THERMAL AND PHYSIOLOGICAL RESPONSES OF THE HUMAN BODY DURING EXERCISE

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İZMİR

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ABSTRACT

THERMAL AND PHYSIOLOGICAL RESPONSES OF THE HUMAN BODY DURING EXERCISE

In this study, the thermal behaviors of the athlete’s bodies were investigated with respect to thermal comfort and exercise intensity experimentally. The relation between Predicted Mean Vote (PMV) which is an thermal comfort index and Ratings of Perceived Exertion (RPE) that measures the exercise intensity and exhaustion level was evaluated statistically. The experiments were carried out with eleven subjects in a conditioned test chamber at School of Physical Education and Sports in Ege University with a bicycle ergometer in 2012 and 2013. The relation between PMV and RPE was analyzed statistically by SPSS and the average correlation coefficient was obtained -0,52. This result mentions that there are a negative moderately correlation. Moreover, the oxygen consumption rate and core body temperature which affect the exercise performance of athletes were divided two groups as high and low and statistically analysis were conducted. Accordingly, while the average correlation coefficient at high oxygen consumption rate group decreases -0,21, the average correlation coefficient at low oxygen consumption rate group increases -0,77. The level of correlation coefficient decreases at the subjects whose oxygen consumption rates are high. Similarly, while the average correlation coefficient at high core body temperature group decreases -0,36, the average correlation coefficient at low core body temperature group increases -0,70. The existed level of correlation coefficients increases at the subjects whose core body temperatures are low.

ÖZET

EGZERSİZ SIRASINDA İNSAN VÜCUDUNUN ISIL VE FİZYOLOJİK CEVAPLARI

Bu çalışmada, egzersiz yapan sporcuların vücutlarının ısıl davranışları, ısıl konfor ve egzersiz yoğunluğu bakımından, deneysel olarak incelenmiştir. Bir ısıl konfor indeksi olan Tahmini Ortalama Oy (PMV) ve egzersiz yoğunluğu ile tükenme seviyesini ölçen Algılanan Zorluk Derecesi (RPE) arasındaki ilişki istatistiksel olarak değerlendirilmiştir. Deneyler on bir katılımcı ile 2012 ve 2013 yılında Ege Üniversitesi Beden Eğitimi ve Spor Yüksekokulunda iklimlendirilmiş bir deney odasında bisiklet ergometresinde ile yürütülmüştür. PMV ile RPE arasındaki ilişki SPSS programı yardımıyla istatistiksel olarak analiz edilmiştir ve ortalama korelasyon katsayısı -0,52 olarak elde edilmiştir. Bu sonuç orta düzeyde ters yönlü bir ilişkiden bahsetmektedir. Ayrıca, sporcuların egzersiz performansını etkileyen oksijen tüketme kapasitesi ve vücut iç sıcaklıkları yüksek ve düşük olmak üzere iki gruba ayrılmış ve istatistiki analizler gerçekleştirilmiştir. Buna göre, ortalama korelasyon katsayısı yüksek oksijen tüketme kapasitesinde -0,21 değerine düşerken, düşük oksijen tüketme kapasitesinde -0,77 değerine yükselmiştir. Daha yüksek oksijen tüketme kapasitesine sahip deneklerde ilişkinin seviyesi düşmektedir. Benzer şekilde, ortalama korelasyon katsayısı yüksek vücut iç sıcaklığında -0,36 değerine düşerken, düşük vücut iç sıcaklığında ise -0,70 değerine yükselmektedir. Vücut iç sıcaklığı düşük olan deneklerde, var olan ilişkinin seviyesi artmıştır.

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CHAPTER 1

INTRODUCTION

Human physiology is a dynamic system which is controlled and regulated by brain. It has different behaviors at different environmental and metabolic conditions. Similarly, humans, to continue their life and go on vital functions, permanently need energy. This energy is generated in the cells by various biochemical reactions. It is used not only in physical effort but also in maintaining homeothermia which is progressing the core body temperature about 37°C. Therefore, the thermal behavior of human body interests a lot of scientists. Currently, due to developed technology the research on thermal behavior of human body is on increase.

Human body is considered as a heat engine where oxygen and food put account as a fuel and energy appears. Some of energy storages in body, rest of it dissipates into the environment as heat. In body, the lowest required energy is called basal metabolism. To illustrate, during sleeping, body generates energy only for the basal metabolism. Basal metabolism depends on sex, age and body fat rate [1].

In human body, many reactions and process occur simultaneously. There is a control center called brain and it controls and reacts. There are also a lot of thermo receptors in human body on the skin and in core of body. They sent continually signals into brain. Thus, brain evaluate the conditions when change. Due to this mechanism, human body can easily adopt the changing conditions.

Nowadays, lots of people do exercise regularly. They not only lose weight but also get rid of stress. Exercise has a lot of positive effects on human life. Therefore, exercise is getting important. When people begin the exercise, human body reacts such as rising core body temperature and sweating. During exercise, human body adapts the exercise conditions. The core body temperature rises depending on energy requirement in human body. Then people sweat and dissipate the heat into the environment. Thus, human body is protected against the excessive heat load by thermoregulatory system. To make easier heat dissipation subjects take some measure such as putting on thin clothes or doing exercise in mornings and evenings.

On the other part, people spend their time in sports hall or gymnasium. During exercise or recovery periods of exercise there is a thermal interaction between human body and environment. This interaction is important to human body. With the thermal comfort studies and developed technology, the air conditioning system is applied especially in big buildings such as sports center, theatres and conference halls.

Similarly, sports economy is growing consistently with rising economic growth of sponsorship. In addition, a lot of people join sports activity as audiences or participants compared to the past. Sportive activities become one of the most important parts of daily life. Several governmental or non-governmental organizations conduct many campaigns and they mention the importance of exercise and they encourage the people to join sportive activities.

In this thesis, the thermal behavior of human body is investigated during exercise. The aim of this research is to analyze the relation between Predicted Mean Vote (PMV) and Ratings of Perceived Exertion (RPE) during exercise. In literature, the researches on PMV and RPE existed [2, 3]. However, there is not any study on the relation between PMV and RPE within the knowledge of the authors. These parameters were evaluated individually in literature and there are also a few studies about thermal comfort during exercise. This study leads to further study about the relation between PMV and RPE, thermal behavior of human body during exercise. For this purpose, several experiments were carried out in School of Physical Education and Sport in Ege University in Izmir with 11 subjects in 2012 and 2013. During the experiments, required measurable parameters such as metabolic heat production, mean radiant temperature, air temperature, core body temperature, skin temperature were measured and recorded.

In Chapter 2 of this thesis, the human thermal system and thermal comfort are mentioned. The human thermoregulatory system and mechanisms are described in detail and the features and importance of human thermoregulatory system are presented. The human thermal comfort is also defined and the required parameters are accounted for. Predicted Mean Vote (PMV) as a thermal comfort index used commonly for evaluating environmental conditions is given. The formulas are shown and the parameters are introduced.

In Chapter 3, the thermal behavior of human body and occurring reactions during exercise, the heat generation and heat loss from the body to environment is mentioned. In addition, some metabolic heat values for various sports are given.

Besides, the Ratings of perceived exertion (RPE) used for evaluating exercise intensity is presented.

In Chapter 4, the existing important studies about thermal behavior of human body during exercise and thermal comfort are summarized in brief. The studies that are related to RPE also evaluated and summarized.

Chapter 5 is the method chapter. The details of exercise, test chamber, experiments, work group, methods and assumptions are given. Some environmental parameters are given, too.

Chapter 6 is the results and discussion chapter. In this section, results of the thesis are given and these results are commented. The results are compared with the previous studies in the related literature. The relation between PMV and RPE is analyzed statistically and commented.

In Chapter 7, the conclusion is given. The implications and limitations are given. Moreover the suggestions about future works are presented.

CHAPTER 2

HUMAN THERMAL SYSTEM AND THERMAL COMFORT

2.1. Thermoregulatory System

The energy is generated consistently in human body and some part of it can be used for mechanical work, the other part which is included vital functions of human body is dissipated into the environment as heat therefore body is in a heat interaction with the environment. The core body temperature must be sustained nearly 37°C during that process. The increase in the body temperature can cause irreparable damages in human body. Similarly, the decreasing of body temperature can be hazardous. This temperature fluctuation is controlled and regulated by brain. Thermoregulatory system is also the heat response of the body to the environment. There are two types of thermoregulations. One of them is the behavioral thermoregulation and the other one is the physiological thermoregulation.

- Behavioral thermoregulation is related to physical activity. For instance put on clothes or take off, move and changing posture [1].
- Physiological thermoregulation is triggered by temperature signals from core and skin. Signals are occurred in the receptors existing in skin and core, they are transmitted to hypothalamus. There are five signals :

1) Warm signal from the core: $\mathrm{WSIG_{cr}} = \begin{cases} \mathrm{T_{cr}} - \mathrm{T_{cr,set}} & (\mathrm{T_{cr}} > \mathrm{T_{cr,set}}) \\ 0 & (\mathrm{T_{cr}} \leq \mathrm{T_{cr,set}}) \end{cases}$

2) Warm signal from the skin: $\mathrm{WSIG_{sk}} = \begin{cases} \mathrm{T_{sk}} - \mathrm{T_{sk,set}} & (\mathrm{T_{sk}} > \mathrm{T_{sk,set}}) \\ 0 & (\mathrm{T_{sk}} \leq \mathrm{T_{sk,set}}) \end{cases}$

3) Cold signal from the core: $\mathrm{CSIG_{cr}} = \begin{cases} 0 & (\mathrm{T_{cr}} \geq \mathrm{T_{cr,set}}) \\ \mathrm{T_{cr,set}} - \mathrm{T_{cr}} & (\mathrm{T_{cr}} < \mathrm{T_{cr,set}}) \end{cases}$

4) Cold signal from the skin: $\mathrm{CSIG_{sk}} = \begin{cases} 0 & (\mathrm{T_{sk}} \geq \mathrm{T_{sk,set}}) \\ \mathrm{T_{sk,set}} - \mathrm{T_{sk}} & (\mathrm{T_{sk}} < \mathrm{T_{sk,set}}) \end{cases}$

5) Warm signal from the whole body: $\mathrm{WSIG_{bm}} = \begin{cases} \mathrm{T_{bm}} - \mathrm{T_{bm,set}} & (\mathrm{T_{bm}} > \mathrm{T_{bm,set}}) \\ 0 & (\mathrm{T_{bm}} \leq \mathrm{T_{bm,set}}) \end{cases}$

These signals are defined as the difference of the neutral temperature of compartments and actual temperature of compartments. They take only positive values [4].

There are some receptors which control temperature in skin and core. The receptors are triggered by depending on the temperature fluctuation. The warm and cold signals are transported to hypothalamus by afferent neurons. Warm and cold signals are evaluated and assessed in hypothalamus then the thermoregulatory system activates to regulate core temperature by effector organs. Effector organs are skin vein, skeletal muscles and sweat glands. Skin veins work for both heat loss and heat production mechanisms, while skeletal muscles produce heat, sweat gland works for heat loss. Figure 2.1 illustrates the peripheral and central thermoregulatory system.

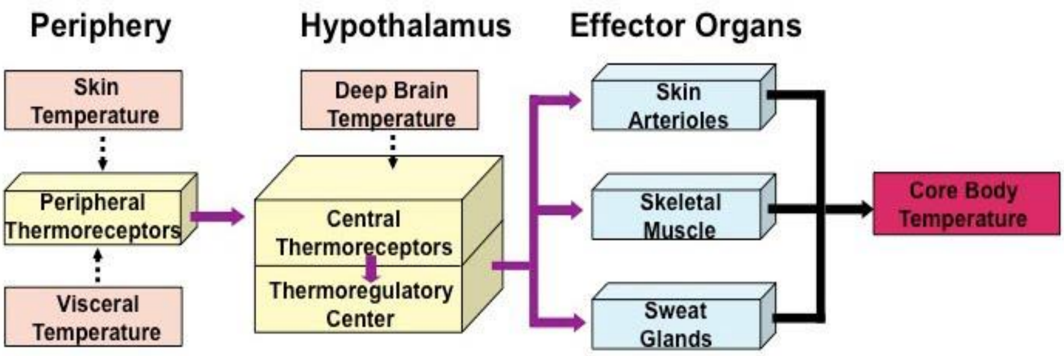

Figure 2.1. The peripheral and central thermoregulatory system [5]

Thermoregulation is closely related to thermal comfort. To provide thermal comfort, the heat balance between environment and body must be equalized. Moreover the generated heat in metabolism should be equal to heat loss from body if there is no mechanical work. Besides, the core and skin temperatures are desired to be neutral as thermal comfort [6].

Thermoregulatory system is controlled by hypothalamus. In hypothalamus, two centers related to temperature control. While the anterior part pertains to protect the human body against heat, the posterior part pertains to protect the human body against cold due to some mechanisms such as heat production mechanism and heat loss mechanism.

The temperature of blood rises and its temperature are getting bigger than the set point of human body temperature as shown in upper site of Figure 2.2. The thermo receptors send the warm signals to hypothalamus by afferent neurons. These signals trigger heat loss center in hypothalamus and the heat loss mechanisms are activated. Vasodilation occurs, surface area expands and the rate of heat loss from the human body to environment rises. In addition to vasodilation, sweat glands are activated and it secretes sweats and it is vaporized by heat in the skin. As a result the skin temperature decreases. When the body temperature is smaller than the set temperature, the hypothalamus is triggered and the heat loss center shuttles down.

On the other hand, when imbalance occurred in human body and the core body temperature falls down as shown in lower site of Figure 2.2, the temperature of blood decreases and its temperature are smaller than the set temperature of human body. Thermo receptors sent cold signals to hypothalamus by afferent neurons. These signals trigger heat production center in hypothalamus and the heat production mechanisms are activated. Vasoconstriction occurs, the surface area is reduced, and the rate of heat loss from the human body to environment declines. In addition to vasoconstriction, the skeletal muscles are activated and shivering starts. Due to shivering, heat is generated in muscles and the core body temperature rises. When the core body temperature is higher than set point temperature, the hypothalamus is triggered and heat production center is shuttled down [7].

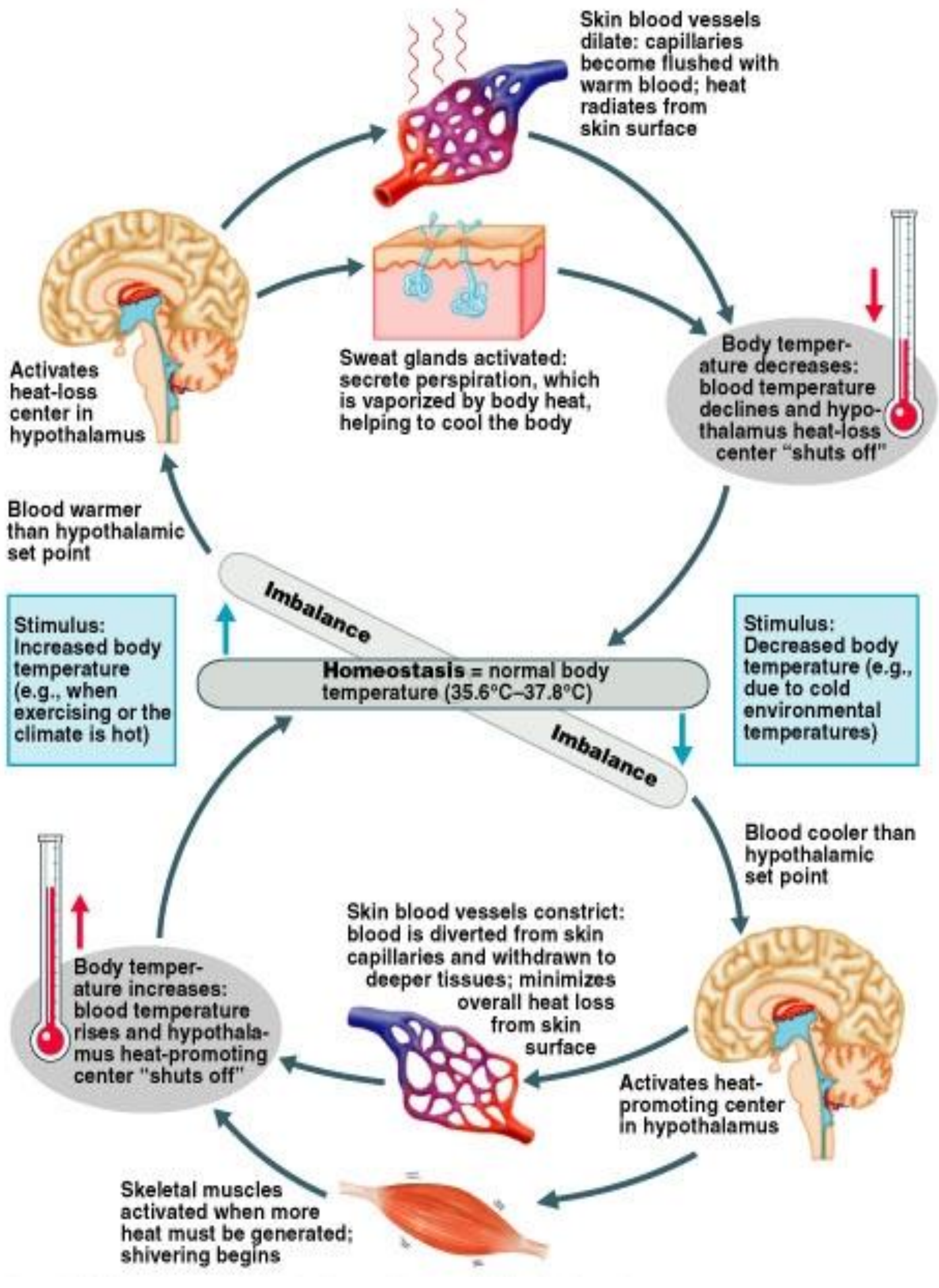

Figure 2.2. The mechanisms of thermoregulation [7]

2.1.1. Heat Production Mechanisms

There are two mechanisms of heat production in human body. They are vasoconstriction and shivering[1].

2.1.1.1. Vasoconstriction

When human are exposed to cold, the body begins to lose heat. The receptors located in core and skin compartment in the human body send signals to hypothalamus and consequently the blood vessels constrict which is called vasoconstriction. Owing to vasoconstriction, the blood flow decelerates and reduces surface area. Hence, the body is protected against a large amount of heat [8].

2.1.1.2. Shivering

Shivering is another way of heat gaining mechanism. When core temperature decreases, muscle strain increases and muscular contraction is occurred and heat generates. Pillars in skin become upright and create an insulation layer. Additively due to epinephrine and nor epinephrine metabolic heat generation rises [6, 9].

2.1.2. Heat Loss Mechanisms

There are two mechanisms of heat loss in human body. They are vasodilation and sweating [1].

2.1.2.1. Vasodilation

When heat loss from body to environment is insufficient, heat loss mechanism starts to act. In vasodilatation, blood vessels enlarge and contain more blood. The surface area expands and blood flow to skin accelerates. Due to this flow, heat transfer from core to skin rises double or triple [6]. This sensible heat is dissipated into the environment and then sweat glands are activated. Human body losses latent heat because of evaporation of some part of this sweat.

2.1.2.2. Sweating

As vasodilation is inadequate, core body temperature continues to rise. The warm signals from the core and the skin compartments are stimulated by the sudomotor activity. Sweat gland works and secretes sweat. Thus the rates of heat transfer increase. When 1 gram sweat evaporates approximately 2.34 kJ heat is dissipated from the human body to the environment [9]. Sudomotor activity is essential to maintain core body temperature. Furthermore this activity protects the human body against the excessive heat load [9, 10].

2.2. Thermal Comfort

People have interacted with the environment throughout the humanity history. They have adapted themselves to the environment. To illustrate, people settled the caves for protecting them against cold weather in winter early on humanity. Cold or warm environmental conditions influence significantly human life. Consequently, the relation between human life and environment attracts interests of scientists' and they investigated this relation especially twentieth century because of improved technology. They explored the optimum thermal conditions for human body in the built environment.

There is a dynamic interaction between human and the environment. Body triggers to control mechanisms against the changing environment conditions to heat balance. The balance between human and the environment is essential. However the heat balance and thermal comfort differ from each other. Even if the heat balance is established, it does not mean that the conditions are proper for thermal comfort. Thermal comfort depends on humans' sensation and satisfaction. Therefore it diverges for every person. Thermal comfort is described as "condition of mind which expresses satisfaction with thermal environment" [1, 11].

Nowadays, thermal comfort is an important issue. Architects and engineers take into consideration this issue when designing buildings. Human spent a lot of their time in indoor at work, home or mall. Comfort or discomfort conditions affect significantly human's effectiveness and daily life performance [12] .Additionally, thermal comfort influences human health.

An index, which is called Predicted Mean Vote (PMV) was developed by P.O. Fanger for evaluating thermal environment in 1970 [1]. This scale contains several measureable parameters such as metabolic heat production, air temperature etc. The thermal behavior of human is different at different gender. The man and woman physiology cannot be identical. Likewise, the human physiology is dependent on age and the rate of metabolic heat generation is different at different ages [1].

Regardless of sex and age, the parameters which influence thermal comfort is divided two groups. These are personal and environmental parameters [1]. The expectation can be considered as a third group.

In addition, three conditions were indicated by Fanger in 1970 for whole body thermal comfort [1, 13]:

1) The body is in heat balance with the environment

2) Skin temperature is within the comfort limits

3) The sweat rate is within the comfort limits.

2.2.1. Environmental Parameters

2.2.1.1. Air Temperature

Air temperature is the temperature of surrounding air. Most of people believe that air temperature is the most important and best known thermal comfort parameter. It also affects the heat exchange between the human body and the environment.

2.2.1.2. Mean Radiant Temperature

Mean radiant temperature is the temperature of the surrounding surfaces of chamber. Mean radiant temperature is an important parameter for buildings whose walls are exposed to the solar radiation. The sun exposure increases the wall or window temperature thus occupants feel discomfort even if the inside temperature is suitable for the human comfort. Similarly, unless the wall's insulation is sufficient, the temperature of walls decreases in winter conditions. Then, people feel cold and discomfort. Furthermore, this discomfort influences the energy budget or expenditure. For instance, much as the conditions are comfortable, people rise the temperature of heating system. Insulation has an impact on both heating and cooling loads and it is an effective parameter for mean radiant temperature [14].

2.2.1.3. Humidity

Humidity is the rate of water vapor in the dry air. Relative humidity is the ratio of the existing water vapor to the maximal vapor capacity of the air under the same temperature. Humidity effects significantly both thermoregulation and thermal comfort. With the increase of relative humidity, the latent heat loss from body goes down depending on the increasing vapor pressure. Then, the sweat rate in human body increases. Residual skin wittedness brings about to feel discomfort. Water loss from the human body depends on the vapor pressure between body and surrounding air [15].

2.2.1.4. Air Velocity

Air movement is a parameter related to heat transfer between body and the environment. At high air velocity, people feel physically discomfort. At still air, people cannot provide heat exchange efficiently between surrounding air and the human body and people cannot breathe easily. Air velocity around 0.2 m/s is a particular suitable condition for thermal comfort.

2.2.2. Personal Parameters

2.2.2.1. Clothing

Humans put on some clothes to reduce heat loss. Clothes reduce to heat loss from the body to the environment by creating an insulation layer between environment and body. This decrease is dependent on materials and thickness of clothes. Typically summer clothes are different from typically winter clothes. Clothes, which are unsuitable for thermal conditions or seasons, can cause thermal discomfort.

2.2.2.2. Activity Level

With the increasing of activity level, the rate of required and generated energy rises. To control and regulate this high energy is a complex process and this high energy level affects the human physiology and thermal comfort. The required energy changes depending on the physical exertion. Table 2.1 illustrates the heat generation of some daily activities in human life.

Table 2.1. Metabolic heat generation values at some activities[16]

Activity	Heat Generation (W/m^2)
Resting	
Sleeping	40
Seating	60
Standing	70
Daily Activity	
Walking (0.89 m/s)	115
Walking (1.79 m/s)	220
Office Activity	
Reading	55
Writing	60
Typing	65
Filling (standing)	80
Packing	120
Home Activity	
Cooking	90-115
Home Cleaning	115-200

2.2.3. Expectation

People have expectations from the environment. With dependent on age, environmental conditions and quality of buildings, the most important expectation is that the zone must be comfortable thermally.

2.3. Predicted Mean Vote (PMV)

Predicted Mean Vote (PMV) proposed by Fanger in 1970 is used frequently to evaluate the environmental conditions in terms of thermal load and sensation [16] . PMV is calculated as below[1],

$$\mathrm{PMV} = [0{,}303\exp(-0{,}036\mathrm{M})]\mathrm{L} \qquad (2.1)$$

where L refers to thermal load on the body (W/m^2) and it is calculated as

$$\begin{aligned}\mathrm{L} = (\mathrm{M}-\mathrm{W}) - 3{,}96^{-8}.\,\mathrm{f_{cl}}[(\mathrm{T_{cl}}+273)^4 - (\mathrm{T_r}+273)^4] - \mathrm{f_{cl}}\mathrm{h_{cl}}(\mathrm{T_{cl}}-\mathrm{T_a}) \\ - 3{,}05[5{,}73 - 0{,}007(\mathrm{M}-\mathrm{W}) - \mathrm{p_a}] - 0{,}42[(\mathrm{M}-\mathrm{W}) - 58{,}15] \\ - 0{,}0173\mathrm{M}(5{,}87-\mathrm{p_a}) \\ - 0{,}0014\mathrm{M}(34-\mathrm{T_a}) \qquad (2.2)\end{aligned}$$

M : metabolic rate of human body (W/m^2)

W : mechanical work rate (W/m^2)

T_a : air temperature (°C)

T_r : mean radiant temperature (°C)

f_{cl} : clothing area factor (dimensionless)

T_{cl} : the mean temperature of outer surface of the clothed body (°C)

h_c : convective heat transfer coefficient (W/m^2°C)

p_a : the water vapor pressure in ambient air (kPa)

Predicted Mean Vote is developed based on the steady state energy balance method. It estimates the mean response of a large number of humans with reference to ASHRAE scale[16]. This scale ranges from +3 to -3 and it defines as

+3 Hot
+2 Warm
+1 Slightly Warm
0 Neutral
-1 Slightly Cool
-2 Cool
-3 Cold

Zero is the neutral value for thermal comfort. This value is also the most comfortable value. Moving away from zero leads to warm and cold discomfort feelings and effects human performance and health.

CHAPTER 3

THERMAL BEHAVIOR OF HUMAN BODY DURING EXERCISE

Exercise is an important activity in human life. People do exercise as a part of daily life. Some people do exercise as professionally. The required rate of energy during exercise depends on exercise intensity [9]. Table 3.1 displays heat generation values of various sport activities.

Table 3.1. Heat generation values for different sport activities[16]

Sport Activity	**Heat Generation (W/m^2)**
Walking on the road (2 km/h)	110
Walking on the road (5 km/h)	200
Volleyball Bicycling (15 km/h)	230
Golf Softball	290
Gymnastic	320
Swimming	345
Bicycling (20 km/h)	350
Basketball Tennis	400
Football	460
Running (15 km/h)	550

During a sport activity, a lot of energy is generated in just a moment. Since all of this energy cannot be dissipated to the environment simultaneously, there will be also storage part Thus, core body temperature begins to rise depending on heat accumulation [9].

Additionally, Ratings of Perceived Exertion is used for evaluate or perceive the exercise intensity during exercise [3], especially professional athletes

3.1. Ratings of perceived exertion

Ratings of perceived exertion (RPE) is an index which is also called as Borg Scale developed by Gunnar Borg [1]. It measures the intensity of physical exercise. It is based on sensation. There are many studies on RPE and its relation with core body temperature and heart rate. RPE has the close relationship between core body temperature and heart rate [3, 17]. Table 3.2 shows the RPE scale.

RPE ranges from 6 to 20 [1]. The participants are asked to about feelings during exercise or recovery period. RPE value changes dynamically during exercise. For example, while the RPE value can be vary between based on exercise duration and intensity. With the increase in RPE will result with, the exercise performance and duration decrease. Additionally, it is shown that the rate of increase in RPE values at hot conditions is bigger than cool conditions at the same work output. Even though the intensity of exercise decreases or remains constant, the brain perceives that the exercise is getting gradually harder [3, 17].

Table 3.2. Borg RPE scale[1]

Scale	Feeling	Activity
6	Very , very light	
7		How you feel
8	Very light	when you occupy in an armchair
9		or lie down in a bed
10		Little or no effort
11	Light	
12		
13	Slightly hard	You feel during exercise
14		or physical activity
15	Hard	
16		
17	Very hard	You have felt the
18		hardest work
19	Very, very hard	you have ever done
20	Maximal Exertion	Do not work this hard!

Figure 3.1 shows rectal temperature changing against time. There are five trials at different power output and the environmental conditions. The trials are performed at cold and hot conditions at four different peak power output (55, 60, 65 and 70). For instance, C70 refers to the trial which is performed at cold conditions with 70 percent peak power output. The rectal temperature equals to roughly 37°C at the beginning of all trials. The rectal temperature depends on the duration; it increases by time. The

reason why H55 trial has the maximum rectal temperature is that H55 trial is the longest trial [3]. (H refers to hot environment while C refers to cold environment)

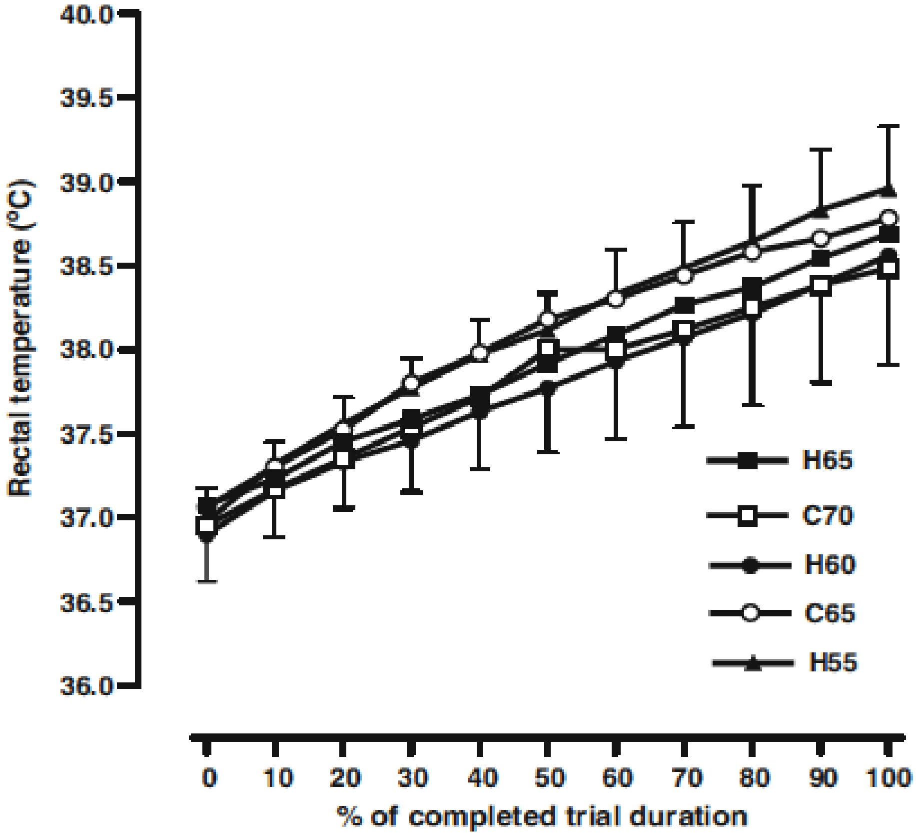

Figure 3.1. Rectal temperatures vs. completed trail duration[3]

During the exercise, a small quantity rising in the core body temperature accelerates various biochemical reactions such as respiration or nerve conduction in the cells. However, this rising has a limiting effect on exercise performance [18]. According to the Figure 3.2, RPE rises linearly dependent on rectal temperature. As the rectal temperature reaches around 39°C, RPE gets the maximum value which is equal to 20 [19].

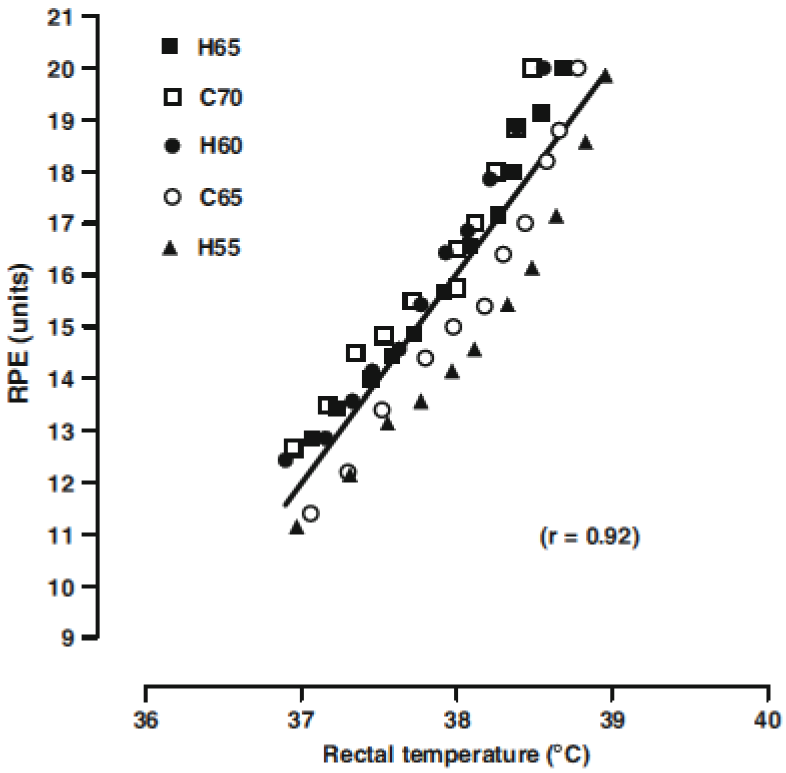

Figure 3.2. The correlation between RPE and rectal temperatures[3]

Figure 3.3 shows the differences between the rate of total heat loss and the rate of heat production is zero at rest. With the beginning of exercise, the rate of heat production increases dramatically. After five minutes, the rate of heat production increases roughly 450 W. The rate of total heat loss also increases as a parabolic curve and finally reaches 410 W at the end of exercise. During exercise, the rate of heat production is bigger than the rate of heat loss. When the exercise is finished, the rate of heat production decreased dramatically at the recovery period (Figure 3.3). After ten minutes, the rate of heat production tends to decrease till initial level. However, at the recovery period, the rate of heat loss is bigger than the rate of heat production. During the first hour after the exercise, the heat loss continues to decrease while, at the end of an hour, the rate of heat production equals to the rate of heat loss [19].

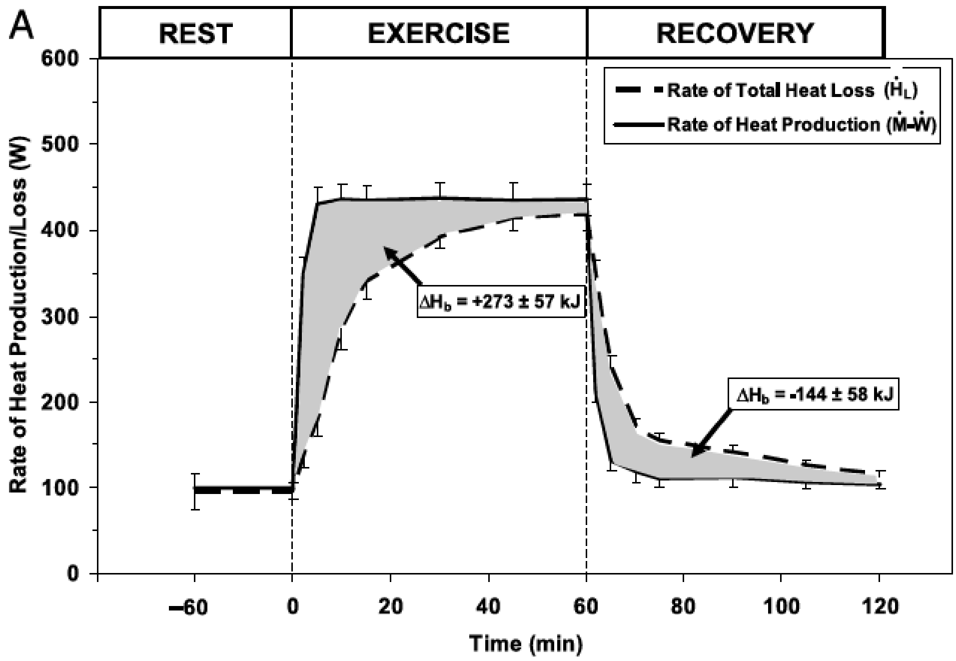

Figure 3.3. Heat productions and loss vs. time [19]

Figure 3.4 shows the mean skin temperatures at three different conditions which are hot (35°C), normal (25°C) and cool (15°C). In hot conditions, mean skin temperature increases and then remains constant. The skin temperature rises at hot conditions to avoid excessive heat load. For this reason, the skin temperature rises. Additionally, vasodilation occurs and the heat is transported from the core to the skin. Thus, the mean skin temperature goes up approximately 2°C during the trial. In normal conditions, with the starting of trials, mean skin temperature reduces roughly 1°C owing to the vaporization of sweat. However, vasodilation occurs and the heat is transferred to skin to dissipate into the environment. The mean skin temperature begins to rise again. At the end of trials, the mean skin temperature reaches the initial level. In cool conditions, the mean skin temperature declines to avoid excessive heat loss. In addition, the mean skin temperature reduces based on the vaporization of sweat and the mean skin temperature goes down nearly 3°C. Then the vasodilation occurs and the mean skin temperature rises. The mean skin temperature stays constant at the end [17].

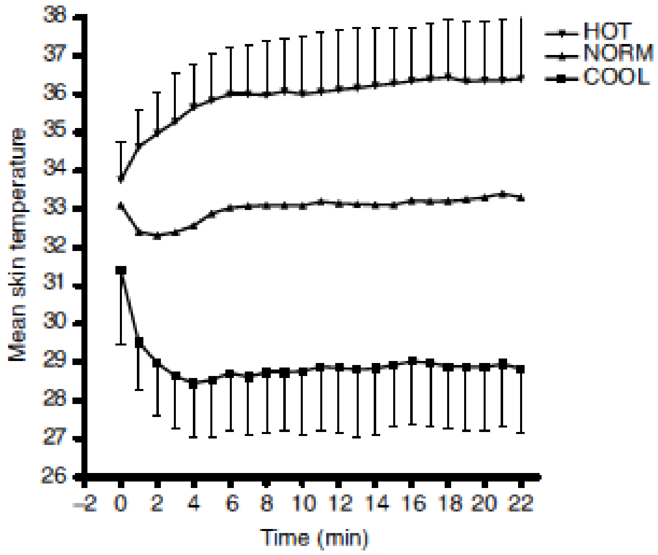

Figure 3.4. The mean skin temperature during trials at three different conditions[17]

Heart rate can be considered as an indicator which demonstrates general situation of human body such as sleeping at home or working in a mine. or the stress those human body exposures The heart rate is shown at Figure 3.5 during exercise. The heart rate rises continually during exercise. Independently of types, duration or intensity of sports, the heart rate always increases [20].

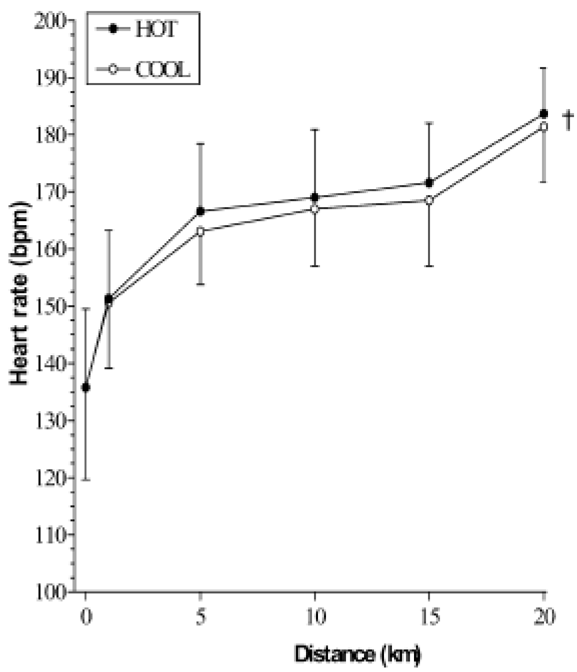

Figure 3.5. The heart rate distribution during exercise at two different conditions[20]

CHAPTER 4

LITERATURE SURVEY

Environmental conditions affect the people life and the scientists have interested in this effect. They have conducted many researches to analyze thermal conditions of the environment and the heat interaction of human body. Moreover, they have also investigated the heat interaction between the human bodies and the environments during different exercise level for different thermal environment. In this part, the studies which are related to thermal comfort and the thermal behavior of human body are summarized briefly.

Parson [21] investigated the gender effects at different environmental conditions (cool and warm).They were at two different groups which consisted of 16 males and 16 females subjects. They spent three hours in office or home environments where create by simulation. According to this research, at the same activity level and clothing insulation value, the differences between two genders with respect to thermal responses are very low. At neutral and slightly warm environmental conditions, females have tendency to be cooler when compared to the males in cool environmental conditions [21].

Kurazumi et al. [22] investigated the radiative and convective heat transfer coefficients of human body, especially focusing on the convective heat transfer from the human body. The tests were carried out at different postures at a conditioned chamber. They evaluated the existing convective heat transfer in literature and they suggested new empirical formulas about the convective heat transfer coefficients of human body at different postures including the convective heat transfer areas in the human body [22].

Stamou et al. [23] investigated the thermal comfort conditions by CFD in the indoor stadium of Galatsi Arena where hosted the sport activities during the Olympic Games of Athens 2004. They stated CFD code and they also showed the different temperature contours of arena. They calculated Predicted Mean Vote (PMV) at various regions of arena at two different inlet air temperatures of the air condition system. When the temperature of inlet air increases from 14 °C to 16 °C, PMV gets closer to zero [23].

Yang et al. [24] investigated the applications of Predicted Mean Vote (PMV) in an air conditioned environment in moist and hot climate region. The experimental studies were carried out in a climate chamber in China. According to these experimental studies, PMV overestimates the thermal sensation's of occupants in the environmental conditions (PMV>0). The difficulty of the application of PMV leads to the development of Actual Mean Vote (AMV). The equations related PMV and AMV are given based on Standard Effective Temperature (SET). A new empirical formula was generated for applying PMV in moist and hot climate regions in China. Furthermore, this formula contributes to energy management and budgets in buildings [24].

Kaynakli et al. [25] evaluated computationally the heat generation at various activities such as sleeping or working and the effects of thermal resistance of clothes on the human body. The changing activity level with predicted mean vote (PMV) is given at several air velocity and clothing insulation values. Their results revealed that the heat losses from the human body segments without clothes were bigger than the other segments. If the clothing insulation value increase, the required ambient temperature decreases [25].

Kilic et al. [26] investigated the heat interactions between the ambient air and human body and analyzed these interactions based on steady state energy balance. Additionally, the heat loss from human body such as convection, conduction, radiation and evaporation and thermal index, Predicted Mean Vote (PMV), was calculated individually. The effects of ambient air temperature on heat loss from human body and thermal comfort indexes were examined. With the increasing of activity level, the skin temperature decreased to maintain human thermal comfort. Similarly, the heat loss from body reduced with decreasing body temperature under the same conditions. With the rising activity level, the increasing body temperature is compensated with decreasing skin temperature. Thus, even if the temperature differences between core body and skin increases, the mean body temperature is stable. At the low ambient temperature, the PMV takes negative values. If the air temperature rises, PMV takes positive values. At high and low ambient temperature, the heat balance between body and environment does not establish therefore, these conditions have negative impacts on human thermal comfort relatively [26].

Jones [27] investigated human thermal model parameters and the heat interaction between body and the environment on human thermal comfort standards. Figure 4.1 shows the comparisons of Fanger and Gagge model at different ambient temperature [27]. It can be said that Gagge model is more stable than Fanger model. At low and high ambient temperatures, the differences between Fanger and Gagge model increases [27].

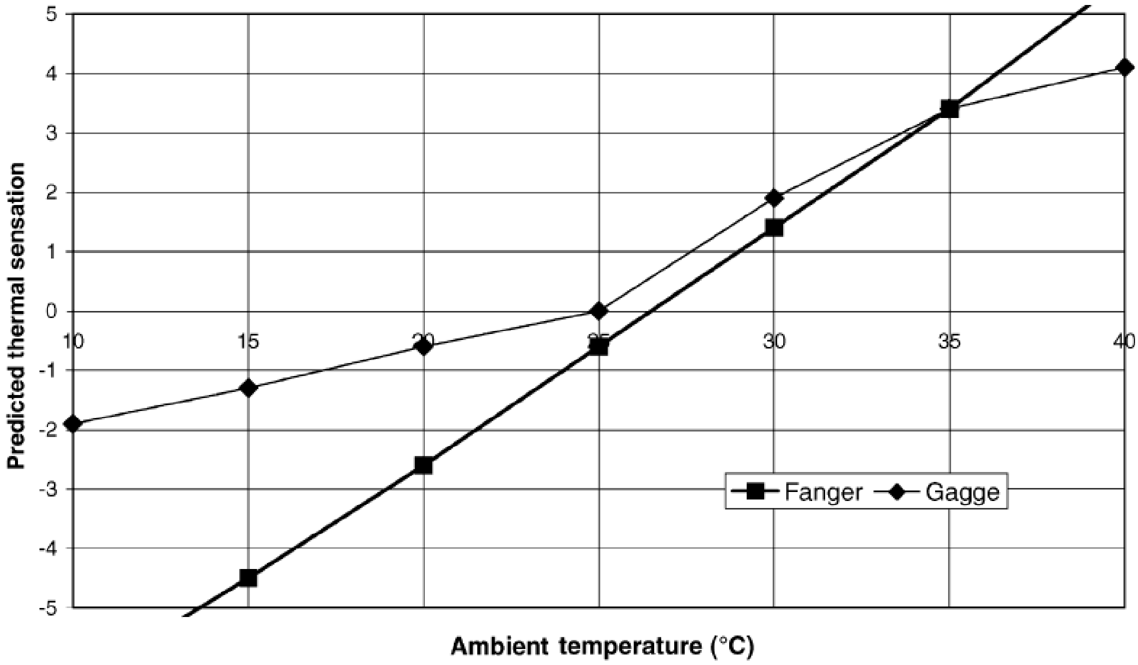

Figure 4.1. The comparison of thermal sensation from Fanger and Gagge models [27]

Ye et al. [28] carried out tests at actual and simulated environments with a new PMV measuring device and compared with the results each other .During tests, the metabolic heat values of occupants and clothing insulation values of occupants were supposed to be equal each other. Humidity or water vapor pressures are also equal. Furthermore the other parameters are kept constant. The tests are performed two different metabolic heat values as 1 met and 1.5 met. There is a similar tendency between 1 and 1.5 met values at lower than 0.5 m/s air velocity value. At higher than 0.5 m/s air velocity, the difference between two met values is not significant and it can be negligible. Operative temperature has the neutral value at 25°C at both 1 and 1.5 met values. Furthermore, while met value rises, the required mean radiant temperature for neutral conditions decrease [28].

Butera [29] studied the heat interaction between body and the environment and gave the required equations for calculations. At this study, the tables related to PMV changing dependent on operative temperature at various air velocity at 58 W/m^2, 81 W/m^2, 116 W/m^2 and 174 W/m^2 metabolic heat rate values and at various clothing insulation values which are 0, 0.25, 0.50, 0.75, 1.0 and 1.50 clo[29]. Figure 4.2 and Figure 4.3 show that the PMV changing depend on air velocity at different metabolic heat value and clothing insulation value [29].

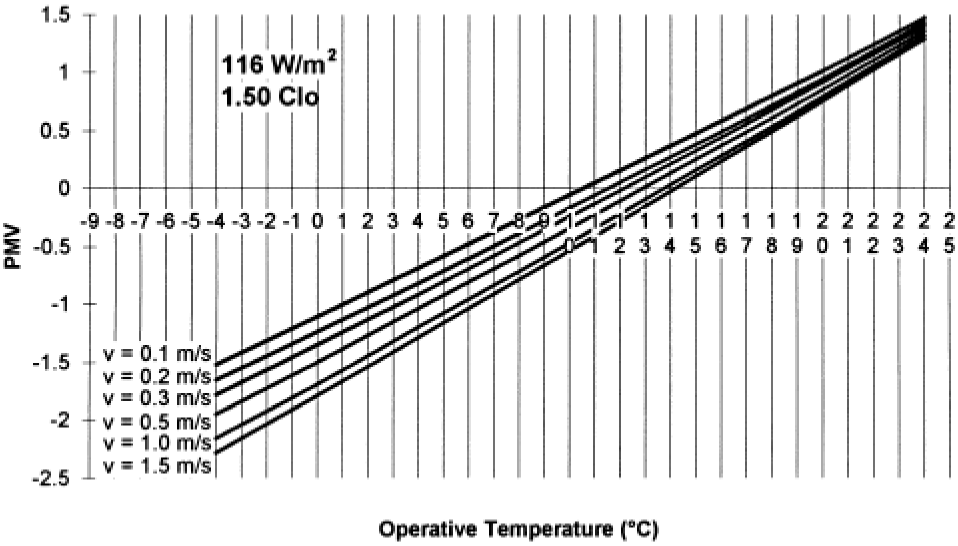

Figure 4.2. PMV vs. operative temperature at 116 W/m^2 at 1.5 clo[29]

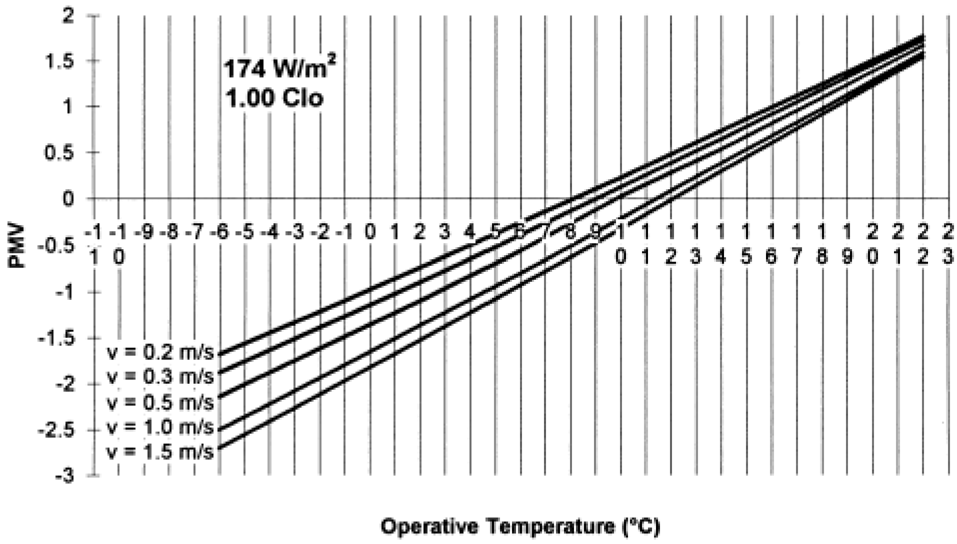

Figure 4.3. PMV vs. operative temperature at 174 W/m^2 at 1 clo [29]

Atmaca [14] examined the thermal comfort parameters such as the humidity, the temperature and the air velocity. The tests were performed while the occupants' skin is dry and wet. According to results, 24°C is the neutral value for thermal comfort. Increase or decrease the temperature value, the discomfort occurs. At higher 0.2 m/s as air velocity, the discomfort also takes place. With respect to relative humidity, the optimal values ranged from 40% to 60% for dry skin, the existence discomfort at wet skin increase [14].

Kenny et al. [19] investigated evaporative and dry heat loss and the changes body heat storage. The values were measured via direct whole body and indirect calorimetry simultaneously. Eight cyclists cycled at 70 W as a rate of external work. In spite of remainder increment of whole core body temperatures, the heat dissipation of whole body was swiftly decreased at the end of cycling at intermediate exercise intensity during 60 minutes. Half of the heat stored during exercise was dissipated at recovery period. The rest of heat storage was stored muscles and the temperatures of muscles grow [19].

Schlader et al. [30] investigated the relation between core body temperature at cold and warm environments during exercise and Rated Perceived Exertion (RPE). The experiments were performed to research the human thermal responses when the ambient conditions change. The results revealed that the skin temperature rises linearly when started at warm environment and was cooled the skin temperatures decreases regularly when started at cold environment and was heated. The RPE values at both situations increases [30].

Crewe et al. [3] predicted the duration of fatigue during exercise at warm conditions with increasing the rate of RPE. Five tests are performed by seven cyclists in comparison with cold conditions. Cyclists are getting tired faster at hot environmental conditions compared to cool conditions. The tests are finished immediately when cyclists feel fatigue and the RPE values reach 20 which is the maximum value of RPE. The increasing rate of RPE is utilized for predicting the exercise duration. It can be clearly seen that RPE rise linearly at a fixed power output. Even if the work output remains constant, brain perceives that the exercise getting harder. Additionally, the warm conditions have negative impacts on RPE and exercise performance [3].

Tucker et al. [17] investigated the human thermal behavior during exercise for various temperatures at a fixed RPE value. The tests were conducted at cold (15°C), norm (25°C) and hot (35°C) by eight cyclists. The relative humidity is constant at 65%. Cyclists are free to decrease or increase work rate to maintain the fixed RPE value. It was found that, the furthest decreasing at a fixed RPE occurs at hot conditions. Thus, the test durations at hot conditions are shorter than the test durations at cold conditions [17].

Balci et al. [9] studied the thermal behavior of human body during maximal and sub-maximal exercises. The data which was used Balci's study and this thesis' data are obtained from the same project but the data are used for different calculations and investigations. They analyzed the human thermoregulatory system during submaximal and maximal exercise. In the research, the relation and interaction between core and skin temperature and heat transfer from skin were examined and viewed by infrared thermal camera [9, 31].

CHAPTER 5

MEASUREMENTS AND METHODS

5.1 Test Chamber

Many experimental tests were conducted within the scope of this research. The tests were carried out in a test chamber at School of Physical Education and Sports in Ege University in Izmir in 2012 and 2013. The test chamber was designed for these tests and isolated from the environmental conditions. The environmental and exercise conditions were adjusted before. The dimensions of test chamber are 6 meters as length, 4 meters as width and 3 meters as height [9]. (Figure 5.1)

Figure 5.1. The test chamber

Air circulation is conducted via three vent holes. The location of vent holes is shown in Figure 5.2. Vent hole 1 is connected to the electrical heater system with fan. While vent hole 2 is connected to the heat recovery unit, vent hole 3 is connected to the electrical heater system.

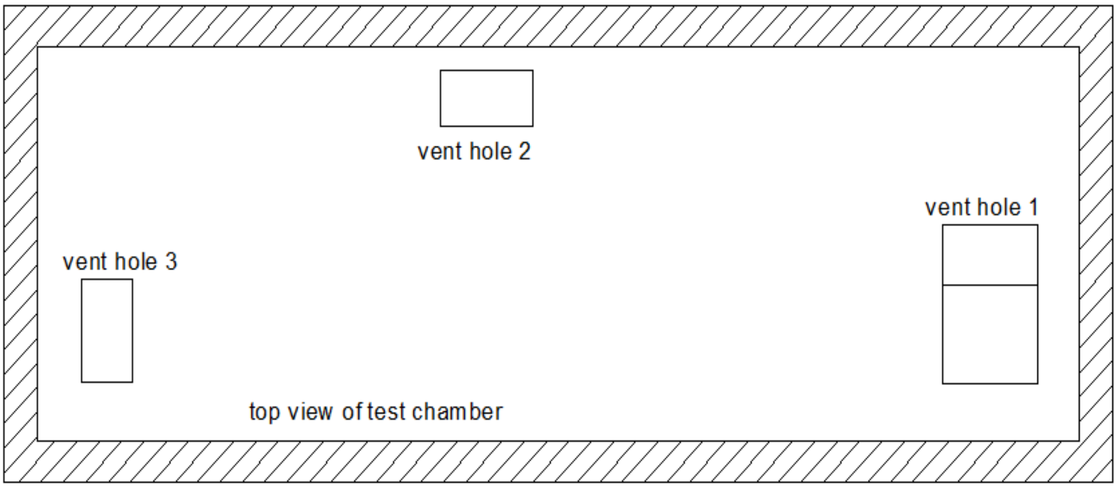

Figure 5.2. The vent holes of the test chamber

Inside photos of three ventilation holes were given in Figure 5.3. Two intake ducts from the heat recovery system and the electrical heater system are given in Figure 5.3a. The heat recovery sytem's exhaust vent can be seen in Figure 5.3b and vent hole 3 (Figure 5.3c) is the exhaust vent of the electrical heater system.

a b c

Figure 5.3. The views of vent holes 1(a), vent hole 2(b) and vent hole 3(c) from inside of test chamber

There is an electrical heater system located top of test chamber (Figure 5.4). There are two electrical heaters whose capacity is 3 kW each and there is also a humidifier inside of the system. The air is aspirated from vent hole 3 and it is heated and humidified, then the air ventilated into vent hole 1.

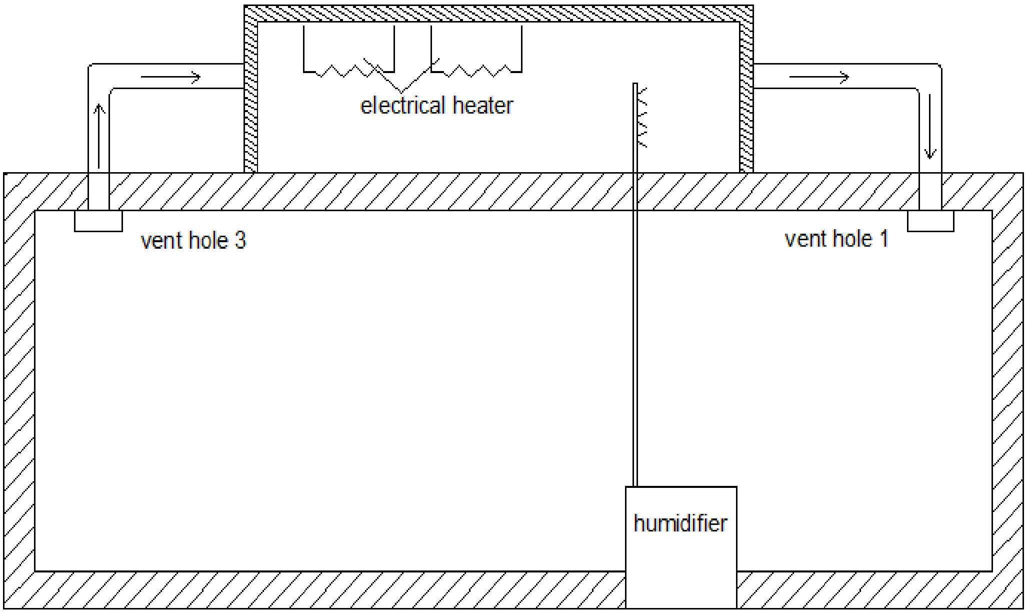

Figure 5.4. Air-conditioned system

There is also an energy recovery unit on the top of test chamber as shown in Figure 5.5. In this unit, there is a heat exchanger. Before the polluted air is defeated into the atmosphere, the energy which polluted air has is regained in this heat exchanger. Then, the fresh air is heated by regained energy in this heat exchanger and it is ventilated to the test chamber. Additionally, the energy recovery unit has two air admission holes on the outer surface of buildings of School of Physical Education and Sports.

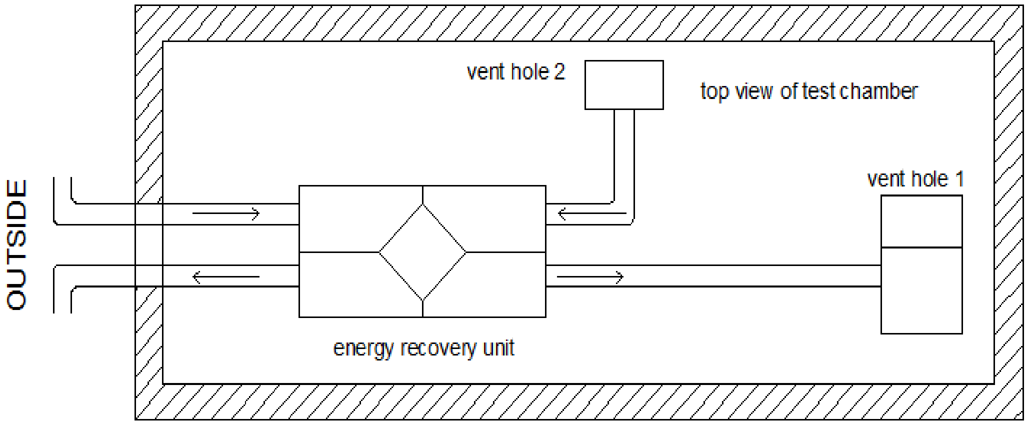

Figure 5.5. Energy recovery unit

5.2 Methods

Experiments were carried out in of Physical Education and Sports at Ege University in Izmir with 11 subjects in 2012 and 2013. Subjects are elite athletes and they do exercise frequently [9]. The experimental outputs were used in this study were obtained from Balci's Master Thesis [9]

During the experiments, some assumptions were assumed [9].

- All of the experiments were carried out at the same time of day for avoiding circadian rhythm changes, heat and humidity which affect the experiment results.
- Test procedure was read and signed by subject and then the parameters were controlled while performing exercise.
- Subjects have done exercise at least for five years and they were used to doing exercise regularly.
- All of the tests were carried out according to the same standards.

Some criteria are looked for determine the subjects to participate the experiments as [9]

- The ages of subject must be between 18 to 30.
- They do not have alcohol and smoking addiction.
- They have been doing exercise for 5 years.
- They do not have some systemic disease and disability.
- They do some endurance exercises regularly at least three days of a week.
- They do not take legal or illegal medicines which affect physical performance and human metabolism.

Firstly, two adaptation performances were carried out to adapt the test chamber, test protocol, cycle ergometer and working group. One or two day after adaptation performances, before they had started to tests, all their anthropometric data were measured. Then, sub maximal and maximal O_2 consumption (VO_{2max}) tests were performed with 30 min interval. Similarly, one or two day after these tests, a submaximal test was performed 60 % of VO_{2max} level for twenty minutes. The subjects were called to the test chamber totally four times[9].

Table 5.1 including the anthropometric data is given[9].

Table 5.1. The anthoropometric data of subjects

SUBJECTS	AGE	WEIGHT (kg)	LENGTH (m)	BSA (m^2)
Subject 1	22	79,5	1,96	2,11
Subject 2	24	67,1	1,79	1,84
Subject 3	22	75,4	1,78	1,93
Subject 4	25	76	1,78	1,93
Subject 5	26	74,7	1,78	1,92
Subject 6	30	85,5	1,80	2,05
Subject 7	18	74,5	1,75	1,89
Subject 8	19	62,2	1,78	1,78
Subject 9	19	74,4	1,90	2,01
Subject 10	20	79,1	1,83	2,01
Subject 11	19	64,4	1,77	1,79
Average	22,18	73,89	1,87	1,93
Std. deviation	3,73	6,88	0,11	0,10

a) Body Surface Area (BSA)

Body surface area is calculated as below according to DuBois formulas [1]

$$A_D = 0{,}202 * m^{0{,}425} * L^{0{,}725} \tag{5.1}$$

The equation was developed for the human body surface area as naked. All of the m (kg) and L (m) values were measured in the beginning of tests. The length was measured with ± % 0,25 m sensitivity. The weight was measured with $\pm 0{,}2$ kg sensitivity. The anthropometric measurements of all subjects were recorded.

b) Metabolic Heat Value

Metabolic heat value can be expressed that the rate of generated energy in human body. Metabolic heat value is calculated as below[1]

$$M = \frac{21 * (0{,}23 * RQ + 0{,}77) * Q_{O_2}}{A_D} \tag{5.2}$$

M expresses the metabolic heat value. RQ is the respiratory quotient and it refers to the molar ratio of Q_{CO_2} exhaled to Q_{O_2} inhaled. Q_{O_2} is the volumetric rate of oxygen consumption. The RQ and Q_{O_2} values are obtained from the mask of gas analyzer which is shown in Figure 5.6 whose sensitivity $\pm$ 100 ml.

Figure 5.6. Facemask and flowmeter of gas analyser

c) Work Rate

Work rate is obtained from cycle ergometer as it is shown in the Figure 5.7. Work rate was adjusted before starting the tests is constant during the experiments for all subjects. The work rates data are transferred to computer.

Figure 5.7. Bicycle

d) Core Body Temperature

Core body temperature was measured by ingestible thermal sensors which transfer data continuously. They sent the data to recorder and the values are recorded. The ingestible thermal sensors and recorder are seen in Figure 5.8. The tests were started after two hours they had ingested the sensors and entered the climate chamber. The sensitivity is 0, 01 °C. (Figure 6.4)

(a) (b)

Figure 5.8. The ingestible thermal sensor(a) and data logger(b) of core body temperatures measurement device

e) Air Temperature

Air temperatures were measured by a recorder at three different points in the chamber and in the test, the average of the recorded values is used. The air temperatures for every subjects and every time steps are displayed Table 5.5. The sensitivity of recorder is $\pm$ 0,4 °C.

Table 5.2. The air temperatures of test chamber during trials (°C) vs. time (min.)

Subj.	02.00	04.00	06.00	08.00	10.00	12.00	14.00	16.00	18.00	20.00	Ave.	Std.Dev
S1	20,90	19,20	19,30	20,60	19,80	19,00	20,00	20,70	19,10	19,40	19,80	0,71
S2	21,31	20,77	21,33	21,72	20,88	20,94	21,54	21,42	20,92	21,22	21,21	0,32
S3	19,94	20,86	21,89	20,40	20,11	21,04	21,88	20,48	20,11	20,90	20,76	0,70
S4	22,10	21,50	21,10	20,90	21,60	22,40	22,50	22,00	21,50	21,50	21,71	0,53
S5	21,55	21,14	20,73	20,73	22,06	22,16	21,56	21,15	20,83	21,52	21,34	0,51
S6	22,30	21,00	20,30	21,60	21,70	20,60	21,20	22,40	21,20	20,40	21,27	0,73
S7	22,70	22,50	22,40	22,50	22,60	22,50	22,50	22,80	22,40	22,70	22,56	0,13
S8	22,30	20,60	20,50	21,70	20,90	20,30	21,60	20,90	20,30	21,70	21,08	0,70
S9	21,68	21,13	21,01	22,49	22,16	21,39	21,08	21,17	22,48	22,04	21,66	0,59
S10	21,50	21,50	22,30	22,80	22,10	21,80	21,70	21,70	23,20	23,10	22,17	0,65
S11	20,70	20,80	20,80	20,70	21,00	20,90	20,90	21,00	21,20	21,10	20,91	0,17

f) Skin Temperature

Skin temperatures were measured by an infrared thermal camera whose sensitivity is ±0,08°C. During the tests, the skin temperatures were measured every two minutes by infrared camera both of in front of and behind the subjects. The distances were set 150 cm between subjects and thermal camera. Skin temperature is supposed the average of the temperatures of seven different points and it is shown in Figure 6.1 in Chapter 6.

g) Mean Radiant Temperature

The mean radiant temperatures of the test chamber were measured and recorded by the devices which are located on the wall [9]. The sensitivity of device is ±0,4°C. The mean radiant temperatures for every subjects and every time steps are displayed in Table 5.6.

Table 5.3. The mean radiant temperatures of test chamber during trials (°C) vs. time (min.)

Subj.	02.00	04.00	06.00	08.00	10.00	12.00	14.00	16.00	18.00	20.00	Ave.	Std.Dev
S1	20,90	19,20	19,30	20,60	19,80	19,00	20,00	20,70	19,10	19,40	19,80	0,71
S2	21,31	20,77	21,33	21,72	20,88	20,94	21,54	21,42	20,92	20,20	21,10	0,45
S3	21,15	21,08	21,42	21,47	21,05	21,08	21,45	21,50	21,10	21,08	21,24	0,19
S4	21,00	20,80	20,50	20,30	20,00	20,60	21,10	20,90	20,70	20,40	20,63	0,34
S5	21,03	20,80	20,50	20,30	20,63	21,07	21,03	20,83	20,57	20,50	20,73	0,27
S6	22,30	21,00	20,30	21,60	21,70	20,60	21,20	22,40	21,20	20,80	21,31	0,69
S7	22,50	22,40	22,40	22,40	22,30	22,40	22,30	22,30	22,30	22,30	22,36	0,07
S8	20,90	20,90	20,80	21,10	21,50	21,10	21,30	21,60	21,20	21,30	21,17	0,26
S9	22,00	21,60	21,10	21,30	21,70	21,60	21,20	20,90	21,30	21,60	21,43	0,33
S10	21,30	21,30	21,30	21,80	21,80	21,60	21,40	21,30	21,50	22,00	21,53	0,26
S11	20,70	20,60	20,60	20,50	20,60	20,70	20,70	20,80	20,80	20,80	20,68	0,10

h) Air Velocity

The air velocity in test chamber is measured that 0,3 m/s during exercise.

i) Clothing Area Factor

During the tests, subjects put on only shirts, ankle and training shoes. Clothing area factor is determined 1,10 clo according to ASHRAE [16].

j) Convective Heat Transfer Coefficient

Convective heat transfer is calculated depending on the air velocity according to ASHRAE as below [16].

$$\mathrm{h_c} = 2.7 + 8{,}7 * V^{0.67} \tag{5.3}$$

$$\mathrm{h_c} = 2.7 + 8{,}7 * (0{,}3)^{0.67} = 6{,}58\ \mathrm{W/m^2\,K}$$

k) Water Vapor Pressure

Water vapor pressure is calculated by the interpolation.

l) Relative Humidity

Relative humidity was measured and recorded by the devices which are located at three different points in test chamber and the sensitivity of these devices is ± 2% relative humidity. Then, the average value of these three measurements was used [9].

Table 5.4. Relative humidity of test chamber during trials (%) vs. time (min.)

Subj.	02.00	04.00	06.00	08.00	10.00	12.00	14.00	16.00	18.00	20.00	Ave.	Std.Dev.
S1	71,40	69,20	75,70	75,70	71,50	73,70	79,50	76,40	71,80	79,10	74,40	3,45
S2	64,00	65,30	67,30	66,90	65,40	67,10	69,20	67,60	67,80	69,30	66,99	1,69
S3	76,90	77,60	74,00	73,00	79,70	80,10	77,00	74,70	81,30	83,38	77,77	3,35
S4	62,90	61,00	60,20	60,40	63,40	67,20	65,80	63,10	62,10	61,00	62,71	2,31
S5	67,50	65,50	65,00	66,10	74,00	71,50	68,10	66,50	65,70	68,50	67,84	2,88
S6	67,50	63,10	62,50	71,10	66,80	62,30	68,80	70,40	64,40	62,60	65,95	3,41
S7	58,80	58,80	59,60	59,60	59,80	60,10	60,40	59,80	60,90	60,30	59,81	0,67
S8	39,94	42,63	43,53	41,88	44,35	47,60	45,96	48,31	51,00	48,90	45,41	3,52
S9	65,20	63,30	65,40	71,10	67,60	65,80	64,20	67,80	73,80	69,00	67,32	3,26
S10	54,40	54,20	57,00	57,10	57,20	57,20	57,00	56,80	58,90	58,40	56,82	1,49
S11	67,10	66,10	65,20	65,70	66,50	67,10	67,60	65,00	62,60	62,20	65,51	1,84

CHAPTER 6

DISCUSSION

6.1 Results

Thermoregulation can be considered as an important parameter that affects the human exercise performance. If a person whose weight is 60 kilograms generates metabolic heat value at 200 W average for thirty minutes

$$200\,W * (30 * 60) = 360000\,J \tag{6.1}$$

Considering with this metabolic energy value, the temperature change of human body can be calculated as

$$Q = m * c * \Delta T \tag{6.2}$$

where c refers to the average specific heat value of the human body which equals to 3470 J/kg°C

$$360000\,J = 60\,kg * \ 3470\,\frac{J}{kg°C} * \Delta T\ °C$$

$$\Delta T = 1{,}73\ °C$$

As it can be seen, the core body temperature rises roughly 1,73℃ if there is no thermoregulation. But this increasement is dangerous to human body and it brings about hyperthermia in human body.

Additionally, the human body can be considered as an inefficient heat machine. The mechanical efficiency is calculated below

$$\eta = \frac{\text{work output}}{\text{metabolic heat value}} \tag{6.3}$$

The mechanical efficiency of human body during exercise is approximately 20%. Table 6.1 displays the mechanical efficiency of human body during exercise. Balci et al. [9] investigated thermal behavior of human body during exercise and he calculated the efficiency is calculated roughly 20%.

Metabolic heat values given in Table 6.1 were calculated by using (5.2) and the values are averaged values of twenty-minute exercise (at 60% peak power output). Work rate was also measured by using bicycle's power arrangement scale and given in Table 6.1. Therefore, efficiency was calculated by using (6.3).

Table 6.1. Mechanical efficiencies of subjects during sub-maximal exercise

Subjects	**Metabolic Heat Value (W/m^2)**	**Work Rate(W/m^2)**	**Efficiency (η)**
S1	432,84	109,75	0,25
S2	374,92	67,90	0,18
S3	551,52	120,78	0,22
S4	425,38	77,60	0,18
S5	371,14	81,76	0,22
S6	408,06	65,37	0,16
S7	540,58	99,03	0,18
S8	524,58	85,28	0,16
S9	391,71	74,47	0,19
S10	378,21	93,46	0,25
S11	387,57	89,22	0,23
		average	0,20

Sports economy is a growing industry and a lot of money is spent for improving sport equipments and devices. The thermal behavior of human body during exercise or at rest becomes one of the most popular topics due to ingestible thermocouples or infrared thermal camera and it is also analyzed dynamically and registered by computer.

Figure 6.1 shows that the changing of average skin temperature of eleven subjects depending on time. The skin temperature decreases dramatically and then increases gradually. Initially, the human body sweats to dissipate heat into environment. Thus, this mechanism achieves and the mean skin temperature decreases roughly 1°C. When core body temperature exceeds 37°C the vazodilation mechanism is activated and the blood flow to skin accelerates. The heat is carried by blood to skin and it is dissipated into environment through skin. Thus, the skin temperature rises. At the end of exercise, the skin temperature decreases depending on accumulation of sweats[9].

Besides, Tucker et al. investigated the mean skin temperatures during exercise. They show that, the mean skin temperatures go down at the first quarter of exercise but they increase again rest of exercise. The mean skin temperatures at both of in the beginning and at the end are nearly same [17]. Fernandes et al. researched the mean skin temperature before, during and after exercise. They detected that the mean skin temperature has the same tendency as stated previously [32].

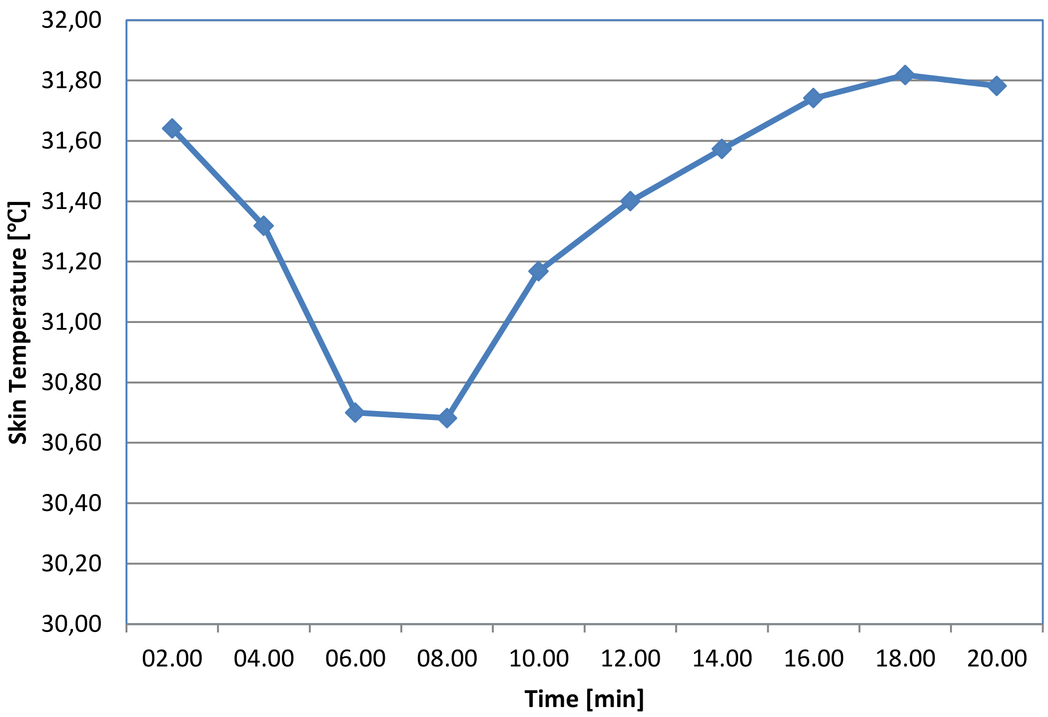

Figure 6.1. Average skin temperatures vs. time

Figure 6.2 shows the PMV distribution during exercise. PMV values were calculated by using (2.1) and (2.2) and these values are average values of eleven subjects. The rate of discomfort of test chamber is high and it is said that it remains roughly 2. When core body temperature rises, it is expected that the rate of discomfort rises but it remains constant. The first inference of this study, the thermoregulatory system in human body is activated and it establishes the thermal equilibrium with environment. Thus, the human body is avoided the high thermal load. Nonetheless, the rate of thermal discomfort is still higher than the initial level of exercise. It is said that, the physical activity leads to occur discomfort in human body depending on exercise intensity and duration. Revel et al. studied the thermal comfort conditions and energy consumption by using PMV. They presented the required factor by dynamic measurements for gym and fitness saloon and pool. According to this study, the thermal conditions of audiences and dry swimmer whose skins are dry are warm and their average PMV values are approximately 1,25. However, the condition for the wet swimmer whose skins are wet is slightly cool with respect to thermal comfort [33]. Vanos et al. evaluated exercise conditions in outdoor for improve recreation region. They analyzed the conditions with regards to COMFA energy balance model [34].

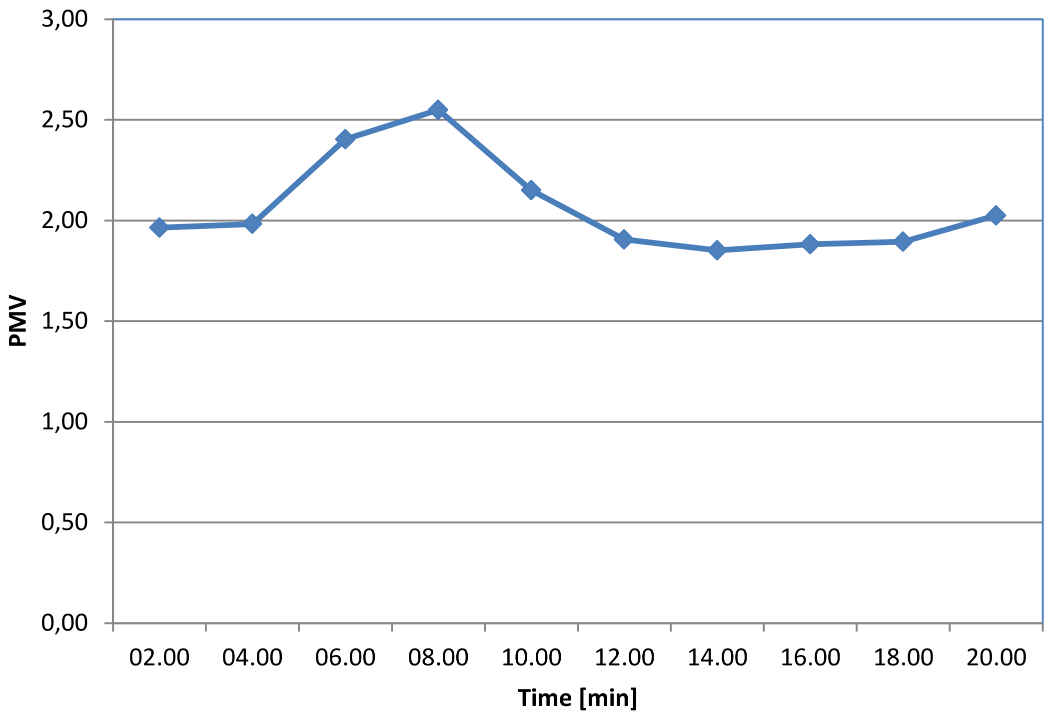

Figure 6.2. The average PMV values vs. time

Figure 6.3 indicates the RPE rising during exercise. RPE is 6 at the beginning of the exercise. After that, RPE increases but the rate of increasing decreases and it remains constant at the end of the exercise. One of the implications of this figure is that even though the work rate is constant, RPE rises. RPE rising affects the exercise performance and brain perceives that the exercise is getting harder and the athlete terminates the exercise. Additionally, the subjects declare that they fell tired during the exercise. Moreover, RPE is in a relationship with core body temperature. Crewe et al. analyzed the RPE and estimated exercise duration by RPE rising. They carried out five experiments at different conditions. During the experiments, RPE rises at constant work output and when RPE reaches 20, they finished the trials[3]. Tucker et al. investigated the exercise intensity at fixed RPE rates at different environmental conditions. They determined that, the work output goes down to continue fixed RPE [17].

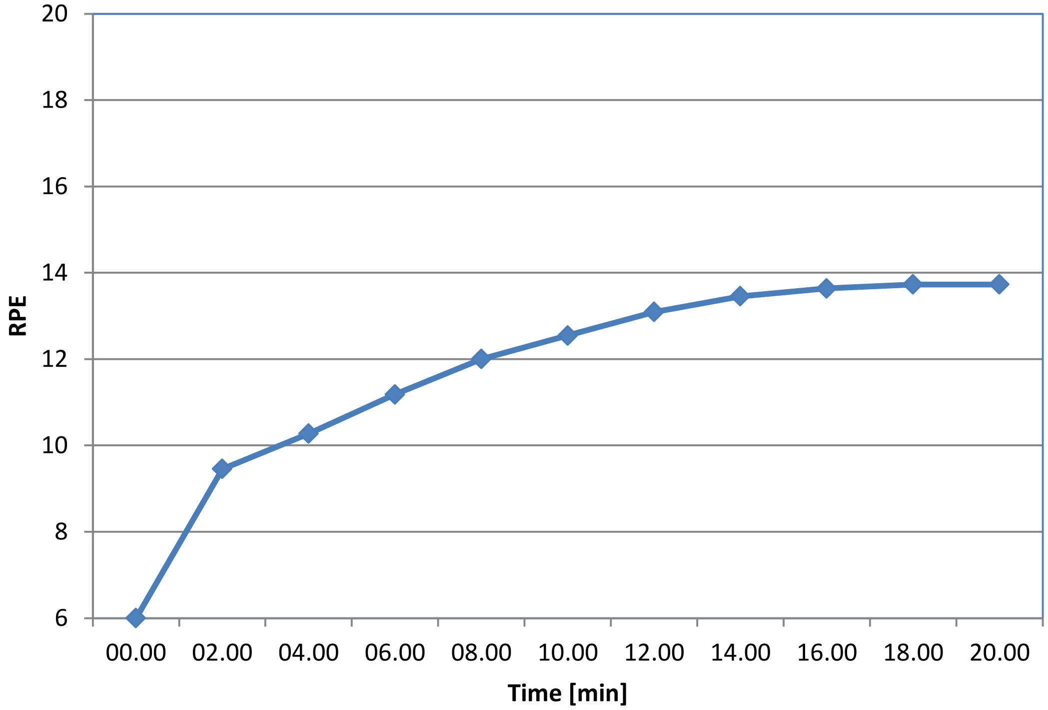

Figure 6.3. The average RPE values vs. time

Figure 6.4 represents the average core body temperatures of eleven subjects during the exercise. Initially, the core body temperature is 36,80°C. Thus, temperature is nearly normal human body temperature at rest. With the exercise, core body temperature rises depending on the rising of metabolic heat value. The core body temperature is going up linearly during exercise. At the end of exercise, core body temperature increases more than 1°C and it reaches 37,90°C. Core body temperature also influences both of skin temperature and RPE. If the core body temperature exceeds set temperature, thermoregulatory mechanisms are activated and vasodilation occurs. Tucker et al. investigated the core body temperature at three different conditions. In all of these conditions, the core body temperature rises [17]. Furthermore, Crewe et al. explain that the rectal temperature is roughly 37°C in the beginning of exercise and it goes up at five different work output and environmental conditions and core body temperature reaches 39°C [3]. They also explain the air temperature affects the core body temperatures and exercise performance. In cool environments, athlete can dissipate the heat easily than hot environments. Therefore, to do exercise or sports activity, the cool environment is preferred [3].Eijsvogels et al. studied the core body temperature during exercise. They show that the core body temperature reaches to 39℃ from 37,5℃ [35].Similarly, Alonso et al. shows that there are a correlation between the high core body temperature and fatigue during exercise [36]

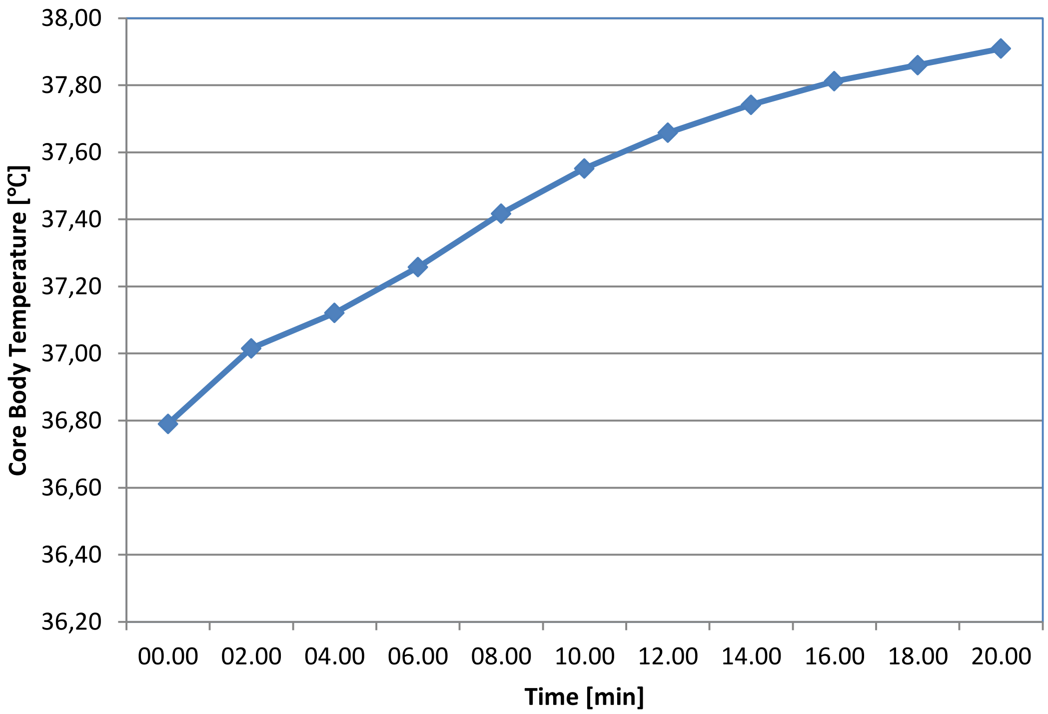

Figure 6.4. The average core body temperature vs. time

Figure 6.5 displays the average metabolic heat rate values during exercise given in Table 6.1. Initially, metabolic heat rate value rises. Because, subjects begin exercise and both of required and generated energy go up. And then, with the getting tired, the metabolic heat value decreases and it goes up again. There is a fluctuation and it is said that the metabolic heat rate at the beginning of exercise is close to the metabolic heat rate at the end of exercise. If we assume that 1 met equals to approximately 60 W/m^2 the metabolic heat rates during exercise are bigger than nearly 7 times. With these high metabolic heat rates, the core body temperature rises. Balci examined the metabolic heat value during exercise. He specifies that, metabolic heat production fluctuates during exercise [9].

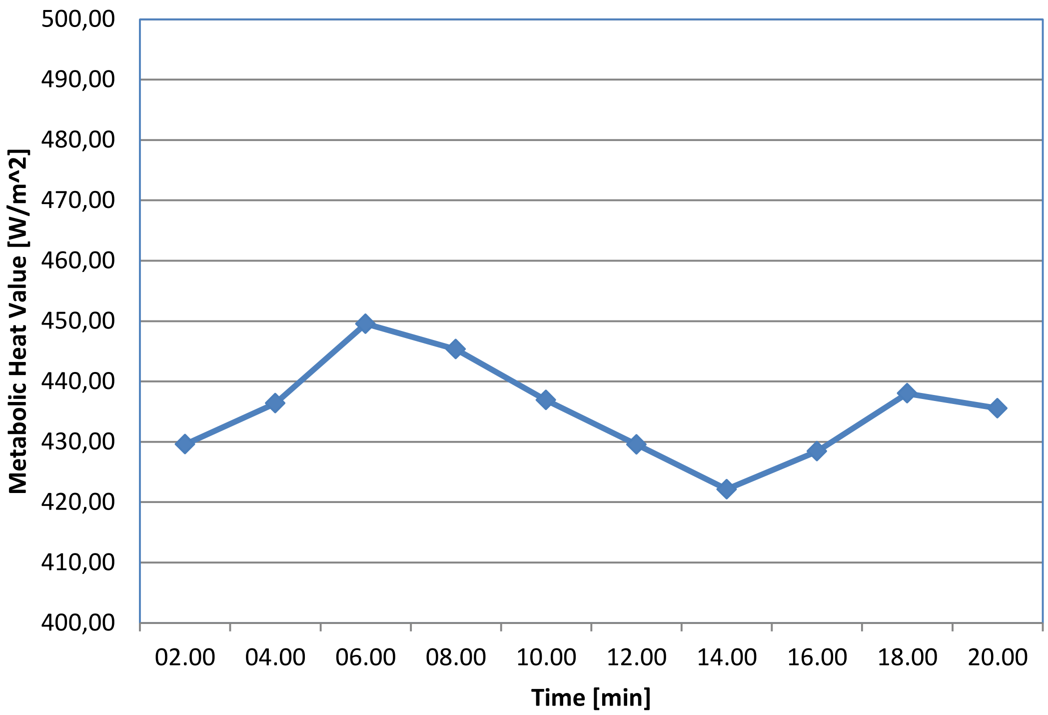

Figure 6.5. The average metabolic heat values vs. time

Figure 6.6 demonstrate the relationship between RPE and the core body temperature. With the starting of exercise, both of them increase with the same trend. RPE keeps constant at the end of exercise, but core body temperature rises gradually. We can say that, even though the RPE and work output remain constant, the core body temperature rises continually. Flouris et al. investigated RPE and the core body temperature during the prolonged exercise in hot conditions. They demonstrate that they increase similar to each other. Both of them affect the exercise performance. When RPE and core body temperature increase, in contrast to them, the exercise intensity decreases [37]. Likewise, Crewe et al. explain the relationship RPE and core body temperature. According to this study, when RPE reaches 20, the core body temperature reaches 39°C. This temperature is bigger than roughly 2°C human core body temperature at rest. They increase together during the exercise and they determine the duration and intensity of exercise [3]. Nybo et al. analyzed that the relation between brain activity and perceived exertion. They suggested that the perceived exertion is relatively related to rising core body temperature [38].

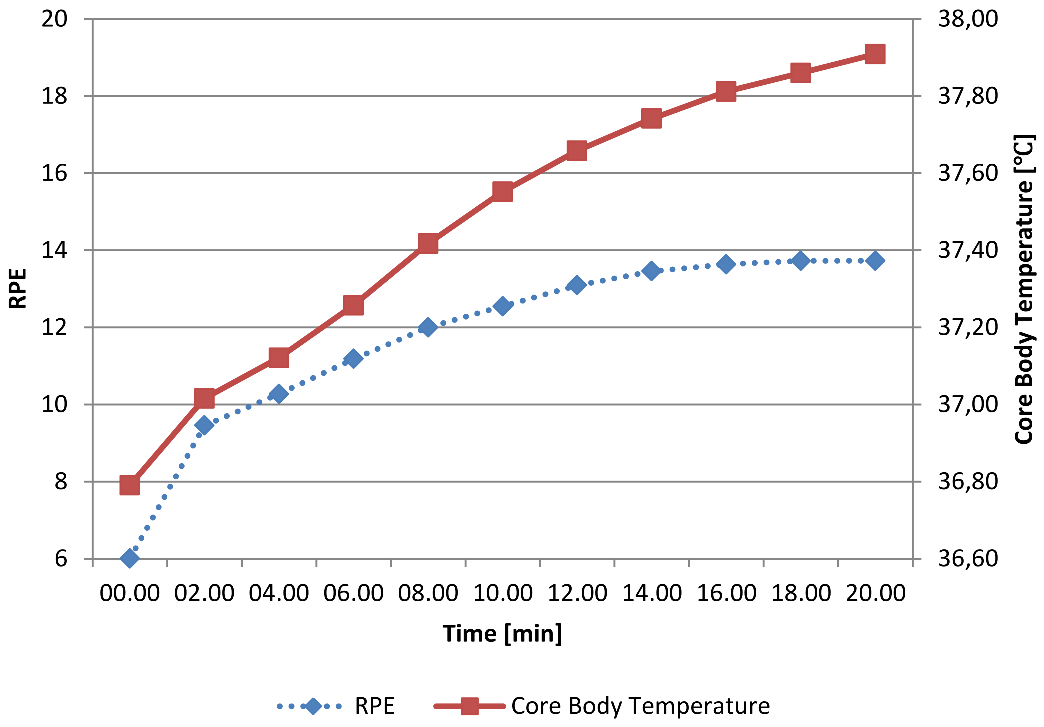

Figure 6.6. The average core body temperatures vs. the average RPE values

Figure 6.7 shows RPE-heart rate relation considering with eleven subject's average values. With the start, RPE and heart rate increase dramatically. Especially heart rate doubles in two minutes. The rate of required energy rises and cells require oxygen and food. Thus, the heart rate increases due to this requirement. To supply requirement, the heart rate remains at higher values during exercise. Nybo et al. investigated the perception of exertion by brain during exercise. They indicated that RPE and heart rate increase linearly and when RPE exceeds 16, heart rate passes over 160. This heart rate in relatively high [38]. Tucker et al. investigated the exercise performance in heat. They stated that the final heart rate and RPE values reaches maximum level and they determine the maximal performance of their own capacity [20]. Lopez Minerro et al. researched the overall RPE and heart rate when cycling. They clarify that, with the increasing RPE, the differences between maximum heart rate and the resting heart rises [39].

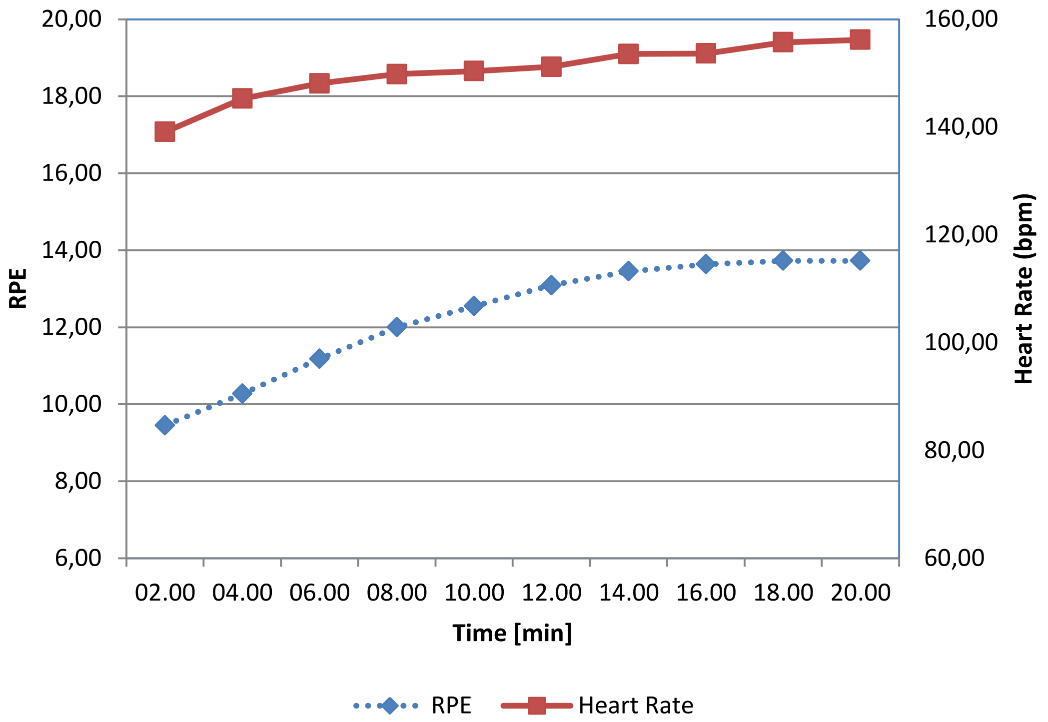

Figure 6.7. The average RPE values vs. the average heart rate values

Figure 6.8 displays the relationship between the average values of operative temperature and PMV. Operative temperature is defined the average of ambient air and mean radiant temperature weighted by their respective heat transfer coefficient[16]. Operative temperature is used commonly for air conditioning. Operative temperature decreases, remains constant and increases. Similarly, PMV remains constant, increases and decreases at the first half of exercise. At the second half, PMV remains roughly constant and the initial and final levels of PMV are very closer to each other. Butera investigated the thermal comfort at different environments. He shows that operative temperature affects the heat transfer and balance between human body and environment. Thus, it affects thermal comfort [29]. Similarly, Ye et al. investigated the effects of operative temperature on thermal comfort at different metabolic heat values. They display that 22°C is relatively suitable for thermal comfort as air temperature [28]

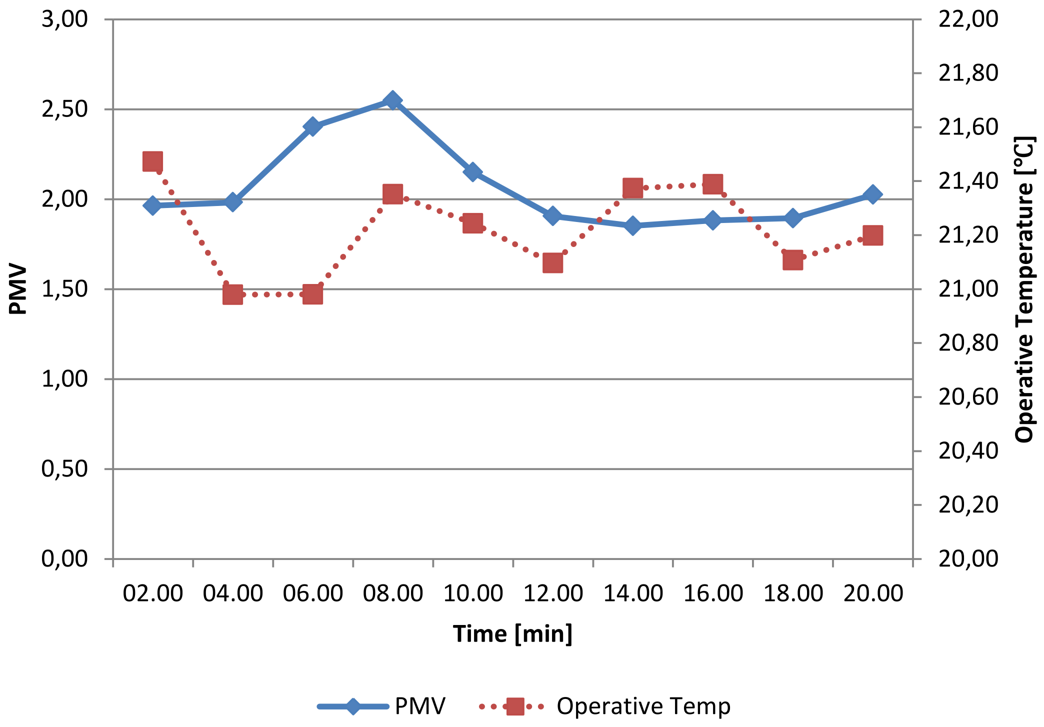

Figure 6.8. The average PMV value vs. operative temperature

6.2. Statistical Analysis

In this thesis, the thermal comfort is calculated and evaluated for every subject and every time steps by Predicted Mean Vote (PMV). Additionally, Ratings of Perceived Exertion (RPE) values for every subject and every time steps are expressed by the subjects and recorded.

Thermal comfort is an important parameter which affects the human life and performance. Similarly, RPE is an essential factor affects the exercise duration and performance. Thermal comfort and RPE are applied and evaluated for exercise conditions such as air temperature, heart rate, core body temperature, etc. independently of each other. There is not any study on the relation between Predicted Mean Vote (PMV) and Ratings of Perceived Exertion (RPE) within the knowledge of the writers in literature. Therefore, the relation between Predicted Mean Vote (PMV) and Ratings of Perceived Exertion (RPE) will be investigated.

In investigations, the first two time steps (02.00 and 04.00) are excluded from. Because, the oxygen consumption in human body does not reach steady state conditions.

Firstly, data set was generated. Shapiro-Wilk normality test was applied and it was shown that the data were appropriate for non-parametric distribution. Spearmen method was used for correlations. In analysis of data, Statistical Package for Social Sciences (version 23.0) was used. ($p \leq 0,05$)

Initially, the data are compared with respect to PMV and RPE each time steps and discussed. At the second stage, the data are divided two groups with respect to two different parameters which are the rate of oxygen consumption and the core body temperature. Consequently, there are three steps.

1) PMV-RPE correlations

2) PMV-RPE correlations at different oxygen consumption rates

3) PMV-RPE correlations at different core body temperatures

6.2.1. First Step: PMV-RPE correlations

At this step, the correlation between PMV and RPE are investigated. The descriptive statistics and Box-Whisker plots of PMV and RPE are shown at Tables 6.2, 6.3 and Figures 6.9, 6.10.

Standard deviation can be defined the square root of the variance. Variance can be defined as the average of the squares of the distance each value is from the mean. Besides, mean value is the average of all values [40]. Similarly, Box Whisker plot Figure is a graphic that is used frequently to explain the data set especially it contains a small number of data [41] and it is shown at Figure 6.9 [42]

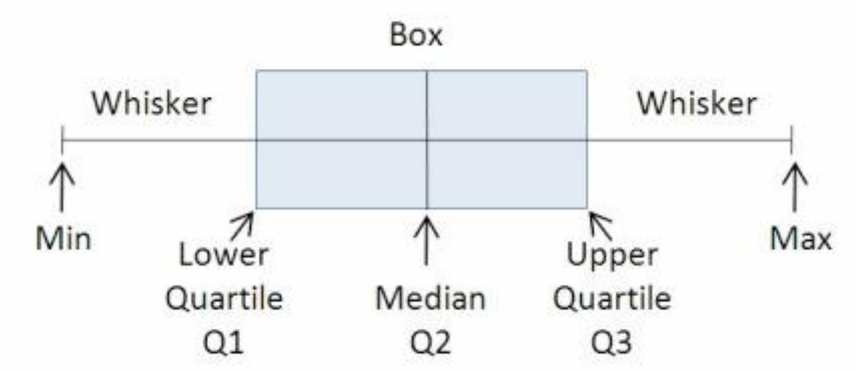

Figure 6.9. The view of Box-Whisker plot

At the first time step (06.00), PMV ranges from 0,85 to 3,95. The standard deviation is 0,93 and variance is 0,87. At the second step (08.00) PMV reaches the maximum value which equals to 4,41. The minimum value of PMV equals to 1,23 at this step is also higher than the other minimum PMV values. The standard deviation and variance have the maximum values because of high PMV value. In the next time step (10.00), PMV ranges from 0,92 to 3,86 and the standard deviation and variance values are 0,92 and 0,83 respectively. At the fourth time step (12.00), PMV ranges from 0,42 to 3,54. The standard deviation is 0,93 and variance is 0,87. At the fifth time steps (14.00) the minimum PMV value is the same as the previous step but the maximum PMV value which equals to 3,61 is higher than the previous step. Therefore, standard deviation and variance values are different, they are 0,97 and 0,95 respectively. At the sixth time step (16.00), the minimum and maximum PMV values are 0,68 and 3,96. Standard deviation equals to 0,94 and variance equals to 0,88. At the seventh time step (18.00), PMV ranges from 0,59 to 4,26 and standard deviation and variance is 1,23 and 1,52 respectively. At the last time steps, PMV ranges from 0,50 to 3,97 and standard deviation and variance equal to 0,99.(Table 6.2,Figure 6.9)

Table 6.2. Descriptive statistics of PMV

	N	Minimum	Maximum	Mean	Std. Deviation	Variance
PMV_6	11	0,85	3,95	2,40	0,93	0,87
PMV_8	11	1,23	4,41	2,54	1,05	1,10
PMV_10	11	0,92	3,86	2,14	0,91	0,83
PMV_12	11	0,42	3,54	1,90	0,93	0,87
PMV_14	11	0,42	3,61	1,85	0,97	0,95
PMV_16	11	0,68	3,96	1,88	0,94	0,88
PMV_18	11	0,59	4,26	1,89	1,23	1,52
PMV_20	11	0,50	3,97	2,02	0,99	0,99
Valid N (listwise)	11					

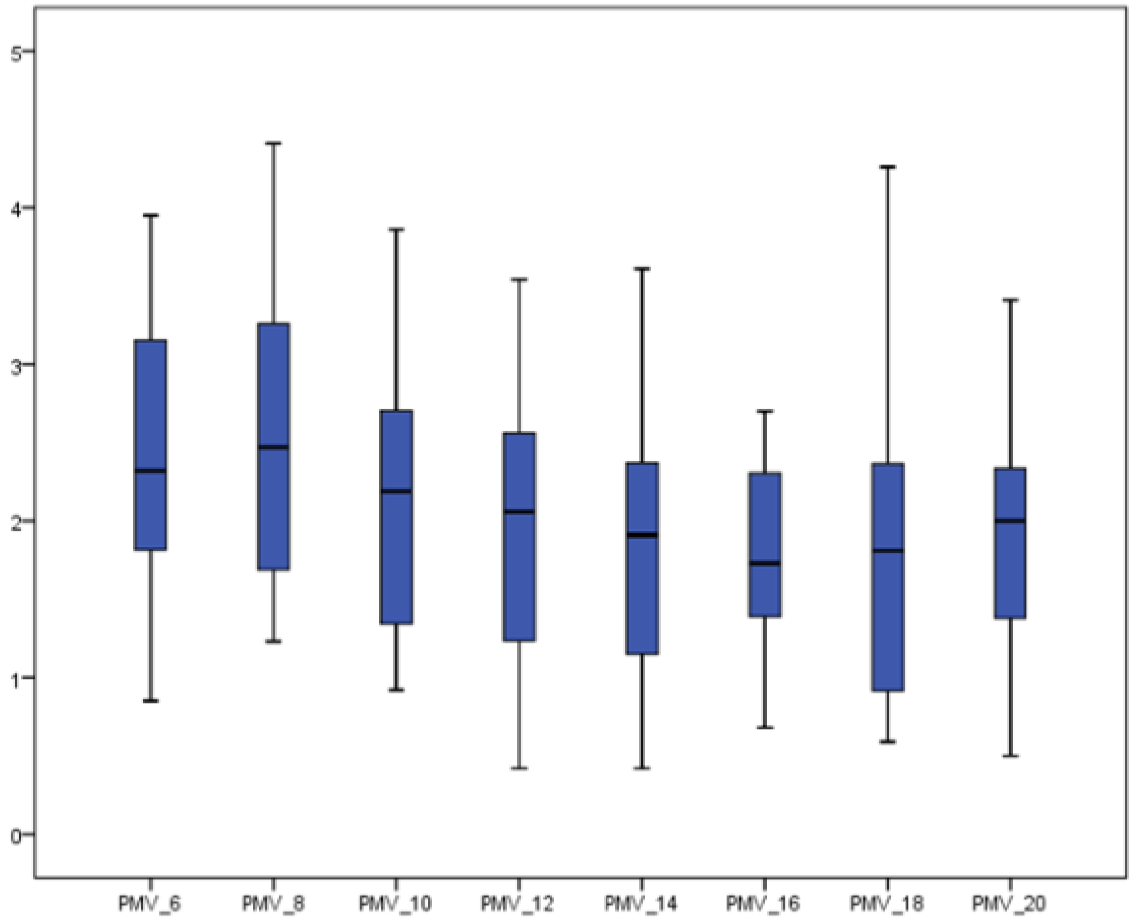

Figure 6.10. Box-Whisker plot of PMV values

At the first time step (06.00), RPE ranges from 8 to 14. The standard deviation is 2,08 and variance is 4,36. At the second step (08.00) RPE ranges from 8 to 15 and standard deviation and variance equal to 2,36 and 5,60 respectively. At the third step (10.00), the minimum RPE value is 8 and the maximum RPE value is 15. The maximum standard deviation and variance values are at this step. They are 2,73 and 7,47. At the fourth time step (12.00), RPE ranges from 9 to 16. The standard deviation equals to 2,58 and variance equals to 6,69. At the fifth time steps (14.00), RPE ranges from 9 to 16. The standard deviation equals to 2,69 and variance equals to 7,27. At the sixth time step (16.00), the minimum and maximum values of RPE are 9 and 16 respectively. The standard deviation equals to 2,57 and the variance equals to 6,65. Both the seventh time step (18.00) and eighth time step (20.00) have the same minimum, maximum RPE values , standard deviations and variances. They are 10, 16, 2,41 and 5,81, respectively. (Table 6.3, Figure 6.10)

Table 6.3. Descriptive statistics of RPE

	N	Minimum	Maximum	Mean	Std. Deviation	Variance
RPE_6	11	8,00	14,00	11,18	2,08	4,36
RPE_8	11	8,00	15,00	12,00	2,36	5,60
RPE_10	11	8,00	15,00	12,54	2,73	7,47
RPE_12	11	9,00	16,00	13,09	2,58	6,69
RPE_14	11	9,00	16,00	13,45	2,69	7,27
RPE_16	11	9,00	16,00	13,63	2,57	6,65
RPE_18	11	10,00	16,00	13,72	2,41	5,81
RPE_20	11	10,00	16,00	13,72	2,41	5,81
Valid N (listwise)	11					

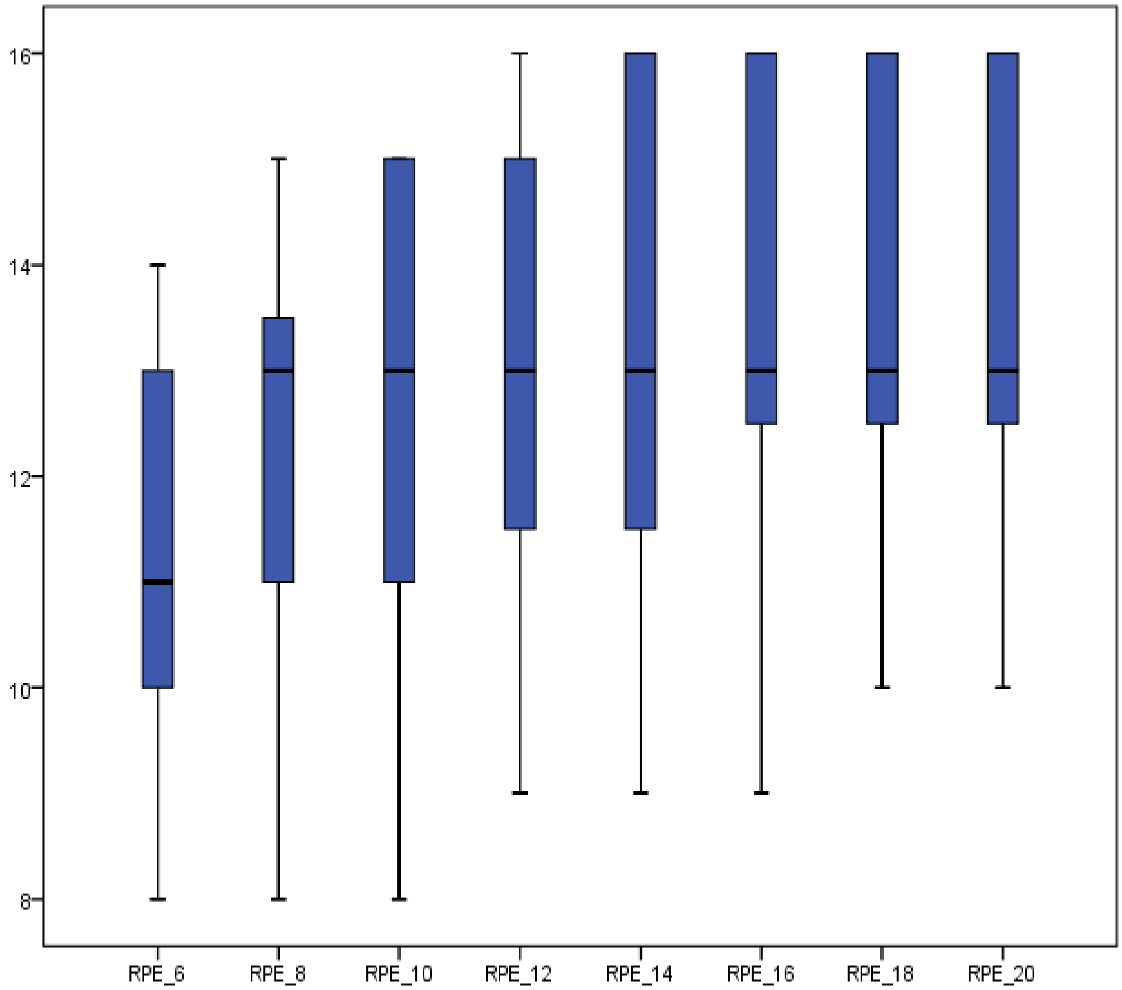

Figure 6.11. Box-Whisker plot of RPE

Before searching the relation between PMV and RPE, the correlation coefficient levels are shown at Table 6.5[41].

Table 6.4. The levels of correlation coefficients

Correlation Coefficient	The Level of Correlation Coefficient
0,00-0,20	very weak
0,20-0,40	weak
0,40-0,60	moderately
0,60-0,85	moderately strong
0,85-1,00	strong
1,00	perfect

The correlation between PMV and RPE is shown at Table 6.6 and 6.7. The correlation coefficients are low at first time steps. Similarly, the levels of significance (p value) at these steps are very high and it means that these correlations are statistically insignificant. At rest of time steps, the correlation coefficients increase and level of significance decrease. The average correlation coefficient is -0,52 and the level of correlation coefficient are moderately. However the correlations at only fifth (12.00), sixth (14.00) and the last (eighth) time steps (20.00) are statistically significant.

Table 6.5. Correlation coefficients, level of correlation coefficients and p value

Time Steps	Corr.Coefficients	Level of Corr. Coefficients	P Values
06.00	-0,27	weak	0,42
08.00	-0,26	weak	0,44
10.00	-0,5	moderate	0,12
12.00	-0,59	moderate	0,06
14.00	-0,66	moderately strong	0,03
16.00	-0,65	moderately strong	0,03
18.00	-0,57	moderately	0,07
20.00	-0,62	moderately strong	0,04
average	**-0,52**	**moderate**	

Table 6.6. Correlation coefficients and level of significance vs. time (min.) (N=11)

Spearman's rho	PMV_06.00	PMV_08.00	PMV_10.00	PMV_12.00	PMV_14.00	PMV_16.00	PMV_18.00	PMV_20.00
RPE_06.00								
cor.coeff.	-0,27	-0,25	-0,26	-0,31	-0,36	-0,4	-0,38	-0,47
sign.	0,42	0,47	0,44	0,35	0,28	0,22	0,25	0,17
RPE_08.00								
cor.coeff.	-0,32	-0,26	-0,39	-0,41	-0,5	-0,53	-0,46	-0,49
sign.	0,33	0,44	0,23	0,22	0,12	0,09	0,15	0,12
RPE_10.00								
cor.coeff.	-0,4	-0,29	-0,5	-0,47	-0,63*	-0,61*	-0,51	-0,54
sign.	0,22	0,4	0,12	0,14	0,04	0,05	0,11	0,09
RPE_12.00								
cor.coeff.	-0,55	-0,49	-0,62*	-0,59	-0,72*	-0,64*	-0,63*	-0,70*
sign.	0,08	0,13	0,04	0,06	0,01	0,04	0,04	0,02
RPE_14.00								
cor.coeff.	-0,47	-0,38	-0,55	-0,54	-0,66*	-0,67*	-0,57	-0,63*
sign.	0,15	0,25	0,08	0,03	0,03	0,02	0,07	0,04
RPE_16.00								
cor.coeff.	-0,41	-0,33	-0,51	-0,49	-0,63*	-0,65*	-0,56	-0,61*
sign.	0,21	0,33	0,11	0,13	0,03	0,03	0,07	0,05
RPE_18.00								
cor.coeff.	-0,42	-0,31	-0,52	-0,5	-0,64*	-0,65*	-0,57	-0,62*
sign.	0,2	0,35	0,1	0,12	0,03	0,03	0,07	0,04
RPE_20.00								
cor.coeff.	-0,42	-0,31	-0,52	-0,5	-0,64*	-0,65*	-0,57	-0,62*
sign.	0,2	0,35	0,1	0,12	0,03	0,03	0,07	0,04

**.Correlation is significant at the 0,01 level (2-tailed)
*.Correlation is significant at the 0,05 level (2-tailed

Additionally, it is tried to find a new formula which includes PMV and RPE values and it is predicted the RPE values owing to this formula by using PMV values. Thus, even if the RPE values of athletes are unknown, the RPE values can be predicted by PMV values. Therefore, different kind of equations given in Table 6.8 were tried

Table 6.7. The table of curve estimation

Dependent Variable: RPE_ave

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	0,76	18,92	1	6	0,01	19,384	-3,111		
Logarithmic	0,76	19,29	1	6	0,01	17,814	-6,753		
Inverse	0,76	19,30	1	6	0,01	5,849	14,505		
Quadratic	0,77	8,26	2	5	0,03	28,881	-11,948	2,025	
Cubic	0,77	8,36	2	5	0,03	26,469	-8,076	,000	,345
Compound	0,76	18,54	1	6	0,01	21,581	,780		
Power	0,76	18,91	1	6	0,01	19,042	-,539		
S	0,76	18,93	1	6	0,01	1,992	1,157		
Growth	0,76	18,54	1	6	0,01	3,072	-,248		
Exponential	0,76	18,54	1	6	0,01	21,581	-,248		

The independent variable is PMV_ave.

Two different equations are selected according to Table 6.8 as linear and exponential because the levels of significance of linear and exponential are 0,01. In addition, the R square values are 0,76 (Table 6.8) and it means that the RPE values can be predicted with approximately 76% accuracy. The estimated models are statistically significant. These equations are shown

$$\text{RPE} = 19{,}384 - 3{,}111 * \text{PMV} \qquad \text{(Linear)} \qquad (6.4)$$

$$\text{RPE} = 21{,}581 * \exp(-0{,}248 * \text{PMV}) \qquad \text{(Exponential)} \qquad (6.5)$$

By using these two equations (6.4 and 6.5) RPE values were estimated and compared with experimental data in Table 6.9.

Table 6.8. The comparison of equations

Time steps	PMV	RPE	Linear	Diff. (%)	Exp.	Diff.(%)
06.00	2,40	11,18	11,92	6,19	11,90	6,06
08.00	2,54	12,00	11,48	-4,51	11,49	-4,40
10.00	2,14	12,55	12,73	1,39	12,69	1,13
12.00	1,90	13,09	13,47	2,84	13,47	2,84
14.00	1,85	13,45	13,63	1,31	13,64	1,39
16.00	1,88	13,64	13,54	-0,77	13,54	-0,75
18.00	1,89	13,73	13,50	-1,67	13,51	-1,66
20.00	2,02	13,73	13,10	-4,81	13,08	-4,99
			average	**-0,005**		**-0,05**

The difference shown in Table 6.9 is calculated as below.

$$\text{Differences} = \left(\frac{\text{calculated RPE value} - \text{experimental RPE value}}{\text{calculated RPE value}}\right) * 100 \qquad (6.6)$$

As it is seen in the Table 6.9, the differences at whole time steps for two different equations are relatively low. The values at two different equations (6.4 and 6.5) are close to each other. As average, the differences are very low and it is negligible. The RPE values of athletes can be predicted by these two equations by PMV values. The graphics of calculated and experimental RPE values are shown at Figure 6.11

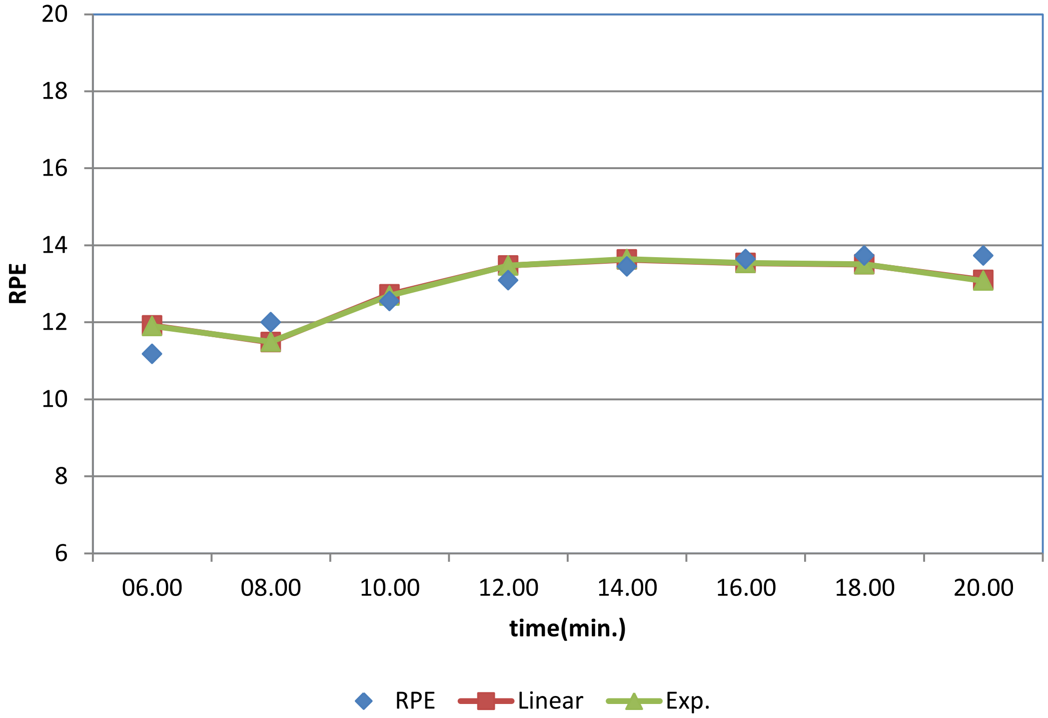

Figure 6.12. The calculated and experimental RPE values vs Time

6.2.2. Second Step: PMV-RPE correlations at different oxygen consumption rates

The subjects are divided two groups according to oxygen consumption (Table 6.10). The oxygen consumptions of four subjects are bigger than the average value. Therefore, there are two groups. S1, S3, S7 and S8 are included H (high) group and S2, S4, S5, S6, S9, S10 and S11 are included L (low) group.

Table 6.9. Oxygen consumption rates of subjects (ml/kg/dk)

Subj.	Age	Weight (kg)	Lenght (m)	BSA(m^2)	vo2	vo2/kg
S1	22	79,50	1,96	2,11	4,64	**58,36**
S2	24	67,10	1,79	1,84	3,17	47,24
S3	22	75,40	1,78	1,93	5,60	**74,27**
S4	25	76,00	1,78	1,93	3,80	50,00
S5	26	74,70	1,78	1,92	3,38	45,25
S6	30	85,30	1,80	2,05	3,85	45,13
S7	18	74,50	1,75	1,89	4,65	**62,42**
S8	19	62,20	1,78	1,78	4,12	**66,24**
S9	19	74,40	1,90	2,01	3,73	50,13
S10	20	79,10	1,83	2,01	3,89	49,18
S11	19	64,40	1,77	1,79	2,93	45,50
Average	22,18	73,87	1,81	1,93	3,98	**53,97**
Std.Dev.	3,74	6,85	0,06	0,11	0,76	9,89

At this step, the correlation between PMV and RPE at high and low oxygen consumption rate is investigated. The descriptive statistics and Box-Whisker plots of PMV and RPE at high and low oxygen consumption rate are shown at Table 6.11, 6.12 and Figure 6.12, 6.13.

As it shown at Table 6.11 and Figure 6.12, the standard deviations and variances values at high oxygen consumptions rate (OH) are higher than the standard deviations and variances values at low oxygen consumptions rate (OL). Because, the PMV values are dependent on the oxygen consumption rates indirectly. Therefore, if oxygen consumption rates increase, the PMV values increase. If the descriptive statistics are handled individually,

At the first time step (06.00) the differences between maximum and minimum PMV values at high oxygen consumption rate are higher than at low oxygen consumption rate. Thus, the standard deviation and variances at high oxygen consumption rate are higher than at low oxygen consumption rate. PMV ranges from 0,85 to 3,95 at high group and PMV ranges from 1,49 to 3,14. Standard deviations are 1,38 and 0,55 respectively. Variance values equal to 1,89 at high group and 0,30 at low group. The minimum standard deviation and variance values of low group are also in this step.

At the second time step (08.00) The minimum and maximum PMV values at high and low group are 1,23, 1,34, 4,41 and 3,65 respectively. At high group, the standard deviation and variance equal to 1,42 and 2,01. At low group, while the standard deviation is 0,80, the variance is 0,65. These values are the maximum standard deviation and variance values at low group.

At the third time step (10.00), PMV ranges from 0,92 to 3,86 at high group. The standard deviation and variance equal to 1,25 and 1,58. On the other hand, PMV ranges from 1,22 to 2,67 at low group. The standard deviation and variance equal to 0,57 and 0,33.

At the fourth time step (12.00), PMV ranges from 0,42 to 3,54 at high group. The standard deviation and variance equal to 1,34 and 1,79. On the other hand, PMV ranges from 0,84 to 2,46 at low group. The standard deviation and variance equal to 0,61 and 0,37.

At the fifth time step (14.00), PMV ranges from 0,42 to 3,61 at high group. The standard deviation and variance equal to 1,38 and 1,90. On the other hand, PMV ranges from 0,65 to 2,08 at low group. The standard deviation and variance equal to 0,56 and 0,31.

At the sixth time step (16.00), PMV ranges from 1,44 to 3,96 at high group. The standard deviation and variance equal to 1,09 and 1,19. On the other hand, PMV ranges from 0,68 to 2,70 at low group. The standard deviation and variance equal to 0,69 and 0,48.

At the seventh time step (18.00), PMV ranges from 0,59 to 4,26 at high group. The standard deviation and variance equal to 1,68 and 2,80. These values are maximum values at high group.On the other hand, PMV ranges from 0,60 to 2,57 at low group. The standard deviation and variance equal to 0,74 and 0,55.

At the last time step (20.00), PMV ranges from 1,31 to 3,97 at high group. The standard deviation and variance equal to 1,21 and 1,46. On the other hand, PMV ranges from 0,50 to 2,43 at low group. The standard deviation and variance equal to 0,66 and 0,44.

Table 6.10. Descriptive statistics of PMV values at high (OH) and low (OL) oxygen consumption rates

	N	Minimum	Maximum	Mean	Std. Deviation	Variance
PMV_6_OH	4	0,85	3,95	2,86	1,38	1,89
PMV_8_OH	4	1,23	4,41	2,98	1,42	2,01
PMV_10_OH	4	0,92	3,86	2,67	1,25	1,58
PMV_12_OH	4	0,42	3,54	2,33	1,34	1,79
PMV_14_OH	4	0,42	3,61	2,41	1,38	1,90
PMV_16_OH	4	1,44	3,96	2,50	1,09	1,19
PMV_18_OH	4	0,59	4,26	2,64	1,68	2,80
PMV_20_OH	4	1,31	3,97	2,71	1,21	1,46
PMV_6_OL	7	1,49	3,14	2,14	0,55	0,30
PMV_8_OL	7	1,34	3,65	2,30	0,80	0,65
PMV_10_OL	7	1,22	2,67	1,85	0,57	0,33
PMV_12_OL	7	0,84	2,46	1,66	0,61	0,37
PMV_14_OL	7	0,65	2,08	1,53	0,56	0,31
PMV_16_OL	7	0,68	2,70	1,53	0,69	0,48
PMV_18_OL	7	0,60	2,57	1,47	0,74	0,55
PMV_20_OL	7	0,50	2,43	1,63	0,66	0,44
Valid N (listwise)	4					

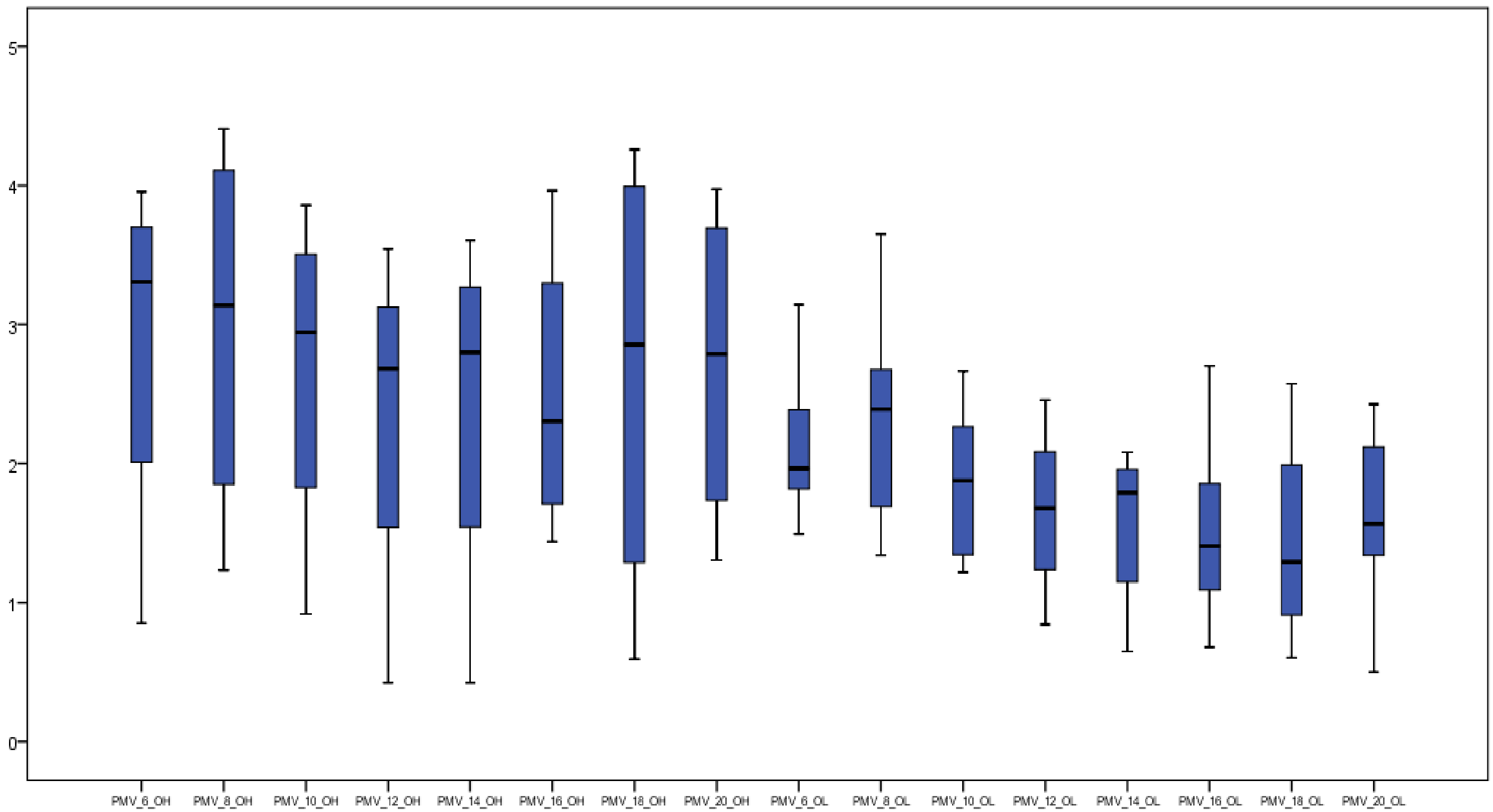

Figure 6.13. The Box Whisker plot of PMV values at high (OH) and low (OL) group vs. time (min.)

As it shown at Table 6.12 and Figure 6.14, the standard deviations and variance values of RPE at high oxygen consumptions rate (OH) are higher than the standard deviations and variances values at low oxygen consumptions rate (OL). Oxygen consumption rate has an impact on metabolic heat value. Therefore, it also affects core body temperature and RPE. If the descriptive statistics are handled individually,

At the first time step (06.00), RPE ranges from 8 to 14 at high group and standard deviation and variance values are 2,65 and 7 respectively. At low group, RPE ranges from 8 to 13. Standard deviation and variance equal to 1,91 and 3,67. Additionally, the variances values are the minimum values among their groups.

At the second time step (08.00), RPE ranges from 8 to 15 at high group. The standard deviation equals to 3,10 and variance 9,85. Besides, at low group, RPE ranges from 8 to 14. The standard deviation equals to 2,12 and variance equals to 4,48.

At the third time step (10.00), RPE ranges from 8 to 15 at high group. The standard deviation and variance at this step has the maximum value which equal to 3,32 and 11 respectively. On the other hand, RPE ranges from 8 to 15. Standard deviation is 2,64 and variance is 6,95.

At the fourth time step (12.00), RPE ranges from 9 to 16 at high group. The standard deviation and variance equal to 3,16 and 10 respectively. At low group, RPE ranges from 9 to 16. The standard deviation equals to 2,48 and variance equals to 6,14.

At the fifth time step (14.00), RPE ranges from 10 to 16 at high group. The standard deviation is 3 and variance is 9. RPE ranges 9 to 16. The standard deviation equals to 2,76 and variance equals to 7,62.The variance value of at this time step is the maximum value among low group.

At the sixth time step (16.00), RPE ranges from 10 to 16 at high group. The standard deviation equals to 2,88 and variance is 8,25. At the low group, RPE ranges from 9 to 16. The standard deviation equals to 2,64 and variance equals to 6,95.

At the seventh time step (18.00), RPE ranges from 10 to 16 at high group. The standard deviation equals to 2,88 and variance is 8,25. On the other hand, RPE ranges from 10 to 16 at the low group. The standard deviation equals to 2,36 and variance 5,57.

At the last time step (20.00), RPE ranges from 10 to 16 at high group. The standard deviation equals to 2,88 and variance is 8,25. On the other hand, RPE ranges from 10 to 16 at the low group. The standard deviation equals to 2,36 and variance 5,57.

Table 6.11. Descriptive statistics of RPE values at high and low oxygen consumption

	N	Minimum	Maximum	Mean	Std. Deviation	Variance
RPE_6_OH	4	8,00	14,00	11,50	2,65	7,00
RPE_8_OH	4	8,00	15,00	12,25	3,10	9,58
RPE_10_OH	4	8,00	15,00	12,50	3,32	11,00
RPE_12_OH	4	9,00	16,00	13,00	3,16	10,00
RPE_14_OH	4	10,00	16,00	13,50	3,00	9,00
RPE_16_OH	4	10,00	16,00	13,75	2,88	8,25
RPE_18_OH	4	10,00	16,00	13,75	2,88	8,25
RPE_20_OH	4	10,00	16,00	13,75	2,88	8,25
RPE_6_OL	7	8,00	13,00	11,00	1,91	3,67
RPE_8_OL	7	8,00	14,00	11,86	2,12	4,48
RPE_10_OL	7	8,00	15,00	12,57	2,64	6,95
RPE_12_OL	7	9,00	16,00	13,14	2,48	6,14
RPE_14_OL	7	9,00	16,00	13,43	2,76	7,62
RPE_16_OL	7	9,00	16,00	13,57	2,64	6,95
RPE_18_OL	7	10,00	16,00	13,71	2,36	5,57
RPE_20_OL	7	10,00	16,00	13,71	2,36	5,57
Valid N (listwise)	4					

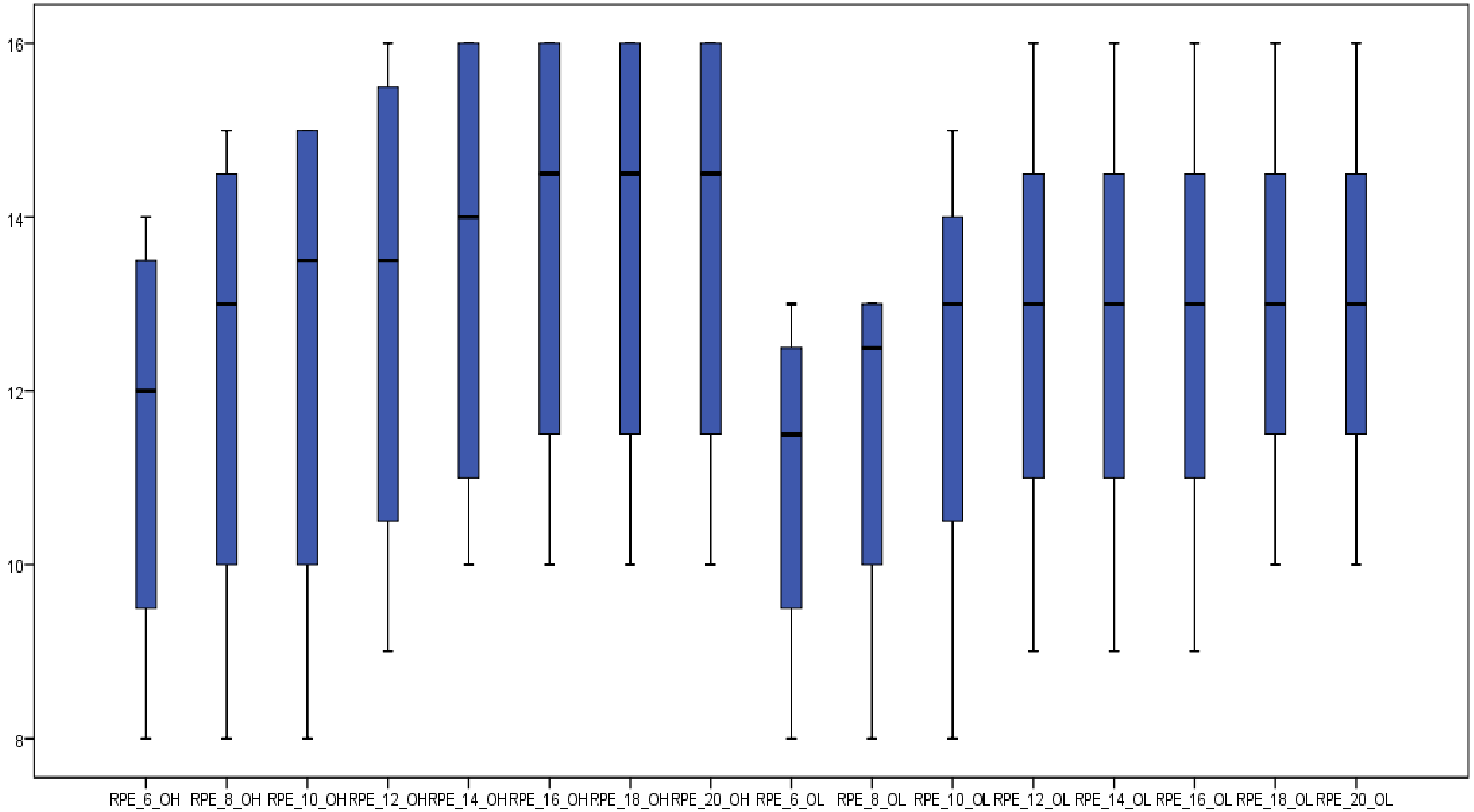

Figure 6.14. Box Whisker plot of RPE values at high (H) and low (L) group vs. time (min.)

The correlation between PMV and RPE at high oxygen consumption rate is shown at Table 6.13 and 6.14. The correlation coefficients fluctuate at positive and negative values and at the second half of exercise the correlation coefficients are higher. However, the average of correlation coefficients is -0,21 which means that the correlation is weak. Similarly, the levels of significance (p values) at all time steps are statistically insignificant.

Table 6.12. Correlation coefficients, levels of correlation coefficient and p values at high oxygen consumption rate

Time Steps	Corr.Coefficients	Level of Corr. Coefficients	P Values
06.00	0,00	very weak	1,00
08.00	0,40	weak	0,60
10.00	0,11	very weak	0,89
12.00	-0,20	very weak	0,80
14.00	-0,63	strong	0,37
16.00	-0,63	strong	0,37
18.00	-0,11	very weak	0,89
20.00	-0,63	strong	0,37
average	**-0,21**	**weak**	

Table 6.13. Correlation coefficients and level of significance vs. time (min.) high oxygen consumption rate (N=4)

Spearman's rho	**PMV_OH_06.00**	**PMV_OH_08.00**	**PMV_OH_10.00**	**PMV_OH_12.00**	**PMV_OH_14.00**	**PMV_OH_16.00**	**PMV_OH_18.00**	**PMV_OH_20.00**
RPE_OH_06.00								
cor.coeff.	0,00	0,40	0,40	0,40	-0,40	-0,40	0,20	-0,40
sign.	1,00	0,60	0,60	0,60	0,60	0,60	0,80	0,60
RPE_OH_08.00								
cor.coeff.	0,00	0,40	0,40	0,40	-0,40	-0,40	0,20	-0,40
sign.	1,00	0,60	0,60	0,60	0,60	0,60	0,80	0,60
RPE_OH_10.00								
cor.coeff.	-0,21	0,11	0,11	0,11	-0,63	-0,63	-0,11	-0,63
sign.	0,79	0,89	0,89	0,89	0,37	0,37	0,89	0,37
RPE_OH_12.00								
cor.coeff.	-0,40	-0,20	-0,20	-0,20	-0,80	-0,80	-0,40	-0,80
sign.	0,60	0,80	0,80	0,80	0,20	0,20	0,60	0,20
RPE_OH_14.00								
cor.coeff.	-0,21	0,11	0,11	0,11	-0,63	-0,63	-0,11	-0,63
sign.	0,79	0,89	0,89	0,89	0,37	0,37	0,89	0,37
RPE_OH_16.00								
cor.coeff.	-0,21	0,11	0,11	0,11	-0,63	-0,63	-0,11	-0,63
sign.	0,79	0,89	0,89	0,89	0,37	0,37	0,89	0,37
RPE_OH_18.00								
cor.coeff.	-0,21	0,11	0,11	0,11	-0,63	-0,63	-0,11	-0,63
sign.	0,79	0,89	0,89	0,89	0,37	0,37	0,89	0,37
RPE_OH_20.00								
cor.coeff.	-0,21	0,11	0,11	0,11	-0,63	-0,63	-0,11	-0,63
sign.	0,79	0,89	0,89	0,89	0,37	0,37	0,89	0,37

**.Correlation is significant at the 0,01 level (2-tailed)

Moreover, it is tried to find a new formula which includes PMV and RPE values for high oxygen consumption rate and it is predicted the RPE values owing to this formula by using PMV values. Thus, even if the RPE values of athletes are unknown, the RPE values can be predicted by PMV values.

Table 6.14. The table of curve estimation at high oxygen consumption rate

Dependent Variable: RPE_AV_OH

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	0,35	3,03	1	6	0,13	18,968	-2,266		
Logarithmic	0,32	2,80	1	6	0,15	18,608	-5,808		
Inverse	0,30	2,57	1	6	0,16	7,359	14,771		
Quadratic	0,48	2,31	2	5	0,19	-33,272	37,476	-7,514	
Cubic	0,48	2,26	2	5	0,20	-15,178	17,236	,000	-0,926
Compound	0,34	3,13	1	6	0,13	20,855	0,835		
Power	0,33	2,90	1	6	0,14	20,275	-0,462		
S	0,31	2,67	1	6	0,15	2,114	1,177		
Growth	0,34	3,13	1	6	0,13	3,038	-0,180		
Exponential	0,34	3,13	1	6	0,13	20,855	-0,180		

The independent variable is PMV_AV_OH.

As it is selected before, linear and exponential equations are selected. These R square values that are shown at Table 6.15 are very low and the estimated models are not statistically significant. These equations are

$$RPE = 18{,}968 - 2{,}266 * PMV \qquad \text{(linear)} \qquad (6.7)$$

$$RPE = 20{,}855 * \exp(-0{,}180 * PMV) \qquad \text{(exponential)} \qquad (6.8)$$

Table 6.15. The comparison of equations at high oxygen consumption rate

Time steps	PMV	RPE	Linear	Diff. (%)	Exp.	Diff.(%)
06.00	2,85	11,50	12,51	0,08	12,49	0,08
08.00	2,97	12,25	12,24	0,00	12,22	0,00
10.00	2,66	12,50	12,94	0,03	12,92	0,03
12.00	2,33	13,00	13,69	0,05	13,71	0,05
14.00	2,41	13,50	13,51	0,00	13,51	0,00
16.00	2,50	13,75	13,30	-0,03	13,30	-0,03
18.00	2,64	13,75	12,99	-0,06	12,97	-0,06
20.00	2,71	13,75	12,83	-0,07	12,80	-0,07
			average	**0,00002**		**-0,0008**

Even though the R squares of linear and exponential equations are low, the differences are very low as it is seen in Table 6.16. Both of equations (6.7 and 6.8)are very close to exact values and they are also negligible. The RPE values of athletes can be predicted by these two equations by PMV values. The graphics of calculated and exact RPE values are shown at Figure 6.14.

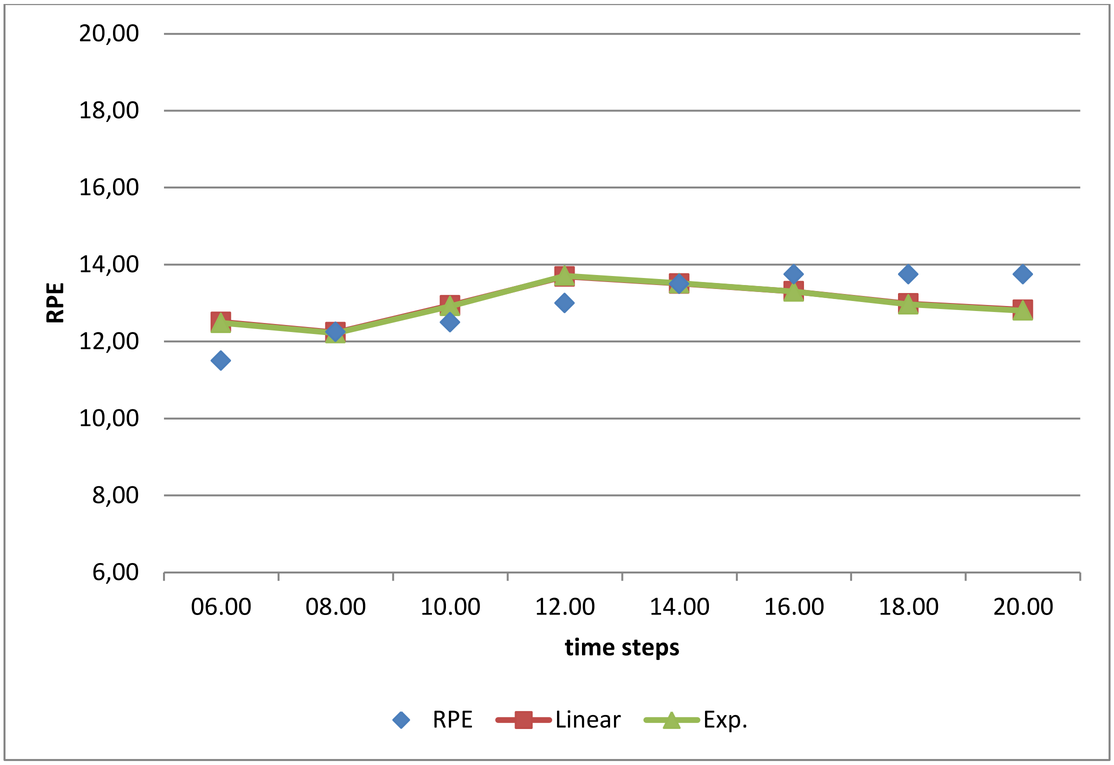

Figure 6.15. The calculated and experimental RPE values vs. time (min.)high oxygen consumption rate (N=4)

The correlation between PMV and RPE at low oxygen consumption rate is shown at Table 6.17 and 6.18. The correlation coefficients are very higher than the correlation coefficients at high oxygen consumption rate. It can be deduced that the rate of oxygen consumption affects the correlation between PMV and RPE values negatively. At the low oxygen consumption rate, PMV is lower and as PMV increases, the levels of correlation coefficients are decreases. Furthermore, the level of significances at low oxygen consumption rate (p value) at the first two time steps is higher than 0,05 and these two data statistically insignificant. At rest of all time steps, data are statistically significant.

Table 6.16. Correlation coefficients, level of correlation coefficients and p values at low oxygen consumption rate

Time Steps	Corr.Coefficients	Level of Corr. Coefficients	P Values
06.00	-0,49	moderately	0,26
08.00	-0,70	moderately strong	0,08
10.00	-0,84	moderately strong	0,02
12.00	-0,75	moderately strong	0,05
14.00	-0,95	strong	0,00
16.00	-0,81	moderately strong	0,03
18.00	-0,82	moderately strong	0,02
20.00	-0,77	moderately strong	0,04
average	**-0,77**	**moderately strong**	

Table 6.17. Correlation coefficients and level of significance vs. time (min.) at low oxygen consumption rate (N=7)

Spearman's rho	**PMV_OL_06.00**	**PMV_OL_08.00**	**PMV_OL_10.00**	**PMV_OL_12.00**	**PMV_OL_14.00**	**PMV_OL_16.00**	**PMV_OL_18.00**	**PMV_OL_20.00**
RPE_OL_06.00								
cor.coeff.	-0,49	-0,71	-0,62	-0,76	-0,55	-0,55	-0,73	-0,76*
sign.	0,26	0,07	0,14	0,05	0,21	0,21	0,06	0,6
RPE_OL_08.00								
cor.coeff.	-0,52	-0,7	-0,93**	-0,96**	-0,89**	-0,85*	-0,93**	-0,82*
sign.	0,23	0,08	0	0	0,01	0,01	0	0,03
RPE_OL_10.00								
cor.coeff.	-0,44	-0,49	-0,84*	-0,76*	-0,93**	-0,76*	-0,73	-0,65
sign.	0,33	0,26	0,02	0,05	0	0,05	0,06	0,11
RPE_OL_12.00								
cor.coeff.	-0,55	-0,65	-0,84*	-0,75	-0,87*	-0,69	-0,71	-0,78*
sign.	0,21	0,11	0,02	0,05	0,01	0,09	0,07	0,04
RPE_OL_14.00								
cor.coeff.	-0,56	-0,62	-0,92**	-0,86*	-0,95**	-0,81*	-0,82*	-0,77*
sign.	0,19	0,14	0	0,01	0	0,03	0,02	0,04
RPE_OL_16.00								
cor.coeff.	-0,56	-0,62	-0,92**	-0,86*	-0,95**	-0,81*	-0,82*	-0,77*
sign.	0,19	0,14	0	0,01	0	0,03	0,02	0,04
RPE_OL_18.00								
cor.coeff.	-0,56	-0,62	-0,92**	-0,86*	-0,95**	-0,81*	-0,82*	-0,77*
sign.	0,19	0,14	0	0,01	0	0,03	0,02	0,04
RPE_OL_20.00								
cor.coeff.	-0,56	-0,62	-0,92**	-0,86*	-0,95**	-0,81*	-0,82*	-0,77*
sign.	0,19	0,14	0	0,01	0	0,03	0,02	0,04

**.Correlation is significant at the 0,01 level (2-tailed)

*.Correlation is significant at the 0,05 level (2-tailed)

Besides, it is tried to find a new formula which includes PMV and RPE values for low oxygen consumption rate and it is predicted the RPE values owing to this formula by using PMV values. Thus, even if the RPE values of athletes are unknown, the RPE values can be predicted by PMV values.

Table 6.18. The table of curve estimation at low oxygen consumption rate

Dependent Variable: RPE_AV_OL

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	0,43	4,52	1	6	0,08	20,805	-3,011		
Logarithmic	0,41	4,18	1	6	0,09	20,354	-7,748		
Inverse	0,39	3,84	1	6	0,10	5,318	19,782		
Quadratic	0,57	3,32	2	5	0,12	-39,563	42,914	-8,684	
Cubic	0,57	3,26	2	5	0,12	-18,811	19,615	,000	-1,074
Compound	0,43	4,60	1	6	0,08	24,426	,783		
Power	0,42	4,26	1	6	0,09	23,559	-,629		
S	0,40	3,92	1	6	0,10	1,939	1,607		
Growth	0,43	4,60	1	6	0,08	3,196	-,244		
Exponential	0,43	4,60	1	6	0,08	24,426	-,244		

As it is selected before, linear and exponential equations are selected. These R square (Table 6.19) values are low and the estimated models are not statistically significant.These equations are

$$\mathrm{RPE} = 20{,}805 - 3{,}011 * \mathrm{PMV} \qquad \text{(Linear)} \qquad (6.9)$$

$$\mathrm{RPE} = 24{,}426 * \exp(-0{,}244 * \mathrm{PMV}) \qquad \text{(Exponential)} \qquad (6.10)$$

Table 6.19. The comparison of equations at low oxygen consumption rate

Time steps	PMV	RPE	Linear	Diff.(%)	Exp.	Diff.(%)
06.00	2,14	11	14,36	23,41	14,49	24,09
08.00	2,3	11,86	13,88	14,55	13,94	14,89
10.00	1,85	12,57	15,23	17,49	15,55	19,18
12.00	1,66	13,14	15,81	16,87	16,29	19,34
14.00	1,56	13,43	16,11	16,62	16,69	19,55
16.00	1,56	13,57	16,11	15,76	16,69	18,71
18.00	1,47	13,71	16,38	16,29	17,06	19,66
20.00	1,63	13,71	15,90	13,76	16,41	16,46
			average	**16,844**		**18,984**

Although the R squares of linear and exponential equations are low, the differences are very low as it is seen in Table 6.20. Both of equations (6.9 and 6.10) are very close to exact values and they are also negligible. The RPE values of athletes can be predicted by these two equations by PMV values. The graphics of calculated and exact RPE values are shown at Figure 6.15.

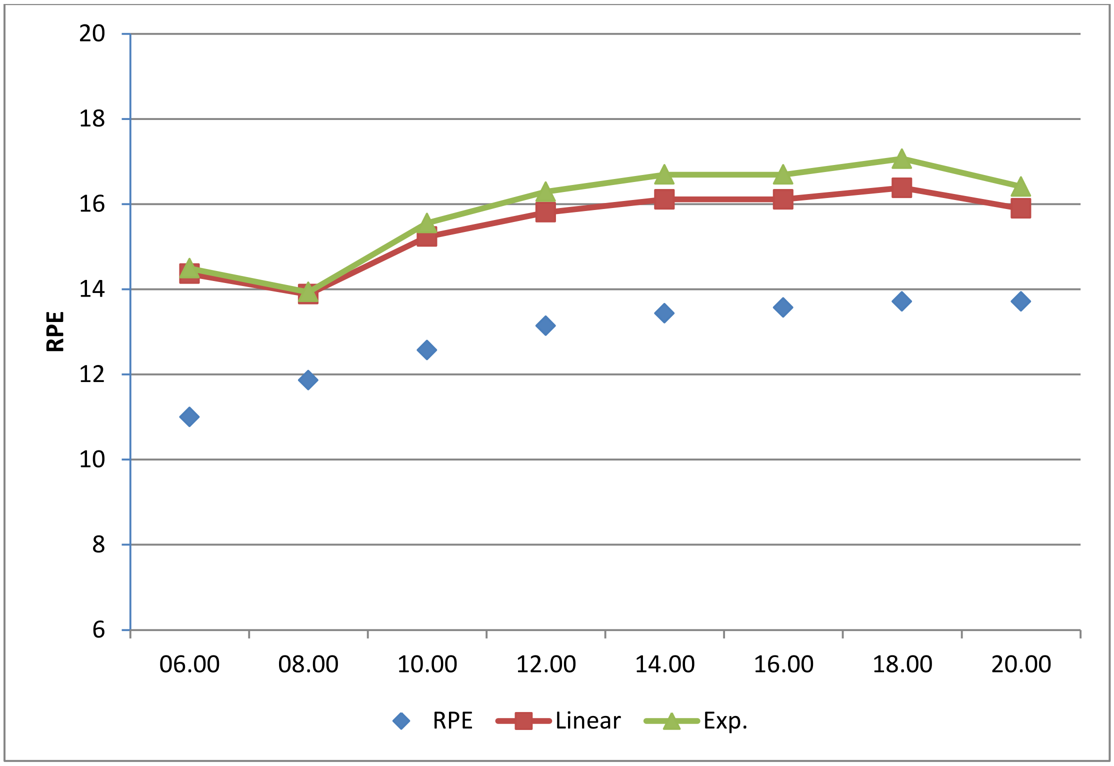

Figure 6.16. The calculated and experimental RPE values vs. time (min.)at low oxygen consumption rate (N=7)

6.2.3. Third Step: PMV-RPE correlations at different core body temperatures

In this part, the subjects are divided two groups according to the core body temperature at the end of the test (Table 6.21). The six of eleven subjects' (S6, S7, S8, S9, S10 and S11) core body temperatures are higher than the average value of eleven subjects. Thus, these six subjects are included in high core body temperature group (CH). The rest of eleven subjects (S1, S2, S3, S4 and S5) are included in low core body temperature group (CL).

Table 6.20. The average core body temperatures of subjects during submaximal exercise tests.

Subjects	Average	Groups
S1	37,37	L
S2	37,47	L
S3	37,59	L
S4	37,54	L
S5	37,17	L
S6	37,89	**H**
S7	37,83	**H**
S8	37,68	**H**
S9	37,86	**H**
S10	37,89	**H**
S11	37,88	**H**
average	**37,65**	

At this step, the correlation between PMV and RPE at high and low core body temperature is investigated. The descriptive statistics and Box-Whisker plots of PMV and RPE at high oxygen consumption rate are shown at Table 6.22, 6.23 and Figure 6.16, 6.17.

As it shown at Table 6.22, the standard deviations and variances values at high core body temperature (CH) are generally higher than the standard deviations and variances values at low core body temperature. Core body temperature increases based on the metabolic heat value. Thus, at higher metabolic heat values, PMV takes higher values than low core body temperature. If the descriptive statistics are handled individually,

At the first time step (06.00), PMV ranges from 1,49 to 3,45 at high group. At this group, the standard deviation and variance values are 0,78 and 0,61.These standard deviation and variance values are the minimum values at high group. Besides, PMV ranges from 0,85 to 3,95 at low group. While the standard deviation equals to 1,15, the variance equals to 1,31. These standard deviation and variance values are the maximum values at low group

At the second time step (08.00), PMV ranges from 1,34 to 4,41 at high group. At this group, the standard deviation and variance equal to 1,06 and 1,12 respectively. PMV ranges from 1,23 to 3,81 at low group. The standard deviation and variance are 1,02.

At the third time step (10.00), PMV ranges from 1,22 to 3,86 at high group. The standard deviation and variance have the same value that is 1,01. At low group, PMV ranges from 0,92 to 3,15 and standard deviation and variance are 0,84 and 0,70 respectively.

At the fourth time step (12.00), PMV ranges from 0,84 to 3,54 at high group. The standard deviation and variance are 1,05 and 1,10. On the other hand, PMV ranges from 0,42 to 2,71. Standard deviation and variance equal to 0,84 and 0,70.

At the fifth time step (14.00), PMV ranges from 0,65 to 3,61 at high group. The standard deviation and variance 1,12 and 1,26. Besides, PMV ranges from 0,42 to 2,66. The standard deviation and variance equal to 0,82 and 0,69 respectively.

At the sixth time step (16.00), PMV ranges from 0,68 to 3,96 at high group. The standard deviation and variance are 1,26 and 1,59. At the low group, PMV ranges 1,37 to 1,98. The standard deviation and variance are 0,31 and 0,10. These standard deviation and variance values are the minimum values at low group.

At the seventh time step (18.00), PMV ranges from 0,60 to 4,26 at high group. The standard deviation and variance are 1,51 and 2,27. These standard deviation and variance values are the maximum values at high group. Additionally, PMV ranges from 0,59 to 1,98 at low group. The standard deviation and variance are 0,56 and 0,31 respectively.

At the last time step (20.00), PMV ranges from 0,50 to 3,97 at high group. The standard deviation and variance equal to 1,21 and 1,46 respectively. At low group PMV ranges from 1,23 to 2,16. The standard deviation and variance equal to 0,37 and 0,14.

Table 6.21. Descriptive statistics of PMV values at high (CH) and low (CL) core body temperature

	N	Minimum	Maximum	Mean	Std. Deviation	Variance
PMV_6_CH	6	1,49	3,45	2,59	0,78	0,61
PMV_8_CH	6	1,34	4,41	2,87	1,06	1,12
PMV_10_CH	6	1,22	3,86	2,34	1,01	1,01
PMV_12_CH	6	0,84	3,54	2,09	1,05	1,10
PMV_14_CH	6	0,65	3,61	2,05	1,12	1,26
PMV_16_CH	6	0,68	3,96	2,08	1,26	1,59
PMV_18_CH	6	0,60	4,26	2,34	1,51	2,27
PMV_20_CH	6	0,50	3,97	2,43	1,21	1,46
PMV_6_CL	5	0,85	3,95	2,18	1,15	1,31
PMV_8_CL	5	1,23	3,81	2,16	1,02	1,02
PMV_10_CL	5	0,92	3,15	1,92	0,84	0,70
PMV_12_CL	5	0,42	2,71	1,69	0,84	0,70
PMV_14_CL	5	0,42	2,66	1,62	0,82	0,69
PMV_16_CL	5	1,37	1,98	1,63	0,31	0,10
PMV_18_CL	5	0,59	1,98	1,36	0,56	0,31
PMV_20_CL	5	1,23	2,16	1,54	0,37	0,14
Valid N (listwise)	5					

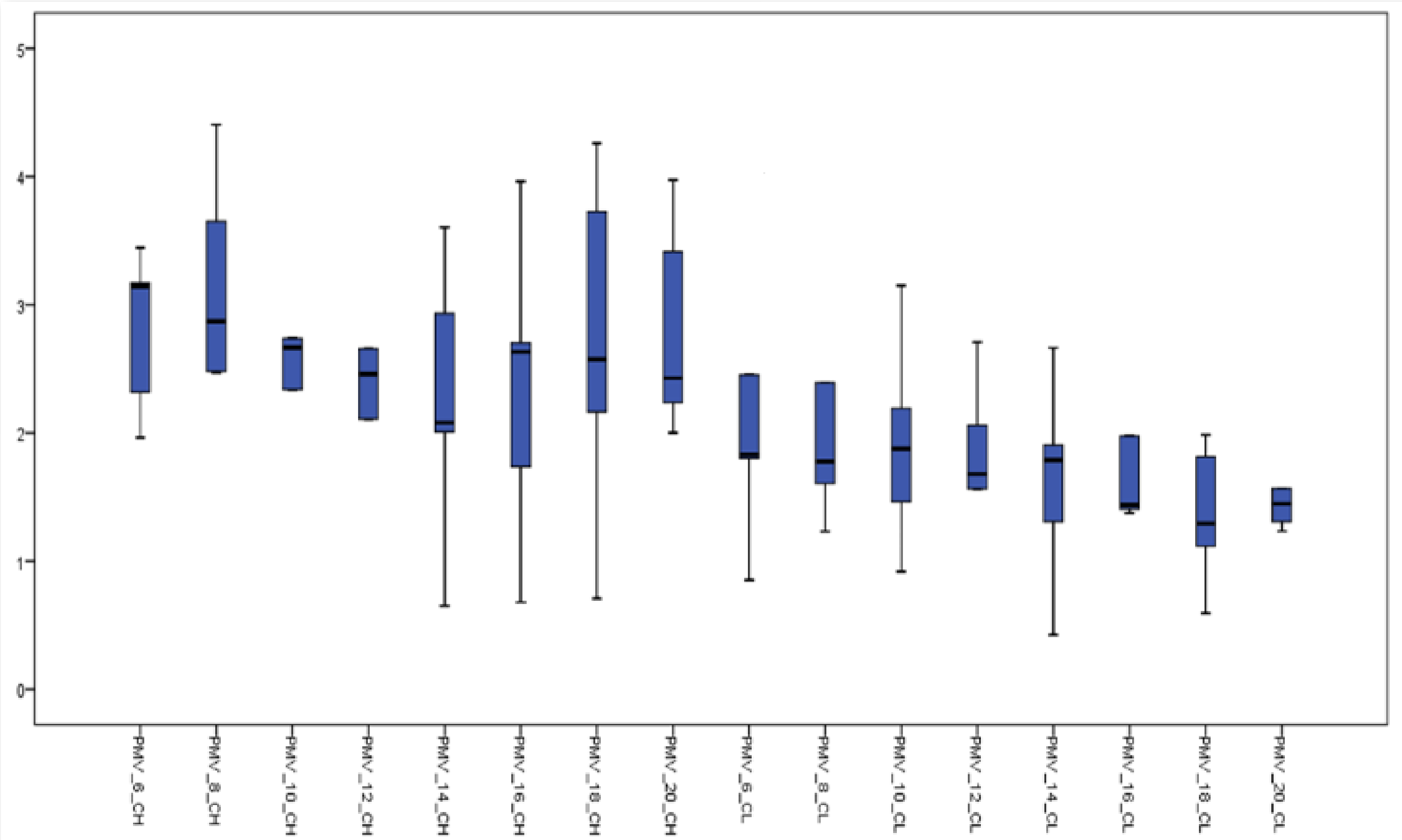

Figure 6.17. Box Whisker plot of PMV values at high (CH) and low (CL) group vs. time (min.)

As it shown at Table 6,23, at high group, RPE values fluctuate more than at low group. Thus, the standard deviations and variances values at high core body temperature (CH) are higher than the standard deviations and variances values at low core body temperature. If the descriptive statistics are handled individually,

Table 6.22. Descriptive statistics of RPE at high (CH) and low (CL) core body temperature

	N	Minimum	Maximum	Mean	Std. Deviation	Variance
RPE_6_CH	6	8,00	14,00	10,50	2,59	6,70
RPE_8_CH	6	8,00	15,00	11,33	3,08	9,47
RPE_10_CH	6	8,00	15,00	11,67	3,39	11,47
RPE_12_CH	6	9,00	15,00	12,33	3,01	9,07
RPE_14_CH	6	9,00	16,00	13,00	3,35	11,20
RPE_16_CH	6	9,00	16,00	13,17	3,25	10,57
RPE_18_CH	6	10,00	16,00	13,33	3,01	9,07
RPE_20_CH	6	10,00	16,00	13,33	3,01	9,07
RPE_6_CL	5	11,00	13,00	12,00	1,00	1,00
RPE_8_CL	5	12,00	14,00	12,80	0,84	0,70
RPE_10_CL	5	12,00	15,00	13,60	1,34	1,80
RPE_12_CL	5	12,00	16,00	14,00	1,87	3,50
RPE_14_CL	5	12,00	16,00	14,00	1,87	3,50
RPE_16_CL	5	13,00	16,00	14,20	1,64	2,70
RPE_18_CL	5	13,00	16,00	14,20	1,64	2,70
RPE_20_CL	5	13,00	16,00	14,20	1,64	2,70
Valid N (listwise)	5					

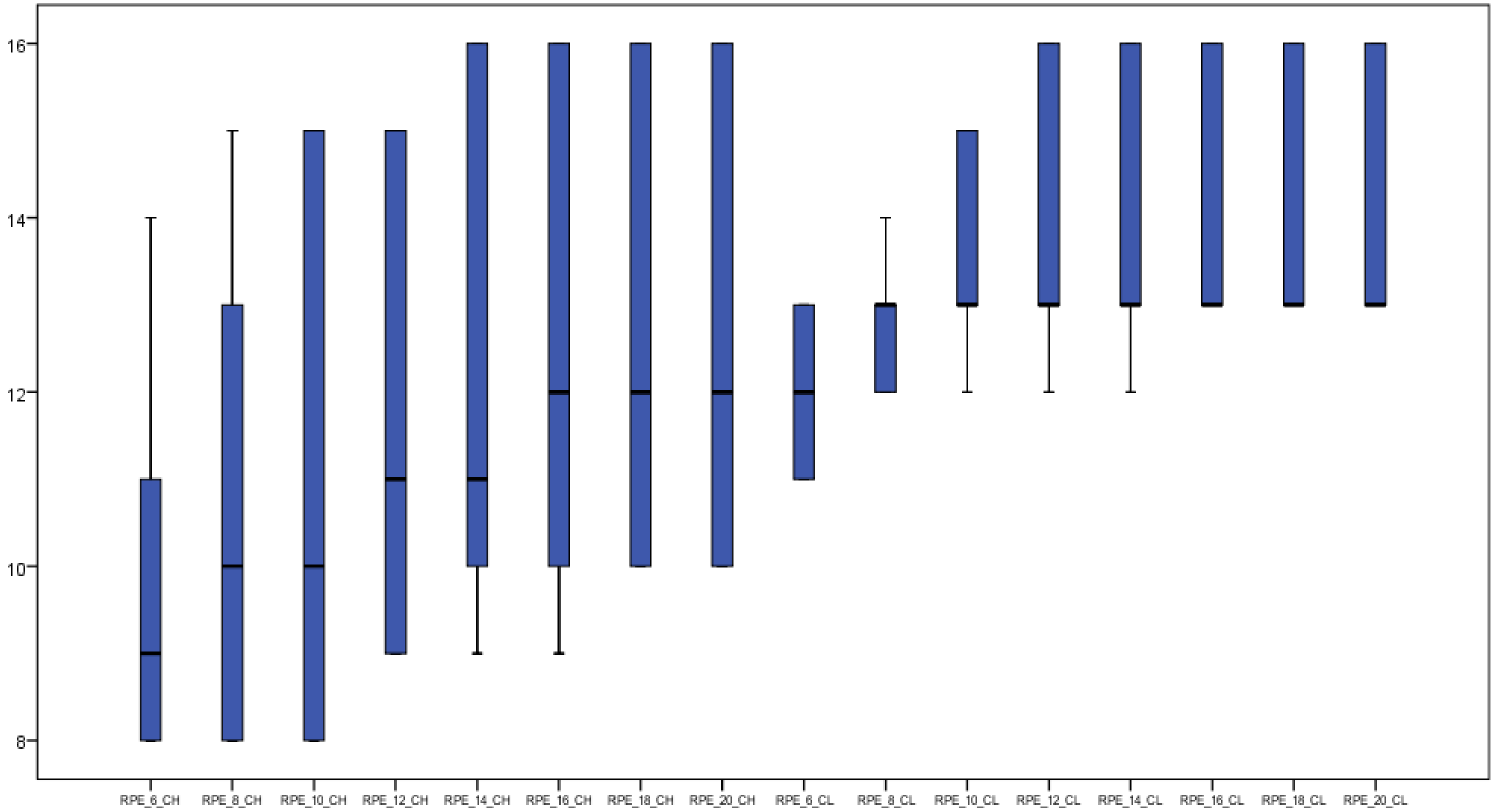

Figure 6.18. Box Whisker Plot of RPE values high (CH) and low (CL) group vs. time (min.

At the first time step (06.00), RPE ranges from 8 to 14 at high group. The standard deviation and variance are 2,59 and 6,70 respectively .These values are the minimum value among the high group. On the other hand, RPE ranges from 11 to 13. Standard deviation and variance are the same which is 1.

At the second time step (08.00), RPE ranges from 8 to 15 at high group. The standard deviation and variance equal to 3,08 and 9,47. Besides, RPE ranges from 12 to 14. Standard deviation and variance are 0,84 and 0,70. These values are the minimum value among the low group.

At the third time step (10.00), RPE ranges from 8 to 15 at high group. The standard deviations and variance are 3,39 and 11,47. These values are the maximum value among the high group. Besides, RPE ranges from, 12 to 15 at low group. The standard deviation and variance equal to 1,34 and 1,80.

At the fourth time step (12.00), RPE ranges from 9 to 15 at high group. The standard deviation and variance are 3,01 and 9,07. At low group, RPE ranges from 12 to 16. The standard deviation and variance equal to 1,87 and 3,50.

At the fifth time step (14.00), RPE ranges from 9 to 16 at high group. The standard deviation and variance are 3,35 and 11,20. At low group, RPE ranges from, 12 to 16. The standard deviation and variance equal to 1,87 and 3,50.

At the sixth time step (16.00), RPE ranges from 9 to 16 at high group. The standard deviation and variance equal to 3,25 and 10,57. On the other hand, RPE ranges from 13 to 16 at low group. The standard deviation and variance 1,64 and 2,70.

At the seventh time step (18.00), RPE ranges from 10 to 16 at high group. The standard deviation and variance equal to 3,01 and 9,07. At low group, RPE ranges from 13 to 16 at low group. The standard deviation and variance 1,64 and 2,70.

At the last time step (20.00), RPE ranges from 10 to 16 at high group. The standard deviation and variance equal to 3,01 and 9,07. At low group, RPE ranges from 13 to 16 at low group. The standard deviation and variance 1,64 and 2,70.

The correlation between PMV and RPE at high core body temperature is shown at Table 6.24 and 6.25. The correlation coefficients are low initially and they increase in time. Nonetheless the average correlation coefficient is 0,36 and the level of average correlation coefficient is weak correlation. Likewise, the levels of significance (p values) at all time steps are higher than 0,05 therefore, all of data are statistically insignificant.

Table 6.23. Correlation coefficients, levels of correlation coefficient and p values at high core body temperature

Time Steps	Corr.Coefficients	Level of Corr. Coefficients	P Values
06.00	-0,06	very weak	0,91
08.00	-0,17	very weak	0,74
10.00	-0,09	very weak	0,87
12.00	-0,37	weak	0,47
14.00	-0,52	moderately	0,30
16.00	-0,76	moderately strong	0,08
18.00	-0,28	weak	0,59
20.00	-0,59	moderate	0,22
average	**-0,36**	**weak**	

Table 6.24. Correlation coefficients and level of significance vs. time (min.) at high core body temperature (N=6)

Spearman's rho	PMV_CH_06.00	PMV_CH_08.00	PMV_CH_10.00	PMV_CH_12.00	PMV_CH_14.00	PMV_CH_16.00	PMV_CH_18.00	PMV_CH_20.00
RPE_CH_06.00								
cor.coeff.	-0,06	0,17	-0,03	-0,12	-0,32	-0,58	-0,03	-0,38
sign.	0,91	0,74	0,96	0,83	0,54	0,23	0,96	0,46
RPE_CH_08.00								
cor.coeff.	-0,06	0,17	-0,03	-0,12	-0,32	-0,58	-0,03	-0,38
sign.	0,91	0,74	0,96	0,83	0,54	0,23	0,98	0,46
RPE_CH_10.00								
cor.coeff.	-0,03	0,29	-0,09	-0,18	-0,5	-0,74	-0,09	-0,41
sign.	0,96	0,57	0,87	0,74	0,31	0,1	0,87	0,42
RPE_CH_12.00								
cor.coeff.	-0,25	0,06	-0,28	-0,37	-0,59	-0,8	-0,28	-0,59
sign.	0,64	0,91	0,59	0,47	0,22	0,06	0,59	0,22
RPE_CH_14.00								
cor.coeff.	-0,21	-0,03	-0,21	-0,33	-0,52	-0,76	-0,21	-0,52
sign.	0,69	0,95	0,69	0,52	0,3	0,08	0,69	0,3
RPE_CH_16.00								
cor.coeff.	-0,21	-0,03	-0,21	-0,33	-0,52	-0,76	-0,21	-0,52
sign.	0,69	0,95	0,69	0,52	0,3	0,08	0,69	0,3
RPE_CH_18.00								
cor.coeff.	-0,25	0,06	-0,28	-0,37	-0,59	-0,8	-0,28	-0,59
sign.	0,64	0,91	0,59	0,47	0,22	0,06	0,59	0,22
RPE_CH_20.00								
cor.coeff.	-0,25	0,06	-0,28	-0,37	-0,59	-0,8	-0,28	-0,59
sign.	0,64	0,91	0,59	0,47	0,22	0,06	0,59	0,22

**.Correlation is significant at the 0,01 level (2-tailed)

*.Correlation is significant at the 0,05 level (2-tailed)

In addition, it is tried to find a new formula which includes PMV and RPE values and it is predicted the RPE values owing to this formula by using PMV values. Thus, even if the RPE values of athletes are unknown, the RPE values can be predicted by PMV values.

Table 6.25. The table of curve estimation at high core body temperature

Dependent Variable: RPE_AV_CH

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	0,38	3,70	1	6	0,10	17,798	-2,326		
Logarithmic	0,38	3,60	1	6	0,10	17,045	-5,556		
Inverse	0,37	3,46	1	6	0,11	6,700	13,078		
Quadratic	0,39	1,57	2	5	0,30	12,148	2,380	-0,967	
Cubic	0,39	1,58	2	5	0,30	14,484	0,000	-0,206	-0,074
Compound	0,39	3,80	1	6	0,10	19,467	0,822		
Power	0,38	3,71	1	6	0,10	18,281	-0,468		
S	0,37	3,58	1	6	0,10	2,034	1,103		
Growth	0,39	3,80	1	6	0,10	2,969	-0,196		
Exponential	0,39	3,80	1	6	0,10	19,467	-0,196		

The independent variable is PMV_AV_CH.

As it is selected before, linear and exponential equations are selected. These R square values (Table 6.26.) are low and they are statistically insignificant. These equations are

$$\mathrm{RPE} = 17{,}798 - 2{,}326 * \mathrm{PMV} \qquad \text{(Linear)} \qquad (6.11)$$

$$\mathrm{RPE} = 19{,}467 * \exp(-0{,}196 * \mathrm{PMV}) \qquad \text{(Exponential)} \qquad (6.12)$$

Table 6.26. The comparison of equations at high core body temperature

Time steps	**PMV**	**RPE**	**Linear**	**Diff. (%)**	**Exp.**	**Diff. (%)**
06.00	2,59	10,50	12,01	12,55	11,72	10,39
08.00	2,87	11,33	11,38	0,45	11,09	-2,15
10.00	2,34	11,67	12,57	7,13	12,31	5,17
12.00	2,09	12,33	13,12	6,06	12,92	4,60
14.00	2,05	13,00	13,21	1,62	13,03	0,20
16.00	2,09	13,17	13,12	-0,34	12,92	-1,90
18.00	2,34	13,33	12,57	-6,08	12,31	-8,32
20.00	2,43	13,33	12,36	-7,81	12,09	-10,25
			average	**1,69556**		**-0,28414**

As shown at previous steps, the R square squares of linear and exponential equations (6.11 and 6.12) are low as it is seen in Table 6.27. Both of equations are very close to exact values and they are also negligible. The RPE values of athletes can be predicted by these two equations by PMV values. The graphics of calculated and exact RPE values are shown at Figure 6.18.

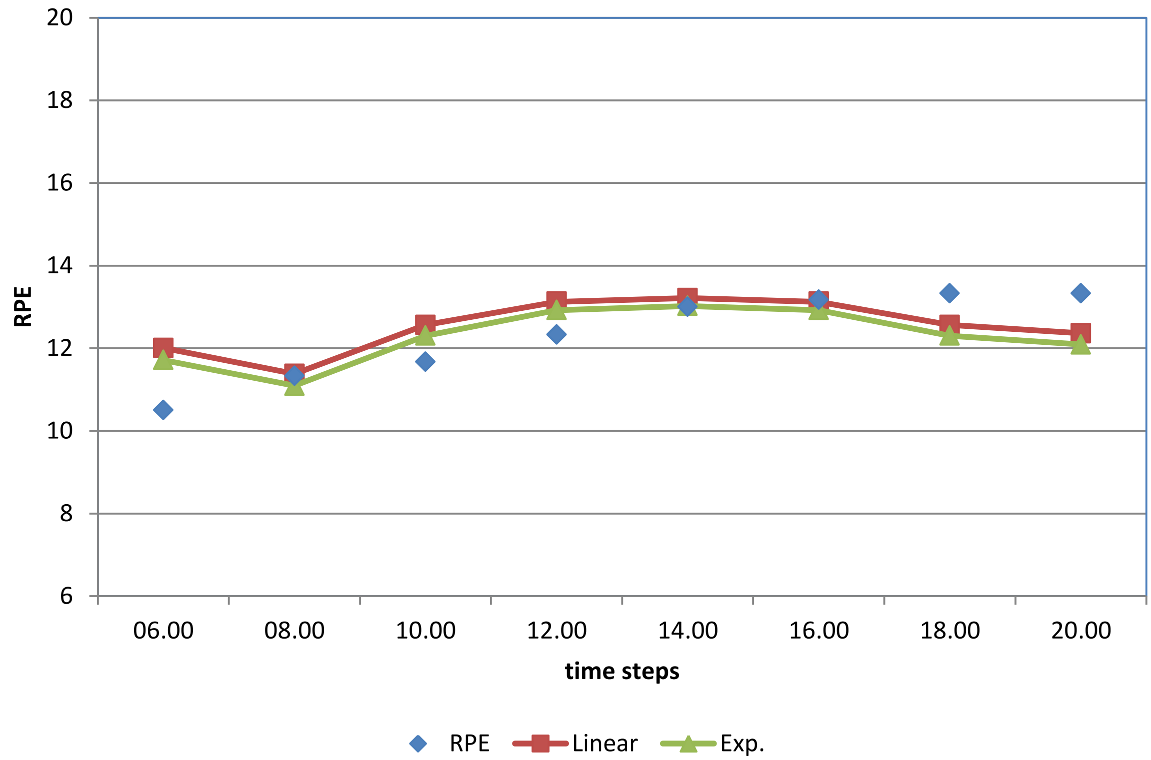

Figure 6.19. The calculated and experimental RPE values vs. time (min.) at high core body temperature (N=6)

The correlation between PMV and RPE at low core body temperature is shown at Table 6.28 and 6.29. Even if correlation coefficients fluctuate, the correlation coefficients are higher when compared at high core body temperature. It can be deduced from, the core body temperature affect the PMV-RPE correlations. However, only two data which are at third (10.00) and fifth (14.00) time steps are statistically significant. At the rest of time steps, the data are statistically insignificant.

Table 6.27. Correlation coefficients, level of correlation coefficients and p values at low core body temperature

Time Steps	Corr.Coefficients	Level of Corr. Coefficients	P Values
06.00	-0,47	moderately	0,42
08.00	-0,74	moderately strong	0,15
10.00	-0,95	strong	0,01
12.00	-0,74	moderately strong	0,15
14.00	-0,95	strong	0,01
16.00	-0,29	weak	0,64
18.00	-0,58	moderately	0,31
20.00	-0,87	strong	0,06
average	-0,70	moderately strong	

Table 6.28. Correlation coefficients and level of significance vs. time (min.) at low core body temperature (N=5)

Spearman's rho	**PMV_CL_06.00**	**PMV_CL_08.00**	**PMV_CL_10.00**	**PMV_CL_12.00**	**PMV_CL_14.00**	**PMV_CL_16.00**	**PMV_CL_18.00**	**PMV_CL_20.00**
RPE_CL_06.00								
cor.coeff.	-0,47	-0,32	-0,47	-0,79	-0,47	-0,47	-0,79	0
sign.	0,42	0,6	0,42	0,11	0,42	0,42	0,11	1
RPE_CL_08.00								
cor.coeff.	-0,53	-0,74	-0,95*	-0,95*	-0,95*	-0,63	-0,95*	-0,58
sign.	0,36	0,15	0,01	0,01	0,01	0,25	0,01	0,31
RPE_CL_10.00								
cor.coeff.	-0,74	-0,95*	-0,95*	-0,74	-0,95*	-0,53	-0,74	-0,95*
sign.	0,15	0,01	0,01	0,15	0,01	0,36	0,15	0,01
RPE_CL_12.00								
cor.coeff.	-0,74	-0,95*	-0,95*	-0,74	-0,95	-0,53	-0,74	-0,95
sign.	0,15	0,01	0,01	0,15	0,01	0,36	0,15	0,01
RPE_CL_14.00								
cor.coeff.	-0,74	-0,95*	-0,95*	-0,74	-0,95*	-0,53	-0,74	-0,95*
sign.	0,15	0,01	0,01	0,15	0,01	0,36	0,15	0,01
RPE_CL_16.00								
cor.coeff.	-0,58	-0,87	-0,87	-0,58	-0,87	-0,29	-0,58	-0,87
sign.	0,31	0,06	0,06	0,31	0,06	0,64	0,31	0,06
RPE_CL_18.00								
cor.coeff.	-0,58	-0,87	-0,87	-0,58	-0,87	-0,29	-0,58	-0,87
sign.	0,31	0,06	0,06	0,31	0,06	0,64	0,31	0,06
RPE_CL_20.00								
cor.coeff.	-0,58	-0,87	-0,87	-0,58	-0,87	-0,29	-0,58	-0,87
sign.	0,31	0,06	0,06	0,31	0,06	0,64	0,31	0,06

**.Correlation is significant at the 0,01 level (2-tailed)
*.Correlation is significant at the 0,05 level (2-tailed)

In addition, it is tried to find a new formula which includes PMV and RPE values and it is predicted the RPE values owing to this formula by using PMV values. Thus, even if the RPE values of athletes are unknown, the RPE values can be predicted by PMV values.

Table 6.29. The table of curve estimation at low core body temperature

Dependent Variable: RPE_AV_CL

	Model Summary					Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	0,83	29,08	1	6	0,002	18,023	-2,495		
Logarithmic	0,79	21,85	1	6	0,003	16,021	-4,321		
Inverse	0,73	16,36	1	6	0,007	9,395	7,278		
Quadratic	0,94	37,90	2	5	0,001	5,599	11,574	-3,887	
Cubic	0,94	40,38	2	5	0,001	12,081	0,000	2,893	-1,302
Compound	0,82	26,68	1	6	0,002	18,962	0,828		
Power	0,77	20,27	1	6	0,004	16,300	-0,326		
S	0,72	15,32	1	6	0,008	2,291	0,549		
Growth	0,82	26,68	1	6	0,002	2,942	-0,188		
Exponential	0,82	26,68	1	6	0,002	18,962	-0,188		

The independent variable is PMV_AV_CL.

As it is selected before, linear and exponential equations are selected. These R square values (Table 6.30) are higher when compared at high core body temperature and they are also statistically significant. These equations are

$$\text{RPE} = 18{,}023 - 2{,}495 * \text{PMV} \quad \text{(Linear)} \quad (6.13)$$

$$\text{RPE} = 18{,}962 * \exp(-0{,}188 * \text{PMV}) \quad \text{(Exponential)} \quad (6.14)$$

Table 6.30 The comparison of equations at low core body temperature

Time steps	PMV	RPE	Linear	Diff. (%)	Exp.	Diff.(%)
06.00	2,18	12,00	12,58	4,64	12,59	4,66
08.00	2,16	12,80	12,63	-1,32	12,63	-1,32
10.00	1,92	13,60	13,23	-2,78	13,22	-2,90
12.00	1,69	14,00	13,81	-1,40	13,80	-1,44
14.00	1,62	14,00	13,98	-0,14	13,98	-0,12
16.00	1,63	14,20	13,96	-1,75	13,96	-1,74
18.00	1,36	14,20	14,63	2,94	14,68	3,30
20.00	1,54	14,20	14,18	-0,14	14,20	-0,03
			average	**0,00818**		**0,05008**

As shown at Table 6.30, the R squares of linear and exponential equations are higher. Both of equations are very close to exact values and they are also negligible. The RPE values of athletes can be predicted by these two equations by PMV values. The graphics of calculated and exact RPE values are shown at Figure 6.18.

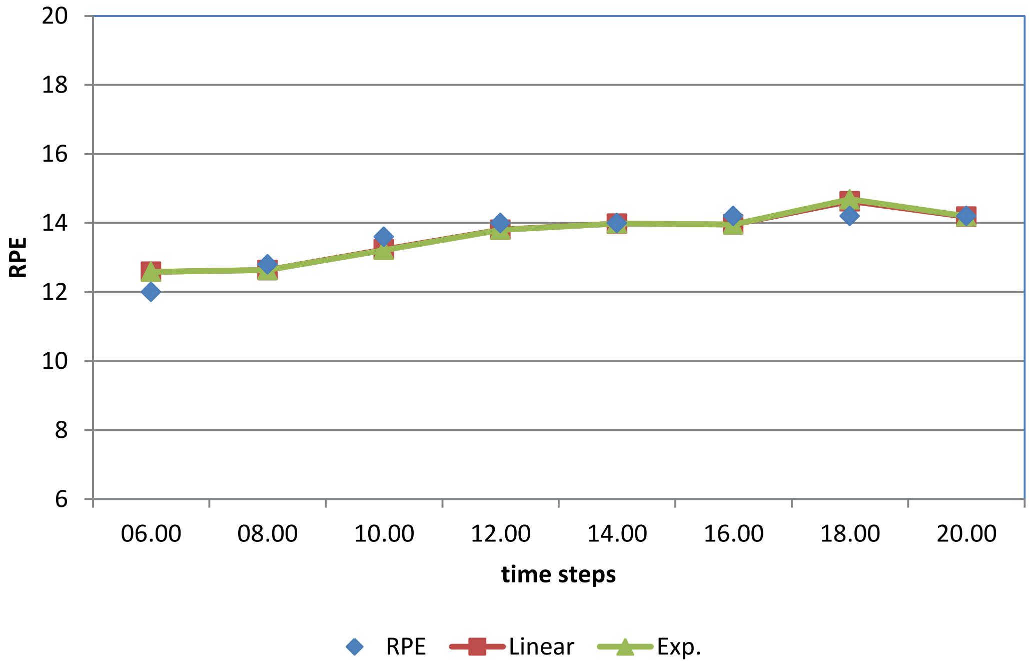

Figure 6.20. The calculated and experimental RPE values vs. time (min.) at low core body temperature (N=5)

CHAPTER 7

CONCLUSION

In the present study, thermal behavior of human body during exercise investigated. Human body can be considered as a heat machine that generates energy and heat and also a dynamic system which is interacted with the environment consistently. There is a control mechanism in the human body called thermoregulatory system controlling human body via thermo receptors.

Additionally, thermal comfort is a popular opinion that related human life. There are a lot of studies on thermal comfort and, due to the developed technology and science, these studies increase the quality of human life. To analyze thermal comfort, Fanger developed an index which is called Predicted Mean Vote (PMV). In this thesis, PMV index is used to analyze thermal comfort conditions. Similarly, Ratings of Perceived Exertion, developed by Gunnar Borg, is used to investigate exercise conditions. There are many studies on RPE scale during exercise in literature. To investigate the relation between PMV and RPE is the purpose of this thesis. Because, there is not any study on the relation between PMV and RPE within the knowledge of the authors. The relations are studied and commented. According to statistical analysis, the correlation coefficients at both low oxygen consumption rate and low core body temperature are higher than the correlation coefficients at both high oxygen consumption rate and high core body temperature. Oxygen consumption rate and core body temperature affects the correlation between PMV and RPE. Furthermore, a new formula can be developed in consequence of the studies on the relation between PMV and RPE. For example, when the thermal condition of a gymnasium is analyzed, the athletes' RPE values who are doing sports in this gymnasium can be predicted. Similarly, the method can be used various environments such as office, school, etc. The numbers of these implications can be increased in the future with the studies on relation between PMV and RPE. Moreover, this research leads to further study about the relation between PMV and RPE and the thermal behavior of human body during exercise.

There were some limitations during this research. These limitations are outlined briefly.

Initially, the subjects who were participated the experiments were selected among the male athletes. The thermal behavior of human body during exercise was investigated on only male athletes. Male and female physiologies are different from each other. Therefore, the implications and predictions from this study cannot be applied female athletes. The female athletes should be included the experiments at further studies.

Secondly, the numbers of samples should be increased. Even though the statistical and comparative analysis were done with 11 subject successfully, the some parameters such as level of significances and correlation coefficients fluctuated in a wide ranges.

One of the limitations is that time steps. The data were obtained two-minute intervals. The duration interval should be decreased. To illustrate, PMV values were collected two-minute interval but it varies every second during these two minutes. Furthermore, data collecting data with small time intervals such as ten or twenty-second gets the data more homogenous. Likewise, there are eleven time steps during exercise. Although the thermal behavior of human body was investigated all eleven time steps, the data at the first two time steps (02.00 and 04.00) were not included at the statistical analysis. Because, at these time steps, the oxygen consumption does not reach steady state and it affects the PMV distribution negatively.

Lastly, PMV values at various subjects and time steps exceed 3 which is the maximum level of PMV. This leads to an undefined situation. The original PMV scale ranges from -3 to +3. A necessity of new scale or formula to evaluate thermal comfort at high metabolic heat values was emerged according to data obtained subjects. Similarly, RPE are based on only sensation. Thus, it does not have exact results and it varies from person to person. There are a lot of studies in literature on RPE and core body relation. According to these studies, there is a strong relationship between RPE and core body temperature. A method that measures RPE values can be derived based on or by using core body temperature.

To sum up, the investigation of PMV- RPE relation must be conducted with including more subjects and short time steps. This thesis also contributes the necessity of new studies and approaches about thermal behavior of human body, thermal comfort and perceived exertion. Also it can lead to the reconsider of existing methods, formulas or scales with more sensitive and dynamic measurements and data.

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