOLOGICAL
AND COMFORT
RESPONSES

by

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ABSTRACT

During exercise and in hot environments, the main cooling mechanism is through sweat evaporation. However, clothing can disrupt evaporation, which leads to decreased performance and in some cases can lead to heat illness. New fabrics and designs have been introduced with the purpose of improving thermoregulatory properties. One of those innovations is a channeled synthetic fabric. The first of three studies evaluated the effects of a channeled synthetic and synthetic t-shirts under a ballistic vest on physiological and comfort responses during exercise in a hot environment. Eight participants, in counterbalanced order, completed two simulated “industrial” protocols for three hours. The overall (0 – 180 min) change in rectal temperature was significantly ($p = 0.04$) lower with channeled synthetic shirt compared to a synthetic shirt. Additionally, overall change in thermal comfort ($p = 0.05$), sweating sensation ($p = 0.06$), and heart rate ($p = 0.07$) were, or tended to be more favorable throughout exercise with channeled synthetic compared to synthetic shirt. We also examined the effects of channeled synthetic shirt and synthetic cycling shirt effects on thermoregulation, thermal comfort, and heart rate. Eight participants attempted a 30-km cycling time trial. Results indicated significantly ($p = 0.04$, $n = 8$) smaller increase in rectal temperature from baseline to 15th km (first dropout) with the channeled synthetic shirt compared to cycling shirt. Also, the change in thermal comfort was significantly ($n = 5$, $p = 0.03$) lower with channeled shirt compared to cycling shirt from baseline to 30th km. A third study examined channeled compression shorts, compression shorts, and cycling shorts effects on thermoregulation, heart rate, and thermal comfort response during 30-km cycling trial in hot a environment. Eight participants completed a 25-km cycling trial. Results revealed no

significant main effect for rectal or skin temperatures, heart rate, and thermal comfort between the three different types of shorts ($n = 8$, $p > 0.05$). In conclusion, wearing a channeled synthetic shirt provided better thermoregulatory or thermal comfort responses compared to synthetic shirt in two studies. Channeled compression shorts did not improve thermoregulatory or thermal comfort responses compared to cycling and compression shorts.

DEDICATION

I dedicate this dissertation to my parents and grandparents who have been a great example as parents to me. Also, I dedicate this dissertation to my wife Svetlana Nepocatych who supported me through this process. Finally, I want to dedicate this dissertation to Dr. Bishop for believing in me and being such an inspiration for my life.

LIST OF ABBREVIATIONS AND SYMBOLS

ANOVA	analysis of variance
T _{re}	rectal temperature
y	year
min	minute
CHS	channeled synthetic t-shirt
SYN	synthetic t-shirt
RCS	regular cycling t-shirt
CCS	channeled compression shorts
COM	regular compression shorts
CYC	regular cycling shorts
HR	heart rate
PAR-Q	Physical Activity Readiness Questionnaire
RPE	rating of perceived exertion
<i>SD</i>	standard deviation
SPSS	Statistical Package for the Social Sciences
RTC	rating of thermal comfort
VO _{2peak}	peak oxygen uptake
*	significant difference ($p < 0.05$)
=	equal to

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CHAPTER I

INTRODUCTION

Daily task performance or exercise in hot environments increases body temperature which might lead to decreased mental and physical performance. Therefore, the human body can sustain a very small, 3 – 4 °C (Hadid et al., 2008), upward fluctuation in body temperature and further increase in temperature raises the risk for heat illnesses (Armstrong et al., 2007). Thus, athletes, police and military personnel are exposed to those harsh environments and there is a need to find interventions to reduce risk for heat illnesses and to increase the safety of people who performs in hot environments.

Heat generated during daily task performance or exercise can be dissipated through convection, radiation, conduction, and evaporation. Therefore, the main cooling mechanism in hot environments is through evaporation of sweat from the skin surface. However, clothing adds addition insulation and can disrupt sweat evaporation from the skin (Gavin, 2003; Xio-Qun Dai et al., 2008) which leads to increased body temperature. Many strategies were introduced to reduce body heat storage. For ballistic vest wearer's strategies such as air movement devices, liquid cooled tubes incorporated into garment, and clothing that increase evaporative properties were introduced. In athletic field strategies such as pre-cooling before exercise and clothing are used. However, most of the strategies require additional equipment, except clothing, which might be expensive and not available in some situations. Thus, many fabrics have been introduced to improve thermoregulatory properties.

The latest manufactures innovation is clothing with integrated channels into synthetic fabric. These channels are proposed to move the moisture away from the body and increase evaporation qualities. If inner and outer channels work, it might offer additional cooling properties which might lead to lower body heat storage and improved performance. This would be beneficial for ballistic vest wearer's and athletes performing their tasks in hot environments.

The first aim of these studies was to examine channeled synthetic fabric effects on physiological responses. Rectal and skin temperatures (chest, forearm, quad), and heart rate were continuously measured. It was hypothesized that rectal temperature and heart rate would be lower with channeled synthetic fabric compared to non-channeled synthetic fabric.

The second aim of these studies was to examine channeled synthetic fabric effects on comfort responses. Clothing comfort sensation, rating of thermal comfort, skin wettedness sensation, and sweating sensation were continuously measured. It was hypothesized that comfort responses would be lower (more comfortable) while wearing channeled synthetic fabric compared to non-channeled synthetic fabric.

Finally, the last aim of these studies was to examine channeled synthetic fabric effects on performance. 30km cycling time trial was used to evaluate performance. It was hypothesized that 30km performance time would be faster (better) with channeled synthetic fabric compared to non-channeled synthetic fabric.

CHAPTER II

EFFECT OF A CHANNELED FABRIC GARMENT UNDER A BALLISTIC VEST ON PHYSIOLOGICAL AND COMFORT RESPONSES DURING EXERCISE

ABSTRACT

Ballistic vests (BV) provide upper-body protection for soldiers, police officers, private security forces, and others. However, BV are constructed with soft padding that acts as an insulator, increasing heat storage and mitigating convection and moisture resistance which reduce evaporation. The current study examined the effects of wearing a synthetic t-shirt (SYN) and a channeled synthetic t-shirt (CHS) under a BV on thermoregulatory, heart rate, and comfort responses. Participants completed two simulated “industrial” protocols that included moderate paced walking and bicep curls for three hours in a hot environment (35.2 ± 0.3 °C with relative humidity of 40.7 ± 1.4 %). Trials were separated by one week, and SYN and CHS were worn in a counter-balanced order. Participants wore full-length poly-cotton pants, running shoes, and a long-sleeved button-up poly-cotton shirt was worn over the BV. Change in rectal temperature was significantly ($p = 0.04$) lower from baseline (0 min) to 180 min with CHS compared to SYN. Similarly, overall change in heart rate approached being significantly lower ($p = 0.07$) with CHS compared to SYN. Although there was no significant difference ($p = 0.49$) in sweat loss between the two t-shirts, change in subjective measure of sweating sensation was more favorable ($p = 0.056$) with CHS compare to SYN during the trial. Additionally, overall changes in clothing comfort ($p = 0.07$) and thermal comfort ($p = 0.05$) were more favorable during the exercise when wearing CHS compared to SYN. In conclusion, CHS resulted in modest decreases in core

temperature and heart rate compared to a synthetic garment, but facilitated overall improved thermal comfort and sweating sensation.

KEY WORDS: synthetic and channeled synthetic clothing, polyester, thermoregulation, microclimate, skin temperature, clothing comfort

INTRODUCTION

Ballistic vests (BV) provide upper-body protection and are required during duty for soldiers, police officers, and private security forces (Ricciardi et al., 2008; Lechmacher et al., 2007). However, BV cover a large portion of the upper body and limit the body's ability to dissipate heat due to increased insulation and decreased convection and moisture resistance which hinders evaporation, the key form of heat transfer in hot environments (Cheuvront et al., 2008; Gavin et al., 2001; Xio-Qun Dai et al., 2008). Increased body temperature may lead to decreased physical and cognitive performance and if prolonged lead to multiple types of heat illness (Armstrong et al., 2007).

According to the U.S. Army hospitalization report (Carter et al., 2005), 37 soldier deaths were attributed to heat illnesses from 1980 through 2002, and 5,246 soldiers were hospitalized due to heat illness. Also, this data indicates a fivefold increase in hospitalization from heat stroke from 1980 to 2001. Tactics and interventions to reduce risk of heat strain injuries are imperative for increasing safety.

Current methods to reduce heat storage while wearing BV include using: 1) air moving devices to increase convection under the BV (Barwood et al., 2009; Hadid et al., 2008); 2) liquid cooled tubing in garments which increase cooling through direct body contact (Cadarette

et al., 2006); and 3) increased evaporative cooling via synthetic fabric garments that wick moisture away from the skin (Wickwire et al., 2007). However, each of these methods has inherent drawbacks. An air cooled garment might harm the skin if outside temperature is high (Shapiro et al., 1982). Liquid cooled garments are effective but delivering cooling can be costly and difficult. Moisture wicking fabrics may increase comfort and provide heat dissipation advantages, cheaply, but only to a small degree.

Thus, many fabrics have been developed to improve thermoregulatory properties. Different fabric compositions have different effects on sweat evaporation and body cooling. A t-shirt made from cotton is effective to reduce heat load after the shirt becomes saturated with sweat (Xiao-Qun Dai et al., 2008). In comparison, other t-shirts made of synthetic material are designed to wick moisture from the surface of the skin to allow for better heat dissipation (Gavin, 2003). In previous research, conflicting evidence exists regarding the impact on thermoregulation of synthetic t-shirt compared to cotton t-shirt. Kwon et al. (1998) found no difference between cotton and synthetic shirts when wind was not present. However with wind present (1.5 m/s) lower rectal temperature was found with a cotton shirt and higher skin and body temperature with a synthetic shirt. Other researchers found no difference in thermoregulation and cardiovascular responses (Gavin et al., 2001; Wingo and McMurray, 2007).

Novel attempts to manufacture clothing that decrease heat storage include the integration of channels into synthetic fabric t-shirts (X-Bionic, X-Technology Swiss R&D AG, Switzerland). These channels are proposed to move moisture away from the body and increase evaporation. However, there is little evidence concerning the efficacy of wearing a channeled synthetic t-shirt (CST) on performance, thermoregulation, or comfort. Evidence suggests

wearing synthetic fabric t-shirts under BV alone is not more advantageous in regards to reducing thermal strain than wearing a cotton t-shirt, but may be perceived as more comfortable than a cotton t-shirt (Wickwire et al., 2007). However, synthetic fabric with inner and outer channels might offer enhanced cooling properties relative to non-channeled synthetic fabric shirts. We are unaware of any published studies comparing the effects of a channeled synthetic fabric on heat transfer. Thus, the purpose of the current study was to compare the effects of wearing a synthetic and channeled synthetic t-shirt under a ballistic protective vest on thermoregulation, heart rate, sweat loss, and subjective ratings of sweating sensation, clothing comfort, and skin wettedness. We hypothesized the following: (i) physiological responses such as heart rate, rectal temperature, skin temperatures, and sweat loss would be lower during the trial while wearing a channeled synthetic shirt compared to a synthetic shirt and (ii) Comfort responses such as sweating sensation, clothing comfort sensation, and skin wettedness sensation would be lower (more favorable) while wearing a channeled synthetic shirt compared to a synthetic shirt.

METHODS

Experimental Approach to the Problem

The following research was designed to compare the effects of a synthetic (SYN) fabric t-shirt to a channeled synthetic fabric (CHS) t-shirt worn under a ballistic protective vest on thermoregulation, heart rate, sweat rate, thermal comfort, rating of perceived exertion (RPE), sweating and clothing comfort sensation, and skin wettedness sensation in a hot environment [35 °C (95 °F) 40% relative humidity]. A single blind, repeated measures counter-balanced design was incorporated.

Participants

Eight males, between 21 and 34 years of age, volunteered to participate in the study. Descriptive data of the participants are shown in Table 1. All participants provided written informed consent in accordance with the local Institutional Review Board.

All participants were physically active and apparently healthy based on ACSM risk stratification criteria and a Physical Activity Readiness Questionnaires. A training status questionnaire indicated that all participants were engaged in cardio-respiratory exercise 3-4 times a week with at least one session lasting 60-90 min in duration. Seventy-five percent of participants also were engaged in weight training (2-4 times per week, 30-60 min per session). Participants were asked to avoid alcohol, caffeine, and physical activities at least 24 hours before every session. Also, participants were asked to avoid heavy food consumption and energy drinks at least 3-4 hours before each session.

Preliminary Testing

Prior to the testing sessions, study design and procedures were explained, informed consent was obtained, screening procedures were completed, and height, weight, and percent body fat were recorded. Using skinfold calipers (Lange, Beta Technology Incorporated Cambridge, Maryland) three skinfold sites were measured (chest, abdomen, and thigh) and percent body fat was estimated from the sum of skinfold sites and age (Pollock et al. 1980). Participants, wearing shorts, were weighed using a digital scale (BWB-800, Tanita Corporation, Japan). Height was measured using a stadiometer (Medart, St. Louis, MO). After all screening procedures, participants completed a graded exercise test to elicit test peak oxygen uptake ($\text{VO}_{2\text{peak}}$).

Graded Exercise Test Protocol

Participants completed a five minute warm-up on a motorized treadmill (Quinton Instrument Co., Seattle, WA) at 4.5 km/h speed with 0% incline. After a warm-up, participants completed a graded exercise test using the Bruce protocol. The highest two consecutive 30-second averages for oxygen uptake were averaged and considered VO_{2peak} .

Clothing

Two different t-shirt compositions were examined. The first was a 100% polyester synthetic t-shirt (SYN) and the second was a channeled synthetic (84% polyamide, 6% elastane, 10% polypropylene) shirt (“Running Speed Shirt Short Sleeves”, X-Bionic, X-Technology Swiss R&D AG, Switzerland). The channeled synthetic shirt (CHS) had inner and outer channels that were incorporated into the t-shirt design with the purpose of improving heat transfer.

Each participant wore the same clothing, except for the t-shirt (SYN or CHS), throughout both trials. The clothing ensemble consisted of a t-shirt (SYN or CHS) worn under a ballistic vest (Zero G Armorwear, Safariland: Armor Holding, Inc., Ontario, CA), long-sleeved button-up poly-cotton shirt worn over the ballistic vest, full-length poly-cotton pants, and running shoes. The order of t-shirt type worn under the ballistic vest was counterbalanced.

Exercise Protocol

After the preliminary testing session, participants completed the two performance trials. At least 72 hours separated the preliminary testing session and the first performance trial. One week separated each performance trial. Participants completed an “industrial protocol” lasting three hours (Figure 1).

“Industrial Protocol”. Participants completed bouts of 12 minutes of walking and 10 arm curls with 17.5 kg followed by 3 minutes of standing rest. Participants walked at a speed that

represented 1.1 L of oxygen consumption and this work rate was determined during the first 10 min of the first trial. During this period, participants had to breathe through a mouthpiece connected to a tube for a measurement of oxygen uptake (TrueOne 2400 Metabolic Cart, ParvoMedics, Parvo, UT). This work rate was held constant for all trials in order to determine if t-shirts had any influence on heat transfer independent of load (Cheuvront et al., 2008). After 12 minutes the motorized treadmill was stopped and participants completed 10 arm curls with 17.5 kg and rested till minute 15. This cycle was repeated twice. After the second cycle, participants sat on a chair in the environmental chamber and rested for five minutes. After five minutes rest, participants started new cycle and continued testing for a total of three hours.

Measurements

Upon arriving at the laboratory, a urine sample was collected in order to determine urine specific gravity (USG) to assess hydration status. If USG was higher than - 1.020 participants were not allowed to start a trial. Participants were provided with water for 20 min after which their urine was analyzed again. This process was repeated until the 1.020 criterion was met. Also, after the three hour industrial trial a urine sample was collected to determine post-exercise hydration status. Next, with dry shorts and no t-shirt, participant's weight was collected on a digital scale (BWB-800, Tanita Corporation, Japan). Post-exercise weight was collected after three hour trial. Participants removed all exercise clothes and thermocouples and changed back into their dry shorts. Sweat loss was calculated as: pre-exercise body weight + fluid ingested – post-body weight – voids (urine during the trial). Participants were allowed to drink water *ad libitum* throughout the test. The total volume of fluids consumed was recorded.

Participants inserted a thermocouple ~ 8 cm past the anal sphincter for measurement of rectal temperature (T_{re}). The rectal probe was securely taped, and the thermocouple wire was fed

out the underwear band and then through the waist of the pants on the right side of the participant. Skin temperature was continuously monitored from thermistors placed on the right forearm and on the right side of the chest approximately 5-6 cm above the nipple. Thermocouples were attached to the skin using adhesive tape, cut around the head of the thermocouple, which held the thermocouple in place without adding insulation. This technique allowed the maintenance of an appropriate skin-to-thermocouple interface. Heart rate monitor (Polar Team System, Polar Electro Inc., Kempele, Finland) was placed around the chest for heart rate (HR) measurement. T_{re} , skin temperatures, and heart rate were recorded every five minutes.

The micro-environment under the BV was continuously assessed (every minute) using a small temperature and humidity monitoring and recording device (DS 1923, Maxim Integrated Products, CA). One monitor was attached inside of the BV in the middle area of the chest and another I-button was attached in the middle of the back providing temperature and humidity measurements between the t-shirt and BV. After the placement of all the equipment, participants dressed and entered the environmental chamber.

During the “industrial protocol” trial, rating of perceived exertion (RPE) using Borg’s 15-point scale (Borg, 1972), rating of thermal comfort (RTC), sweating sensation, clothing comfort sensation, and skin wettedness were recorded every five minutes. The RTC scale ranged from 0.0 (unbearably cold) to 8.0 (very hot) (i.e. the closer to a rating of 4 would be considered ideal). The sweating sensation scale range from 0 (not at all) to 10 (heavily). The clothing comfort sensation scale range from 0 (very comfortable) to 10 (very uncomfortable). The skin wettedness scale range from 0 (dry) to 10 (dripping wet). All rating scales were explained by the investigators and presented visually to participants.

The exercise trial was terminated if rectal temperature reached 39.3 °C; participant asked to stop; participant showed any symptoms of heat or other injury or illness; or participant reached heart rate max. However, none of this happened during the trial.

Statistical Analyses

Change (Δ) in rectal and skin temperatures, heart rate, micro-environment, RPE, thermal comfort, sweating and clothing comfort sensation, and skin wettedness were calculated from baseline (0 min) to 180 min. Paired t-test was used to analyze the change in all variables between a channeled synthetic t-shirt and a synthetic t-shirt. Baseline rectal and skin temperatures, sweat loss, pre- and post- USG, and water consumption were analyzed using a paired t-test. Significance was accepted at the $p < 0.05$ level. Data were reported as means and standard deviations (SD). Statistical analyses were performed on a commercially available statistical platform (IBM SPSS Statistics 19, Illinois, Chicago).

RESULTS

Heat Chamber

The temperature in the heat chamber was 35.2 ± 0.3 °C with relative humidity of 40.7 ± 1.4 %. There was no significant difference ($p > 0.05$) in temperature or relative humidity between the trials.

Physiological Measurements

There were no significant differences in baseline rectal temperature between treatments (CHS = 37.46 ± 0.37 °C, SYN = 37.49 ± 0.29 °C, $p = 0.67$). Change in T_{re} (ΔT_{re}) was significantly lower with CHS compared to SYN from baseline to min 180 min ($p = 0.04$) (Table 2). Figure 2 represents the mean rectal temperature response at each data collection point.

There were no significant differences in baseline forearm temperature (CHS = 34.16 ± 0.78 °C, SYN = 34.15 ± 0.29 °C, $p = 0.95$) or chest temperature (CHS = 33.53 ± 0.99 °C, SYN = 33.64 ± 0.99 °C, $p = 0.53$). Also, there was no significant change in forearm ($p = 0.36$) or chest ($p = 0.51$) temperatures from baseline to 180 min between the two t-shirts (Table 2). Figure 2 and 3 represent the mean forearm and chest temperature responses at each data collection point.

Similarly to T_{re} results, overall change in heart rate approached being significantly lower ($p = 0.07$) with CHS compared to SYN (Table 2). Mean heart rate responses during the trial are presented in Figure 5.

There was no significant difference ($p = 0.67$) in water consumption between CHS (1.98 ± 1.02 L) and SYN (1.85 ± 0.66 L) or sweat loss ($p = 0.49$) between CHS (1.84 ± 0.38 L) and SYN (1.91 ± 0.29 L). Also, there was no significant difference in pre- ($p = 0.67$) and post- USG ($p = 0.54$) measurements between the two trials.

Comfort Measurements

There was no significant change in RPE ($p = 0.21$) or skin wettedness sensation ($p = 0.29$) from baseline to 180 min between the two shirts (Table 2). Furthermore, overall (0 to 180 min) change in RTC was significantly ($p = 0.05$) lower with CHS compared to SYN (Table 2). Mean RTC at each data collection point are presented in Figure 6. Change in sweating comfort sensation approached being significantly lower ($p = 0.06$) with CHS compared to SYN from baseline to 180 min (Table 2). See Figure 7 for mean sweating sensation response during the trial. Finally, overall change in clothing comfort sensation approached significance ($p = 0.07$) and was lower from baseline to 180 min with CHS compared to SYN (Table 2). Figure 8 represents the mean clothing comfort sensation during the trial.

Micro-Environment

There was no significant overall change in front temperature ($p = 0.78$), back temperature ($p = 0.19$), front relative humidity ($p = 0.16$), or back relative humidity ($p = 0.17$) under the shirt between the two shirts. Mean front and back temperatures, and front and back relative humidity under the ballistic vest are presented in Table 3.

DISCUSSION

Channeled synthetic t-shirt (CHS) manufacturers purport (without published evidence) that their product enhances body cooling by creating an environment conducive to increase evaporation compared to similar non-channeled t-shirt designs (X-BIONIC, <http://www.x-bionic.com/>, 2009). Data from our laboratory (Ballilioni et al., unpublished) support these claims as undershirt temperature was drastically reduced during indoor cycling. However, the insulating properties of BV represent an increased challenge to mitigating heat stress. Thus, the purpose of the current study was to compare the effects of non-channeled synthetic and channeled synthetic t-shirt design under a ballistic protective vest on thermoregulation, heart rate, and comfort responses in a hot environment (35 °C [95 °F] and 40% relative humidity).

The most significant finding of this study indicated that overall change in T_{re} was lower during exercise with CHS compared to SYN. This pattern contrasted our findings (Ballilioni et al., unpublished) for cyclists wearing a CHS during indoor cycling in which lower changes ($p = 0.04$) in T_{re} were only evident in the first 15-km (~30 min) of a 30-km (60 min) cycling bout compared to synthetic shirt.

It is plausible that increased moisture saturation over the course of the cycling time trial mitigated any benefits later in cycling. In the current investigation, humidity between the

treatment shirts and skin for the chest and back averaged > 95% for both CHS and SYN (Table 3). We are unsure of the mechanisms responsible for changes in T_{re} during different exercises, but it appears that inner and outer channels incorporated into the t-shirt design were effective in keeping body temperature lower during exercise.

The majority (Wingo and McMurray, 2007; Ha et al., 1995; Yasuda et al., 1994; Dai et al., 2008) but not all (Kwon et al., 1998; Gavin et al., 2001) evidence suggested that synthetic fabric t-shirts resulted in lower skin or core temperatures over cotton or wool t-shirts when BV were not worn. Wickwire et al. (2007) found no thermoregulatory advantage when wearing synthetic fabric t-shirts compared to cotton shirts under BV. However, most (Wingo and McMurray, 2007; Wickwire et al., 2007) of these investigations did find improved subjective thermal comfort ratings for SYN. The current study also found lower changes in thermal comfort ratings with CHS compared to SYN (Table 2). This indicated that CHS provided not only some thermoregulatory advantages but also lower thermal comfort rating which means that participants felt cooler with CHS compared to SYN during the three hour trial. The present study supports Balilionis et al. (unpublished) study who found better (lower) ($p = 0.03$) changes in thermal comfort responses with a channeled synthetic shirt compared to non-channeled synthetic cycling shirt during 30-km cycling performance trial.

Furthermore, changes in quad and forearm skin temperatures were not different between the two shirts. Similarly, Balilionis et al. (unpublished) found no difference in changes between the channeled shirt and the synthetic shirt in forearm and chest temperatures. However, Balilionis et al. (unpublished) found a lower change ($p = 0.01$) in chest temperature during the 30-km cycling performance trial with a channeled synthetic shirt compared to a non-channeled synthetic shirt. In the current study, overall change in chest temperature was not different

between CHS and SYN. The difference between studies can be attributed to different study design. It is a possibility that channeled synthetic shirt is not capable to reduce chest temperature in micro-environment which was created by ballistic vest. It can be concluded that channels were not able to aid to chest cooling.

Wearing CHS resulted in overall lower change in heart rate compared to SYN. This indicated that CHS was effective in reducing cardiovascular strain during three hours of exercise in the heat compared to SYN. However, Balilionis et al. (2011) found no difference in heart rate during a 30-km cycling performance trial between channeled and regular shirts. It is worth noting, that the intensity of the exercise was lower, and the duration was three times longer in the present study compared to the previous cycling study. It might be speculated that the longer exercise duration provoked different responses and channels that are incorporated into CHS were more effective in reducing cardiovascular strain compared to SYN during three hours exercise. Thus, future research should investigate heart rate response during longer durations of exercise.

Finally, change in sweating comfort sensation was lower with CHS compared to SYN (Table 2). This indicated that participants felt that they were sweating less. The difference in these subjective measures could be attributed to the channels that were incorporated into the shirt. SYN is purported to “wick the moisture away”; however, in the present study, CHS provided better sweating comfort sensation compared to SYN. In addition, lower change in clothing comfort sensation was with CHS compared to SYN. This leads to the conclusion that participants felt better with the CHS shirt. Wickwire et al. (2007) reported lower sweating and wettedness sensations with a synthetic shirt compared to a cotton shirt. Furthermore, in the present study, no difference was observed in sweat loss or water consumption between shirts. However, manufacturers (X-bionic, <http://www.x-bionic.com/>, 2009) claim that CHS helps to

utilize sweat better by an improved evaporation process. Although sweat loss was not different, overall change in rectal temperature was lower with CHS during the three hour trial compared to SYN. Thus, it can be speculated that CHS aided the cooling process by moving the moisture away from the body through the channels for sweat evaporation.

CONCLUSIONS

In conclusion, a channeled synthetic t-shirt had better effects on physiological and comfort responses compared to a synthetic shirt. Thermoregulation was better with channeled synthetic shirt. Overall lower changes in rectal temperature and in heart rate were observed with channeled synthetic shirt compared to a synthetic shirt. Participants also indicated that they sweated less and felt more comfortable with channeled synthetic shirt compared to non-channeled synthetic shirt. Overall, people who wear ballistic vests might benefit by wearing a channeled synthetic shirt under the ballistic vest. This might decrease the risk for heat illness, enhance comfort level, reduce cardiovascular stress, and extend activity level for longer durations. However, there is a need for further studies with longer duration, and slightly hotter and cooler environments in order to determine if channeled synthetic shirts will provide the same benefits as in this study.

REFERENCES

- Armstrong LE, Casa DJ, Millard-Stafford M, Moran SW, Roberts WO (2007). American College of Sports Medicine position stand. Exertional heat illness during training and competition. *Med Sci Sports Exerc*, 39(3): 556-572.
- Armstrong LE (2000). Performing in extreme environments. Human Kinetics, Champaign.
- Balilionis et al. (2011). Channeled fabric effects on thermoregulation, cardiovascular response, thermal comfort, and exercise performance. *Unpublished Dissertation*.
- Barwood MJ, Newton PS, Tipton MJ (2009). Ventilated vest and tolerance for intermittent exercise in hot, dry conditions with military clothing. *Aviat Space Env Med*, 80(4): 353-359.
- Borg G (1972). Perceived Exertion: A note on “history” and methods. *Med Sci Sports*, 5: 90-93.
- Cadarette BS, Chevront SN, Kolka MA, Stephenson LA, Montain SJ, Sawka MN (2006). Intermittent microclimate cooling during exercise-heat stress in U.S. Army chemical protective clothing. *Ergonomics*, 49: 209-219.
- Carter III A, Chevront SN, Williams JO, Kolka MA, Stephenson LA, Sawka MN, Amoroso PJ (2005). Epidemiology of hospitalizations and deaths from heat illness in soldiers. *Med Sci Sports Exerc*, 1338-1344.
- Chevront SN, Goodman DA, Kenefick RK, Montain SJ, Sawka MN (2008). Impact of a protective vest and spacer garment on exercise-heat strain. *Eur J Appl Physiol*, 102: 577-583.
- Dai X, Imamura R, Liu G (2008). Effects of moisture transport on microclimate under T-shirts. *Eur J Appl Physiol*, 104: 337-340.
- Gavin TP, Babington JP, Harms CA, et al. (2001). Clothing fabric does not affect thermoregulation during exercise in moderate heat. *Med Sci Sports Med*, 33(12): 2124-2130.
- Gavin TP (2003). Clothing and thermoregulation during exercise. *Sports Med*, 33(13): 941-947.
- Ha M, Yamashita Y, Tokura H (1995). Effects of moisture absorption by clothing on thermal responses during intermittent exercise at 24 °C. *Eur J Appl Physiol*, 71: 266-271.
- Hadid A, Yanovich R, Erlich G, Moran DS (2008). Effect of a personal ambient ventilation system on physiological strain during heat stress wearing a ballistic vest. *Eur J Appl Physiol*, 104: 311-319.
- <http://www.x-bionic.com/> (2009). X-Technology Swiss R&D AG, Switzerland.

- Jackson AS and Pollock ML (1978). Generalized equations for predicting body density of men. *Br J Nutr*, 40: 497-504.
- Kwon A, Kato M, Kawamura H, et al. (1998). Physiological significance hydrophilic and hydrophobic textile materials during intermittent exercise in humans under the influence of warm ambient temperature with and without wind. *Eur J Appl Physiol*, 78: 487-493.
- Lechmacher EJ, Jansing P, Kupper T (2007). Thermophysiological responses caused by ballistic bullet-proof vests. *Am Ind Hyg Assoc J* 59: 557-562.
- Ricciardi R, Deuster PS, Talbot LA (2008). Metabolic demands of body armor on physical performance in simulated conditions. *Military Med*, 173: 817-824.
- Sanders AG, Dugas JP, Tucker R, Lambert MI, Noakes TD (2005). The effects of different air velocities on heat storage and body temperature in humans cycling in a hot, humid environment. *Acta Physiol Scand*, 183: 241-255.
- Shapiro Y, Pandolf KB, Sawka MN, Toner MM, Wismann FR, Goldman RF (1982). Auxiliary cooling: comparison of air-cooled vs. water-cooled vests in hot-dry environments. *Aviat Space Environ Med*, 53: 785-789.
- Simmons SE, Saxby BK, McGlone FP, Jones DA (2008). The effect of passive heating and head cooling on perception, cardiovascular function and cognitive performance in the heat. *Eur J Appl Physiol*, 104: 271-280.
- Thompson WR, Gordon NF, and Pescatello LS (2010). Risks associated with physical activity. In: *ACSM's Guidelines for Exercise Testing and Prescription*. Philadelphia, PA: Wolters Kluwer; Lippincott Williams & Wilkins Benefits, p. 2-17.
- Wendt D, Van Loon LJC, Van Marken Lichtenbelt (2007). Thermoregulation during exercise in the heat. *Sports Med*, 37(8): 669-682.
- Wickwire J, Bishop PA, Green JM, Richardson MT, Lomax RG, Casaru C, Curtner-Smith M, and Doss B (2007). Physiological and comfort effects of commercial “wicking” clothing under a bulletproof vest. *Int J Ind Ergonomics*, 37: 643-651.
- Wingo JE and McMurray RG (2007). Cardiovascular and thermoregulatory responses to treadmill running while wearing shirts with different fabric compositions. *Biol Sport*, 24(2): 177-187.
- Xiao-Qun Dai, Ritsuko Imamura, Guo-Lian Liu, and Fu-Ping Zhou (2008). Effect of moisture transport on microclimate under T-shirt. *Eur J Appl Physiol*, 104: 337-340.
- Yasuda T, Miyama M, Muramoto A, Yasuda H (1994). Dynamic water vapor and heat transport through layered fabrics. III. Surface temperature change. *Text Res J*, 64: 457-461.

TABLES

Table 1. Physical characteristics of participants: age (y), weight (kg), height (cm), percent body fat (%), and $\text{VO}_{2\text{peak}}$ (ml/kg/min) (n = 8).

Characteristics	Means \pm SD
Age (y)	27.7 \pm 4.8
Weight (kg)	83.0 \pm 12.3
Height (cm)	178.0 \pm 7.9
% body fat	12.2 \pm 2.6
$\text{VO}_{2\text{peak}}$ (ml/kg/min)	49.0 \pm 3.9

Table 2. Mean (\pm SD) change in rectal, forearm, and chest temperatures, heart rate, rating of perceived exertion, rating of thermal comfort, clothing comfort sensation, sweating comfort sensation, and skin wettedness sensation from baseline to 180 min between channeled synthetic and synthetic t-shirts (n = 8).

Variable	Change from 0 min to 180 min with CHS	Change from 0 min to 180 min with SYN	<i>p</i>
T _{re} (°C)	0.50 \pm 0.31	0.66 \pm 0.33	0.04
T _{arm} (°C)	2.03 \pm 0.72	2.23 \pm 0.90	0.36
T _{chest} (°C)	3.55 \pm 0.92	3.78 \pm 0.72	0.51
HR (b/min)	44.0 \pm 22.5	51.8 \pm 17.6	0.07
RPE	6.0 \pm 1.7	7.0 \pm 1.9	0.21
RTC	1.7 \pm 0.8	2.6 \pm 0.5	0.05
Clothing Comfort Sensation	2.7 \pm 1.3	3.8 \pm 1.7	0.07
Sweating Comfort Sensation	6.5 \pm 2.3	7.7 \pm 1.8	0.06
Skin Wettedness Sensation	6.6 \pm 2.7	7.6 \pm 1.7	0.29

T_{re} – rectal temperature; T_{arm} – forearm temperature; T_{chest} – chest temperature; HR - heart rate; RPE – ratings of perceived exertion; RTC – rating of thermal comfort; *p* – significance

Table 3. Mean (\pm SD) front temperature, back temperature, front relative humidity, and back relative humidity under the ballistic vest wearing channeled synthetic and synthetic shirts (n= 8).

	At 180 min with CHS	At 180 min with SYN
Front Temp ($^{\circ}$ C)	35.78 \pm 0.65	35.85 \pm 0.59
Back Temp ($^{\circ}$ C)	36.69 \pm 0.50	36.91 \pm 0.37
Front RH (%)	95.89 \pm 1.86	96.29 \pm 2.08
Back RH (%)	97.86 \pm 0.97	98.07 \pm 0.75

CHS – channeled synthetic shirt; SYN – synthetic shirt; temp – temperature; RH – relative humidity. No significant differences between treatments ($p > 0.05$).

FIGURE CAPTIONS

Figure 1. Exercise Protocol.

Figure 2. Rectal temperature (mean \pm SD) during 180 min of exercise while wearing a channeled synthetic shirt or a synthetic t-shirt (n = 8).

Figure 3. Forearm temperature (mean \pm SD) during 180 min of exercise while wearing a channeled synthetic or a synthetic t-shirt (n = 8).

Figure 4. Chest temperature (mean \pm SD) response during 180 min of exercise while wearing a channeled synthetic or a synthetic t-shirts (n = 8).

Figure 5. Heart rate (mean \pm SD) during 180 min of exercise while wearing a channeled synthetic or a synthetic t-shirt (n = 8).

Figure 6. Participants rating of thermal comfort response (mean \pm SD) during 180 min of exercise while wearing a channeled synthetic or a synthetic t-shirt (n = 8).

Figure 7. Participants mean sweating sensation response (mean \pm SD) during 180 min of exercise while wearing a channeled synthetic or a synthetic t-shirt (n = 8).

Figure 8. Participants clothing comfort sensation response (mean \pm SD) during 180 min of exercise while wearing a channeled synthetic or a synthetic t-shirt (n = 8).

FIGURES

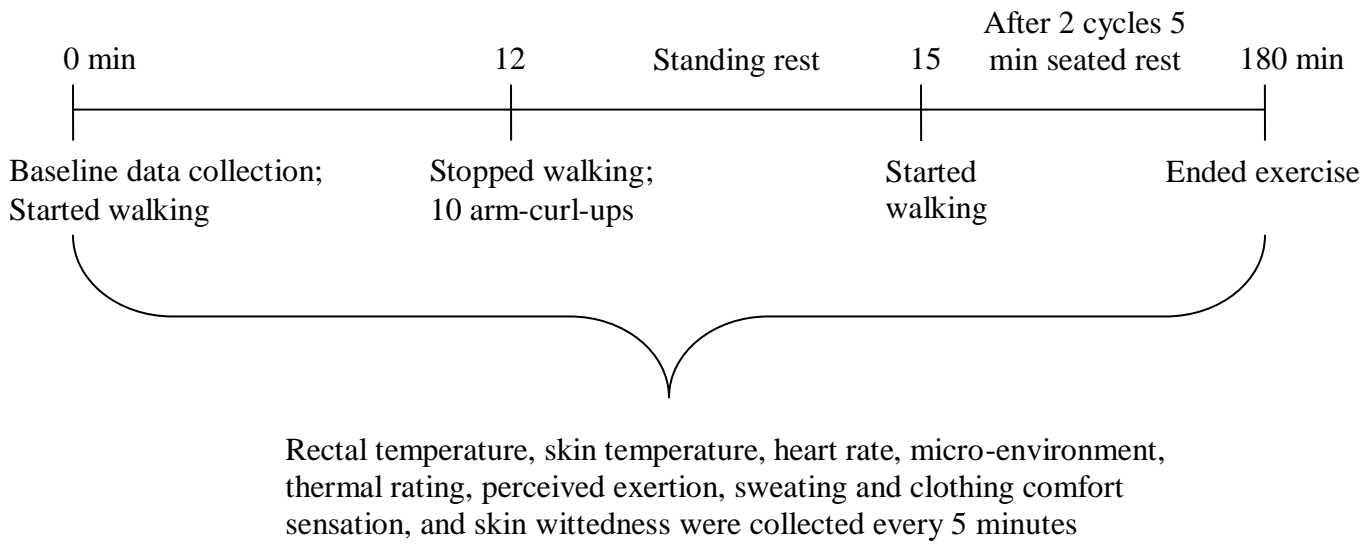
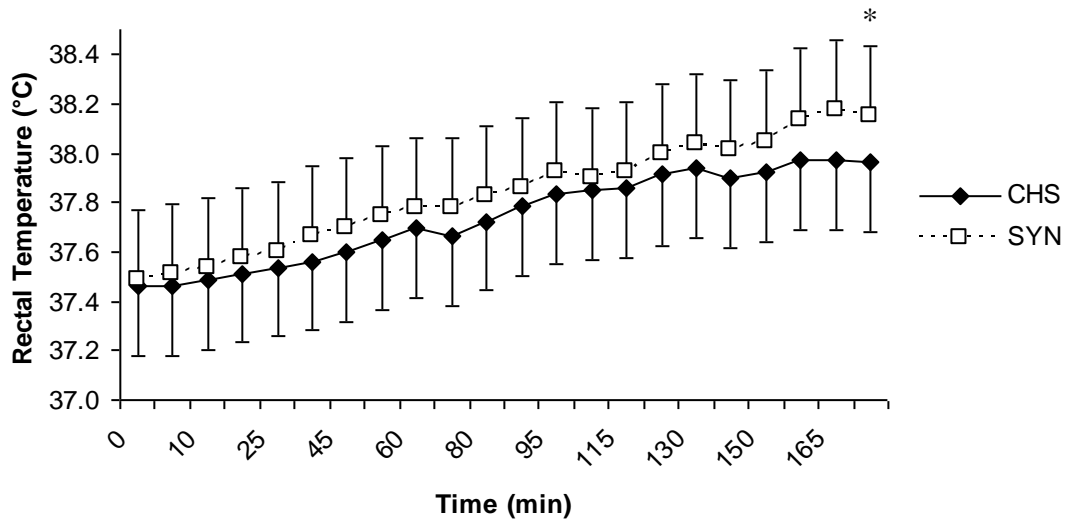


Fig 1.



* - a significantly ($p < 0.05$) lower change in T_{re} between channeled synthetic shirt and synthetic shirt from baseline (0 min) to 180 min

Fig 2.

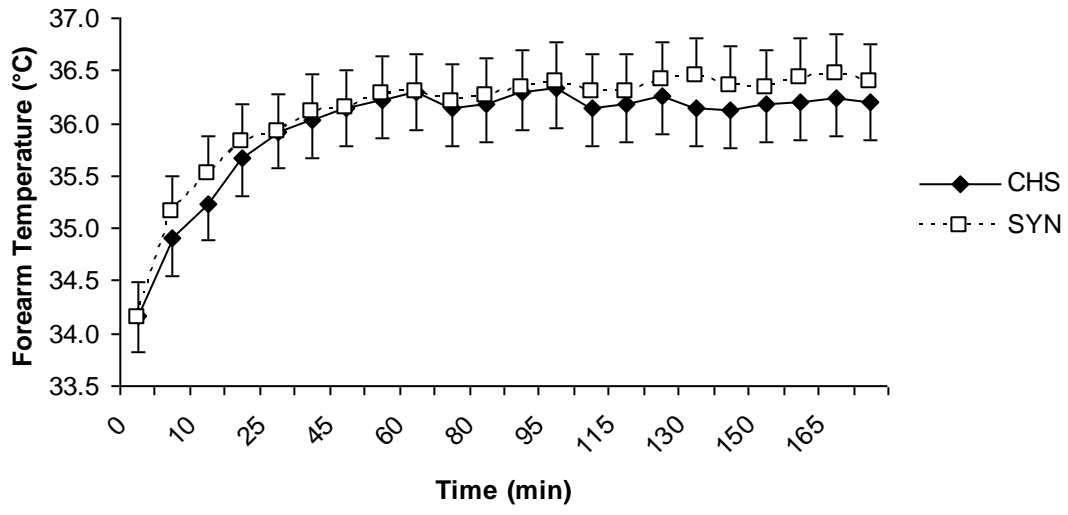


Fig 3.

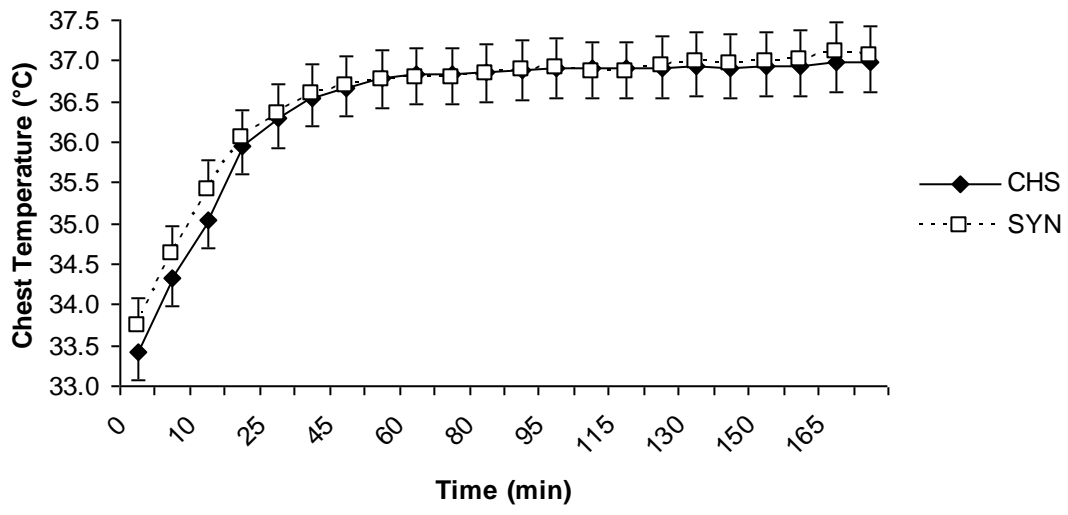
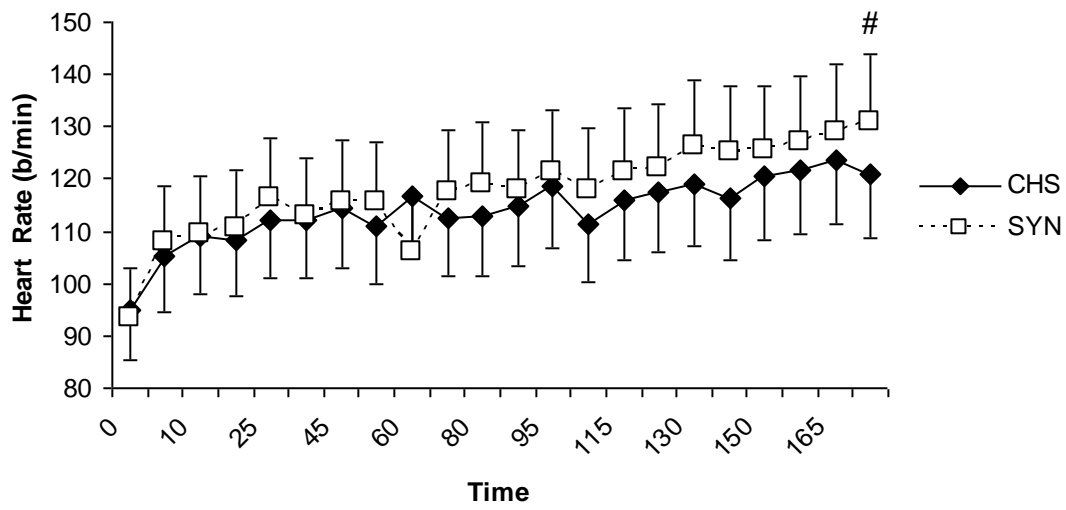
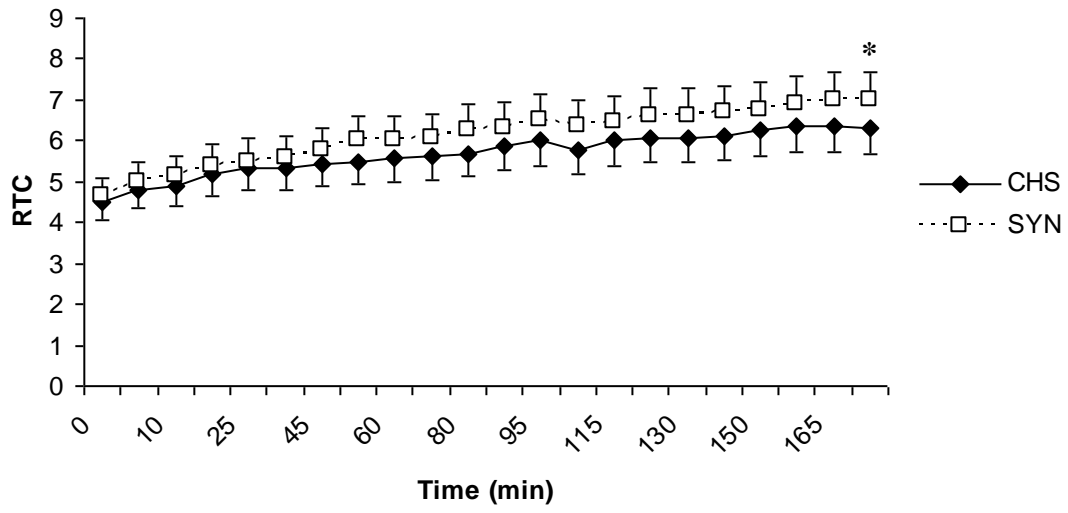


Fig 4.



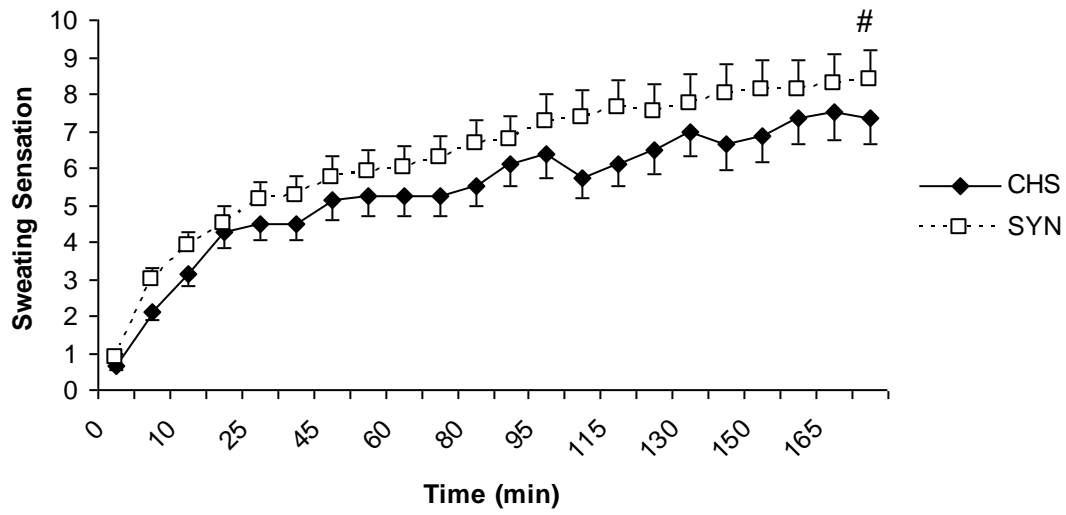
- overall (0 min – 180 min) change in heart rate approached being significantly lower ($p = 0.07$) with channeled synthetic shirt compared to synthetic shirt

Fig 5.



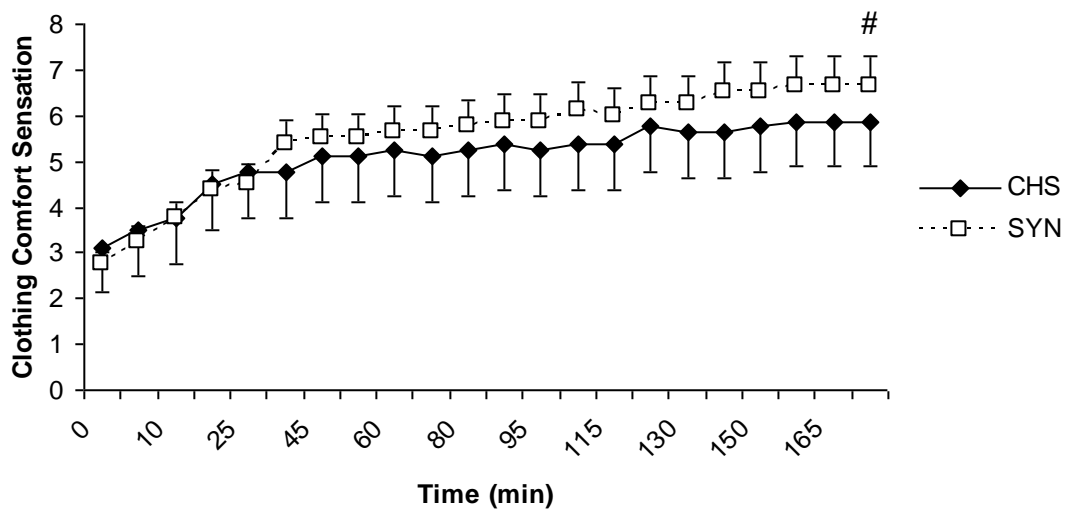
* - overall (0 min – 180 min) change in rating of thermal comfort was significantly lower ($p = 0.05$) with channeled synthetic shirt compared to synthetic shirt

Fig 6.



- overall (0 min – 180 min) change in sweating sensation approached being significantly lower ($p = 0.07$) with channeled synthetic shirt compared to synthetic shirt

Fig 7.



- overall (0 min – 180 min) change in clothing comfort sensation approached being significantly lower ($p = 0.07$) with channeled synthetic shirt compared to synthetic shirt

Fig 8.

CHAPTER III

CHANNELED FABRIC CLOTHING EFFECTS ON THERMOREGULATION, HEART RATE, AND THERMAL COMFORT

ABSTRACT

The human body may store heat during exercise in hot environments, which leads to increased body temperature that can decrease performance. Clothing can be a barrier to heat transfer and can hinder sweat evaporation from the skin; thus, the purpose of the present study was to evaluate the effects of a channeled synthetic t-shirt (CHS) and a regular synthetic cycling t-shirt (RSC) on thermoregulation, heart rate, sweat loss, thermal comfort sensation, and rating of perceived exertion during a 30-km cycling trial in a hot (35.1 ± 0.2 °C, relative humidity $40 \pm 1.6\%$) environment with 2.8 m/s air flow. In a counterbalanced repeated-measures design, eight participants attempted two 30-km cycling trials, separated by 72 hours, wearing two different shirts. All clothing worn during the trials was the same except for shirt type. Only 5 participants were able to complete the 30-km trial under our rectal temperature limit (39.3 °C). In one trial, participants wore RSC, in another trial, participants wore CHS that had inner and outer channels incorporated into the fabric. Results indicated that change in rectal temperature (ΔT_{re}) was lower ($p = 0.04$, $n = 8$) for CHS compared to RSC from the baseline to 15th km. Wearing CHS resulted in significantly lower change in chest skin temperature from baseline to 30th km ($p = 0.01$, $n = 5$), decreased change in micro-environment temperature inside the front of the shirt from baseline to 15th km ($p < 0.01$, $n = 8$), and better change in thermal comfort from baseline to 30th km ($p = 0.03$, $n = 5$) compared to RSC. There was no significant ($p > 0.05$) change in heart rate, forearm

and quadriceps skin temperatures, RPE, and sweat loss. In conclusion, wearing CHS provided better thermoregulatory and thermal comfort response compared to RSC, however heart rate response was not affected.

KEY WORDS: rectal temperature, skin temperature, thermoregulation, RPE

INTRODUCTION

During exercise in hot environments, heat storage can increase dramatically and negatively impact performance. The human body can sustain a very small, 3 - 4 °C, upwards fluctuation in body temperature (Hadid et al., 2008). Further temperature increases escalate an individual's risk for experiencing heat illnesses (Hadid et al., 2008).

Heat generated during exercise can be dissipated through convection, radiation, conduction, and evaporation. In hot environments, clothing can disrupt these processes (Gavin, 2001; Xio-Qun Dai et al., 2008). In these conditions, the primary cooling mechanism is through evaporation of sweat from the skin surface. However, clothing can hinder sweat evaporation from the skin (Gavin et al., 2001; Xio-Qun Dai et al., 2008). Increased heat storage can lead to decreased physical and cognitive performance (Wendt et al., 2007; Gavin et al., 2001; Simmons et al., 2008). Thus, many fabrics with improved evaporative characteristics have been introduced for the purpose of improving thermoregulatory properties. Cotton, synthetic, and wool fabrics are the most used fabrics in manufacturing athletic apparel. Each fabric has different effects on sweat evaporation and body cooling.

Wool fibers transfer moisture from the body to the exterior layer of the fabric for heat dissipation (Gonzalez, 1995). However, this process is slow and results in the wool becoming

heavy from moisture saturation. Cotton helps to reduce heat load after the fabric becomes saturated with sweat (Xiao-Qun Dai et al., 2008). Synthetic fabrics are designed to wick moisture away from the skin surface and increase heat dissipation (Gavin et al., 2001). Synthetic fabrics are the most popular material for today's athletes because they are lighter, do not absorb moisture, and result in drier skin surface compared to cotton and wool fabrics (Gonzalez, 1995).

In previous research, conflicting evidence exists regarding the impact of synthetic, wool, or cotton fabrics on thermoregulation. Kwon et al. (1998) found no significant difference between cotton, wool, and synthetic shirts in a hot environment (30 °C) with no wind present. Although, with airflow of 1.5 m/s, higher skin and rectal temperatures were observed with the synthetic shirt, whereas, lower rectal temperature was found with the wool shirt. In addition, Gavin et al. (2001) found no significant difference between seminude, cotton, and synthetic shirt in mean body temperature, core temperature, mean skin temperatures, and heart rate in a hot environment (30 °C). Wingo and McMurray (2007) likewise found no significant difference in thermoregulatory and cardiovascular responses while wearing synthetic, cotton, or no t-shirts in a temperate environment (22 °C). However, final rectal temperature was lower with the synthetic shirt compared to cotton shirt but no difference was observed between synthetic shirt and no shirt, and no shirt compared to cotton shirt. Finally, Wickwire et al. (2007) found no significant differences in heart rate, core and skin temperatures between synthetic and cotton shirts in a hot environment (35 °C).

There is little research concerning the impact of channeled synthetic t-shirts (CHS) on thermoregulation. CHS have inner and outer channels designed into the fabric. It was hypothesized that the channels would help move the moisture away from the skin to aid evaporation. Thus, the purpose of this study was to evaluate the effects of CHS and a non-

channeled regular synthetic shirt (RCS) on thermoregulation, heart rate, sweat loss, thermal comfort sensation, and rating of perceived exertion (RPE) during a 30-km cycling trial in a hot environment. We hypothesized the following: (1) heart rate would be lower with CHS compared to RCS, (2) rectal and skin temperatures would be lower with CHS versus RCS, and (3) thermal comfort and RPE would be lower with CHS compared to RCS.

METHODS

Experimental Approach to the Problem

This study was designed to compare the effects of regular non-channeled synthetic cycling t-shirt and channeled synthetic t-shirt on thermoregulation, heart rate, and thermal comfort responses during a 30-km cycling trial in a hot environment (35 °C, 40% relative humidity) with 2.8 m/s wind. A single blind, counter-balanced repeated measures design was used.

Participants

Eight males (21-31 years of age) volunteered to participate in the study. Sample size was estimated based on power analyses with an alpha level set at 0.05 and a power of > 0.8. Participants' age, weight, height, body fat percentage, and VO_{2peak} were 27 ± 4 yr, 80.6 ± 7.9 kg, 178.7 ± 5.3 cm, $11.6 \pm 5.0\%$, 48.9 ± 4.7 ml·kg⁻¹·min⁻¹, respectively. All participants provided written informed consent in accordance with the local Institutional Review Board.

All participants had been involved in physical activity 5-6 times per week. A training status questionnaire indicated that 75% of the participants were engaged in cycling exercises. All participants were engaged in cardio-respiratory exercise (cycling or running) 3-4 times per

week for at least 60 min in one session. Also, a training status questionnaire indicated that 88% participants were engaged in weight lifting exercise 2-3 times per week.

Prior to the study, each participant completed a Health Status Questionnaire (ACSM Risk Stratification) and a Physical Activity Readiness Questionnaire (PAR-Q) to determine any health risks. A positive answer on the PAR-Q excluded the individual from the study. In addition, a training status questionnaire was given to the participants. Participants were asked to avoid alcohol and physical activity for 24 hours before reporting to the laboratory. Participants were also instructed to avoid heavy food consumption, caffeine, and energy drinks at least 3-4 hours before each session. Finally, participants were instructed to drink water before the trial to make sure that they were well hydrated.

Preliminary Testing

Prior to the testing sessions, the study design and procedures were explained to participants, informed consent was obtained, screening procedures were completed, and height, weight, and percent body fat from the sum of three skinfolds (Pollock et al., 1980) were recorded. Participants, wearing shorts, were weighed using a digital scale (BWB-800, Tanita Corporation, Japan). Height was measured using a stadiometer (Medart, St. Louis, MO). After all screening procedures, participants completed a graded exercise test to elicit their peak oxygen uptake (VO_{2peak}) using a computerized metabolic system (TrueOne 2400, Parvo Medics, Parvo, Utah).

Graded Exercise Test Protocol

Participants completed a five minute warm-up on a electronically braked cycle ergometer (Velotron, Racer Mate Inc., Seattle, WA) with a work rate of 75 watts. After the warm-up, participants started cycling at a work rate of 100 watts. Every two minutes power output was

increased by 25 watts. The graded exercise test continued until volitional exhaustion. The highest two consecutive 30-second averages for oxygen uptake were averaged and considered $\text{VO}_{2\text{peak}}$.

Clothing

Regular synthetic cycling shirt (RSC) (100% polyester) and channeled synthetic shirt (CHS) (84% polyamide, 6% elastane, 10% polypropylene) (“Running speed shirt short sleeves”, X-Bionic, X-Technology Swiss R&D AG, Switzerland), were worn. CHS synthetic shirts had inner and outer channels designed into the fabric. Each participant wore the same clothing, except for the t-shirt (RSC or CHS), throughout both trials. Clothing consisted of the t-shirts, biking shorts, and biking shoes. The order of t-shirts worn was counterbalanced.

Exercise Protocol

After the preliminary testing session, participants completed two 30-km cycling trials in a counterbalanced order. All trials including preliminary testing and treatment sessions were separated by 72 hours. Trials were conducted in a hot environment (35 °C, 40% relative humidity) with a fan blowing at 2.8 m/s. Wind speed was measured with an anemometer (Anemo-thermometer, Control Company, TX) at the cycle ergometer handlebar. Seat and handlebar height were set identically for both trials for each participant. Before the 30-km trial, participants completed a five-minute warm-up in the environmental chamber at a work rate of 75 watts. After the warm-up, participants rested for 30 seconds prior to the commencement of the 30-km cycling trial (Fig 1). Time, resistance, and distance traveled were measured and recorded with the software of the ergometer. The trial was stopped if rectal temperature exceeded 39.3 °C, and this occurred for three participants. Trials were identical.

Hydration status. Upon arriving at the laboratory, a urine sample was collected in order to determine urine specific gravity (USG) to assess hydration status. If USG was higher than

1.020 participants were not allowed to initiate a time trial. Participants were provided with water for 20 minutes after which their urine was analyzed again. This process was repeated until the 1.020 criterion was met. A urine sample was also collected after the 30-km trial.

Rectal (T_{re}) and skin temperatures. Participants inserted a thermocouple (RET-1, Physitemp Instruments Inc., Clifton, NJ) eight centimeters past the anal sphincter for measurement of T_{re} . The rectal probe was securely taped, and the thermocouple wire was fed out the underwear band and then through the waist of the cycling shorts on the right side of the participant. Rectal and skin temperature was continuously monitored from thermocouples (SST-1, Physitemp Instruments Inc., Clifton, NJ). Skin thermocouples were placed at the following sites: right calf, right forearm and chest. Thermocouples were attached to the skin using adhesive tape, cut around the head of the thermocouple, which held the thermocouple in place without adding insulation. This technique allowed the maintenance of an appropriate skin-to-thermocouple interface.

Heart rate (HR). HR was recorded using a wireless heart rate monitor (Polar Electro, Kempele, Finland) which was attached by strap to the chest.

Rating of perceived exertion (RPE). Participants were asked to rate warm-up and the 30-km cycling trial, using Borg's 15-point scale (6 = no exertion at all and 20 = maximal exertion) (Borg, 1974). The scale was explained in detail and supported by a visual aid.

Rating of thermal comfort (RTC). Participants were asked to rate thermal comfort during the 30-km cycling trial. The RTC scale ranged from 0.0 (unbearably cold) to 8.0 (Very Hot) and 4.0 represented comfortable temperature. The scale was explained in detail and supported by a visual aid.

Water consumption. Participants were allowed to drink water *ad libitum* throughout the test. The total volume of fluids consumed was recorded at the end of the trial.

Power output (watts). Power output was recorded using a computerized system and recorded to a data collection sheet. Participants were blinded to the power output values. Power output was adjusted every kilometer as desired by the participant during the first 30-km trial. Power output was adjusted to the participants' needs whenever they told the investigator that they wanted to increase or decrease power output. During the second 30-km trial power output was kept the same as in first 30-km trial session.

Sweat loss. Participant's weight was measured before and after each trial and adjusted for fluid intake to determine sweat loss. Sweat loss was calculated as (Sanders et al., 2005): Sweat loss (L) = [Pre-exercise body weight (kg) + fluid ingested (L) – post-exercise body weight (kg)]. None of the participants had to urinate during the trial.

Micro-Environment. Micro-environment was continuously monitored using an i-button (DS 1923, Maxim Integrated Products, CA). The i-button is a small temperature and humidity monitoring device. The i-button was attached in front of the heart rate monitor and in back of the heart rate monitor strap under the shirt.

Baseline rectal temperature, skin temperatures (forearm, chest and calf), heart rate, and micro-environment were recorded prior to the warm-up. After the warm-up (5 min) RPE and HR were recorded. Rectal temperature, skin temperature, HR, RPE, and RTC were recorded every kilometer and at the end of the trial. The micro-environmental temperature and humidity were collected every minute.

Statistical Analyses

Change (Δ) in rectal and skin temperatures, heart rate, micro-environment, RPE, and thermal comfort were calculated from baseline to 15 km and from baseline to 30 km. Data were analyzed at 15-km, because that was the last time point completed by all 8 participants. A paired t-test was used to analyze the change in all variables between channeled synthetic t-shirt and synthetic cycling t-shirts. Baseline rectal and skin temperatures, sweat loss, pre- and post- USG, and water consumption were analyzed using a paired t-test. Change in micro-environment was calculated from 1 min to 30 min (last time point with 8 participants) and from 30 min to 60 min. A paired t-test was used to analyze the changes in micro-environment. An alpha level of 0.05 was used for all hypothesis tests. Data were reported as means and standard deviations (SD). Statistical analyses were performed on a commercially available statistical platform (IBM SPSS Statistics 19, Illinois, Chicago).

RESULTS

Heat chamber temperature was 35.1 ± 0.2 °C with relative humidity of 40 ± 1.6 %. There was no significant difference ($p > 0.05$) in temperature or relative humidity between the trials.

USG before the trial was not significantly ($p = 0.74$) different between CHS (1.07 ± 0.02) and RSC (1.06 ± 0.04). Also, there was no significant ($p = 0.47$) difference in USG between treatments after the 30-km trial.

Three participants were stopped in both trials because T_{re} reached 39.3 °C. Two participants were stopped slightly later in CHS trial compared to RSC trial. One participant was stopped at 28 km with CHS and at 24 km with RSC. A second participant was stopped at 18 km with CHS and at 16 km with RSC. The third participant was stopped at 28 km in both trials.

However, in the statistical analyses all eight participants were included to analyze the change in all variables from baseline to 15 km. All three participants that were stopped during the trials were excluded from statistical analyses that analyzed the changes in variables from baseline to 30 km (i.e. $n = 8$ for 15-km analyses, $n = 5$ for 30-km analyses).

Baseline T_{re} was not significantly ($p > 0.05$) different between CHS (37.45 ± 0.33 °C) and RSC (37.49 ± 0.28 °C) trials. A significantly smaller change ($p = 0.04$) was found in T_{re} with CHS compared to RSC from baseline to 15 km (Table 1). There was no significant ($p = 0.83$) change in T_{re} from baseline to 30 km between the shirts. Mean rectal temperatures during 30-km time trial while wearing CHS or RSC are presented in Figure 1.

There were no significant changes ($p > 0.05$) in forearm or quadriceps skin temperatures between the two t-shirts at any time period (Table 1). A significantly ($p = 0.01$) smaller change was found in chest temperature from baseline to 30-km with CHS compared to RSC. However, there was no significant ($p > 0.05$) change found in chest temperature from baseline to 15 km between the two shirts. Mean chest temperatures during the 30-km trial are presented in Figure 3.

There was no significant ($p > 0.05$) change in heart rate or RPE at any time period between the two t-shirts (Table 1). Also, there was no significant difference ($p = 0.06$) in water consumption between CHS (0.97 ± 0.43 L) and RSC (1.09 ± 0.51 L). Furthermore, no significant ($p = 0.88$) difference was observed in sweat loss between CHS (1.46 ± 0.31 L) and RSC (1.48 ± 0.39 L).

A significantly smaller ($p = 0.03$) change was observed for rating of thermal comfort (RTC) from baseline to 30-km with CHS compared to RSC (Table 1). There was no significant difference in change in RTC ($p > 0.05$) from baseline to 15 km between the two t-shirts. Figure 4 shows RTC response while wearing CHS or RSC during 30-km time trial.

Significantly ($p < 0.01$) smaller mean change was found in front temperature under the CHS ($\Delta = -3.4 \pm 1.6$ °C) compared to RSC ($\Delta = 1.1 \pm 1.4$ °C) from baseline to 30 min. No significant change in front micro-environmental (Micro-E) temperature under the shirt was found from 30 min to 60 min between the two shirts. Front Micro-E relative humidity was significantly ($p = 0.03$) lower with RSC ($\Delta = 16.8 \pm 10.3$ %) compared to CHS ($\Delta = 32.3 \pm 12.5$ %). No significant ($p > 0.05$) change in front Micro-E relative humidity under the shirt was found from 30 min to 60 min between the two shirts. Finally, no significant ($p > 0.05$) change was found in Micro-E back temperature or relative Micro-E humidity at any time period between the two shirts.

DISCUSSION

Little is known about the physiological impact of channeled synthetic shirts during exercise in hot environments. The manufacturer of the channeled t-shirt (X-BIONIC, <http://www.x-bionic.com/>, 2009) used in this investigation claim that the inner and outer channels incorporated into the fabric help to move the moisture away from the skin surface which aids in the evaporation process. Therefore, the purpose of the present study was to compare the impact of wearing a CHS with a RCS on thermoregulation, heart rate, sweat loss, thermal comfort sensation, and rating of perceived exertion during a 30-km cycling trial in a hot environment (35.1 ± 0.2 °C, 40 ± 1.6 % relative humidity) with 2.8 m/s wind.

The main finding of the present study was that the channeled synthetic shirt did provide some thermoregulatory and comfort advantages compared to a regular non-channeled synthetic shirt. Participants started the 30-km cycling trial with similar T_{re} and intensity (with no significant difference in speed and RPM) with both t-shirts. This indicated that any change in T_{re}

between the two shirts may be attributed to a real difference in t-shirt heat dissipation capacities. As specified in the results, several participants were stopped earlier in both trials because their T_{re} reached 39.3 °C. This reduced our statistical power for testing.

The new power was calculated from our measured SD for T_{re} , our sample of 5, with a power of 0.80, and a two-tailed p of 0.05. Under these conditions we could detect an effect size of 0.18 °C. We felt this was acceptable and hence continued to analyze from 0-30 km, treating it as a separate analysis.

The change in T_{re} was lower with CHS compared to RSC from the baseline to 15 km. This suggests that CHS had a better effect on heat dissipation capacities as evidenced by a lower core temperature for ~30 minutes. The current study supports another study (Balilionis et al., unpublished) study in which investigators found a thermoregulatory benefit wearing a channeled synthetic shirt under a ballistic vest compared to a non-channeled synthetic shirt in a hot environment (35 °C). Therefore, to some extent, the manufacturer's claim that channels incorporated into the shirt help to remove the warm air was supported by the current study. However, there was no difference in change in T_{re} from the baseline to the 30 km. The reason for the difference disappearance might be increased relative humidity under the CHS shirt. It maybe, that eventually the sweat production over-whelmed the CHS ability to remove the moisture. Micro-environmental data indicated that the change in relative humidity was lower with RSC compared to CHS from baseline to 30 min. There is a possibility that a higher relative humidity under CHS slowed down heat dissipation and T_{re} during second half of the 30-km trial resulting in no difference between trials. Therefore, in the future there is a need to investigate CHS and RSC effects on performance with prolonged cycling duration.

Furthermore, conflicting results exist among comparisons of different t-shirt fiber types and thermoregulation responses. Kwon et al. (1998) found significantly lower rectal and skin temperatures with wool and cotton t-shirts compared to the synthetic t-shirts in hot environment (30 °C) with wind present at 1.5 m/s. However, the differences between the present and Kwon studies are worth noting. In the Kwon study, a lower environmental temperature was used compared to the present study. Also, full-length garments were used which are not very applicable during exercise in hot environments.

In the study by Gavin et al. (2001) there was no significant difference observed in rectal and mean skin temperatures while wearing a synthetic shirt, a cotton shirt, or seminude in a hot environment (30 °C) during 30 min running and 15 min walking. Gavin et al. (2001) concluded that during this exercise bout in a hot environment, clothing had no effect on thermoregulation. Therefore, in the present study the change in chest (baseline 30 km) and core temperatures (baseline 15 km) were lower with a channeled synthetic shirt compared to a synthetic shirt. The difference in findings between these two studies might be that researchers used a different exercise protocols and environmental temperatures. In the current study higher environmental temperature was used compared to Gavin et al. (2001). Also, the intensity of the exercise was higher in the present study. Therefore, there is a need for further studies to determine channeled synthetic garment effects on thermoregulation during lower intensity exercises.

Similar results were found by Wickwire et al. (2007). Researchers found no significant differences in rectal or skin temperatures (except chest temperature) between synthetic and cotton t-shirts worn under the ballistic vest during two hours of exercise in a hot environment (35 °C). Wearing shirts under a ballistic vest could have altered the microenvironment and the t-shirt heat dissipation properties.

Finally, Wingo and McMurray (2007) found no significant change in rectal and skin temperatures during 45 min of exercise with a cotton shirt, a synthetic shirt, or seminude in a 22°C environment. However, core temperature was significantly lower during the last minute of exercise with a synthetic shirt compared to a cotton shirt but it was not different from seminude. It was concluded that the synthetic shirt provided better thermoregulatory and thermal comfort benefits than the cotton shirt.

To our knowledge there are no published studies on synthetic channeled-fabric. Thus, it is impossible to make direct comparisons with previous studies but it can be speculated that CHS would have greater benefits than a cotton shirt because the present study results showed that change in T_{re} was lower with CHS compared to a synthetic shirt. However, there is a need for further studies to determine how CHS affects thermoregulation in different environments and different exercise types.

Furthermore, no difference was observed in forearm and quadriceps skin temperatures at any data collection point. This supports the Wickwire et al. (2007) results, who observed no significant difference at any skin temperature sites (except chest) between cotton and synthetic shirts. Therefore, in the current study, change in chest temperature was lower from the baseline to the 30 km with CHS compared to RSC. Lower chest temperature indicates that inner- and outer- channels in the CHS shirt seemed to have a positive effect on cooling the chest area which contributed to a lower rectal temperature.

Even though some differences in thermoregulatory response were observed between shirts, change in heart rate was not different between the trials. These results support Wickwire et al. (2007) and Wingo and McMurray (2007) who found no significant differences in heart rate

response between cotton and synthetic shirts. Thus heart rate results indicated that CHS had no advantage over RCS in reducing cardiovascular strain during the 30-km cycling trial.

Finally, a lower change in thermal comfort was observed with channeled synthetic shirt compared to synthetic shirt from baseline to 30 km. This indicates that participants felt cooler during the trial with CHS compared to SYN. The results of the present study support Wingo and McMurray (2007) findings. In Wingo and McMurray (2007) study thermal comfort was enhanced with synthetic shirt compared to cotton shirt. Enhanced thermal comfort in present study can be attributed to the inner and outer channels, which overall, reduced thermal strain and chest skin temperature.

CONCLUSIONS

In conclusion, wearing a CHS provided slightly better thermoregulatory and thermal comfort responses compared to a RCS. Front temperature under the CHS indicated that inner and outer channels incorporated into the shirt were somewhat effective in reducing local temperature under the t-shirt. Rectal and chest skin temperatures were lower with CHS compared to RSC during 30-km cycling trial. The enhancement in the rectal and chest skin temperature was attributed to the channels that are incorporated into the fabric. In addition participants felt cooler with CHS compared to RSC. In conclusion, individuals wearing CHS might feel cooler and have lower chest and T_{re} temperatures (~30 min) in environments and exercise durations similar to this study.

REFERENCES

- Borg, G (1972). Perceived Exertion: A note on “history” and methods. *Med Sci Sports*, 5: 90-93.
- Gavin TP (2003). Clothing and thermoregulation during exercise. *Sports Med*, 33(13): 941-947.
- Gavin T.P., Babington J.P., Harms C.A., et al. (2001) Clothing fabric does not affect thermoregulation during exercise in moderate heat. *Med Sci Sports Med*, 33(12): 2124-2130.
- Gonzalez RR (1995). Biophysics of heat exchange and clothing: applications to sports physiology. *Med Exerc Nutr Health*, 4: 290-305.
- Hadid A, Yanovich R, Erlich G, Moran DS (2008). Effect of a personal ambient ventilation system on physiological strain during heat stress wearing a ballistic vest. *Eur J Appl Physiol*, 104: 311-319.
- <http://www.x-bionic.com/> (2009). X-Technology Swiss R&D AG, Switzerland.
- Jackson A.S. and Pollock M.L.(1978) Generalized equations for predicting body density of men. *Br J Nutr*, 40: 497-504.
- Kwon A., Kato M., Kawamura H., et al. (1998). Physiological significance hydrophilic and hydrophobic textile materials during intermittent exercise in humans under the influence of warm ambient temperature with and without wind. *Eur J Appl Physiol*, 78: 487-493.
- Simmons SE, Saxby BK, McGlone FP, Jones DA (2008). The effect of passive heating and head cooling on perception, cardiovascular function and cognitive performance in the heat. *Eur J Appl Physiol*, 104: 271-280.
- Thompson W.R., Gordon N.F., and Pescatello L.S (2010). Risks associated with physical activity. In: *ACSM's Guidelines for Exercise Testing and Prescription*. Philadelphia, PA: Wolters Kluwer; Lippincott Williams & Wilkins Benefits, p. 2-17.
- Thompson W.R., Gordon N.F., and Pescatello L.S (2010). Risks associated with physical activity. In: *ACSM's Guidelines for Exercise Testing and Prescription*. Philadelphia, PA: Wolters Kluwer; Lippincott Williams & Wilkins Benefits, p. 2-17.
- Wendt D., Van Loon LJC, Van Marken Lichtenbelt (2007). Thermoregulation during exercise in the heat. *Sports Med*, 37(8): 669-682.

- Wickwire J., Bishop P.A., Green J.M., Richardson M.T., Lomax R.G., Casaru C., Curtner-Smith M., and Doss B (2007). Physiological and comfort effects of commercial “wicking” clothing under a bulletproof vest. *Int J Ind Ergonomics*, 37: 643-651.
- Wingo J.E. and McMurray R.G (2007). Cardiovascular and thermoregulatory responses to treadmill running while wearing shirts with different fabric compositions. *Biol Sport*, 24(2): 177-187.
- Xiao-Qun Dai, Ritsuko Imamura, Guo-Lian Liu, and Fu-Ping Zhou (2008). Effect of moisture transport on microclimate under T-shirt. *Eur J Appl Physiol*, 104: 337-340.

TABLES

Table 1. Mean (\pm SD) change in rectal, forearm, quad, and chest temperatures, heart rate, RPE, RTC, front and back temperatures and relative humidity's under the shirts for regular synthetic cycling and channeled synthetic t-shirts from baseline to 15th km (n = 8) and from baseline to 30th km (n = 5).

	Change from baseline to 15- km with CHS	Change from baseline to 15- km with RSC	<i>p</i>	Change from baseline to 30- km with CHS	Change from baseline to 30-km with RSC	<i>p</i>
T _{re} (°C)	0.72 \pm 0.24	0.87 \pm 0.14	0.04	1.42 \pm 0.39	1.44 \pm 0.33	0.83
Forearm temp (°C)	1.71 \pm 0.68	1.62 \pm 0.65	0.82	1.60 \pm 0.50	1.82 \pm 0.66	0.64
Quad temp (°C)	2.94 \pm 0.57	3.1 \pm 0.92	0.74	3.60 \pm 0.66	3.65 \pm 0.73	0.86
Chest temp (°C)	2.78 \pm 0.48	2.71 \pm 0.70	0.79	2.78 \pm 0.42	3.12 \pm 0.57	0.01
HR (beats/min)	27.3 \pm 8.8	30.3 \pm 5.2	0.34	39.4 \pm 12.4	42.2 \pm 11.1	0.63
RPE	3.2 \pm 2.1	3.5 \pm 2.0	0.62	6.4 \pm 4.1	7.0 \pm 2.5	0.50
RTC	0.9 \pm 0.6	1.0 \pm 0.6	0.56	1.3 \pm 0.9	2.1 \pm 0.3	0.03
Front Micro-E temp (°C)	-3.40 \pm 1.63	1.13 \pm 1.41	< 0.01	-1.22 \pm 0.83	-0.81 \pm 1.70	0.53
Back Micro-E temp (°C)	1.52 \pm 1.22	1.70 \pm 0.57	0.58	0.41 \pm 1.29	1.54 \pm 0.97	0.15
Front relative humidity (%)	32.31 \pm 12.50	16.81 \pm 10.34	0.03	42.74 \pm 3.43	35.01 \pm 10.36	0.14
Back relative humidity (%)	4.76 \pm 8.73	3.89 \pm 6.26	0.76	9.53 \pm 8.32	7.10 \pm 8.73	0.15

T_{re} – rectal temperature; temp – temperature; HR - heart rate; RPE – ratings of perceived exertion; RTC – rating of thermal comfort; Micro-E – micro-environment; *p* – significance

FIGURE CAPTIONS

Figure 1. Exercise Protocol.

Figure 2. Rectal temperature (mean \pm SD) during 30-km cycling trial while wearing a channeled synthetic t-shirt or a synthetic t-shirt (n = 8 during first 15 km and n = 5 from 15th km to 30th km).

Figure 3. Chest temperature (mean \pm SD) during 30-km cycling trial while wearing a channeled synthetic t-shirt or a synthetic t-shirt (n = 8 during first 15 km and n = 5 from 15th km to 30th km).

Figure 4. Participants ratings of thermal comfort (mean \pm SD) during 30-km cycling time trial while wearing a channeled synthetic t-shirt or a synthetic t-shirt (n = 8 during first 15 km and n = 5 from 15th km to 30th km).

FIGURES

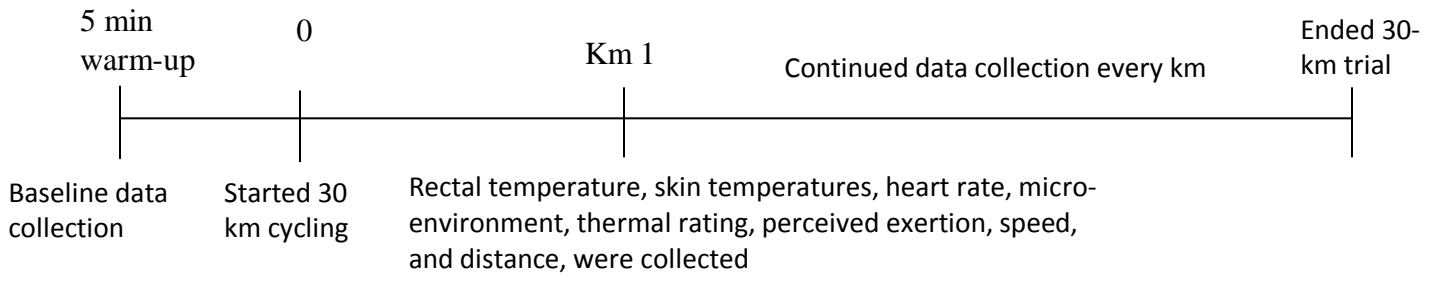
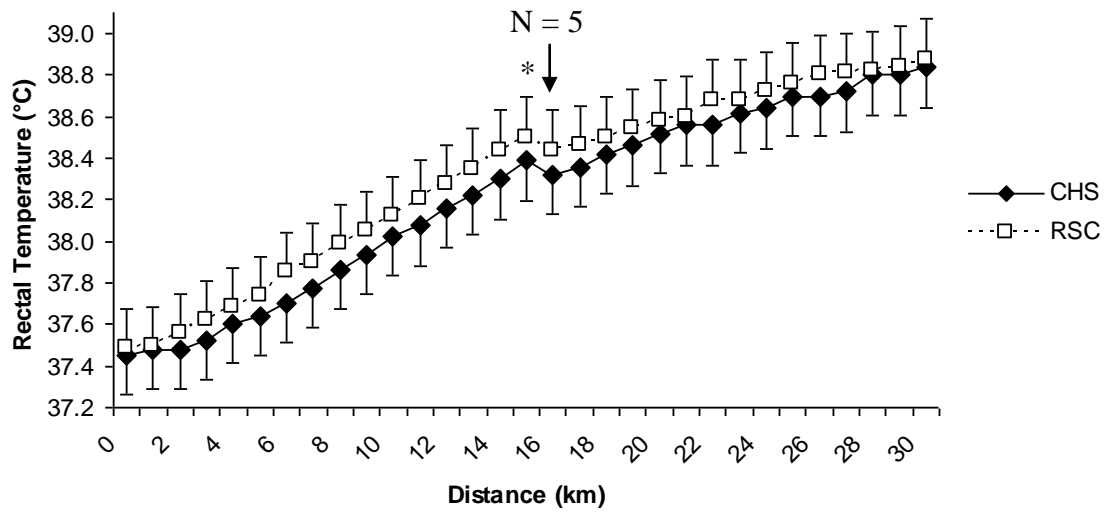


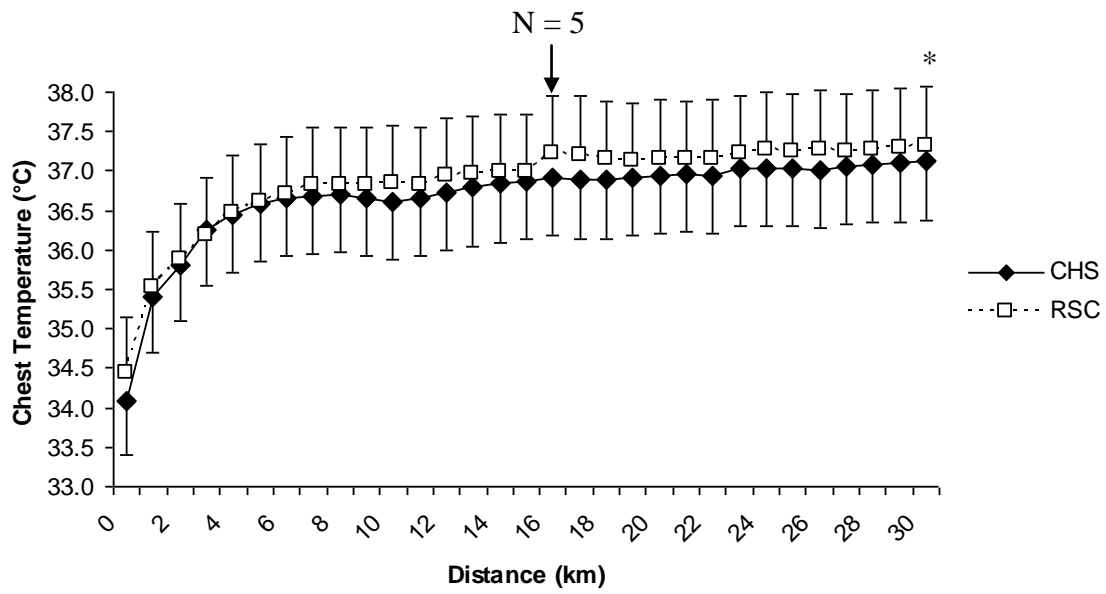
Fig 1.



Note: Drop in rectal temperature at 16th km occurred because three participants were removed from further analyses

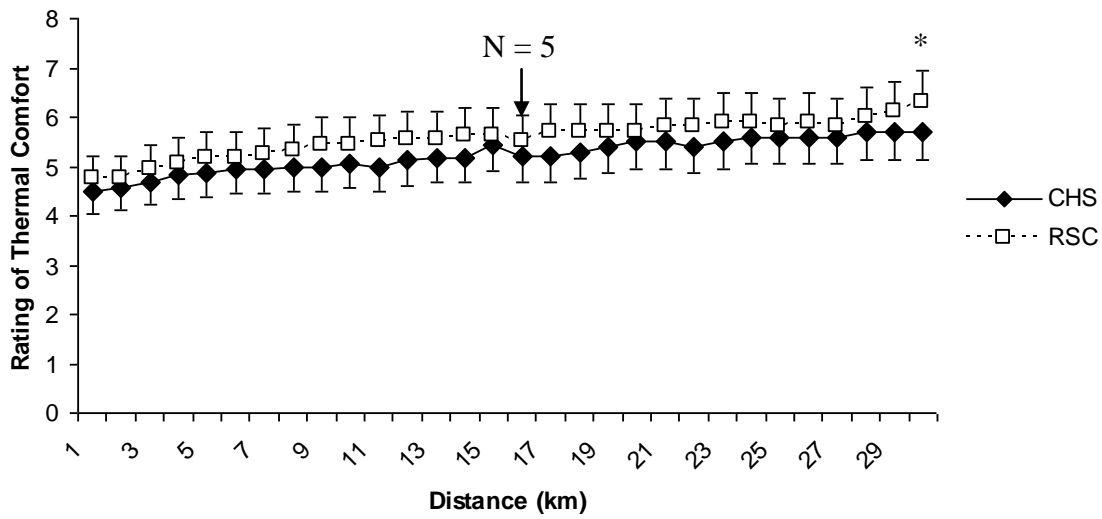
* - a significantly ($p < 0.04$) lower change in T_{re} between CHS and SYN shirt from baseline to 15 km

Fig 2.



* - a significantly ($p < 0.01$) lower change in chest temperature between CHS and SYN shirt from baseline to 30 km

Fig 3.



Note: Drop in rating of thermal comfort at 16th km occurred because three participants were removed from further analyses

* - a significantly ($p < 0.03$) lower change in thermal comfort between CHS and SYN shirt from baseline to 30 km

Fig 4.

CHAPTER IV

COMPRESSION GARMENT EFFECTS ON THERMOREGULATION, HEART RATE, AND THERMAL COMFORT SENSATION

ABSTRACT

This study compared the effects of channeled-fabric compression shorts (CCS), regular compression shorts (COM), and regular cycling shorts (CYC) on thermoregulation, heart rate, rating of perceived exertion (RPE), thermal comfort sensation, and sweat loss during a 30-km cycling trial in a hot (35 °C, 40% relative humidity) environment with 2.8 m/s air flow. In a repeated-measures counterbalanced design, eight active males attempted three 30-km cycling trials, each separated by 72 hours. Two participants were stopped at 25th km in all three trials during the 30-km time trial due to rectal temperature reaching termination criteria. All data were analyzed for all eight participants for 25-km instead of 30-km to preserve statistical power. Results indicated no significant difference ($p = 0.89$) in final core temperature among CCS (38.73 ± 0.39 °C), COM (38.74 ± 0.36 °C), and CYC (38.73 ± 0.38 °C). Furthermore, there was no significant ($p > 0.05$) main effect for heart rate, skin temperatures, RPE, and thermal comfort among the three different shorts. In conclusion, none of the shorts (CCS, COM, or CYC) altered thermal or heart rate responses, RPE or thermal comfort responses.

KEY WORDS: sport clothing, cycling shorts, thermal responses, compression clothing

INTRODUCTION

Previously, compression garments have been used in clinical settings for patients with circulatory problems (Simon et al., 2004; Agnelli, 2004). Compression garments supposedly increase venous blood flow and reduce venous stasis in the limbs due to the compression (Perlau et al., 1995). Recently, compression garments have been introduced to athletics and their use has spread worldwide at a fast pace. Possible performance and recovery benefits from wearing compression garment have been reported by researchers (Scanlan et al., 2008; Doan et al., 2003).

Compression garment manufacturers claim (e.g. www.X-BIONIC.com) that a compression garment stabilizes the muscle which increases blood flow to working muscles, thereby leading to improved performance. In addition possible benefits to performance, manufacturers state that compression garments with inner and outer channels in the fabric cools the body and aids sweat evaporation from the clothing by moving the moisture and warmth away from the skin. In previous research, conflicting evidence exists regarding the impact on thermoregulation of compression garments. Duffield and Portus (2007) found a significantly higher mean skin temperature throughout a 30-min intermittent exercise protocol with a full-body compression garment compared to control. However, there were no significant differences in heart rate or sprint times. Doan et al. (2003) reported significantly higher skin temperature with compression shorts compared to gym shorts during a five-minute warm-up. Houghton et al. (2009) found no significant difference in rectal temperature among compression shorts and control during a 4 x 15 minute repeated bout exercise. In addition, they found significantly higher mean skin temperature while wearing a compression garment.

Therefore, it appears that a regular compression garment seems to have some effect on thermoregulation. However, there are no published studies about channeled compression shorts which have inner and outer channels in the fabric design. These compression shorts might be beneficial for athletes for heat dissipation which in long run might lead to improved performance. Balilionis et al. (unpublished) found improved thermoregulatory and thermal comfort responses while wearing a channeled synthetic shirt during a 30-km cycling performance trial compared to synthetic shirt. Thus, the purpose of the current study was to compare the effects of regular biking shorts, regular compression shorts, and channeled compression shorts on physiological and comfort responses. A 30-kilometer cycling trial was chosen to assess the effects of the three different types of shorts on thermoregulation, heart rate, rating of perceived exertion (RPE), rating of thermal comfort sensation (RTC), and sweat rate.

METHODS

Experimental Approach to the Problem

The research was designed to compare the effects of regular cycling shorts (CYC), regular compression shorts (COM), and channeled compression shorts (CCS) on thermoregulation, heart rate, RPE, thermal comfort sensation, sweat loss, during a 30-km cycling trial in a hot environment (35 °C (95 °F), 40% relative humidity) with 2.8 m/s air flow. A single blind, repeated-measures counter-balanced study was conducted to evaluate the three shorts types.

Participants

Eight males, ranging from 21 to 31 years of age, agreed to participate in the study (Table 1). Sample size was estimated based on power analyses with an alpha level set at 0.05 and a

power of 0.8 to detect an effect of 0.2 °C difference in core temperature. Before testing, each participant was informed about procedures and provided their informed consent. The study was approved by the local Institutional Review Board.

All participants had been involved in at least 250 minutes of cardio-respiratory (cycling or running) activities per week. Exercising habits were obtained through a training status questionnaire. Each participant was screened with a Health Status Questionnaire (ACSM Risk Stratification) and a Physical Activity Readiness Questionnaire (PAR-Q) to determine any health risks prior to the study. Participants with a positive answer on the health questionnaires were excluded from the study. Finally, participants were asked to avoid alcohol, caffeine, and physical activities at least 24 hours before every session.

Preliminary Testing

During preliminary testing, screening procedures were completed and height, weight, and estimated percent body fat were recorded. Using skinfold calipers (Lange, Beta Technology Incorporated Cambridge, Maryland) three skinfold sites were measured (chest, abdomen, and thigh) and percent body fat was estimated from the sum of skinfold sites and age (Pollock et al. 1980). Participant's seminude weight was recorded with a digital scale (BWB-800, Tanita Corporation, Japan).

After screening procedures, a graded exercise test was completed to obtain participant's peak oxygen uptake ($VO_{2\text{peak}}$). Participants completed a five-minute warm-up on a stationary cycle (Velotron, Racer Mate Inc., Seattle, WA) with a work rate of 75 watts. Participants started a test at a work rate of 100 watts and work rate was increased by 25 watts every two minutes. A computerized metabolic measurement system (PARVO Medics, Salt Lake City, Utah) was used

to measure each participant's VO_{2peak} . The highest two consecutive 30-second averages for oxygen uptake were averaged and considered VO_{2peak} .

Clothing

Three different types of shorts were examined: (i) regular cycling shorts (100% polyester), (ii) regular compression shorts (100% polyester), and (iii) channeled compression shorts (84% polyamide, 10% polypropylene, 6% elastane) (X-Bionic, X-Technology Swiss R&D AG, Switzerland). Channeled synthetic shorts had inner and outer channels that were incorporated into the shorts design which might have an effect on heat transfer.

Each participant wore the same clothing except for the shorts throughout the trials. Clothing consisted of a cycling t-shirt (100% polyester), shorts that were assigned to that testing trial, socks, and running shoes. All shorts were medium size. The trial order of shorts worn was counterbalanced.

In order to determine the compression provided by the shorts, each participant's quadriceps circumference was measured with a tape. A blood pressure cuff was inflated to 20 mm Hg and placed on an object with the total circumference matched to participant's quad size. The shorts were placed on top of the cuff. The change in cuff pressure was considered as the pressure provided by the shorts. Overall, the highest pressure was recorded with channeled compression shorts (11 ± 2 mm Hg) and regular compression shorts (11 ± 1 mm Hg) compared to regular cycling shorts (5 ± 1 mm Hg).

Exercise Protocol

Preliminary testing and each 30-km cycling trial was separated by 72 hours. Experimental sessions included three treatments administered in counterbalanced order: 1) regular cycling shorts (CYC), 2) regular compression shorts (COM), and 3) channeled

compression shorts (CCS) in hot environment (35 °C, 40% relative humidity) with 2.8 m/s air flow (measured with anemometer (Anemo-thermometer, Control Company, TX) at the cycle ergometer handlebar) provided by a fan.

The remaining three experimental sessions followed the same pattern. After arriving at the laboratory, participants provided a urine sample for hydration status based on urine specific gravity (USG). The criterion for USG was 1.020 and all participants met this criterion. Also, the post-exercise urine sample was collected in order to determine post-exercise hydration status. Next, with non-exercise shorts each participant was weighed on a digital scale (BWB-800, Tanita Corporation, Japan). Post-exercise weight was also collected with the same non-exercise shorts. Sweat loss was estimated as (Sanders et al., 2005): $\text{Sweat loss (L)} = [\text{Pre-exercise body weight (kg)} + \text{fluid ingested (L)} - \text{post-exercise body weight (kg)}]$. None of the participants had to urinate during the trial so urine weight was not included into the sweat loss formula.

Participants inserted a thermocouple (RET-1, Physitemp Instruments Inc., Clifton, NJ) eight centimeters past the anal sphincter in order to measure rectal temperature (T_{re}). After that, skin thermocouples (SST-1, Physitemp Instruments Inc., Clifton, NJ) were taped in such a way as not to add insulation, on the right side of the chest, forearm, and quad. Finally, a heart rate monitor (Polar Electro, Kemplee, Finland) was placed around the chest to measure heart rate (HR) through the trial.

A small metal device which records local temperature and humidity (i-button DS 1923, Maxim Integrated Products, CA), was taped on the right side of the quadriceps under the shorts in order to record the temperature and relative humidity of the microenvironment under the shorts.

Participants dressed in a cycling shirt, entered the heat chamber and were seated on the stationary cycle. The cycle seat was adjusted before the trial and kept the same for all three trials. After five minutes of warm-up with a power output of 75 watts, participants were asked to complete a 30-km trial as fast as possible. Power output was adjusted every kilometer as desired by the participant during the first 30-km trial session, and the same power output was used during the following two sessions. Time, resistance, and distance traveled were measured and recorded with the software of the ergometer. Trials were identical.

The 30-km trial was stopped if: (i) rectal temperature reached 39.3 °C or (ii) a participant asked to stop due to volitional exhaustion. During the trial, participants were allowed to drink water at *ad libitum*. The total volume of water consumed was recorded.

Baseline rectal temperature and skin temperatures (forearm, chest and quadriceps) were recorded prior to the 30-km cycling trial. During the trial, rectal temperature, skin temperature, HR, rating of perceived exertion (RPE) using Borg's 6-20 scale (Borg, 1972), rating of thermal comfort (RTC) using an 8-point scale (scale ranged from 0.0 unbearably cold to 8.0 very hot), and speed were collected every kilometer during the 30-km trial and at the end of the trial. Local temperature and humidity under the shorts were recorded every minute.

Statistical Analyses

Statistical analyses were performed on a commercially available statistical platform (IBM SPSS Statistics 19, Illinois, Chicago). One-way repeated-measures analyses of variance (ANOVAs) were used to analyze the difference among regular cycling shorts, regular compression short, and channeled compression shorts for different variables. Differences among shorts for any variable that demonstrated significance were examined by a LSD post-hoc multiple comparison test. Rectal temperature, skin temperatures, HR, RPE, and RTC over time

for each treatment were analyzed using two-way repeated measures ANOVAs (condition x distance). Significance was accepted at the $\alpha < 0.05$ level. Data were reported as means and standard deviations (SD).

RESULTS

The heat chamber temperature was 35.1 ± 0.8 °C with relative humidity of $40.0 \pm 1.4\%$. There was no significant difference ($p > 0.05$) in temperature or relative humidity between the trials.

Two participants were stopped in all three trials due to T_{re} reaching 39.3 °C. Both participants reached 39.3 °C at 25 km in all three conditions. In order to maximize statistical power, it was decided to keep all participants into statistical analyzes, which meant that all statistical analyses were performed on 25-km data and the last 5-km data were not included in the analyses.

There was no significant ($p = 0.36$) differences in baseline T_{re} among CCS (37.31 ± 0.27 °C), COM (37.28 ± 0.29 °C), and CYC (37.26 ± 0.28 °C). Also, the T_{re} main effect was not significantly different ($p > 0.05$) among CCS, COM, or CYC at 25 km during the trial (Fig 1). Final (25-km) T_{re} was not significantly different ($p = 0.85$) among the three types of shorts (Table 2). In addition, there was no significant difference in final forearm ($p = 0.47$), chest ($p = 0.16$), or quadriceps ($p = 0.56$) skin temperatures between the three shorts (Table 2).

Furthermore, the main effect was not significantly different ($p > 0.05$) for HR, RPE, speed and thermal comfort sensation during the 25-km trial among CCS, COM, and CYC (Table 2). Mean heart rate response over distance are presented in Figure 2. Whereas, water consumption was significantly ($p < 0.05$) lower with CYC (0.92 ± 0.20 L) compared to CCS (1.04 ± 0.24 L),

and COM (1.05 ± 0.21 L). Sweat loss was not significantly ($p = 0.20$) different after the cycling trial among shorts (Table 2).

Finally, main effect was not significantly different ($p > 0.05$) for temperature or relative humidity under the shorts during among CCS, COM, and CYC (Table 2).

DISCUSSION

Manufacturers of channeled compression shorts claim that these shorts help to keep the body cooler by improving moisture dissipation from the skin surface. Therefore, the purpose of the present study was to compare channeled compression shorts to regular cycling shorts and regular compression shorts regarding thermoregulation, heart rate, and thermal comfort sensation during 25-km cycling trial in a hot (35 °C, 40% relative humidity) environment with 2.8 m/s air flow.

The current study found no difference between the shorts in thermoregulatory, heart rate, or thermal comfort during a 25-km cycling trial with the same clothing except for shorts. However, it is worth noting that CCS and COM provided two times higher compression compared to the CYC shorts. Therefore, the compression provided with CCS and COM may be not sufficient enough to benefit thermoregulation or heart rate. There is a need for further research to determine the optimal compression level that could positively influence physiological responses.

Furthermore, no difference was found for heart rate. Heart rate measure can be used as an indirect method of assessing venous return (Ali et al., 2007). Duffield and Portus (2007) also reported no significant difference in heart rate during repeated run sprint performance between a compression garment and control. Berry et al. (1990) found no difference in heart rate response

during an exhaustive run between a compression garment and control. Similarly, Duffield et al. (2010) found no difference in heart rate response during sprint performance between compression and control garments.

However, a few studies have reported beneficial effects of compression garments on heart rate (Ali et al., 2007), venous edema (Vayssairant et al., 2000), or plasma volume (Chatard et al., 2004). Ali et al. (2007) reported that with a compression garment, a lower heart rate was observed during a 10-km run and this was associated with improved venous return. However, in the present study HR was not different among the trials. Thus it can be assumed that venous return was similar among the three different shorts in our study. The reason for the discrepancy between the present and Ali et al. (2007) studies may be related to different pressures provided by the clothing. In the present study, clothing pressure was lower compared to Ali et al. (2007) and perhaps with higher clothing pressure, the HR would be lower. Therefore, it can be concluded that COM and CCS did not improve venous return and did not reduce HR compared to CYC under the conditions of our study.

Wearing COM or CCS did not differentially affect core and skin temperatures compared to CYC. This indicates that the compression garments did not influence heat removal from the body different compared to CYC. This supports the study by Houghton et al. (2009) who found no difference in core temperatures between compression garment and control during 4 x 15 minutes of exercise in a 17 °C environment. Furthermore, there was no difference in quadriceps, forearm, or chest skin temperatures further supporting that CCS alone was not better in reducing quadriceps skin temperatures compared to COM or CYC. Duffield and Portus (2007) reported significantly lower skin temperatures with a control compared to a compression garment. Doan et al. (2003) also reported increased skin temperature during a five minute warm-

up with a compression garment compared to gym shorts. The difference between the studies can be attributed to different exercise environments. In the present study we used 35 °C and in the Duffield and Portus (2007) study the temperature was 15 °C. They speculated that prolonged exercise or exercise in a hot environment might increase core temperature due to increased skin temperature under the compression garment. However, this was not the case in our study. There was no difference in skin temperatures among shorts and rectal temperature was not different between the three conditions.

Inner and outer channels were incorporated into the CCS shorts design. According to the manufacturer these channels help to remove the moisture and warmth from the body. However, CCS evidenced no advantage in heat removal compared to COM and CYC. Similar local temperature and relative humidity under the shorts further suggests that wearing CCS or COM did not reduce thermal strain. However, Balilionis et al. (unpublished) found lower rectal and chest temperatures during a 30-km cycling trial while wearing a channeled synthetic shirt compared to a regular synthetic shirt. Lower temperatures were associated with channels that are incorporated into the design which theoretically facilitated movement of moisture off the skin and improved cooling. This benefit was not seen in the present study. This might be due to a smaller body surface area that is covered by the compression shorts compared to a t-shirt.

Moreover, no difference was found in RPE or thermal comfort among shorts. This supports Houghton et al. (2009) who found no difference in RPE between compression and control shorts during intermittent exercise. This indicates that compression or channeled compression shorts did not affect perception during the trial. Also, no difference in thermal comfort among shorts indicates that participants perceived thermal comfort similarly, regardless of treatment.

During the cycling trial participants consumed less water during CYC compared to CCS and COM. However, there was no difference in sweat loss. This indicates that the compression garment (CCS or COM) did not affect sweating mechanisms. As rectal temperature results indicated, CCS or COM were not able to lower rectal temperature compared to CYC. Thus, evaporative mechanisms were not different among the shorts. This means that channels that were incorporated into CCS shorts did not improve cooling the skin surface compared to CYC and COM.

CONCLUSIONS

In conclusion, wearing channeled compression shorts did not provide any thermoregulatory or cardiovascular benefits compared to CYC and COM. Channels that are incorporated into the CCS shorts did not improve moisture evaporation and heat transfer from the skin. Finally, there was no difference in thermal comfort among the shorts, suggesting, that none of the shorts provided an advantage over the others in increasing the perception of wearers' thermal comfort.

REFERENCES

- Ali A, Caine MP, Snow BG (2007). Graduate compression stockings: physiological and perceptual responses during and after exercise. *J Sports Sci*, 25: 413-419.
- Agnelli G (2004). Prevention of venous thromboembolism. *Circulation*, 110: 4-12.
- Berry MJ, Bailey SP, Simpkins LS (1990). The effect of elastic tights on the postexercise response. *Can J Sport Sci*, 15: 144-148.
- Borg G (1972). Perceived Exertion: A note on “history” and methods. *Med Sci Sports*, 5: 90-93.
- Chatard JC, Atlaoui D, Farjanel J (2004). Elastic stocking, performance and leg pain recovery in 63-year-old sportsmen. *Eur J Appl Physiol*, 93: 347-352.
- Doan BK, Kwon Y, Newton RU, Shim J, Pooper EM, Rogers R., et al. (2003). Evaluation of a lower-body compression garment. *J Sports Sci*, 21: 601-610.
- Duffield R and Portus M (2007). Comparison of three types of full-body compression garments on throwing and repeat-sprint performance in cricket players. *Br J Sports Med*, 41: 409-414.
- Duffield R, Cannon J, King M (2010). The effects of compression garments on recovery of muscle performance following high-intensity sprint and plyometric exercise. *J Sci Med Sport*, 13: 136-140.
- Houghton LA, Dawson B, and Maloney SK (2009). Effects of wearing compression garments on thermoregulation during simulated team sport activity in temperate environmental conditions. *J Sci Med Sport*, 12: 303-309.
- <http://www.x-bionic.com/> (2009). X-Technology Swiss R&D AG, Switzerland.
- Jackson AS and Pollock ML (1978). Generalized equations for predicting body density of men. *Br J Nutr*, 40: 497-504.
- Perlau R, Frank C, Fick G (1995). The effect of elastic bandages on human knee proprioception in the uninjured population. *Amer J Sports Med*, 23: 251-255.
- Sanders AG, Dugas JP, Tucker R, Lambert MI, Noakes TD (2005). The effects of different air velocities on heat storage and body temperature in humans cycling in a hot, humid environment. *Acta Physiol Scand*, 183: 241-255.
- Scanlan AT, Dascombe BJ, Reaburn PRJ, and Osborne M (2008). The effects of wearing lower-body compression garments during endurance cycling. *Int J Sports Physiol Perform* 3: 424-438.

Simon DA, Dix FP, McCollum CN (2004). Management of leg ulcers. *BMJ*, 328: 1358-1362.

Vayssairant M, Ziani E, Houot B (2000). Placebo controlled efficacy of class 1 elastic stockings in chronic venous insufficiency of lower limb. *J Mal Vasc*, 25: 256-262.

TABLES

Table 1. Participants mean (\pm SD) age (y), weight (kg), height (cm), percent body fat (%), $VO_{2\text{peak}}$ (ml/kg/min), and leg circumference (cm) (n = 8).

Characteristics	Mean (\pm SD)
Age (y)	25.1 \pm 4.5
Weight (kg)	78.29 \pm 10.27
Height (cm)	176.88 \pm 7.36
% body fat	10.14 \pm 4.69
$VO_{2\text{peak}}$ (ml/kg/min)	48.53 \pm 4.69
Leg circumference (cm)	57.00 \pm 4.47

Table 2. The main effect of rectal, forearm, quadriceps, and chest temperature, heart rate, rating of perceived exertion, rating of thermal comfort, speed, RPM, temperature and relative humidity under the shirts, water consumption, and sweat loss responses during 25-km cycling time trial while wearing channeled compression shorts, compression shorts, and cycling short (n = 8).

	CCS	COM	CYC	p
	Means ± SD	Means ± SD	Means ± SD	
T _{re} (°C)	38.73 ± 0.39	38.74 ± 0.36	38.73 ± 0.38	0.85
Forearm temp (°C)	36.05 ± 0.37	36.05 ± 0.51	35.95 ± 0.48	0.47
Quadriceps temp (°C)	37.13 ± 0.46	37.06 ± 0.39	37.08 ± 0.50	0.56
Chest temp (°C)	36.83 ± 0.43	36.84 ± 0.51	36.73 ± 0.49	0.16
HR (beats/min)	171.0 ± 19.8	169.0 ± 16.2	168.9 ± 18.3	0.40
RPE	15.4 ± 1.7	15.8 ± 1.7	15.6 ± 2.1	0.52
RTC	6.19 ± 0.65	6.06 ± 0.78	6.06 ± 0.78	0.58
Speed (km/h)	28.18 ± 3.98	28.10 ± 3.82	28.35 ± 3.78	0.10
RPM	94.94 ± 13.45	94.82 ± 12.89	95.47 ± 12.67	0.22
I-button temp (°C)	35.05 ± 1.28	34.33 ± 2.62	35.04 ± 0.88	0.41
I-button relative humidity (%)	46.77 ± 4.16	51.54 ± 15.48	46.71 ± 3.86	0.37
Water consumption (L)	1.04 ± 0.24*	1.05 ± 0.21#	0.92 ± 0.20*#	0.02
Sweat loss (L)	1.53 ± 0.23	1.44 ± 0.31	1.59 ± 0.28	0.2

T_{re} – rectal temperature; HR - heart rate, RPE – ratings of perceived exertion; RTC – rating of thermal comfort, RPM – revolutions per minute, CCS – channeled synthetic shorts, COM – regular compression shorts, CYC – regular cycling shorts

* - significant ($p = 0.002$) difference between channeled compression short and cycling shorts

- significant ($p = 0.03$) difference between regular compression shorts and cycling shorts

FIGURE CAPTIONS

Figure 1. Rectal temperature response during the cycling trial while wearing channeled compression shorts, regular compression shorts, and cycling shorts (n = 8).

Figure 2. Heart rate response during the cycling trial while wearing channeled compression shorts, regular compression shorts, and cycling shorts (n = 8).

FIGURES

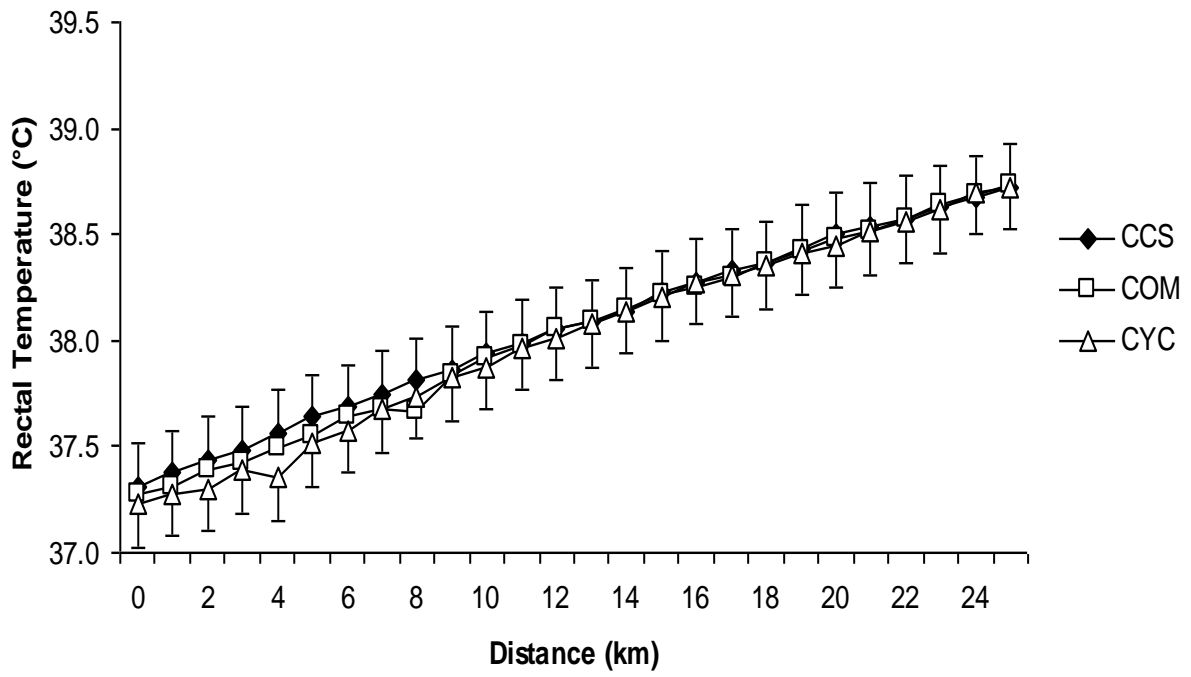


Fig 1.

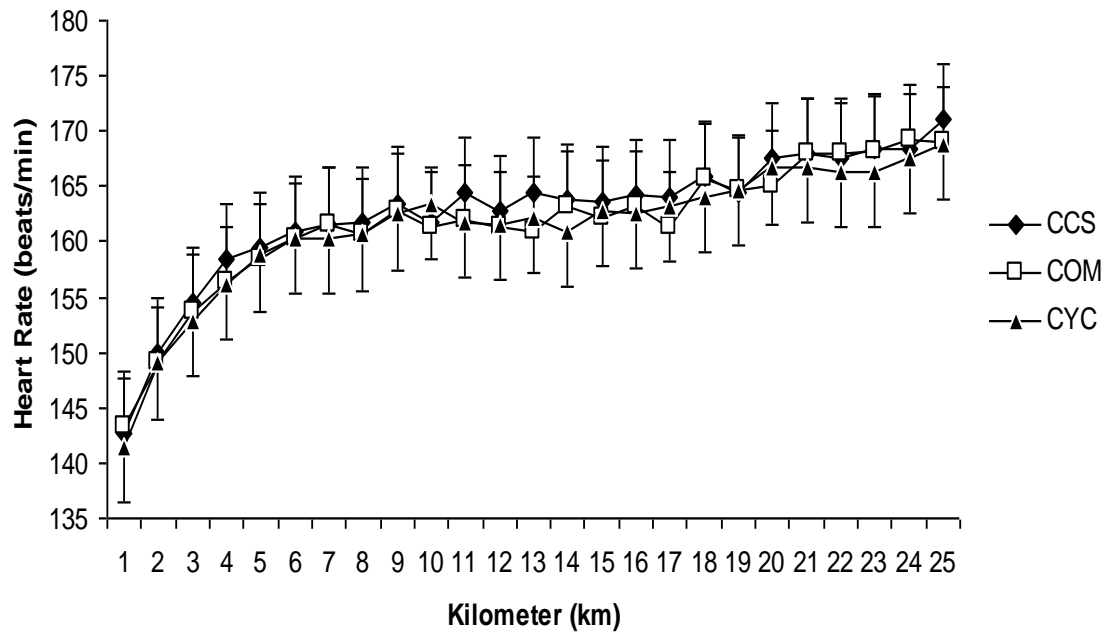


Fig 2.

CHAPTER V

CONCLUSIONS

Conclusions from first two studies suggest that channeled synthetic t-shirt provided slightly better thermoregulatory responses compared to a non-channeled synthetic shirt. Rectal and temperatures were lower with a channeled synthetic shirt compared to a synthetic shirt. In addition, better thermal comfort response was observed with channeled synthetic shirt compared to synthetic shirt. Overall, people might benefit by wearing channeled synthetic shirt, thus, it can reduce the risk for heat illnesses and enhance comfort levels. This is very important for athletes and ballistic vest wearer's who may endure long hours of heat exposure. In contrast to first two studies, channeled compression shorts did not provide any thermoregulatory, cardiovascular, or thermal comfort benefits compared to regular cycling shorts and regular compression shorts.