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# Effect of Fluid Balance on Thermoregulatory Responses in Obese Individuals during Exercise in the Heat

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## ABSTRACT

Hot and humid weather in Malaysia seems to discourage obese individuals from exercise in the outdoor. The purpose of this study was to examine the effect of fluid balance on thermoregulatory responses in obese individuals during exercise in hot condition. A total of 10 obese (23.0 ± 5.2 years; 92.2 ± 9.2 kg; BMI: 32± 2.5 $m^2$/kg; 32.4 ± 2.6% BF) and 10 normal weight individuals (21.0 ± 1.8 years; 65.6 ± 4.2 kg; BMI: 23.0 ± 1.2 $m^2$/kg; 11.1 ± 1.1% BF) were recruited for this study. Subjects underwent 50 min of cycling at 50% $VO_{2max}$ under 4 conditions: (i) euhydrated in thermoneutral condition (24.5°C; 53.8 rh) (EUT), (ii) hypohydrated in thermoneutral condition (HYT), (iii) euhydrated in hot condition (34.7°C; 54% rh) (EUH) and (iv) hypohydrated in hot condition (HYH). Subjects were instructed not to ingest fluid for 8 hours prior to the hypohydrated condition trials. No significance difference was found between obese and normal weight groups in heart rate (HR), $VO_2$, core temperature ($T_{core}$), skin temperature ($T_{sk}$) in all the 4 trials. Sweat loss in the normal weight group was greater than the obese group (1.21% vs. 0.75% ΔBW; 1.70% vs. 0.99% ΔBW) in EUT and EUH trials (p=0.035; p=0.017, respectively). HR in EUH trials were significantly higher than EUT trials at 10 min in the normal weight group and at 20 min of exercise in the obese group ($p<0.05$). HR in HYH trials were significantly higher than HYT trials at 0 min in the normal weight group and at 10 min the in obese group ($p<0.05$). With ~ 1% of

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BW loss prior to exercise, obese individuals have similar physiological responses as normal weight individuals when exercising in the heat (35°C; 64% rh) for 50min at 50% $VO_{2max}$ of cycling.

*Keywords:* Euhydrated, heat, heart rate, hypohydrated, sweat rate, obese

## INTRODUCTION

According to World Health Organization (WHO) (2017), more than 650 million out of 1.9 billion adults (13% of the world population) in the world are obese. "The Economist Intelligence Unit" (2017), which covered Malaysia, Singapore, Indonesia, Thailand, Philippines and Vietnam also mentioned that Malaysia was the most obese in the region with the highest obesity and overweight prevalence sample in the country (13.3% and 38.5% respectively). It is estimated that 45.3% of Malaysian population are obese ("Malaysia's obesity", 2014). Also according to Ministry of Health Malaysia (IPH, 2015) the obese patient are often related to diseases such as hypertension and diabetes.

Exercise is well known as an excellent therapeutic intervention for controlling obesity (Chan & Woo, 2010; DiPietro et al., 2013; Foster-Schubert et al., 2012). A minimum of 150 min per week of moderate intensity physical activity was recommended by American College of Sports Medicine (ACSM) guideline for the overweight and obese individuals (ACSM, 2013). Although the recommendation has been made but the obesity rate in the Malaysia does not seem to be changing over the recent years. This may be due to the process of urbanization, wealth increase and changes in industrial work nature causing a decrease in physical activity level in Malaysia population (Davey et al., 2013).

Malaysia is a country with tropical climate which its temperature and humidity (~32°, 70% rh) can be relatively constant throughout the year. Most people tend to stay and work in the thermoneutral zone around 23°C as they perceive as a comfortable ambient temperature which greatly reduce the desire to go for outdoor activities (Yang et al., 2015). Therefore, ambient temperature in Malaysia could be one of the factors which discouraged people to exercise at outdoor, especially in obese individuals. An obese individual possesses additional insulation provided by layers of adiposity, potentially disadvantageous during heat stress conditions and more susceptible to heat injury (Chung & Pin, 1996). When the ambient temperature rises above the upper thermoneutral zone limit, physiologic processes to amplify heat dissipation are activated resulting an increase in metabolic rate. In an obese individual, exposures to ambient temperature above the thermoneutral zone would also increase metabolism as processes are activated to increase heat dissipation against a smaller thermal gradient (Frank et al., 1986). In addition, overweight and obese individuals have higher metabolic rate, heart rate and core temperature than normal weight individuals (Bar-Or et al., 1969), which may cause thermoregulatory and circulatory strain during exercise in the heat.

Hydration level of an individual can determine the efficiency of the body to maintain optimal thermoregulation. Hypohydration condition may cause extra stress on the body as the intracellular and extracellular volume decreased (Sawka et al., 2001). Human body starts sweating under hot condition to dissipate excessive heat generated in the body in order to maintain an optimal $T_{core}$ (~37°C) (Boone, 2014). But with the average ambient temperature in Malaysia being approximately ~32-35°C and with the daily exposure to the outdoor hot conditions it may induce certain level of acclimation effects on people living inside the country. Obese individuals may be more at risk for heat-related illness and less efficient at the thermoregulatory responses due to lower sweat rate and lower thermal sensation as compared to non-obese individuals (Kanikowska et al., 2013). However, the heat tolerance threshold with hypohydrated conditions in obese individuals is not well documented.

To our knowledge, studies of thermoregulatory function and fluid balance in overweight and obese are limited. The extent to which hypohydration increases thermoregulatory and circulatory strain in obese individuals is not clear. It is essential to evaluate the amount of heat-induced physiological strain in obese individual can tolerate during exercise in hot conditions. Therefore, the purpose of this study was to examine the effects of fluid balance on thermoregulatory responses in obese individuals during exercise in the heat. Understanding the heat-induced physiological strain and different hydration levels which can be tolerated by the obese individuals are important, as the findings of this study could add into the exercise guideline and precaution for obese individuals when exercising in the heat.

## METHOD

### Subjects

A total of 10 obese (23.0 ± 5.2 years; 92.2 ± 9.2 kg; BMI: 32± 2.5 $m^2/kg$; 32.4 ± 2.6 %BF) and 10 normal weight individuals (21.0 ± 1.8 years; 65.6 ± 4.2 kg; BMI: 23.0 ± 1.2 $m^2/kg$; 11.1 ± 1.1% BF) were recruited for this study. An individual with a body fat ranged from 30% or more and a body mass index (BMI) of 30 $kg.m^{-2}$ and above was classified as obese, whereas the normal weight individual has a body fat ranged from 10%-22% and BMI of 24 $kg.m^{-2}$ (ACSM, 2013).

### Experimental Design

Subjects undertook 1 preliminary testing and 4 experimental trials in randomized order. The preliminary testing included anthropometric measurements, submaximal and maximal oxygen consumption ($VO_{2max}$) tests (Modified Astrand Cycling Protocol to determine the $VO_{2max}$ and maximal heart rate ($HR_{max}$) during exercise in order to prescribe the intensity of exercise for the subsequent 4 experimental trials. For submaximal test, subjects underwent at least 4 stages of cycling on cycle ergometer (Corival, Lode, Netherlands) with gradually increased intensity of 30 W at every stage. Subjects were required to cycle for 4 min and maintain the pedal cadence between 60-70 rpm for each stage. After all stages were completed, subjects were provided with a 5 min recovery time and then followed by an incremental load of 30 W every 2 min until exhaustion. Subjects were instructed to maintain a pedal cadence between 80 to 100 rpm during exercise and to exercise to volitional fatigue. The test was terminated when the subject could not maintain a pedal cadence of 60 rpm. Rating Perceived Exertion (RPE) (Borg, 1998) was recorded at every stage. $VO_2$ and HR were constantly recorded using metabolic cart (K4B2, COSMED, Italy) and heart rate monitor (Polar, FT4, Finland).

The experimental trials included cycle ergometer exercise under four different environmental conditions: (1) Euhydrated hot condition (EUH), (2) Hypohydrated hot condition (HYH) [humidity fixed at 70%] and (3) Euhydrated thermoneutral condition (EUT), (4) Hypohydrated thermoneutral condition (HYT) [humidity fixed at 30-40%]. Each experimental trial consisted of 50 min of cycling on a cycle ergometer at 50% $VO_{2max}$ per session. Subjects were instructed to cycle on the ergometer for 5 min at 60 rpm as a warm up before the trial and another 5 min after the trial to cool down their body. Each experimental trial was separated for at least 3 days apart. Hydration status of the subjects was determined using urine specific gravity (USG) and changes in body weight.

Subjects were instructed to avoid the ingestion of alcohol, caffeine, any drugs and tobacco, strenuous physical activity 24 hours before the testing day. Subjects were instructed to avoid heavy breakfast and blood glucose level maintained between 4-6 $mmol.L^{-1}$. Subjects were instructed not to ingest fluid for 8 hours prior to the hypohydrated condition trials (HYH & HYT). For euhydrated condition trials (EUH & EUT ), subjects were instructed to ingest fluid at 6 $ml.kg\ BW^{-1}$ every 2-3 hours a day before the trials. Upon arrival to the laboratory, urine sample of subjects were collected to ensure they were in euhydrated condition (USG< 1.0100) for EUH and EUT trials, and in mild hypohydrated conditions (USG> 1.0200, body weight loss ≤ 1%) for HYH and HYT trials.

Baseline measurements such as body weight, blood glucose level, resting HR, resting Blood Pressure (BP) and USG were measured were recorded before the commencement of the experiment trial. During the experimental trials, $VO_2$ and HR were constantly recorded. Rating perceived exertion (RPE) and thermal comfort sensation (TCS) (ASHRAE Std.55, 1966) were taken every 10 min during the exercise.

Skin temperature ($T_{sk}$) and core temperature ($T_{core}$) were monitored throughout the whole trial. $T_{core}$ was measured using the sterile disposable indwelling temperature probe (YSI 400 Series; Mallinckrodt Medical, Kansas City, MO). The temperature probe was inserted 10 cm beyond the anal sphincter of the subject. The skin temperature sensors (i-button, Maxim) were placed on subject's arm, chest, thigh and back calf to measure the mean $T_{sk}$ using the formula Tsk= 0.3 (Chest) + 0.3 (Arm) + 0.2 (Thigh) + 0.2 (Calf) (Ramanathan, 1964). Six ml per kg BW of water was prepared for the subject to drink in ad-libitum manner at the 20-min time point.

For ambient temperature control, three heated lamps were placed on top and surrounding the ergometer and ambient temperature were maintained at ~ 35°C with 64% rh for EUH and HYH trials. For EUT and HYT trials, ambient temperature was maintained at ~ 23°C with 44% rh. The consistency in temperature and humidity throughout the experimental trials were monitored using a thermohygrometer (Kestrel 4000, USA) every 5 min. Post-exercise measurements on resting HR, BP, USG, body weight and blood glucose were collected again at the end of the trials.

### Statistical Analysis

All data was analyzed using IBM SPSS Statistics Window version 23. Statistical significant level was set at P< 0.05. Data was expressed as mean ± standard deviation (SD) in the text, tables and figures. Two-way repeated measures ANOVAs were used to assess differences between trials across time for measured variables.

## RESULTS

### Heart Rate Responses

No significant difference was found between obese and normal weight groups in heart rate (HR) responses during 4 experimental trials. EUT and HYT trials showed lower HR readings compared to hot conditions (EUH & HYH).

For obese group with euhydrated state, HR responses in EUH were significantly higher than EUT after 20 min of exercise (131 vs 123bpm; p=0.037), whereas in hypohydrated state, HR was significantly higher in HYH than HYT after 10 min of exercise (127 vs 118 bpm; p<0.002) (0.95 vs 1.05% ΔBW) (Figure 1).

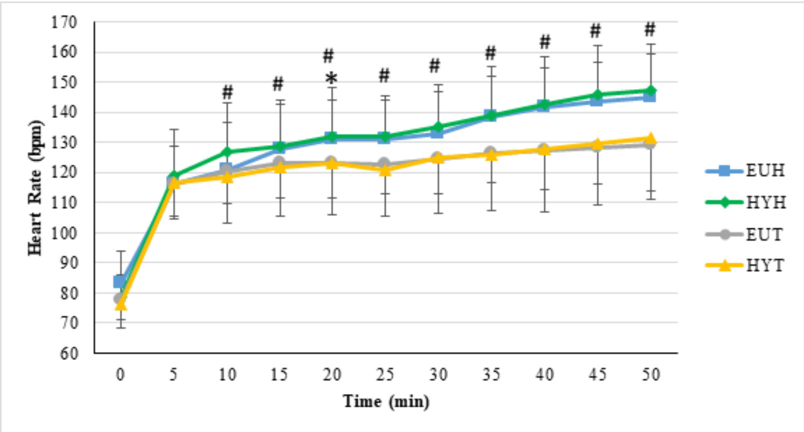


*Figure 1.* Heart rate for Obese group during all 4 trials (* denotes significant main effect between denotes significant main effect between EUH & EUT; # denotes significant main effect between HYH & HYT).

For normal weight group with euhydrated state, HR responses in EUH were significantly higher than EUT conditions after 10 min of exercise (126 vs 121 bpm; $p<0.025$). HR in HYH trials were significantly higher than HYT trials at 0 min (83 vs 76 bpm; $p<0.008$) onwards in the normal weight group in hypohydrated state (1.10 vs 1.13% ΔBW) (Figure 2).

## Oxygen Uptake ($VO_2$) Responses

The $VO_2$ remained constant throughout the 50 min of cycling during 4 experimental trials in both group. (Figure 3 & Figure 4).

## Thermoregulatory Responses

$T_{core,}$ (Figure 5 & Figure 6) and $T_{sk}$ (Figure 7 & Figure 8) were similar in both hot and thermoneutral conditions in all 4 experimental trials. Sweat loss (Figure 9) in normal weight group was significantly greater than obese group (1.21% vs. 0.75% ΔBW; 1.70% vs. 0.99% ΔBW) in EUT and EUH trials ($p=0.035$; $p=0.017$, respectively).

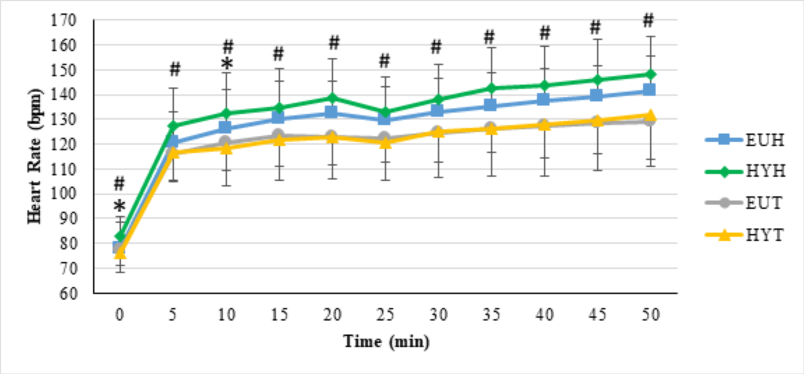


*Figure 2.* Heart rate for Normal Weight group during all 4 trials. (* denotes significant main effect between EUH & EUT; # denotes significant main effect between HYH & HYT).

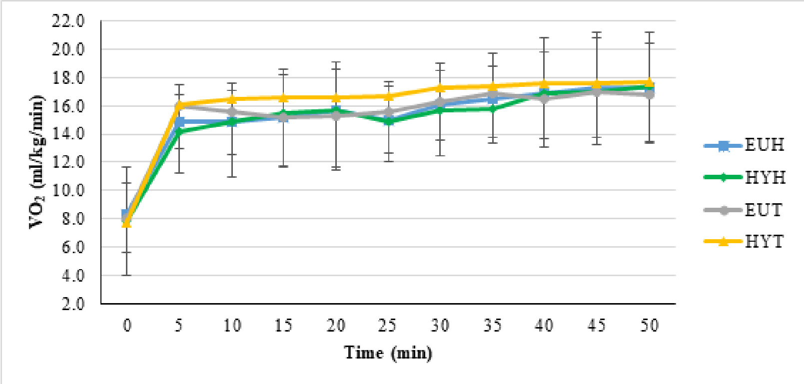


*Figure 3.* $VO_2$ for Obese group during all 4 trials (* denotes significant main effect between trials).

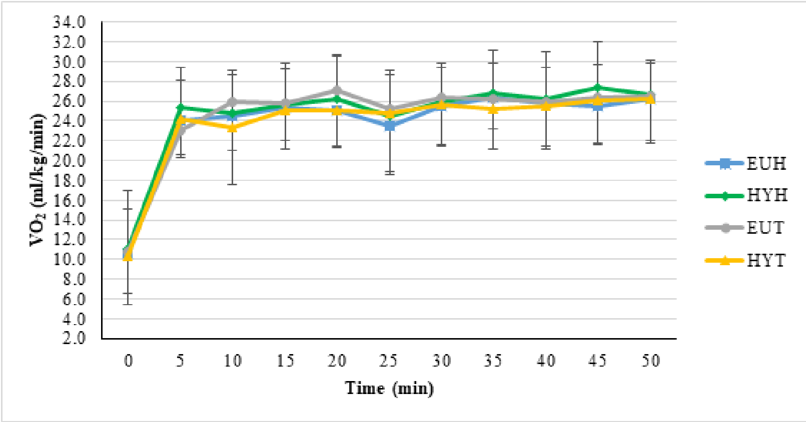


*Figure 4.* $VO_2$ for Normal Weight group during all 4 trials (* denotes significant main effect between trials).

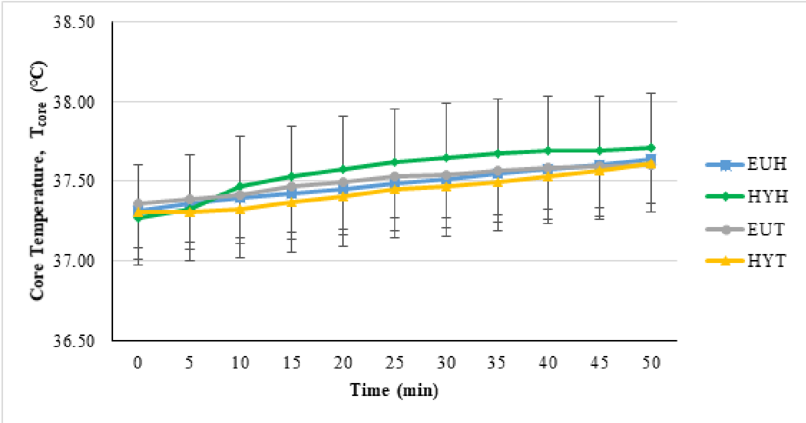


*Figure 5.* $T_{core}$ for Obese group during all 4 trials (* denotes significant main effect between trials).

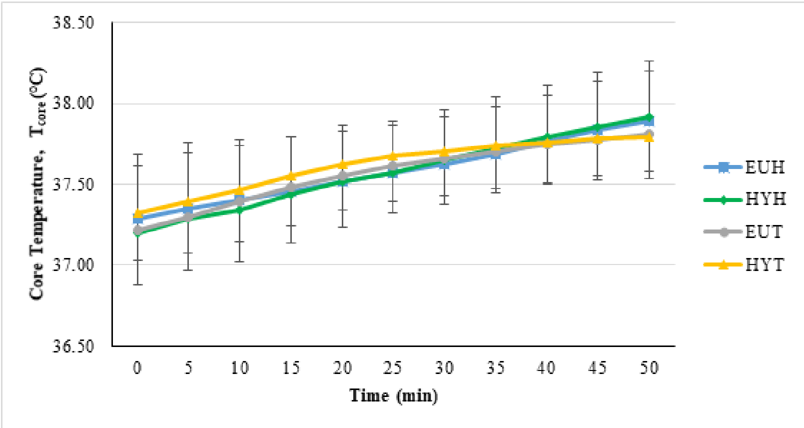


*Figure 6.* $T_{core}$ for Normal Weight group during all 4 trials (* denotes significant main effect between trials).

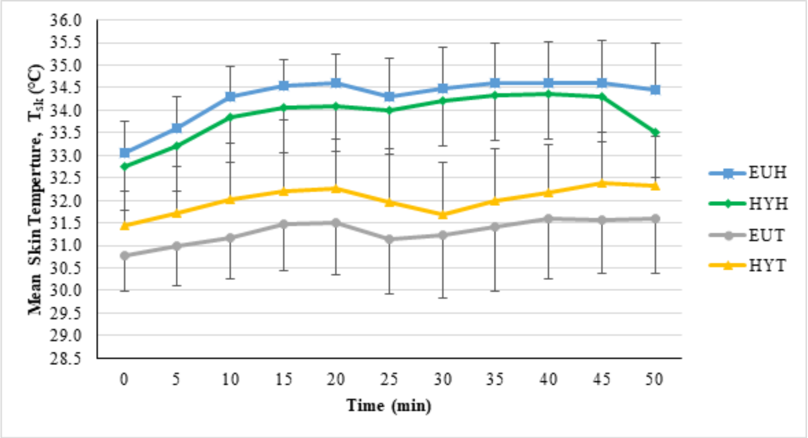


*Figure 7.* $T_{sk}$ for Obese group during all 4 trials (* denotes significant main effect between trials).

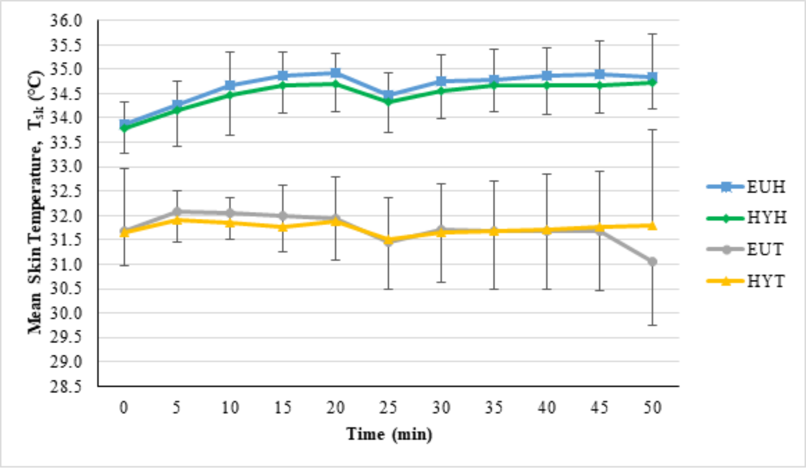


*Figure 8.* $T_{sk}$ for Normal Weight group during all 4 trials (* denotes significant main effect between trials).

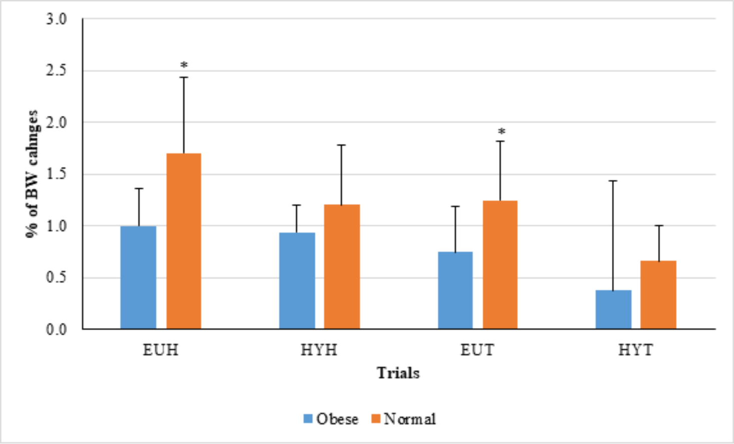


*Figure 9.* Sweat loss rate for Obese and Normal Weight group (* denotes significant main effect between group).

### Subjective Responses

The TCS for both obese and normal weight groups in hot condition trials were similar. For obese group with hypohydrated state, TCS was significantly higher than normal weight group in thermoneutral condition after 20 min of exercise (0.6 vs -0.4; $p=0.016$), whereas in euhydrated state, both groups showed no significant differences.

No significant difference was found between obese and normal weight groups in RPE responses during 4 experimental trials. For obese group with hypohydrated state, RPE responses in hot conditions were significantly higher than thermoneutral conditions state at the end of exercise (14.0 vs 12.2; $p=0.002$), whereas for normal weight group, RPE was significantly higher during last 10 min of exercise (12.2 vs 11.6; $p=0.024$).

## DISCUSSION

Based on the results, the $VO_2$ reading for both groups remained constant, which capped at 50% of the subject's $VO_{2max}$ throughout the whole experimental trials, besides that HR increased gradually and significant differences were found between hot and thermoneutral conditions for both groups indicating obese subjects displayed similar oxygen demands as they exercised under either hot or thermoneutral; either euhydrated or hypohydrated conditions. Transfer of heat through flowing blood is the most important heat exchange pathway in body (Gonzalez-Alonso, 2012). Heart rate can immediately react to a metabolic and environmental condition changes and it is a reflection of demand for the body's circulatory system or it can be known as the immediate effector of complex vasomotor response of the body (Moran et al., 1995). The non-exercising muscles blood flow is reduced to meet the increased demand of skin blood circulation for heat dissipation when exercising under heat (Nielsen et al., 1993). Blood flow and blood volume redistribution from deep to superficial vessels must occur to facilitate the heat loss process which leads to increase of heart rate and vasodilation of the vessels (Rowell, 1983). When exercising under hot conditions, the heat from external setting had put on extra strain on the heart. The heart act as the main driving force in the body to drive bloods to all parts of body in order to increase the blood flow to facilitate the heat dissipation process which resulted in a gradual increase of HR, $T_{core}$ and $T_{sk}$ during all experimental trials. In the present study's result, it was found that with sufficient water ingestion prior to exercise in heat might reduce an individual's strain during the exercise when compared to hypohydrated states as the results showed similar physiological responses in hot and thermoneutral conditions for both obese and normal weight groups.

It is known that exercise caused a rise in heat production of muscles which leads to increase of metabolic rate especially in a warmer environment setting. Human body will automatically regulate the $T_{core}$ to a constant level around (~37°C) (Boone, 2014). A 50 min moderate intensity exercise was associated with gradual increased in body $T_{core}$ (Figure 5 & Figure 6) and there was a correlation between both body $T_{core}$ and $T_{sk}$ in hot condition trials (r=0.543, p=0.000) (Table 1). The $T_{sk}$ for obese and normal weight groups were similar in all 4 trials with hot condition showing a higher mean $T_{sk}$ reading as compared to thermoneutral conditions trials. When exercising in hot environment, it caused an increase in the body skin blood flow and sweat rate to enhance the heat dissipation process in the body. This is an automatic thermoregulatory response of human body to attain a balance between heat production and heat loss (Gagge & Gonzalez, 2010; Kenny et al., 2010). The body $T_{core}$ acts as one of the most influencing homeostatic parameter in the body, it controls the body's cellular function and organismal survival ability. The central nervous system (CNS) will put the body $T_{core}$ maintenance to priority when thermal increment is sensed by the receptors from either ambient or internal environment (Morrison, 2016). This explains the higher mean $T_{sk}$ when subjects were exercising under EUH and HYH conditions due to the increased skin blood flow to facilitate the heat dissipation process. It is noticeable that in current study, the overall mean $T_{sk}$ and $T_{core}$ in obese groups were indeed lower than the normal weight group when exercising under heat condition. The adipose tissue in obese subjects may act as an insulator to heat and blunted the heat transfer process (Chudecka et al., 2014; Savastano et al., 2009). A higher body fat percentage in the obese group may result in a lower skin blood flow during heat exposure, which further lowers the mean $T_{sk}$ as compared to normal weight group.

According to Sawka et al. (2007), hyperthermia and the development of dehydration may cause sodium imbalance which can results in lower aerobic exercise performance levels when exercising under heat. This study showed an increase of $T_{core}$ for both group in all 4 trials throughout the 45 min exercise period. Lee et al. (2008) reported that a warm and humid environment might positively affect the $T_{core}$ during exercise. However in the present study, no significant difference was found between both groups for $T_{core}$. Similar to the study conducted by Heikens et al. (2011), the study measured the $T_{core}$ of both normal weight and obese individuals and no significant difference was found at the end of the study. Thomas (2015) also mentioned that weather condition would not affect the ability of human body to regulate its body temperature and no significant relationship was found between body fat percentage and sweat rate (p>0.05). In this present study, the greatest body weight changes were found in EUH condition among the 4 trials for both groups (Obese: 1 % ΔBW & Normal Weight: 1.7% ΔBW). The obese group was not sweating as much as expected in the hot conditions compared to other similar studies (Osayande et al., 2016; Podstawski et al., 2014). Normal weight group had produced more sweat as compared to obese group in EUH and EUT trials (EUH: 22.38 vs 17.99 L/min; EUT: 15.86 vs 13.80 L/min).

The overall $T_{core}$ and mean $T_{sk}$ were lower resulting in a lower sweating rate in the obese group as compared to the normal weight group when exercising under hot condition. This could be explained that the body thermoregulatory system receptors were still adjusting to the stimulus receiving from internal and external environments and it has contributed to a lower physiological strain index (PSI) in the obese group. The circulatory and thermal components such as HR and $T_{core}$ were used to obtain the PSI reading. From the obtained results, the overall HR and $T_{core}$ in hypohydrated hot condition (HYH) were the highest among all 4 trials in both groups. It was noticeable that physiological strain is caused by $\geq$ 1% of body fluid loss. RPE responses were highest when both groups were exercising in HYH condition. The obtained results shown that 50 min of exercise under hot conditions would induce a higher HR and $T_{sk}$ while the $T_{core}$ and $VO_2$ would remain constant throughout the exercising period. Although sweat loss rate in term of body weight changes in the normal weight group was significantly higher than the obese group but no significant was found in physiological responses when compared to the normal weight group. The obese group and normal weight group were showing similarities in all 4 physiological responses in HR, $VO_2$, $T_{core}$, $T_{sk}$ throughout all 4 trials.

## CONCLUSION

Having greater subcutaneous adipose tissues in obese individuals did not impose greater thermoregulatory and circulatory strain during exercise in the heat. With ~ 1% of BW loss prior to exercise, the heart rate (HR), oxygen uptake ($VO_2$), core body temperature ($T_{core}$) and skin temperature ($T_{sk}$) in obese individuals were similar as normal weight individuals when exercising for 50min at 50% $VO_{2max}$ of cycling in the heat (35°C; 64% rh). Therefore, exercise programme for obese individuals should not be restricted to indoor exercises only. Obese individuals can enjoy exercising outdoors, which have greater feelings of revitalization, increased energy and positive engagement.


## ACKNOWLEDGEMENT

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Table 1

*Pearson Product-moment Correlations between Core temperature and Mean Skin temperatures when exercising under hot conditions.*

| | | $T_{core}$ |
|---|---|---|
| Mean $T_{sk}$ | r value | 0.543** |
| | sig. (2-tailed) | 0.000 |

**. Correlation is significant at the 0.01 level (2-tailed)

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