

CARDIOVASCULAR AND THERMOREGULATORY RESPONSES TO TREADMILL RUNNING WHILE WEARING SHIRTS WITH DIFFERENT FABRIC COMPOSITION

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Abstract. Clothing must be worn in many athletic and occupational situations as part of a uniform or for protection from the environment, but clothing interferes with sweat evaporation and heat dissipation. Thus, the heat dissipation qualities of clothing worn by athletes, soldiers, and others working and/or competing at moderate to high workloads is important. The purpose of this study was to determine if a synthetic shirt purported by the manufacturer to be advantageous in dissipating heat permits more effective heat dissipation than a cotton shirt during exercise in a temperate environment. **Methods:** Nine active males ran on a treadmill at 65% $\text{VO}_{2\text{peak}}$ for 45 min in 22°C while wearing cotton sweatpants and either a long-sleeve synthetic shirt (SS), cotton shirt (CS), or no shirt (NS). The first and second trials were counterbalanced, and the third trial was determined by default. At least one week lapsed between trials. **Results** (means \pm SD): There were no differences in RPE, VO_2 , change in rectal temperature (ΔT_{re}), or change in heart rate (ΔHR) between conditions ($p > 0.05$). Final T_{re} in SS ($38.8 \pm 0.3^\circ\text{C}$) was lower than CS ($39.1 \pm 0.4^\circ\text{C}$) but not different than NS ($38.9 \pm 0.2^\circ\text{C}$). Mean skin temperature was lower in NS than CS ($p < 0.05$). Total water loss was lowest in NS ($1.1 \pm 0.3\text{L}$, $p < 0.05$), while SS ($1.4 \pm 0.3\text{L}$) and CS ($1.5 \pm 0.3\text{L}$) were similar ($p > 0.05$). Thermal sensation was lower in SS and NS than CS. **Conclusion:** Wearing a synthetic shirt provides a limited thermoregulatory benefit compared to a standard cotton shirt, but comfort is enhanced.

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Keywords: Clothing - Heart rate - Exercise - Body temperature - Thermoregulation

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Introduction

During exercise, body temperature increases because of heat energy generated by muscular work and the metabolic processes associated with the activity. Humans can only endure a fluctuation in body temperature of approximately 4°C. Therefore, the heat generated during exercise must be dissipated from the body or hyperthermia can occur, which can inhibit performance by compromising muscle function and metabolism and leading to premature fatigue [1,2]. Heat can be dissipated via convection and radiation of heat from the skin surface to the environment, but heat is dissipated primarily by evaporation of sweat from the skin [1].

The safest and most efficient way to exercise in warm conditions is with as much skin surface exposed as possible in order for maximal evaporation to occur. However, this is not always practical or feasible because clothing must be worn in many athletic and occupational situations, but clothing interferes with sweat evaporation [10]. Thus, the heat dissipation qualities of clothing worn by athletes, soldiers, and others working and/or competing at moderate to high workloads is important, and this becomes even more important when the work is performed in environmentally stressful conditions (high heat and humidity, for example). This has prompted the development of permeable clothing by clothing manufacturers in an effort to produce garments that are both comfortable and efficient at dissipating heat.

Cotton and similar fabrics are only effective in reducing heat load after the garment becomes soaked with sweat. As the moisture seeps through the garment, evaporation begins to occur. However, a soaked shirt or pair of shorts is not usually comfortable to wear [10] as evidenced by the practice of an athlete changing sweat-soaked shirts, shorts, etc. during the course of an event. Furthermore, the soaking of the garment can result in excessive skin wettedness, or hidromeiosis, which reduces sweat rate and heat dissipation via evaporation [8,10,11]. Unfortunately, removing any saturated clothing prevents the sweat soaked into the garment from vaporizing, so the water in the discarded clothing is wasted in the sense that it only dehydrates the athlete without offering any heat dissipation.

Synthetic fabrics designed to wick moisture to the surface of the garment have been developed as an alternative to cotton. The synthetic fabric under investigation in this study consists of 100% polyester fiber that has been treated electrostatically so that moisture produced via perspiration is spread out over the garment and transported away from the skin to the garment surface for evaporation. Despite its



purported thermoregulatory advantage in enhancing sweat evaporation, the heat dissipation qualities of this fabric have not been tested during exercise. Thus, it is unknown whether it is better suited for heat dissipation than cotton apparel. The purpose of this study was to determine if a synthetic shirt (SS) permits more effective heat dissipation than a cotton shirt (CS) during exercise in a temperate environment. We hypothesized that measures of thermal and cardiovascular strain would be lower during SS than CS.

Materials and Methods

Subjects: Nine active males voluntarily consented to participate. This sample size is sufficient to detect a change in rectal temperature (ΔT_{re}) effect size of $d=0.5$ SD (where d equals the difference between the expected largest and smallest means within a factor divided by σ , the expected mean within-cell standard deviation [13] across the 3 measures of change in rectal temperature synthetic shirt [SS], cotton shirt [CS], and no shirt [NS]) analyzed in a one-way repeated measures ANOVA, assuming the test-retest correlation for ΔT_{re} is ~ 0.9 and power ~ 0.8 [9]. Subject characteristics were as follows (means \pm SD): age = 25 ± 3 years, height = 176.5 ± 8.6 cm, weight = 79.2 ± 11.3 kg, %body fat estimated from bioelectrical impedance analysis = $11.3 \pm 3.5\%$, and peak oxygen uptake (VO_{2peak}) 57.9 ± 5.7 ml/kg/min.

Procedures: Subjects visited the laboratory 4 times. All testing took place in an environment maintained at $22 \pm 1^\circ\text{C}$ and $26 \pm 11\%$ relative humidity. On the first visit (VO_{2peak}) was determined from a graded exercise test (GXT) employing a modified Åstrand [12] protocol on a treadmill (Quinton Q65 Series 90 Treadmill, Quinton Instrument Company, Bothel, WA). Expired gases were analyzed using open-circuit spirometry on an electronic metabolic measurement system (TrueMax 2400 Metabolic Measurement System, PARVO Medics, Salt Lake City, UT). The highest 30-second VO_2 value recorded was considered VO_{2peak} . This value was then used to set the exercise workload ($65\% VO_{2peak}$) during each of the successive visits to the laboratory.

Each of the remaining 3 visits to the laboratory followed an identical protocol and was separated by approximately 1 week. Cotton sweat pants, polyester running shorts (Burlington Industries, Inc., Greensboro, NC, lined with CoolMax[®] fabric manufactured by DuPont[®], Wilmington, DE), socks (Wrightenberry Mills, Inc., Burlington, NC, and also made with CoolMax[®] fabric by DuPont[®], Wilmington, DE), and shoes were worn for all trials while the upper body was covered by either a long-sleeve SS or CS, or no shirt (NS). These conditions occurred in random



order and were counterbalanced for trials 1 and 2 with the condition in the third trial being determined by default.

Twenty-four hours prior to each of the visits, subjects were instructed to consume 2/3 fluid ounces of water per pound of body weight to ensure euhydration upon start of the next day's exercise session. Upon arrival at the laboratory, subject's shoes and clothing that was to be worn for that trial were weighed in grams (g) using a digital scale (Pro Plus Motion Detection System Model 2101 Stand-On Scale, Health-o-meter, Inc., Bridgeview, IL). Each subject then provided a urine sample for assessment of hydration status based on urine specific gravity (USG). USG was measured using a refractometer (American Optical Corp., Keene, NH). The highest allowable USG was 1.025, and each subject met this criterion. Subjects then dressed in the clothes that were to be worn for that trial (except for the shirt) and inserted a rectal thermometer (Model 401 YSI thermistor, Yellow Spring Instruments, Yellow Springs, OH) 12 cm past the anal sphincter.

Body mass was then obtained in kilograms (kg) with the shirt to be worn for that trial (in the case of SS and CS) draped over the subject's shoulder. Next, skin thermistors (Model 409A YSI, Yellow Spring Instruments, Yellow Springs, OH) were placed on the forehead, left medial anterior thigh, left upper arm, left upper back over the scapula, and left side of the abdomen (a skin thermistor was also used to obtain temperature at the fingertip of the left hand, but this thermistor was handed to the subject at each time point when skin temperature was recorded). Mean skin temperature (T_{sk}) was calculated from the following formula [7]: $T_{sk} = 0.07$ (head) + 0.14 (arm) + 0.05 (finger) + 0.39 (thigh) + 0.18 (abdomen) + 0.17 (back). Temperatures were displayed on a YSI Precision 4000A Thermometer (Yellow Spring Instruments, Yellow Springs, OH) and a Cole Parmer Five Channel Thermistor Thermometer (Cole Parmer Instrument Company, Vernon Hills, IL). Additionally, electrocardiogram (ECG) electrodes were attached in the standard 3-lead ECG configuration to monitor HR during the exercise trial. If applicable, then the subject donned the shirt being tested that day.

The subject then sat for 5 min while heart rate, all temperatures, and thermal sensation (sensation of temperature based on a Likert scale ranging from 0.0 = unbearably cold to 8.0 = unbearably hot [5,15]) were recorded. Upon completion of the 5-min rest period, the subject began the exercise trial with a 2-min brisk walk at approximately 3.5 mph to serve as a warm-up. Upon completion of the warm-up, the subjects completed a 45-min treadmill run at a grade of 1.5% and speed intended to elicit 65% VO_{2peak} . A fan (Patton[®] High Velocity Fan model U2-1487, Patton Electric Company, Inc., New Haven, IN) was fastened to the front of the treadmill and set at an angle which directed airflow at the upper body of the



subject. The fan was set to operate at the lowest level (~2.4 m/s) and served to elicit some convective heat loss during the exercise trial and aid in the evaporative response. Oxygen uptake (VO_2) was measured during the last 2.5 min of the first 5-min segment, then during the last 2.5 min of each 10-min segment thereafter throughout the trial. Additionally, subjects were allowed to drink from a pre-weighed container of water *ad libitum* throughout the test. Heart rate (HR), rectal temperature (T_{re}), skin temperature (T_{sk}) at each of the different sites, rating of perceived exertion (RPE) [3], and thermal sensation were recorded at the same time points as VO_2 . Additionally, the time at which the first visible sign of sweat appeared on the forehead was recorded.

Upon completion of the 45-min run, subjects sat in a chair for an additional 20 min. HR, T_{re} , T_{sk} , RPE, and thermal sensation were measured at 5-min intervals. During this recovery, subjects were allowed to continue to drink from the pre-weighed container of water, and the amount consumed was then measured. After recovery, subjects were weighed while wearing the exercise clothing and shoes. Subjects were then asked to change clothing, and the shoes and clothing were placed in a pre-weighed plastic bag in order to prevent further evaporation before weighing. Then the exercise clothing and shoes were weighed. Based on subject weights, volume of fluid consumed, and clothing weights pre and post exercise, sweat loss and sweat rate were calculated. Upon completion of the study, subjects were compensated by being given a SS, a CS, one pair of running socks, one pair of running shorts, one pair of sweat pants, and a water bottle.

Statistical analyses: Descriptive statistics were computed for all variables, including the subject characteristics (height, weight, body fat percentage, and $\text{VO}_{2\text{peak}}$). All statistical procedures utilized a totally within subjects design with $\alpha=0.05$.

Data for different variables were analyzed using one-way repeated measures analyses of variance (ANOVAs). When appropriate, pairwise comparisons were made using a Bonferroni-adjusted alpha level to compare individual conditions.

T_{re} , VO_2 , HR, and thermal sensation measured over time for each condition (SS, CS, and NS) were analyzed using two-way repeated measures ANOVAs (condition \times time) for each variable. All statistical analyses were performed using SPSS statistical software (SPSS, Inc., Chicago, IL).

Results

All data are presented as means \pm SD. All subjects were adequately hydrated before each trial based on average USG of 1.012 ± 0.008 , and water consumed was



similar under each condition: SS = 0.7 ± 0.5 L, CS = 0.8 ± 0.4 L, and NS = 0.6 ± 0.3 L.

Cardiovascular, metabolic, and perceptual responses. While HR rose over time during exercise, there were no significant differences between conditions for change in heart rate (Δ HR) (Table 1). Even though RPE was no different among conditions, average thermal sensation during the CS trials was significantly higher than the other two conditions, and this trend persisted until the end of exercise such that final thermal sensation was highest for the CS condition compared to the other two.

Table 1

Cardiovascular, metabolic, and perceptual responses during 45 min of treadmill running at $\sim 63\%$ $\dot{V}O_{2peak}$ while wearing a synthetic shirt, cotton shirt, or no shirt

Variable	Condition		
	Synthetic Shirt	Cotton Shirt	No Shirt
RPE	12 \pm 1	12 \pm 1	12 \pm 1
$\dot{V}O_2$ (ml/kg/min)	37.5 \pm 3.1	37.8 \pm 2.9	37.8 \pm 3.5
Δ HR (bt/min)	15 \pm 8	19 \pm 8	15 \pm 5
Mean Thermal Sensation	4.8 \pm 0.4	5.3 \pm 0.5*	4.4 \pm 0.7
Final Thermal Sensation	5.6 \pm 0.5	6.1 \pm 0.6*	5.2 \pm 0.9

RPE, rating of perceived exertion, $\dot{V}O_2$, oxygen uptake; Δ HR, change in HR from 5 min to 45 min; * $p < 0.05$ CS vs. SS and NS trials

Thermoregulatory responses. The metabolic and thermal strain of the exercise resulted in substantial water loss (>1 L) during the 45 min in all conditions, but total water loss was lower in NS (1.1 ± 0.3 L) compared to SS (1.4 ± 0.3 L) and CS (1.5 ± 0.3 L). Sweat rate followed a similar trend with a lower sweat rate during the NS trials compared to the other two conditions (Fig. 1; $p < 0.05$).



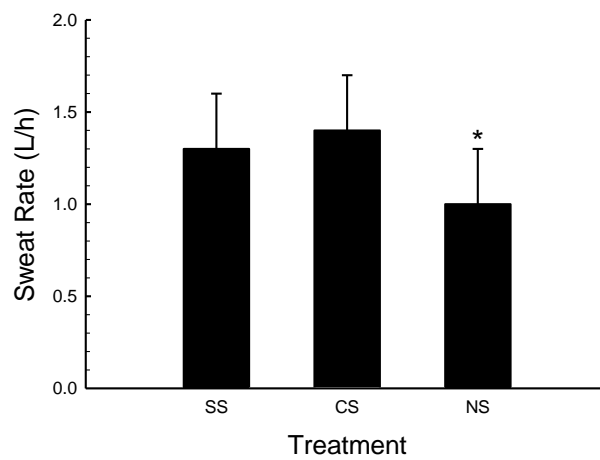


Fig. 1
Sweat rate during 45 min of treadmill running at ~63% VO_{2peak} while wearing a synthetic shirt (SS), cotton shirt (CS), or no shirt (NS); * $p < 0.05$ NS vs. SS and CS

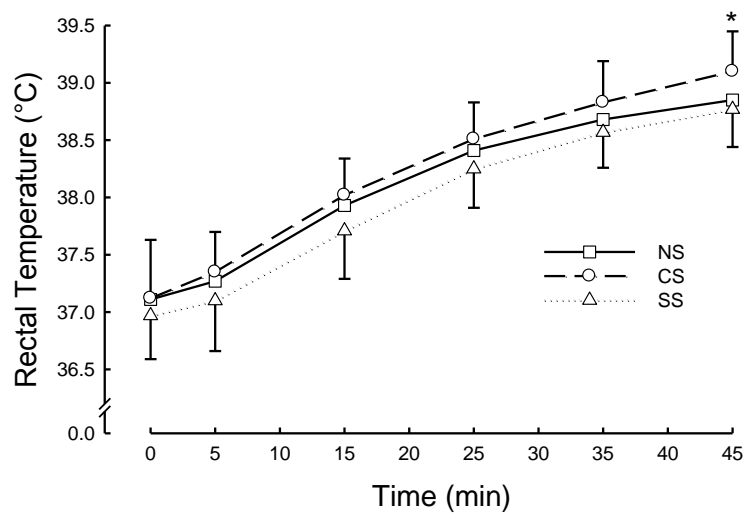


Fig. 2
Rectal temperature during 45 min of treadmill running at ~63% VO_{2peak} while wearing a synthetic shirt (SS), cotton shirt (CS), or no shirt (NS); $p > 0.05$ comparing conditions; * $p < 0.05$ SS vs. CS at the end of exercise



While T_{re} rose nearly 2°C from the start to end of exercise, there was no difference among treatment conditions (Fig. 2); however, T_{re} was significantly lower for the SS trials ($38.8\pm 0.3^{\circ}\text{C}$) than for the CS trials ($39.1\pm 0.4^{\circ}\text{C}$) in the final min of exercise. In addition to measuring T_{re} response over time, change (post – pre) in T_{re} during each of the three conditions was calculated, and no differences were evident: SS = $1.80\pm 0.37^{\circ}\text{C}$, CS = $1.98\pm 0.42^{\circ}\text{C}$, and NS = $1.74\pm 0.24^{\circ}\text{C}$. Thus, the rate of change in T_{re} during exercise was similar across conditions as well (mean rate for all 3 conditions = $0.04\pm 0.01^{\circ}\text{C}/\text{min}$).

T_{sk} initially dropped at the start of exercise because of commencement of fan airflow. Nevertheless, responses were similar for the SS and CS treatments across time while NS was lower. The change (post – pre) in mean skin temperature (ΔT_{sk}) response for each of the three conditions was as follows: SS = $-0.3\pm 1.3^{\circ}\text{C}$, CS = $-0.6\pm 1.3^{\circ}\text{C}$, and NS = $-1.5\pm 1.1^{\circ}\text{C}$, and the decrease was significantly greater in the NS than SS trials ($p<0.05$).

Discussion

The purpose of this study was to determine if a synthetic shirt (SS) purported to enhance sweat evaporation was more effective in heat dissipation than a cotton shirt (CS) worn during exercise in a temperate (22°C) environment. Thermal strain based on hydration and exercise intensity was similar across conditions since subjects began the trials in a similar hydration state, exercised at the same metabolic rate ($\sim 63\% \text{VO}_{2\text{peak}}$), and consumed a comparable amount of fluid during the trials.

The main finding is that under these environmental conditions and in similar clothing ensembles except for the shirt, there were no differences in thermoregulatory or cardiovascular responses while wearing CS, SS, or no shirt (NS). This finding is consistent with a similar study [6] that used a warmer environment with less clothing worn during exercise, but contrary to that of Easler *et al.* [4] who found higher core temperature in subjects running at $65\% \text{VO}_{2\text{peak}}$ when wearing a cotton shirt versus a nylon shirt or no shirt condition. The reason for the discrepancy is unclear, but may be related to differences in clothing ensembles, exercise protocol, and/or state of subject acclimatization.

The reason for the lack of difference in thermoregulatory and cardiovascular responses among shirt conditions in the current study is most likely related to the similarities in metabolic rate during exercise and the apparent similarities in heat dissipation qualities of the garments. Snellen [14] asserts that core temperature is mainly dependent on metabolic rate and is independent of ambient temperature



over a broad range of ambient temperatures and conditions. Since ambient conditions (temperature and relative humidity) and VO_2 were similar between conditions, the metabolic heat production was similar, so differences in core temperature were thus influenced by differences in the heat dissipation/heat storage qualities of the garments. Either the garments were the same in their capacities to store and dissipate heat, or perhaps any differences were masked by the convective heat loss elicited by the fan air flow.

Even though T_{re} was no different on average across conditions, T_{re} at the end of exercise was lower for the SS than the CS condition (Fig. 2). The reason for this finding is unclear. Fig. 2 shows the T_{re} during the SS trials was lower at rest than the others. Thus, since a similar rate of rise of T_{re} occurred across conditions, the final T_{re} measurement would be expected to be lower for the SS trials. However, statistical analysis revealed no significant resting T_{re} differences between conditions ($p=0.643$), so the final T_{re} may reflect a real difference in the heat dissipation capacities of the shirts, not just a result of starting at different T_{re} temperatures. Based on the trend at the end of exercise, differences in T_{re} might have been more pronounced had exercise continued, so perhaps the exercise duration in this study was not sufficient for differences in heat dissipation between shirts to manifest. Additional research incorporating exercise extending beyond 45 min is warranted to further investigate this finding.

Despite no difference in thermoregulatory or cardiovascular responses between shirt conditions, an important finding was that mean thermal sensation was ~9% lower (indicating greater thermal comfort) during the exercise in SS versus CS. The reason for this outcome is uncertain, but it is possible that the synthetic shirt was more permeable than the cotton shirt, so greater convection during the SS trials enabled subjects to feel cooler even though this did not translate into differences in T_{re} or HR between shirt conditions. Thermal sensation in the SS trials was not significantly different than in the NS trials, which implies subjects experienced little or no more discomfort when wearing the synthetic shirt than no shirt. This finding has important practical application because comfort can become a critical factor in certain settings. If individuals can be kept more comfortable and perception of heat can be minimized, individuals may be able to continue a given task more adequately than if perception of heat becomes exacerbated. In some situations in which human lives may be at stake, such as in military operations or firefighting, cessation of the task may not be an option. Hence, continuation of the activity at an optimal comfort level is desired. Thus, based on these findings, this may best be accomplished while wearing a synthetic garment instead of a cotton garment.



We conclude that wearing a synthetic shirt provides a limited thermoregulatory benefit compared to a standard cotton shirt, but comfort is enhanced. The final T_{re} (at 45 min) and the thermal sensation responses over time were lower in the SS than in the CS conditions. Additionally, extrapolation of T_{re} to more prolonged exercise indicates a potential thermoregulatory benefit of a lower core temperature while wearing the SS garment. Hence, individuals might feel more comfortable and cooler while wearing a synthetic shirt versus a cotton shirt in ambient conditions similar to those in this study and during periods of exertion extending beyond 45 min.

Further research beyond 45 min is necessary to see how SS and CS might differ. Additionally, further research without the use of a fan would be useful to more clearly discern differences between SS and CS. Finally, replicating the study with the use of a 100% synthetic fabric uniform (shirt and pants) could enable differences between the synthetic fabric and cotton to be more clearly seen.

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