Physiological Response to Submaximal Exercise in Cold and Hot Ambient Temperature

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ABSTRACT

Malaysia experiences hot and humid tropical weather throughout the year, causing the ambient temperature to fluctuate. These temperature changes contribute to the physiological response that can cause fatigue and dehydration and decrease blood flow for skeletal muscle function. This study aims to investigate the effect of cold and hot ambient temperature on physiological changes related to heart rate, blood pressure, respiratory rate, and body temperature. Twenty (n = 20, male = 10, female = 10; age range 19 - 33 years) voluntary healthy participants, cycled for 10 minutes at submaximal intensity in two different conditions; indoor (Cold – 20 °C) and outdoor (Hot – 30 °C). A significant difference in body temperature was observed between conditions before and after submaximal exercise ($P<0.05$). The female group demonstrated a significantly higher body temperature compared to the male group. No significant difference was observed in the heart rate, blood pressure, and respiration rate. In this preliminary work, we found that acceleration in body temperature during submaximal exercise in hot and cold ambient temperatures does not affect other selected physiological changes. Future studies using a large sample size-controlled ambient

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temperature (climate chamber) and exercise protocols are warranted to explore the physiological responses of different ambient temperatures during exercise.

Keywords: *Ambient Temperature; Physiological Temperature; Body Endurance; Gender Differences*

Introduction

Heart rate will increase as the heat increase as the sympathetic nervous system is activated. However, the amount of blood pumped to the heart slightly causes the number of stroke volumes to be limited—stroke volume, cardiac output and blood pressure decrease when dehydration occurs due to heat. Blood flowing to the working skeletal muscles would reduce, especially those doing labour work or physical exercise involving skeletal muscle contraction. These activities triggered the sympathetic nervous system to be activated and withdraw the vagal control led to the increment of heart rate and systolic blood pressure. Blood flow to skeletal muscle increases, thus leading to body heat loss [1].

Humans are capable to thermoregulate as an effective way to withstand variation in environmental temperature. In contrast, an increase in internal temperature (± 3 °C) can lead to serious health problems such as acute heat stroke, cardiovascular disease, chronic kidney disease, and even worse, death. Cardiovascular adjustment is crucial for thermal regulation during exercise or work by controlling environment temperature [2-3].

The principles of convective and evaporative heat loss explained that the changes of temperature between the inspired air and body core, ambient humidity, and ventilation rate would affect respiratory heat exchange. Although significant differences in respiratory heat loss in cold or dry conditions, due to the relatively poor air conductivity of the air, it still affects the total heat loss throughout the body [4].

The core temperature during exercise will increase proportionally with metabolic rate [5-6]; exposure to high external temperatures can increase the core temperature even when the level of metabolic heat production is almost at rest. This passive heat stress condition will occur when dry heat rise from the environment exceeds the potential for evaporative heat loss, resulting in body heat storage. This condition could often encounter during the hot season with high air temperature and humidity. It is also a commonly used experimental approach for investigating reflex thermoregulatory and cardiovascular control in response to increasing core and skin temperatures [7].

The thermal comfort studies involve a few main physical meteorological variables, thermal adaptation such as behaviour adaptation, physiological factors and psychological factors in assessing thermal environment. In our previous studies, all of those meteorological, physiological and psychological approaches had been investigated through in situ field study measurements to measure meteorological variables, questionnaire survey and simplified thermal manikin to determine the interaction of humans with the environment [8]. The thermal manikin has become a significant device or tool to correlate human thermoregulation with the thermal environment by simple observation and measurement. The black plastic corrugated cardboard made from polypropylene showed thermal conductivity, *k* between 0.1 and 0.22 W/m·K, which is almost similar to the thermal conductivity exhibited from the human epidermal skin layer with 0.21 W/m·K. Based on the results, the simplified thermal manikin was statistical significantly correlated well with the human skin surface. A simple linear regression (human skin regression) was established as shown as below:

$$T_h = 0.152T_{tm} + 30.823 \tag{1}$$

The thermal properties of manikin enable it to be relevant as an indicator for pre assumption of UHI effect as it could have shown a distinct temperature difference between green and built-up areas. The thermal manikin can directly reflect the effects and influents from the surrounding thermal environment. In this study, the benchmark value for UHI indication using thermal manikin was set at 42.43 ºC based on temperature variation at G. It assumes no UHI phenomenon occurred, and it does not contain artificial buildings and infrastructure. The manikin temperature more significant than the benchmark temperature would possibly have the effect of UHI. This study also allowed a better understanding of human thermal comfort by finding out the most comfortable environment conditions for humans, especially in a tropical climate.

Figure 1 shows 30-year monthly averages of the in-shade afternoon wet bulb globe temperature (WBGT) heat index levels for the hottest month in each geographic grid cell (0.5×0.5 °N areas; approximately 50×50 km at the equator) for the period 1980–2009. When hourly WBGT (the measure combines, within a single index, temperature, humidity, wind speed, and heat) exceeds 26 °C, hourly work capacity will reduce in heavy-labour jobs, and above 32 °C, any work activity is made difficult. South East Asia is a tropical country that has hourly WBGT exceeding 26 °C [9].

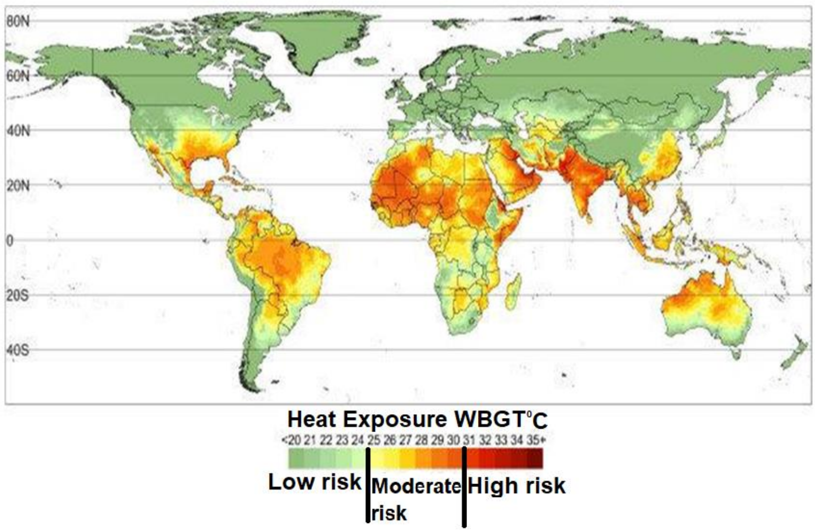


Figure 1: Grid Cell-Specific Monthly Average Wet Bulb Globe Temperature (WBGT) Max in-Shade Level (Afternoon) in the Hottest Month of Each Grid Cell, Based on CRU (Climate Research Unit, University of East Anglia, UK) data for 1980-2009 [9].

The previous studies prove that heart rate, blood pressure, respiration rate, and body temperature are the critical parameters to assess physiological responses towards ambient temperature changes. However, there is a lack of study that focuses on all four physiological parameters. Thus, this study determines the effect of physiological response during exercise between two different temperatures. Cold temperature (20 °C) and hot temperature (30 °C) were used as environment temperature. Blood pressure, heart rate, respiratory rate and internal body temperature were measured before and after exercise.

Materials and method

This section details the method undertaken during this experiment works throughout the study. The materials and statistical analysis are discussed further in this section.

Participation selection

Participants consisted of 20 healthy adults comprising 10 male and 10 female university students—ranging age from 19 to 33 years old. Data collection took place at Biomedical Signal Processing Laboratory. Participants were informed about the testing protocol before undergoing moderate exercise. All participants were free from any injuries, structural cardiac, cerebrovascular, chronic renal or hepatic diseases and not taking any medication at the time of testing.

Experimental design

Figure 2 shows the flowchart of this experiment that was conducted for 2 days consecutively.

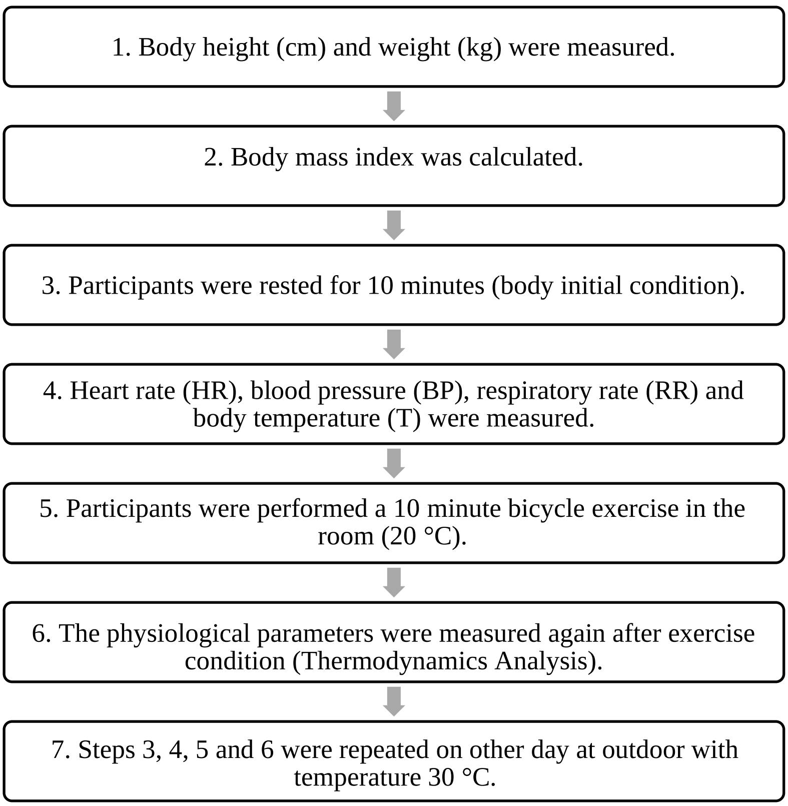


Figure 2: Detailed steps of the experiment conducted.

Equipment

Table 1 shows the equipment used in this experiment, and the usage of the equipment is shown as follows.

Table 1: List of equipment and its usage

Equipment	Usage
Digital Scale With Height Meter (SMS-E-DS12 Digital Scale)	To measure body weight and height
Vital Sign Measurement (Life Scope - Nihon Kohden - Irvine, CA, USA)	To measure blood pressure To measure heart rate.
Body Temperature digital thermometer (Rossmax TG380, Berneck, Switzerland)	To measure body temperature
Environment Temperature (Thermolab digital thermometer water-resistant: IP65)	To measure environmental temperature.
Bicycle (NordicTrack GX 5.0 PRO, Logan Utah, USA)	For exercise activity - Resistant 5

Procedure

As shown in Figure 2, at the beginning of the experiment, body height (BH, cm) and body weight (BW, kg) were measured with minimal clothing and without shoes. Body weight and height were assessed using a digital weight scale with a height meter from Nazmed SMS Malaysia type SMS-E-DS12 Digital Scale. Then, body mass index (BMI, kg•m−2) was calculated as the BW, and BH squared ratio.

Participants were instructed to refrain from drinking water and eating food to avoid the metabolic effects of drinking and food. Participants were free from caffeine and tobacco at least 3 hours before doing exercise. The experiments were conducted to measure physiological changes in two different environmental temperatures for passive and active conditions for the low and high temperatures at 20 °C and 30 °C, respectively. Physiological parameters were measured before and after the exercise, including heart rate (HR), blood pressure (BP), respiration rate (RR), and body temperature (T).

Participants were asked to rest for 10 minutes before the experiment was conducted to normalise physiological condition from any physical activity effect, assumed as body initial condition. While measuring the physiological parameters, participants were told to be quietly seated for 5 minutes to measure HR, BP, RR and T. Next, participants were asked to do the exercise using a static cycle with five-level resistance for 10 minutes. After that, the physiological parameters were measured again for after exercise condition.

Participants were required to do exercise on 2 days consecutively. They performed bicycle exercises (Nordic Track GX 5.0 PRO, Logan Utah, USA) for 10 minutes in cold temperature for the first day. The activity was conducted inside a room by setting the air-conditioner at 20 °C temperature. For the second day, the participants performed the same exercise for 10 minutes under hot temperature. The activity was conducted outdoors under a shaded area during daytime with a temperature of 30 °C.

Measure physical changes

HR and BP were measured by vital sign measurement equipment (Life Scope - Nihon Kohden - Irvine, CA, USA). A digital thermometer (Rossmax TG380, Berneck, Switzerland) was used to measure body temperature before and after exercise during cold and hot temperatures. Respiratory rate was measured by counting the number of participant breaths taken per minute.

Statistical analysis

Four separate 2 x 2 ANOVA was used to compare heart rate, blood pressure, respiratory rate and body temperature before and after exercise for different ambient temperatures. All results were analysed using Statistical Package for Social Sciences (SPSS, IBM, New York, USA) and presented in the next section.

Results and discussion

This section will be presented the details of the effect of cold and hot temperature on physiological and physiological changes composed of HR, BP, RR and T and discuss them in more detail in this section.

Participant details

Table 2 shows participant details, including their age, height and weight. Participants consisted of 10 males and 10 females with an average age of 24.6 ± 3.2 years old, average height 164.5 ± 9.7 cm and average weight 63.2 ± 15.8 kg.

Table 2: Participant’s detail

n	20
Age	24.6 ± 3.2
Height (cm)	164.5 ± 9.7
Weight (kg)	63.2± 15.8

Performance measure results

The heart rate (HR), blood pressure (BP), respiratory rate (RR) and body temperature (T) is shown in Figure 3. By averaging the results of participants' measurements, there is an increment in all physiological parameters measured before and after exercise for both low and high-temperature conditions. Furthermore, comparing low and high environmental temperature effects on physiological changes is different for all parameters. Heart rate, respiration rate, and body temperature tend to increase in hot temperature either in relaxed conditions or after exercise. These studies show the same results as the article [10-11], where indoor and outdoor temperatures cause an increment in body temperature.

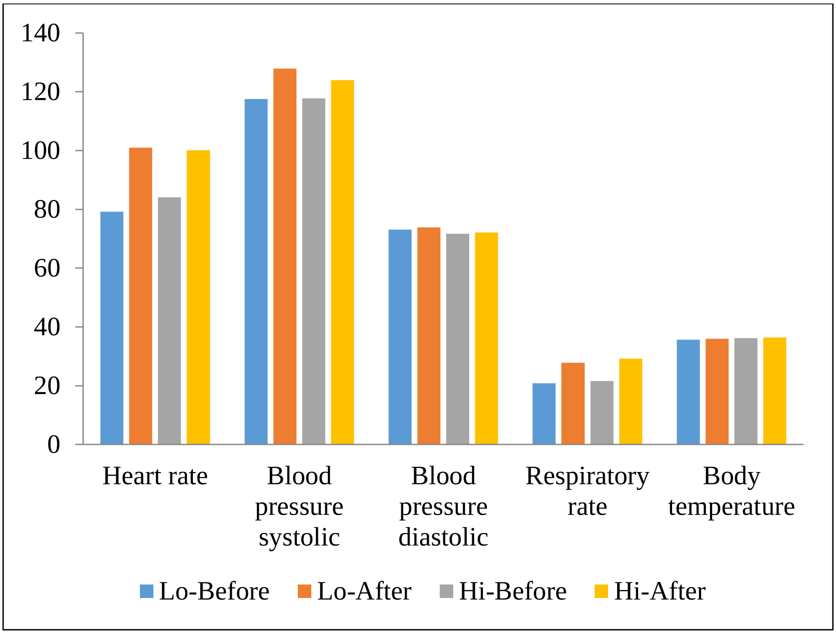
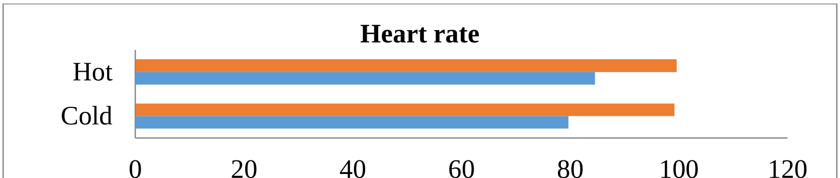


Figure 3: Performance measures changes during the experiment. Heart rate (HR; bpm), blood pressure (BP; mm Hg), respiratory rate (RR; breaths per minute) and body temperature (T; °C).

The human body can maintain a consistent temperature when constant heat exchange with the environment occurs, according to the 2nd law of thermodynamics. The body becomes hot when metabolic processes occur in the body, and heat exchange between the body and the external environment is achieved through conduction, convection, radiation, and evaporation. However, heat exchange cannot occur well when the body is exposed to high temperatures for a long time. It will increase heart rate reading as it escalates proportionally to body temperature by activating the sympathetic nervous system, but the heart will experience low volume stroke [12]. Furthermore, the thermoregulation system fails due to high temperatures that could lower through dehydration, salt depletion, and increased surface blood circulation. That is why the previous report said hyperthermia and hypothermia are often associated with morbidity or cardio-respiratory death [13-15].

Meanwhile, blood pressure measurement showed a lower systolic and diastolic for after exercise condition. These findings coincide with article [11], where the blood pressure decreased with indoor and outdoor temperature increases. For the body to diffuse heat to the environment, the veins of the skin are expanding, resulting in a low reading in blood pressure [11]. It has also been reported that systolic blood pressure and heart rate increase under cold exposure [15-17].

However, due to participants' various conditions, the standard deviations of all these measurements broadly vary from 0.47 °C - 23.46 °C. The impact of environmental temperature changes on human physiology, further analysis has been done by using ANOVA. Figure 4 – 7 shows the effects of hot and cold temperature on the physiological parameters (heart rate, blood pressure, respiratory rate and body temperature). It could infer that temperature differences have significantly affected body temperature, while participants' heart rate, blood pressure, and respiration rate changes are insignificant.



	Cold	Hot
after	99.21	99.63
before	79.68	84.58

Figure 4: Average heart rate reading in 2 days of the experiment under hot and cold temperatures.

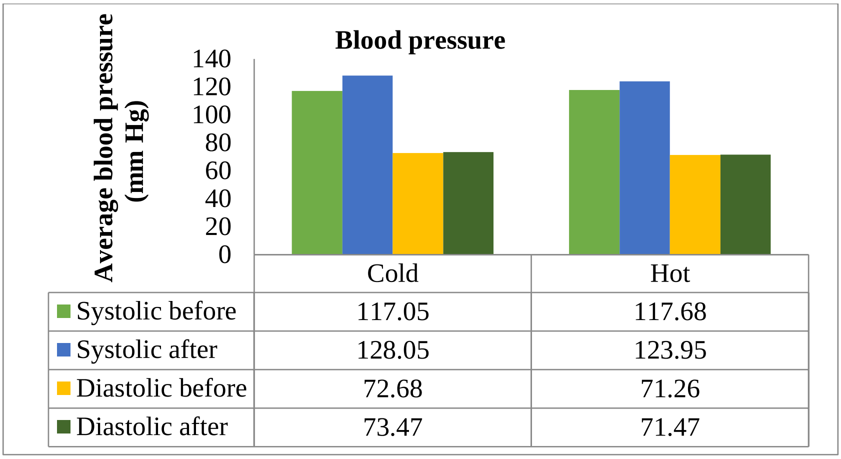


Figure 5: Average blood pressure reading (systolic/diastolic) in 2 days of the experiment under hot and cold temperatures.

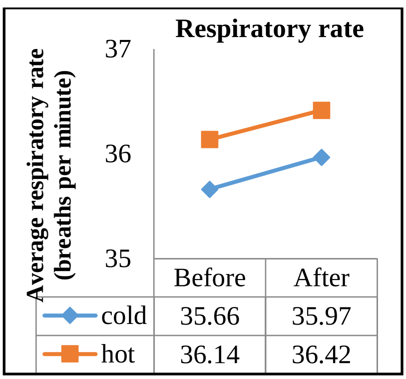


Figure 6: Average respiratory rate reading in 2 days of the experiment under hot and cold temperatures.

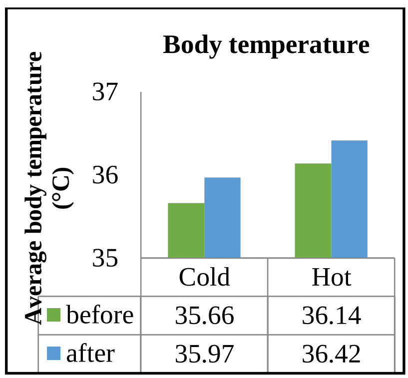
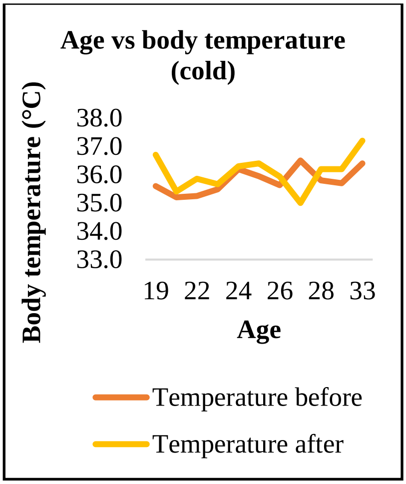


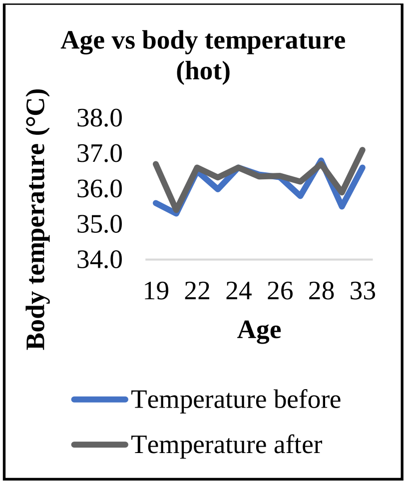
Figure 7: Average body temperature reading in 2 days of the experiment under hot and cold temperatures, *p < .05.

The effect of ambient temperature on the body temperature was supported in a previous study [18] on the impact of morning light intensity and environment temperature on body temperature and alertness. This study estimated that high temperatures would increase the rate of sleepiness and reduce work performance by increasing the average skin temperature and distal-proximal skin temperature gradient (DPG). The outcome of this study was estimated where hot conditions would cause mean skin temperature, proximal, distal skin temperature and DPG. In addition, a study conducted to investigate the relationship between temperature, illuminance, and sound level with psychological parameters (blood pressure, heart rate and skin temperature) also shows that body temperature (taken at the wrist) has a linear relationship with air temperature [19]. This could ensure that body temperature is the parameter mainly affected by ambient temperature, as shown by the current study.

Since the body temperature parameters are affected by the ambient temperature, the study identifies the factors that influence body temperature changes. This study emphasises three main aspects by observing participants' age, gender, and body mass index (BMI), as shown in Figure 8 - 10. The most significant factor of these three factors is gender. In Figure 10, the female group shows a higher body temperature than the male in relaxation and after exercising. On the other hand, age and BMI contributed irregularly to body temperature changes.

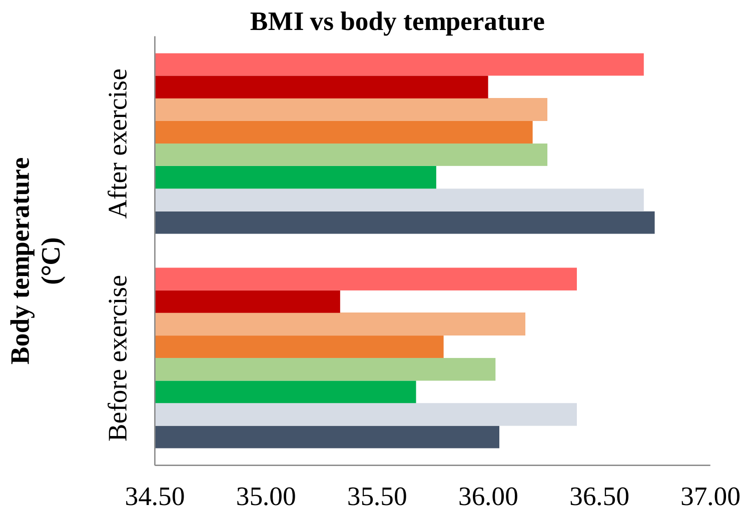


(a)



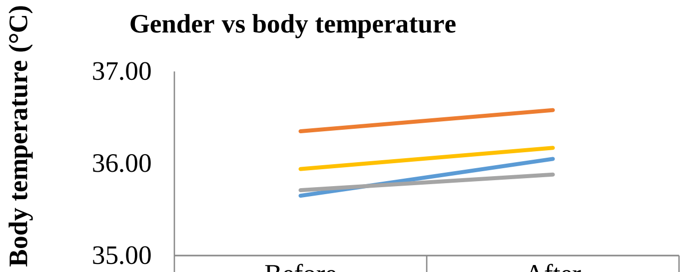
(b)

Figure 8: Age affects body temperature in cold environments (a) and hot environments (b).



	Before exercise	After exercise
hot temperature (obese)	36.40	36.70
cold temperature (obese)	35.33	36.00
hot temperature (overweight)	36.17	36.27
cold temperature (overweight)	35.80	36.20
hot temperature (normal)	36.03	36.27
cold temperature (normal)	35.68	35.77
hot temperature (underweight)	36.40	36.70
cold temperature (underweight)	36.05	36.75

Figure 9: BMI affects body temperature.



	Before	After
cold temperature (female)	35.65	36.05
hot temperature (female)	36.35	36.58
cold temperature (male)	35.71	35.88
hot temperature (male)	35.94	36.17

Figure 10: Effect of gender on body temperature before and after the exercise.

Based on these studies [20-21], women are found to be more sensitive to cold environments based on physiological parameters. This is because women have different morphologies, including a higher surface-area-to-volume ratio for body segments, a smaller average body size, less muscle mass and a higher surface-area-to-mass ratio. Gender-related body morphology differences affect heat balance and cause differences in thermal perception, body temperature distribution and thermoregulation. Women are generally more prone to optimum temperature changes than men, causing discomfort at colder temperatures. In addition, the complex process of human adaptation will probably be the reason for the gender differences [22].

Conclusion

The overall aim of this study was to assess the effect of hot and cold temperatures on physiological changes that do indeed affect HR, BP, RR and T. The results show that temperature differences significantly affect body temperature, although HR, BP, and RR are insignificant. Such a study was undertaken to improve the understanding of how the difference in temperature affects physiological changes. Since these preliminary results are limited only to the general background of subjects, an extension of specific background subjects may be applied with further subjects, as well as, large sample size, controlled ambient temperature, and exercise protocols are warranted to explore the physiological responses during exercise in the future work. However, the above study will only be able to address the physiological factors of thermal comfort. Hence, future work should address the other aspects of thermal comfort, which are the insulating factors due to clothing and environmental factors. It is known that the type of clothing strongly influences the rate of heat transfer from the human body and can be measured by measuring the resistance offered by clothes (clo) where 1 clo is equal to 0.155 m^2.K/W. Meanwhile, in the environmental factors, the dry bulb temperature, relative humidity, air velocity, and the mean radiant temperature (Tmrt) are important variables to understand thermal comfort better. Since many factors are involved in reaching thermal comfort, many combinations of the above conditions can provide comfort and should be examined in detail in the future.

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