Physiological profile of Olympic style Tae Kwon Do match

Georgios C. Korellis
University of Nebraska at Omaha

Follow this and additional works at: https://digitalcommons.unomaha.edu/studentwork
Please take our feedback survey at: https://unomaha.az1.qualtrics.com/jfe/form/SV_8cchtFmpDyGfBLE

Recommended Citation
https://digitalcommons.unomaha.edu/studentwork/607

This Thesis is brought to you for free and open access by DigitalCommons@UNO. It has been accepted for inclusion in Student Work by an authorized administrator of DigitalCommons@UNO. For more information, please contact unodigitalcommons@unomaha.edu.
PHYSIOLOGICAL PROFILE OF OLYMPIC STYLE TAE KWON DO MATCH

A Thesis

Presented to the

School of Health, Physical Education, and Recreation

and the

Faculty of the Graduate College

University of Nebraska.

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

University of Nebraska at Omaha

by

Georgios C. Korellis

June 2005
THESIS ACCEPTANCE

Acceptance for the faculty of the Graduate College, University of Nebraska, in partial fulfillment of the requirements for the degree Master of Science, University of Nebraska at Omaha.

Committee

[Signatures]

Chairperson  

[Signature]  

Date  

[Date]
Olympic style Tae Kwon Do training may achieve accepted training intensity threshold for effective aerobic capacity training, energy expenditure thresholds and elevation in excess post-exercise oxygen consumption. Little work regarding the acute metabolic demands during Olympic style Tae Kwon Do competition has been done before. The purpose of this study was to examine the physiological demands of a match in Olympic style Tae Kwon Do. Physiological assessment included measurement of oxygen uptake (VO₂), heart rate (HR), blood lactate concentration (BL), rate of perceived exertion (RPE) and body temperature (BT).

A total of 7 subjects between the ages of 19 and 27 years served as subjects for this study. All performed a 1.5 mile run test for establishing an estimated baseline measurement for VO₂ max. On subsequent visits, subjects engaged in a three minute-three round Olympic style Tae Kwon Do match in which they were asked to perform as competitively as possible.

Across the three rounds (three minutes per round) of the Tae Kwon Do match, no significant difference existed for VO₂, HR, LA and BT or number of kicks performed.
However, differences were seen between the first and third round of the match when examining their RPE. After the end of the third round RPE scores were significantly greater than the scores reported after the end of the first round (18.4 ± 1.81 vs 14.4 ± 2.29). Mean VO$_2$ was 38.8 ± 3.46 ml/kg/min corresponding to 85.9 % of their estimated VO$_2$max where as mean HR was 185.9 ± 7.40 bpm corresponding to 94.7 % of their age estimated HR max. The average BL of the match was 14.5 ± 4.17 mmol/L whereas the average BT was 99.0 ± 0.96 degrees Fahrenheit.

In conclusion, Olympic style Tae Kwon Do competition taxed both the aerobic and anaerobic energy systems. The mean VO$_2$ value for the match was 38.8 ± 3.46 ml/kg/min which corresponded to 85.9 % of VO$_2$max. Mean BL of 14.46 ± 4.17 was significantly correlated with mean RPE (r = 0.71) indicating an extensive involvement of anaerobic glycolysis suggesting that both aerobic and anaerobic training is needed for this sport.
Acknowledgements

This project required the work, time and patience of many exceptional people. Therefore, I wish to thank the following:

The subjects – for reasons that should be quite clear. Applied and basic scientific research could not be performed if persons like yourselves were not willing to be examined, questioned, poked, etc. It was appreciated how every one of you gave outstanding efforts in a series of tests that were challenging at very least.

The spectators – for the interest you showed and your willingness to support this study with your presence and your active involvement during the data collection.

Kenji Narazaki, and William Vincent – My fellow G.A’s for your intellectual input, encouragement, and the countless hours you helped me with this project.

Master William Guy, Anastasia Kyvelidou and Petros Kyprianou – for the very special role each one of you played in this study and the dedication you showed. Without you nothing would have been possible.

Dr. Richard Latin and Dr. James Thomas – for serving on my committee and providing a tremendously helpful feedback which imparted strength to this study. You are true intellectuals and your help was appreciated.

Dr. Kris Berg, my committee chair – for the stimulating conversations, patience and time spent working with me, explanations of anything and everything relating to our great discipline, and for being a true motivator and mentor. Your influence on my academic career at UNO has brought me many opportunities and a definite intellectual
enhancement. Your exemplary guidance and devotion for our discipline has fueled my desire to challenge myself in future academic endeavors. Thank you.

My amazing parents, Constantinos and Evaggelia, and my grandparents, Anastasios and Panagiota – your support and love is immeasurable. This endeavor would not have been possible without your presence in my life. Words cannot express my deep gratitude for you all.

My one and only brother, Odysseas – you left me so soon and yet you knew we had so many things to do, so many moments to share. I know now you are watching from the Heavens above and you are smiling. Since I cannot do much to have you back, I want you to know that your flame still burns inside me and it gives me strength to carry on for the journey we were supposed to make together. I miss you.
# Table of Contents

<table>
<thead>
<tr>
<th>Chapter 1</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem</td>
<td>4</td>
</tr>
<tr>
<td>Statement of Purpose</td>
<td>4</td>
</tr>
<tr>
<td>Hypothesis</td>
<td>4</td>
</tr>
<tr>
<td>Delimitations</td>
<td>4</td>
</tr>
<tr>
<td>Limitations</td>
<td>5</td>
</tr>
<tr>
<td>Definitions</td>
<td>6</td>
</tr>
<tr>
<td>Significance</td>
<td>7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter 3</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Review of Literature</td>
<td>8</td>
</tr>
<tr>
<td>Chronic effects of anaerobic/aerobic sports</td>
<td>8</td>
</tr>
<tr>
<td>Acute effects of anaerobic/aerobic sports</td>
<td>13</td>
</tr>
<tr>
<td>Injuries in Olympic style Tae Kwon Do</td>
<td>17</td>
</tr>
<tr>
<td>Summary</td>
<td>20</td>
</tr>
</tbody>
</table>
Chapter 4

Methods . 21
   Subjects . 21
   Design . 21
   Data Collection . 23
   Data Analysis . 25

Chapter 5

Results . 26
   Hypothesis 1a . 26
   Hypothesis 1b . 28
   Hypothesis 1c . 29
   Hypothesis 2 . 31

Chapter 6

Discussion . 32
   VO\textsubscript{2} and HR . 32
   RPE and BL . 35
   Body temperature and Kicks . 38
   Assessment of Motive and Effort During Match . 40
   Comparison with ACSM Recommendations . 41
   Limitations . 42
## Table of Figures

<table>
<thead>
<tr>
<th>Figures</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>Side view of portable metabolic device.</td>
<td>23</td>
</tr>
<tr>
<td>Figure 2</td>
<td>Rear view of portable metabolic device.</td>
<td>23</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Summary of VO$_2$ during each round and for entire match</td>
<td>27</td>
</tr>
<tr>
<td>Figure 4</td>
<td>Summary of mean VO$_2$ every 10 seconds of each round</td>
<td>28</td>
</tr>
<tr>
<td>Figure 5</td>
<td>Summary of mean HR during each round and for entire match</td>
<td>29</td>
</tr>
<tr>
<td>Figure 6</td>
<td>Summary of BL responses during each round and for entire match</td>
<td>30</td>
</tr>
<tr>
<td>Figure 7</td>
<td>Summary of RPE during each round and for entire match</td>
<td>31</td>
</tr>
<tr>
<td>Figure 8</td>
<td>Summary of body temperature during each round</td>
<td>39</td>
</tr>
<tr>
<td>Figure 9</td>
<td>Summary of number of kicks during each round and entire match</td>
<td>40</td>
</tr>
<tr>
<td>Tables</td>
<td>Page</td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>Table 1. Descriptive characteristics of subjects</td>
<td>26</td>
<td></td>
</tr>
</tbody>
</table>
Chapter One

Introduction

Tae Kwon Do was originally practiced in Korea. The first evidence for the practicing of Tae Kwon Do by the Koreans was dated almost 2000 years ago during the Koguryo dynasty. At present, this Korean national martial art is practiced in two forms, under two different organizing bodies. The more traditional form is under International Tae Kwon Do Federation (ITF) and includes both fighting and various crushing techniques and defensive martial arts. In contrast, the World Tae Kwon Do Federation (WTF) places stronger emphasis on sport performance (Heller, Peric, Dlouha, Kohlikova, Melichna & Novakova, 1998).

Tae Kwon Do gained acceptance as a demonstration event in the Olympic games of Seoul and Barcelona in 1988 and 1992 respectively and finally as a new official Olympic event in Sidney in 2000. Although in traditional Tae Kwon Do both hands and legs were used for self-defense reasons, the modern Tae Kwon Do has changed dramatically. Tae Kwon Do can be divided into three sub-divisions: Olympic style Tae Kwon Do which is mainly focused on competition drills, traditional style Tae Kwon Do which deals more with self defense techniques, and demonstration Tae Kwon Do solely focused on breaking objects such as wood, bricks and marble by performing kicking and punching drills. The fact that a demonstration of the breaking abilities is a part of the examination of the prospective trainee to advance into a higher grade has lead scientists to study the mechanics of this subdivision of the sport. Specifically, Cavanagh and Landa (1976) studied the arm and pelvic movements before striking a piece of wood.
Olympic style Tae Kwon Do has attracted the interest of scientists because research in this domain has immediate applications in high level athletes both for maximizing their performance and for reducing the possibility of injury. As a full contact sport, injury rates in Olympic style Tae Kwon Do are very high, especially in the lower extremities due to the excessive use of legs. Therefore, many prospective studies were conducted to reveal the frequency, the number and the type of injury that occurs during high level competitions in Olympic style Tae Kwon Do concluding that sprains and head concussions are the most common injuries among the athletes (Kazemi & Pieter, 2004; Koh & Cassidy, 2004; Pieter & Zember, 1999; Serina & Lieu, 1991). Due to the current rules and regulations of the sport, the points one can achieve during an Olympic style Tae Kwon Do bout are solely by kicking. The forward round house kick is the fastest and one of the most powerful kicks used during an Olympic style Tae Kwon Do match, and therefore scientists tried to learn more about it by performing biomechanical analyses investigating the speed and the kinetic energy of this specific kick (Serina & Lieu, 1991). Typical values of speed and kinetic energy for spinning kicks were found to be 15 ms\(^{-1}\) and 200 Joules, respectively.

While the literature dealing with the biomechanical parameters of the sport appears to be rich, not much research exists regarding the physiology of the sport. Despite the fact that all disciplines of the Tae Kwon Do martial art are considered to be highly demanding for most muscle groups, relatively little is known about the energy demands of the event during competition. However, without knowledge of the metabolic and cardiovascular requirements of the sport, training cannot be suitably matched.
Several studies have investigated physiological responses during competitions in other types of combat sports such as kickboxing, wrestling and pencak silat (Aziz, Tan & Teh, 2002; Terbizan & Seljevoldt, 1996; Zabukovec & Tiidus, 1995). A major study in the field of Tae Kwon Do actually investigated the physiologic profile of a Tae Kwon Do athlete, but it did not address the Olympic Tae Kwon Do style (Heller et al., 1998).

Most of the studies were focused on the metabolic characteristics of a Tae Kwon Do exercise bout or a form that involved specific and predetermined movements (Glass, Reeg & Bierma 2002; Imamura, Yoshitaka, Nishimura, Nakazawa, Nishimura, & Shirota, 1999; Kim & Jin, 2001; Lee, 1997; Liu, Zhang & Li, 2000; Melhim, 2001, Toskobic, Blessing & Williford, 2002). However, none of the above studies have explicitly investigated the acute physiological response during Olympic style Tae Kwon Do competition. Therefore, the purpose of this study is to profile the acute physiological responses of Olympic style Tae Kwon Do athletes during an actual match. This profile will include measurement of the oxygen uptake (VO$_2$), heart rate (HR), blood lactate concentration (BL), rate of perceived exertion (RPE), and body temperature. This information may provide insight into the training needs of Olympic style Tae Kwon Do athletes.
Chapter Two

Purpose

The aim of this investigation was to examine the physiological demands of a match in Olympic style Tae Kwon Do. Physiological assessment included measurement of oxygen uptake ($V_O^2$), heart rate (HR), blood lactate concentration (BL), rate of perceived exertion (RPE), and body temperature. The assessment of these variables provided adequate information to profile the physiological needs of the match.

Hypotheses

The following hypotheses were tested:

1) Oxygen uptake, heart rate and blood lactate concentration recordings after the end of the third round would be significantly greater than the recordings after the end of the first and second round.

2) Rating of perceived exertion would be significantly related to the oxygen uptake and blood lactate concentration recordings at the end of each round.

Delimitations

The participants of this study were 7 males between the ages of 19-27 years involved with Olympic style Tae Kwon Do and had the rank of black belt. Participants were free from cardiovascular risks and musculoskeletal problems. Data collection took place in the gymnastics room in the School of Health, Physical Education and Recreation at the University of Nebraska at Omaha. The subjects played a three minute, three round match with a one minute break between the first and second round.
Limitations

The following limitations applied to this study:

1) The subjects were asked to play as normally as they would during an actual competition. However, this could not be quantified and therefore there was subjectivity regarding the effort exerted.

2) The ability to properly perform their fighting bouts while wearing the portable gas exchange telemetry device. This may have altered the dynamics and kinematics of the movement.

3) Participants were aware that they only had to compete once per day. This may have caused them to push themselves harder during the match. Had the participants known that they had to compete more times during the same day, results may have been different.

4) The small sample size resulted in a low power of the present study which limited the ability to generalize from the results of the study.

5) Although the environment and atmosphere in which the matches took place were designed to give the impression and feeling of a real competition, several parameters were lacking. Firstly, despite the fact that audience was present during the day the matches took place, the number was very small (10-15 spectators) and not representative of the number of the spectators during a real competition. Also, although one judge was utilized in order to count the points and provide the players with feedback, three judges are used during a real Olympic Tae Kwon Do match.
Definitions

The following terms are defined below to clarify reading:

**Tae Kwon Do (TKD):** the mental training and the techniques of unarmed combat for self-defense as well as health, involving the skilled application of punches, kicks, blocks, and dodges with bare hands and feet to the rapid destruction of the moving opponent or opponents. “Tae” stands for jumping or flying, to kick or smash with the foot. “Kwon” denotes the fist-chiefly to punch or destroy with the hand or fist. “Do” means an art or the right way.

**Tae Kwon Do Forms:** A known - predetermined pattern of movement with alternating kicks and punches.

**Oxygen Uptake (VO₂):** the ability to extract oxygen from the atmosphere via the respiratory system and transport it in the blood to the working tissues (muscles) for energy. The highest rate at which oxygen is consumed is termed the maximal oxygen consumption (VO₂max).

Portable gas exchange telemetry system: a high technology portable device that allows remote data acquisition of the exchange of carbon dioxide and oxygen.

**Lactate threshold:** the point during increasingly intensive exercise at which blood lactate begins to accumulate above resting levels.

**Rate of perceived exertion (RPE):** a scale of 6-20 that gives a quantitative identification of the feeling of fatigue. It indicates a subjective sensation of effort.

**Respiratory exchange ratio (RER):** VCO₂/VO₂. RER provides an indication of the type of molecules (either carbohydrates or fats) which are being used to fuel the body.
During pure carbohydrate metabolism, there is an equal amount of CO2 produced for the O2 consumed (RER = 1). During fat metabolism, there is less amount of CO2 produced for the O2 consumed.

**Metabolic equivalent (MET):** A physiological concept that represents a simple procedure for expressing energy cost of physical activities as multiples of resting metabolic rate (RMR). This unit is used to estimate the amount of oxygen used by the body during physical activity. 1 MET is equivalent to resting oxygen consumption (3.5 ml/kg/min).

**Significance**

Little redundant work regarding the metabolic demands during Olympic style Tae Kwon Do competition has been done before. The quantification of the energy demands of an actual Tae Kwon Do match play as well as how an Olympic style Tae Kwon Do match affects perception of effort, will provide insight about proper sport specific conditioning based on the actual demands of the sport. Knowledge of the sport-specific physiology may improve how fitness coaches plan the conditioning of Olympic style Tae Kwon Do athletes.

Also, the magnitude of the results will provide an indication as to how Olympic style Tae Kwon Do compares to other combat sports and activities and whether it meets the minimum ACSM requirements for the development of cardiovascular fitness (American College of Sports Medicine, 1998).
Chapter Three

Review of Literature

The sport of Tae Kwon Do has been examined in a number of different areas. Researchers in the field of biomechanics, psychology, physical therapy and physiology have adopted several techniques to study this sport utilizing simple field techniques and more complicated laboratory tools. Attempts have also been made to validate the instruments used to collect data insuring that the results obtained would be due to real differences rather than measurement error. To organize this review and analysis, the literature has been classified in three categories. The first category consists of descriptive studies that deal with the chronic effects of anaerobic and aerobic sports. The second topic includes studies that deal with the acute effects of anaerobic and aerobic sports, and the third category consists of studies that deal with the most common injuries that occur during Olympic style Tae Kwon Do matches.

Chronic effects of anaerobic/aerobic sports

A pioneer study by Pieter, Taaffe, and Heijmans (1990) investigated and compared the cardiorespiratory effect between two different basic Tae Kwon Do forms as well as two series of combinations. The two combinations as well as the two forms differed in content, with the first one involving only kicking techniques and the second one involving both kicking and punching techniques. For this study, seven male students from a Tae Kwon Do class at the University of Oregon with a mean age of 21.1 years and a mean experience of 31.3 months were recruited. Each subject had to repeat every form 15 times with a 45 second rest interval between trials. For the series of combination I,
subjects had to perform a front kick and a side kick, a front kick and a roundhouse kick, a roundhouse-roundhouse kick, a side kick-back kick and a roundhouse-back kick with both legs. On the other hand, for combination II each subject had to perform a front kick, two punches and a side kick, front kick, two punches and a roundhouse kick, two punches, a side kick and a back kick, two punches, a roundhouse kick and a back kick. After each cycle (for both combinations), subjects started from the beginning followed by a one minute resting interval. During the last 10 seconds of each trial, HR and resting interval were recorded as a measure of exercise and recovery. The results showed no significant differences between the two forms; the same exercise HR was recorded no matter if the form was executed ten or fifteen times. However, significant differences occurred among HR during the work and rest intervals. Specifically, the exercise HR was significantly higher than the one recorded for recovery with a recording of 159.8 b/min exercise HR for form I versus 126.9 b/min for form II. Significant differences were also found between both combinations were compared to forms with the exercise HR for combinations being higher (p<.05) than those for the forms and that combinations resulted in a 90-91% of the age-predicted HR max.

A similar study performed by Kim and Jin (2001) also revealed that Tae Kwon Do practice can significantly improve cardiovascular functioning in healthy young males. The study involved 17 Tae Kwon Do black-belt men who completed separately two Tae Kwon Do forms, a 15 minute run on a treadmill test and a submaximal exercise test on a cycle ergometer. Exercise HR for Tae Kwon Do practice, running and the cycle test were found to be approximately 80% of the age-predicted HR max and close to 70 % of VO2
max. Specifically, mean HR for form one and two was 153.1 and 156.2 b/min, respectively whereas for running and submaximal cycle test were 157.2 and 157 b/min, respectively.

High cardiopulmonary stress was also reported by Glass, Reeg, and Bierma (2002) indicating that the high HR and VO\(_2\) recordings during Tae Kwon Do training reveals a unique opportunity for both fit and unfit individuals to participate. Researchers recruited 18 novice Tae Kwon Do practitioners with mean age of 19.3 ± 2.1 years and determined their caloric cost and cardiovascular responses to a typical sequence of Tae Kwon Do training. Following a similar fashion as the studies mentioned previously, each subject had to perform twice a sequence of techniques that involved 12 front kicks against a pad, 30 seconds of butterfly stretch, 12 forearm strikes against a pad, 30 seconds of crunch sit-ups, 12 rear leg sidekicks against a pad, 15 seconds of quadriceps stretch and 30 seconds of pushups. The method of indirect calorimetry and the non-protein RER revealed a mean total caloric expenditure of 78.5 ± 28.9 Kcal for men and a 43.4 ± 15.8 for women. Both groups exceeded 75% of their age predicted HR max for the exercise bouts as well as a 6 METS of intensity and an RER of 1.0. The mean HR and VO\(_2\) for men were 160 ± 14.7 bpm and 1.99 ± 0.7 L/min while for women were 154.8 ± 22.9 b/min and 1.3 ± 0.7 b/min, respectively. Women were found to expend fewer calories per minute and also significantly lower ventilatory response to exercise than men (p<0.05).

On the other hand, Imamura, Yoshimura, Nishimura, Nakazawa, Nishimura, and Shirota (1999) in a study they conducted on Karate using similar methodology, found different results than those presented above. Specifically, seven male black belt Karate
practitioners with a mean age of 21.3 years were involved in the study. The purpose of the investigation was to examine whether each exercise and an entire Karate training session can achieve accepted training intensity threshold for effective aerobic capacity training, energy expenditure thresholds and elevation in excess post-exercise oxygen consumption (EPOC). The mean percentage of the VO$_2$ max and HR for the whole session was 47.4 ± 5.9 and 72.6 ± 9.2, respectively.

Terbizan and Seljevold (1996) compared the physiological characteristics of young wrestlers grouped by age. A sample of 328 male wrestlers with a mean age of 16 years were recruited and tested on different physiological tests. Participants were divided into three groups according to their age (G1: 15 years or less, G2: 16 years and G3: 17 years of age and above). Body composition was estimated by both hydrostatic weighing and skinfold measurement; grip strength and muscular endurance were measured using handgrip dynamometer and maximum sit-ups, pushups and bench press in 30 seconds respectively, and flexibility was assessed using the sit and reach, shoulder lift and trunk extension test. Regarding aerobic and anaerobic capacity, participants performed the 1.5 mile run and the 30 second anaerobic Wingate test. Psychomotor skills of each athlete were also assessed using reaction time tests. Finally balance and agility were measured using the stick test and the side step set respectively. The results revealed that aerobic power was not significantly different among the groups. However, significant differences were reported in grip strength with the group 1 having an average score of 41.9 kg where athletes from groups 2 and 3 had 46.9 kg and 47.6 respectively. The same pattern was repeated when assessment of muscular endurance took place. Group1 completed
significantly fewer bench press repetitions and group 2 fewer repetitions than group 3. In respect to flexibility and anaerobic measurements (when covaried for weight and fat free weight), no significant differences occurred. Finally, reaction time, balance and agility were not significantly different between the groups.

Following a similar methodology, Neumayr, Hoertnagl, Pfister, Koller, Eibl and Raas (2003) investigated the physical and physiological factors associated with success in professional alpine skiing. The study examined 20 female and 28 male ski athletes pre and post-seasonally with respect to aerobic power, muscle strength and racing performance. Participants were separated according to the different disciplines of the sport (down hill, super giant, giant slalom, and slalom). The findings suggested that the physical variables did not significantly differ over the seasons. However, significant increases in aerobic power for both groups were recorded with the females having a 16% increase in the maximum power output in just one year (Wmax = 3.7 [1997] to 4.3 W/kg [1998]) and the males a 12% increase over two seasons (Wmax = 4.2 [1997] to 4.7 W/kg [1999], p<0.001). As far as the muscle strength is concerned, significant differences were only gender specific with the females having achieved about 60% of the male values for peak torque. No differences between right and left leg and development over the season within each group were reported.

Rannou, Prioux, Zouhal, Gratas-Delamarche and Delamarche (2001) found that national handball players had a VO₂ max of 57.7 + 3.1 ml/kg/min while international handball players and sprint trained athletes reported VO₂ max scores of 58.7 + 0.9 and 60.2 + 1.1 ml/kg/min, respectively. These results were obtained by a sample of 46
handball players aged between 19-28 years. Interestingly, a similar VO$_2$ max of 44.1 + 1.3 ml/kg/min was recorded by Bunc and Psotta (2001) when they investigated the physiological profile of young soccer players.

**Acute effects of anaerobic/aerobic sports**

The acute physiological responses of an Olympic style Tae Kwon Do bout is a topic that still needs further scientific investigation as not much evidence exists to explicitly depict the physiological profile of an Olympic style Tae Kwon Do athlete. However, a study by Toskovic, Blessing and Williford (2002) comparing the acute cardiovascular and metabolic effects of novice and experienced men and women participants during a single bout of dynamic Olympic style Tae Kwon Do exercise appears to be innovative in the field. A total of 28 men and women were assigned into four groups: novice Olympic style Tae Kwon Do men (MN), experienced Olympic style Tae Kwon Do men (ME), novice Olympic style Tae Kwon Do women (FN), and experienced Olympic style Tae Kwon Do women (FE). Initially, percent body fat and maximum oxygen uptake were measured, and then a 20 minute dynamic Olympic style Tae Kwon Do exercise session of basic punches, kicks, jumping, kicks, steps and stances were performed. The results showed no significant differences between groups in HR and % HR max responses to the dynamic Olympic style Tae Kwon Do exercise. The highest intensity recorded was for male novice group and it was 72 + 6.0 % VO$_2$ max. A moderate to heavy response to RPE was reported rating the difficulty of their exercise. Relative energy expenditures revealed a significant gender effect ($p< 0.001$) indicating that men consumed more energy than women. Specifically, the 20 minute bout required
approximately 316.5 + 61.0 Kcal for male novice group, 286.5 + 35.6 Kcal for male experienced group, 194.8 + 20.1 Kcal for female novice group and 201.6 + 39.1 Kcal for female experienced group. The results indicated that this form of exercise can develop and maintain cardiovascular fitness in healthy adults.

Acute aerobic and anaerobic power responses to the practice of Olympic style Tae Kwon Do were investigated by Melhim (2001) who recruited 19 Olympic style Tae Kwon Do practitioners with a mean of 10.4 months of Olympic style Tae Kwon Do training experience. Specifically, resting HR, aerobic and anaerobic power as well as anaerobic capacity were measured. Significant differences in anaerobic power and anaerobic capacity were observed (p = 0.05) with 28% and 61.5% increases in anaerobic power and capacity, respectively. Results suggested that the practice of Olympic style Tae Kwon Do can promote anaerobic power and anaerobic capacity but not aerobic capacity in healthy male adolescents.

In a similar study by Heller et al. (1998) the physiological profile of both male and female Tae Kwon Do black belt athletes that practiced the traditional form of Tae Kwon Do (ITF) was investigated. For that study, 23 black belt Czech Tae Kwon Do athletes with an age range of 16-23 years and a training history of 4-6 years participated. The subjects underwent a number of physiological and kinanthropometric tests such as pulmonary function, flexibility, vertical jump, muscular strength, reaction time, anaerobic test, aerobic test and BL concentration test to establish a data base. Following the baseline testing, a field testing of an actual two minute – two round Tae Kwon Do match took place. During the match, measurements of BL, HR and a time motion analysis were
performed. The results revealed that on average only 17-18% of the total time corresponded to contact fighting, and another 57% and 50% for the first and second rounds, respectively was spent in non-contact fighting activities. The activity during the fight was shown to be intermittent, with 3-5 s bouts of maximum exercise with low intensity periods alternating at an average ratio ranging from 1:3 to 1:4 indicating indirectly the athlete’s reliance on the ATP-CP system for energy production. BL concentration increased significantly (p<0.05) to a mean of 11.6 + 0.8, corresponding to 81% of the highest values found during a maximum laboratory anaerobic test, while HR during fight was close to maximum.

The metabolic cost and acute aerobic and anaerobic responses of karate fighting were investigated by Beneke, Beyer, Jachner, Erasmus and Hutler (2004). For the purposes of the study 10 male nationally and internationally ranked karate athletes were recruited and engaged in two to four fights scheduled and judged as in a real championship match. A portable spirometric device was used to measure VO\textsubscript{2} continuously and BL was determined immediately before and minute by minute after each fight. A total of 36 fights were analyzed with the referee’s decisions to cause an activity ratio of about 2:1. The results revealed a high metabolic rate in karate fights with fractions of aerobic energy to be 77.8 %. Anaerobic alactic and lactic energy sources were calculated to be 16.0% and 6.2% respectively, implying that aerobic metabolism is the predominant source of energy, and there is anaerobic supplementation mainly by high-energy phosphates.
Another study by Imamura, Yoshimura, Nishimura, Nishimura and Sakamoto (2003), investigated the VO₂, HR and BL responses during 1,000 punches and 1,000 kicks in collegiate karate practitioners. Six female black belt athletes participated in the study and performed 1,000 punches and 1,000 kicks with alternating arms and legs in the parallel stance in which the feet were shoulder width apart. The results revealed for 1,000 punches a mean VO₂ of 406 + 39 ml/min corresponding to 17.1 + 4.1% of VO₂ max and a mean HR of 108.2 + 13 bpm corresponding to 57.1 + 6.2% of HR max. Mean VO₂ for 1,000 kicks was 941 + 173 ml/min corresponding to 41.1 + 8.8% of VO₂ max and mean HR was 156.6 + 12 bpm corresponding to 82.7 + 5.8% of HR max. The RPE and BL responses immediately after performing 1,000 punches were 11.3 + 0.8 and 1.0 + 0.4 mmol/L and after 1,000 kicks were 15.7 + 1.0 and 3.0 + 0.9 mmol/L respectively.

A descriptive study by Zabukovec and Tiidus (1995) involved elite kickboxers and investigated their physiological response to a maximum aerobic power test, anaerobic Wingate test and a Cybex knee extension peak torque test. Also, anthropometric evaluation and somatotype determination was performed as well. A total of four elite professional kickboxers were recruited for the study with an average age of 27 years and average kickboxing experience of 7 years. The results revealed that elite kickboxers had a mean body fat content of 8.1% and were rated as mesomedial body types. Their mean VO₂ max was 62.7 ml/kg/min reflecting the relatively intense nature of their training. The mean anaerobic capacity reported was 10.5 W/kg and the mean peak anaerobic power found to be 18.8 W/kg values that ranked them above the 95th percentile for the general male population of similar age. Finally, the mean absolute knee extension (180°/sec)
peak torque values reported in this study was 168 Nm reflecting the importance of kicking power in this sport.

A similar descriptive study was conducted by Aziz, Tan and Teh (2002) investigating the physiological responses during competitive matches and profile of thirty elite pencak silat practitioners. An actual competitive duel was simulated were HR was monitored throughout the match. Capillary BL concentration was measured before the match and at the end of every round. Anthropometry, vertical jump, isometric grip strength, VO₂ max and the Wingate 30 s anaerobic test were performed to determine the physiological characteristics of the participants. The results showed an 84 % of the estimated HR maximum response after the match. BL levels ranged from 6.7 to 18.7 mmol/L during the match suggesting that competitive pencak silat matches were characterized by both high aerobic and anaerobic responses.

**Injuries in Olympic style Tae Kwon Do**

A prospective study by Kazemi and Pieter (2004), in which the authors identified and compared the injury rates in male and female adult Canadian Olympic style Tae Kwon Do athletes relative to total number of injuries, type and body part injured. Specifically, injury data from 219 male and 99 female participants of Canadian national Olympic style Tae Kwon Do championships in Toronto with a mean age of 24.2 years for males and 21 years for females were documented describing the athlete, nature, site, severity and mechanism of the injury. The results showed that lower extremities were the most commonly injured body region in the men (32/1000 athlete exposures) where the face and the spine followed with a ratio of 18.3/1000 and 13.8/1000 athlete exposures,
respectively. Interestingly, all of the injuries for the female participants were recorded to
the lower extremities with the foot sustaining most of the injuries (15.2/1000).
Specifically, for the male athletes the top five injuries were the sprain (22.8/1000), joint
dysfunction, contusion and strain with a ratio of (13.7/1000, 11.4/1000 and 9.1/1000),
respectively. The authors concluded that lower extremities were more susceptible to
injuries due to the more frequent use of the legs during an Olympic style Tae Kwon Do
match especially during the delivery or the receiving of a kick.

Similarly, a prospective study by Pieter and Zember (1997) that reported the
injury rates in children participating in Olympic style Tae Kwon Do competition also
revealed that lower extremities was the most commonly injured body part (21.83/1000).
A sample of 3,341 boys and 917 girls was involved in the study, and their data were
collected using check-off forms that described the athlete, nature and severity of injury.

Interestingly, a similar study by the same researchers (Pieter & Zember, 1999)
reported that the head was the most often injured body part both in boys and girls
(6.10/1000 and 4.55/1000, respectively) whereas contusion was the most often occurring
injury type for both boys (8.41/1000) and girls (7.80/1000). However, in this study a
significant difference between the two genders appeared regarding the total number of
incidents recorded. Finally, receiving a blow was stated as the major injury mechanism
with 20.93/1000 recorded incidents for boys and 16.25 for girls.

The above finding was supported by a study by Serina and Lieu (1991), in which
the injury potential of Olympic style Tae Kwon Do kick on thorax was investigated. The
authors concluded that kick with an initial spin could cause greater injury than kicks
without recording higher values of maximum thoracic compression and peak viscous
tolerance. Specifically, thrust kicks were found to compress the chest 30-40% more than
swing kicks but 80-90% of the peak viscous tolerance values of that of the swing kicks.
For the purposes of this study, three male black belt athletes agreed to participate. Each
subject had to perform three trials per kick (rear roundhouse, spin roundhouse, step aside
and back kicks) to a target paddle and then break a pine board.

Head blows and concussion incidents were found to be very frequent during
interviewed a total of 2328 competitors after the match, and the results showed that 226
of every 1000 athletes had been exposed to head blows and 50 of every 1000 had
experienced concussions. These results suggest that blocking skills should increase for
minimizing the occurrence of such incidences.

In a similar study, Roh and Watkinson (2002) investigated the fighting conditions
under which blows to the head commonly take place. A retrospective videotape analysis
of 48 matches at the 14th World Olympic style Tae Kwon Do Championships in 1999
was performed. Analyses of the situation that led up to and followed a head blow in 64
athletes as well as the frequency they occurred were performed. A total of 35 incidents of
head blow occurred, and all of these head blows were associated with a direct head or
face contact after an attacker's offensive kick, and head-blow-receiver's offensive action
with absence of a blocking skill.
Summary

Olympic style Tae Kwon Do training can achieve accepted training intensity threshold for effective aerobic capacity training, energy expenditure thresholds and elevation in excess post-exercise oxygen consumption. A long term systematic practice of the sport can produce significant cardiopulmonary strain indicating high HR and VO$_2$ recordings revealing a unique opportunity for both fit and unfit individuals to participate.

On the other hand, a single bout or Olympic style Tae Kwon Do training can also be a safe solution for people who are trying to regulate their body weight since a 20 minute bout requires approximately $316.5 + 61.0$ Kcal for male novices and $194.8 + 20.1$ Kcal for female novices. The high intermittent 3-5 seconds with maximum intensity nature of the sport suggest that the reliance of the Olympic style Tae Kwon Do athlete on the ATP-CP energy system is great. Therefore, BL concentrations are increased during a single Olympic style Tae Kwon Do bout.

Due to the current rules and regulations of the sport, the points one can achieve during an Olympic style Tae Kwon Do bout are solely by kicking. Therefore, the injury rates during an Olympic style Tae Kwon Do competition are very high especially those that involved the lower extremities. Sprains are the most common injury that occurs in such competitions with the head blows and concussions to be the most serious ones. These results suggest that an improvement of the blocking skills and abilities of Olympic style Tae Kwon Do athletes should be of primary importance in order to minimize the occurrence of such incidences.
Chapter Four

Methods

Subjects

Seven male subjects between the ages of 19-27 years were asked to volunteer to participate in the current study. The subjects had the minimum rank of black belt. All subjects were free from any known cardiovascular, pulmonary or metabolic diseases and any musculoskeletal injuries. All participants were also required to sign an informed consent that was approved by the Institutional Review Board prior to participation.

Design

After completing the informed consent process and prior to any data collection session, each subject was matched by weight. Participants were asked to visit UNO HPER Building a total of three times.

On the first visit preliminary testing was performed on the participants to measure their anthropometric and metabolic profiles. These tests were conducted in the Exercise Physiology Laboratory and Indoor Track facility at the UNO HPER Building, respectively, several days before the field testing. In advance, each subject was asked to avoid having high intensity and/or volume of physical activities within 24 hours before the participation. After the confirmation of age, the subject’s height (cm) and body weight (kg) were measured by a medical scale with stadiometer. The subject’s skinfold thickness was measured at three sites with a skinfold caliper based on a specific standardized procedure (American College of Sports Medicine guidelines). Finally, the
subject’s percent body fat (%) was calculated using a generalized equation (the Jackson-Pollock equations).

Then, each subject was asked to move to the upper level of the building and engage into a 1.5 mile run test. The 1.5 mile run protocol consisted of a total of 15 consecutive laps. Throughout the protocol, the investigator observed the subject’s lap time with a stopwatch. The protocol was continued until the completion of the 15 laps. Immediately after termination, HR (bpm) and RPE were measured and the time needed to complete the test was recorded. Then, the experimental equipment was removed from the subject’s body and 5 minute cooldown was performed at a self-selected speed. The VO\(_2\) max (ml/kg/min) was estimated via a 1.5 mile run test equation. Each preliminary testing was designed to take about 45 minutes.

On the second and third visit, field testing was performed at the Rock Climbing Room located in the HPER Building within several days after the preliminary testing to assess the physiological demands of an actual Olympic style Tae Kwon Do match. The mat in that room was similar to the type and material of the actual mat used during international and Olympic style Tae Kwon Do meetings. One participant of each paired group was randomly assigned to act as a monitored subject. Both the monitored subject and the non-monitored subject performed an 11 minute Tae Kwon Do match. Each match was designed and administered in the same way as a real match (three minutes per round – three round match play with one minute recovery following the first and second round) including the participation of crowd, a judge and a referee. Also, during the game a record of the total number of kicks performed in each round by the monitored subject,
was taken. Before the match both participants were asked to mimic real competition as much as possible. Only a single measurement for one subject was executed in each match. Each match was designed to take about 45 minutes. Up to three matches were performed in a day. In advance, both monitored subject and non-monitored subject were asked to avoid having high intensity and/or volume of physical activities within 24 hours before the participation.

After performing 10 to 15 minutes of moderate intensity warm-up including running, hopping and stretching the major muscles, a portable metabolic system (MedGraphics VO2000 portable metabolic measurement system; Medical Graphics Corp., St.Paou, MN) and its accessory components, including a flexible face mask, a pneumotach, an umbilical cord, and a battery unit, were fitted on the subject’s body to collect the subject’s VO$_2$ (ml/kg/min) and HR (bpm) every 10 seconds during the protocol. A standardized procedure was used for the fitting (Figure 1 and Figure 2). Then the subject was asked to resume warm-up for about 5 minutes while wearing the instruments.

![Figure 1. Side view of portable system](image1.png)
![Figure 2. Rear view of portable system](image2.png)
After the completion of the second warm-up, the monitored subject returned to the court and the match was initiated. After the completion of the match, the system was connected to the computer and the stored data were downloaded. From the data collected, VO$_2$ (ml/kg/min) and HR (bpm) was identified for every 10 seconds. During the match HR and VO$_2$ were monitored continuously, where BL concentration and body temperature was recorded before, after each round and at the end of the match. RPE was measured after each round and at the end of the match.

**Data Collection**

All data collection took place at the University of Nebraska at Omaha in the HPER Building. During the first visit data were collected in the Exercise Physiology lab and Indoor Track facility. The track was measured to cover a one mile distance in ten laps. The subject was asked to wear a HR monitor (Polar S610i Heart Rate Monitor; Polar Electro Oy, Kempele, Finland) on his/her right wrist and a heart rate transmitter (Polar T61 Coded Transmitter; Polar Electro Oy) on the chest underneath his/her shirt to measure the subject’s resting HR (bpm). A 10 minute warm-up at a self selected walk/jog took place before the commencement of the test.

During the second and third visits, measurements of VO$_2$, BL concentration, RPE and body temperature took place.

A finger stick was done for measuring BL concentration using an Accusport Portable Lactate Analyzer (Indianapolis, IN). A lancet was used to puncture the skin. The first drop of blood was wiped away, and the second drop was drawn into a pipette in order to avoid contamination by sweat. The first sampling was performed right before the
beginning of the match. Then, blood samplings RPE and body temperature measurements were conducted during designed one-minute intervals following a three minute round. The final blood sampling RPE and body temperature measurement was performed immediately after the completion of the match. RPE was measured using the 6-20 rating Borg scale of exhaustion (Appendix C). After the completion of the match, the monitored subject had to fill out a questionnaire pertaining to the effort they put and the motivation they had throughout the match (Appendix D).

Data analysis

Descriptive statistics (M + SD) were calculated for each variable measured (VO2, BL, RPE, body temperature and kicking frequency). One way analysis of variance for repeated measures (ANOVA) incorporating each round of the match was used for every measure of each variable. A Tukey post hoc testing was done when F ratios were found to be significant. A Pearson r was calculated to show how RPE related to each physiologic variable. The alpha level was set at P < 0.05.
Chapter Five

Results

The seven subjects who participated in the study were black belt athletes with experience in Olympic style Tae Kwon Do competition. They were lean and possessed a moderate level of aerobic fitness. The 1.5 mile run test revealed an estimated mean VO\textsubscript{2} max of 45.1 + 8.06 ml/kg/min with a mean run time of 11.40 + 2.06 min. VO\textsubscript{2} max was estimated by the following equation:

\[ VO_2 \text{ max} = 88.2 - 0.1656 \text{ body weight in kg} - 2.76 \text{ time in minutes} + 3.716 \]

(ACSM, 1998). Table 1 provides the mean and standard deviation of selected characteristics.

Table 1. Descriptive characteristics of subjects (M + SD; N = 7)

<table>
<thead>
<tr>
<th>Variable</th>
<th>M + SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>23.7 + 2.56</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>78.2 + 9.89</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>177.3 + 7.15</td>
</tr>
<tr>
<td>VO\textsubscript{2} max (ml/kg/min)</td>
<td>45.1 + 8.06</td>
</tr>
<tr>
<td>Body Fat (%)</td>
<td>10.9 + 3.74</td>
</tr>
</tbody>
</table>

Hypothesis 1a. VO\textsubscript{2} recordings after the end of the third round will be significantly greater than the recordings after the end of the first and second round.

VO\textsubscript{2} followed an increasing trend throughout the first round with a peak at the end of the second round followed by a drop during the third round. However, these fluctuations were not found to be significant and therefore the hypothesis was rejected. Figure 3
summarizes the mean VO$_2$ during each round. A more detailed representation of VO$_2$ response every 10 seconds provides better picture as to how VO$_2$ fluctuated during the whole game (Figure 4). The N for each 10 seconds data varied because of equipment malfunction and therefore the VO$_2$ values were different than shown in Figure 3.

Figure 3. Summary of VO$_2$ during each round and for entire match (M + SD)
Figure 4. Summary of mean VO$_2$ responses every 10 seconds of each round and match including the 1 minute rests between the rounds. The N size for each 10 seconds data varied because of equipment malfunction and therefore the VO$_2$ values are different than shown in Figure 3.

**Hypothesis 1b. HR recordings after the end of the third round will be significantly greater than the recordings after the end of the first and second round.**

HR recordings throughout the match followed an increasing trend with the third absolute values greater than first and second round. However, these differences in HR for each round were not high enough to be significant (p>0.05), and therefore the hypothesis was rejected. Figure 5 summarizes HR during each round.
Hypothesis 1c. BL concentration after the end of the third round will be significantly greater than the recordings after the end of the first and second round. BL measurements followed a similar pattern as the one for VO₂. During the second round BL accumulation was found to be higher than both the first and the third round but the differences were not significant (P>0.05). Consequently, the hypothesis was rejected. Figure 6 shows the BL response for each round.
To profile the physiological requirements of an Olympic style Tae Kwon Do match further descriptive information including RPE was obtained. RPE rose from round to round with the third round significantly higher than the mean of the first round (p< 0.05). Figure 7 depicts the trend of the RPE scores.
* Values are significantly different from each other (p< 0.05).

Figure 7. Summary of RPE during each round and the for the entire match (M + SD)

**Hypothesis 2. RPE will be significantly related to VO\textsubscript{2} and BL concentration.**

Pearson product moment correlation (one-tailed) was used to determine whether significant relations between these variables existed. Results revealed a significant correlation between mean RPE and mean BL during the first round. (r = 0.71, p<0.05) but not VO\textsubscript{2} (r = 0.25, p>0.05). However, RPE did not relate significantly with VO\textsubscript{2} or BL concentration during the other rounds. Therefore, the hypothesis was only partially supported by the data.
Chapter Six

Discussion

The main findings of the study indicate that across the three rounds (three minute per round) of the Olympic style Tae Kwon Do match, no significant difference existed for VO$_2$, HR and BL. However, differences were seen between the first and third round of the match when examining RPE. After the end of the third round RPE scores were significantly greater than the scores reported after the end of the first round.

VO$_2$ and HR

During the match, the mean VO$_2$ was 38.8 + 3.46 ml/kg/min corresponding to 85.9% of the subjects' estimated VO$_2$ max. This indicates a relatively high aerobic demand of the sport. No other studies have measured VO$_2$ during an actual competition as in the present study, and only traditional lab designed protocols were used to measure VO$_2$. A similar VO$_2$ of 38.2 + 7.8 ml/kg/min was found by Melhim (2001), during a series of predetermined Tae Kwon Do punching and kicking drills. Other studies incorporating similar protocols of Tae Kwon Do alternating continuous kicking and punching for 15-20 minutes revealed a mean VO$_2$ of 42.0 + 5.6 ml/kg/min (Toskovic, Blessing & Williford, 2002) just above the mean VO$_2$ max recorded during the Tae Kwon Do match in the present study. Interestingly, the highest 10 second peak VO$_2$ value of the match recorded during this study was 48.7 + 4.41 ml/kg/min accounting for a 107.95% of the VO$_2$ max as estimated from the 1.5 mile run test. This result may well be explained in part to the inability of a running test to accurately predict the maximum oxygen capacity of an Olympic style Tae Kwon Do athlete. The movement patterns and muscle
fibers recruited and trained are quite different than for running. Olympic style Tae Kwon
Do athletes are trained to become more efficient in explosive movements causing a sport
specific development of musculature in the trunk and the lower extremities. Therefore, a
running test to assess VO$_2$ max lacks specificity apparently resulting in a lower,
inaccurate score for aerobic fitness. However, this assumption is not supported by the
findings of Terbizan and Seljevoldt (1996). When they applied the same field test for
estimating VO$_2$ max in young wrestlers, they averaged a VO$_2$ max that ranged from 51
ml/kg/min to 53 ml/kg/min. However, no information regarding their type of training or
their familiarity with running mechanics was discussed.

Mean HR of the match during this study was 185.9 + 7.40 bpm corresponding to
94.7% of their age estimated HRmax, whereas mean HRmax of the match was 202.1 +
11.46 bpm corresponding to 103% of their age estimated HRmax. These findings indicate
that Olympic style Tae Kwon Do athletes perform at supramaximal intensity during an
actual competition. Heller et al. (1997) performed a field investigation similar to the one
of this study incorporating elite Tae Kwon Do athletes practicing the traditional form of
the sport (ITF). Specifically, video recordings of each subject were made during a
national elite competitive tournament (two rounds-two minutes each) performing time
motion analysis while HR was recorded every 5 seconds. Interestingly, during both first
and second round of the match HR values were close to the HRmax (184 + 6 and 186 + 7
bpm, respectively) supporting the results of the present study where HR was 182.0 + 7.68
and 186.6 + 6.10 bpm for the two respective rounds. In terms of HR responses, both
styles of Tae Kwon Do seem to result in similar HR responses at least for the first two
rounds. Karate sparring matches also seem to elicit similar mean HR responses (Imamura et al., 1996). In these matches a mean HR of 191.8 + 9.4 bpm, equivalent to 96.7 + 4.2% of HRmax, was recorded during 20 consecutive karate sparring matches each of 2 minutes duration. However, the duration of the protocol (20 matches x 2 min = 40 min) may have interacted with the intensity of the activity and explained in eliciting such high HR values. Twenty minutes of continuous Tae Kwon Do kicking and punching produced similar HR response of 89.9 + 5.8 % HRmax (Toskovic, Blessing & Williford, 2002) suggesting that isolated drills lasting 20 minutes may produce high HR responses. The present study elicited even higher HR responses with only a total of 9 minutes of exercise possibly because of the heightened intensity associated with competition rather than drills.

Tae Kwon Do forms are a predetermined pattern of movement involving both punching and kicking. They are an integral part of a basic training session and have been reported to cause a HR response of 160 bpm (Pieter, Taaffe & Heijmans, 1990). Although such an intensity can be beneficial in improving aerobic fitness for the untrained individual, these values are well below the maximal values reached during a real match as recorded from this study. Therefore, a competitive Olympic style Tae Kwon Do athlete may need to engage in some training at a match-specific intensity to optimize training.

From the analysis of the results of each athlete individually, it was observed that four of the seven participants met most of the accepted physiologic criteria for considering achieving VO2 max. These participants achieved a HR within 10 bpm of their estimated HR max, BL above 10 mmol/L, RPE >19 or 20 and RER > 1.10. The
other three participants achieved at least two of those four criteria. Because competition was 9 minutes duration, the findings reveal the high aerobic nature of the sport and the importance it has on Olympic style Tae Kwon Do performance.

The mean VO$_2$ of 38.8 ± 3.86 ml/kg/min during competition suggests that a relatively high aerobic capacity can be beneficial and possibly an important determinant of the ability to sustain perform at high intensity over all of the three rounds. Also, during national and international Olympic style Tae Kwon Do tournaments, an athlete may compete in six individual matches in a row with approximately half an hour break between each match to win first place indicating the importance of aerobic conditioning. A well trained aerobic capacity may facilitate maintaining a larger number of kicks over each round and thus increase the possibility of scoring more points. Also, aerobic training should accelerate resynthesis of phosphocreatine often bursts of high intensity within rounds and between rounds.

Finally, a more sport specific approach might be utilized in improving conditioning for Olympic style Tae Kwon Do. High interval training with short recoveries may be effective to increase sport specific aerobic fitness and develop the energy systems in a way that corresponds to work - rest ratios typical of a match.

RPE and BL

The most significant findings of RPE and BL were that the participants by the end of third round perceived fatigue to be greater than that of the first round (p < 0.05) and that BL explained 50.4 % of the RPE variance during the first round (r = 0.71, p< 0.05). The mean RPE for the match was 16.6 + 1.68 indicating that the participants perceived
the match to be "very hard". Surprisingly, during the second round of the match a significant negative correlation between RPE and HR was observed indicating that HR tended to drop while RPE increased ($r = -0.87$, $p<0.05$). Specifically, 76% of the variance of the participants’ RPE was explained by their HR values. Perhaps the inverse relationship can be explained by the fact that fatigue produced in the first round forced a reduction in work rate in the second round which produced a lower HR. Also, due to the small N of the study, such finding may have occurred because of sampling error.

Also the mean BL of the match was $14.46 \pm 4.17$ mmol/L with a mean maximum value of $16.8 \pm 5.56$ mmol/L. BL accumulation was strongly but negatively associated to VO$_2$ ($r = -0.97$, $p<0.01$) indicating that as VO$_2$ increased BL levels dropped. This too may be explained by the mounting fatigue and forced recruitment of additional muscle fibers. When these results in RPE and BL are compared to the ones recorded in a study by Imamura et al. (2003), an interesting comparison is derived. Specifically, an RPE of $15.7 \pm 1.0$ and a BL of $3.0 \pm 0.9$ mmol/L were recorded after 1,000 kicks performed by karate practitioners with a tempo of 1 kick per second, whereas during the present study a total of $81.1 \pm 20.38$ kicks were performed resulting in only about 8.9 kicks per minute or 0.15 kicks per second. However, both RPE and BL were still greater in the present study in which participants were engaged in a real competitive Olympic style Tae Kwon Do match. These differences perhaps may be explained due to the static nature of the single kicking protocol where participants had to perform the kicks in the same location on the mat. Also, the absence of an opponent and the dynamic nature of a real match seem to create a safer, less uncertain environment for the participants reducing the amplitude of
their physiological responses. These assumptions can be partially supported by the study of Imamura et al. (1996). When they simulated real karate sparring matches to investigate changes in RPE, they recorded a mean of 19.0 + 2 indicating that participants achieved near maximum effort. Although their protocol was long duration and continuous in fashion, the maximum results from RPE can be also attributed to the high intensity nature of the matches. However, a similar 20 minute continuous drill of Tae Kwon Do kicking and punching resulted in a mean RPE of only 13.1 + 1.4 (Tosovic, Blessing & Williford, 2002).

The high BL values obtained during the Olympic style Tae Kwon Do match revealed that the glycolytic system was heavily taxed during periods of match play. Specifically, BL values at the end of the first, second and third round were 12.4 + 3.97 mmol/L, 16.1 + 5.61 mmol/L and 14.9 + 4.09, respectively. Such results are in accordance with an earlier study by Heller et al, (1997) who found that at the end of the second round of an International Tae Kwon Do Federation (ITF) Tae Kwon Do match, BL values where 11.4 + 3.2 mmol/L. Although not many differences regarding the rules between ITF Tae Kwon Do style and World Tae Kwon Do Federation (WTF) Olympic style Tae Kwon Do exist during a real competition, the fact that the referee has to stop the play every time a point is scored in ITF style could affect the BL values. Athletes with higher aerobic capacity could faster oxidize lactate causing a drop in their blood levels (McArdle, Katch & Katch, 2004). Consequently, BL may be higher in Tae Kwon Do athletes who compete in the Olympic style rather than the traditional style of the sport.
In general, male Olympic style Tae Kwon Do athletes in the present study produced higher BL concentrations than other individual sports that considered anaerobic in nature. Smekal et al. (2000) reported a mean BL of 2.1 + 0.88 mmol/L during a tennis match while others indicated a 12 + 1.6 mmol/L following a maximal aerobic test on a ergometer in professional alpine skiers (Neumayr et al., 2003) and a 4.2 + 1.9 mmol/L after a single karate match (Beneke et al., 2004).

**Body Temperature and Kicks**

Difference in body temperature across the rounds was assessed to better understand the thermal load imposed in Olympic style Tae Kwon Do athletes during a competition match. Body temperature rose about 0.4 degrees Fahrenheit from round to round (Figure 8). While not a large change, it suggests that Olympic style Tae Kwon Do athletes exposed to a series of matches should be concerned with ingesting enough fluid to minimize heat illness or impaired performance. No data on body temperature has been reported elsewhere. During the first round of the match, body temperature revealed a positive correlation with the number of kicks performed ($r = 0.78$, $p<0.05$). During the second round, body temperature was significantly related with $VO_2$ ($r = -0.69$, $p<0.05$) indicating that $VO_2$ dropped as body temperature tended to increase. As with RPE, BL and HR, this suggests that the heat load increased across the match regardless of the actual $VO_2$ of a given round. The same trend was observed during the third round where the association between body temperature and $VO_2$ was $r = -0.77$ ($p<0.05$). Body temperature was also found to relate to BL ($r = 0.75$; $p<0.05$). This finding suggests
mounting fatigue and heat load from round one to round two. This is not surprising considering that only one minute separated rounds.

The most strenuous action of Olympic style Tae Kwon Do is the kick. Consequently, the number of kicks per round was counted to assist in gauging the intensity of each round. The number of kicks performed across rounds did not reveal any significant differences. A mean for the match of $27.0 \pm 6.78$ kicks per round was recorded revealing the relatively high kicking frequency during the game (Figure 9). RPE was significantly related to the number of kicks performed ($r = 0.72$, $p < 0.05$), revealing a tendency for the RPE to rise as the number of kicks performed increased. Specifically, the coefficient of determination showed that 52% of the variance of the participants’ RPE was explained by the total number of kicks they performed during this round.

Figure 8. Summary of body temperature during each round and for the entire match ($M \pm SD$).
Assessment of Effort During Match

A questionnaire consisting of five questions was given at the end of every match to each subject to assess their motivation and effort throughout the match and to evaluate how close to a real competition participants felt the match to be (see Appendix C). In the first question “how close was your performance effort during this match to real competition”, five of seven subjects felt that their performance effort was the same as a real competition whereas one thought his effort to be less and one believed it to be more than a real competition. When they were asked “what was the tactical strategy you
followed during this match”, five subjects said that they followed a defensive tactical strategy during the match whereas one subject followed an attacking strategy and one used a balanced attacking and defending strategy. In the question “how important was winning the match”, three subjects thought this to be important, one believed it was extremely important, one stated it was somewhat important, one very important and one rated it to be not important. Finally, for the last question “how much energy did you expend during the match you just completed”, five of the subjects felt that they expended the same energy as in a real competition whereas two answered somewhat more than in a real competition. The last two subjects explained that carrying the device and having to perform with it imposed a noticeable extra physical load. These two participants were the lightest and shortest ones (mean body weight = 65.1 kg and mean height =167.5 cm). Possibly, due to their small mass and height, wearing the portable metabolic device (device weight = 0.74 kg) may have imposed a more noticeable load.

**Comparison with ACSM Recommendations**

The results of this study indicate that engaging in a three round, three minutes per round Olympic style Tae Kwon Do match can satisfy the ACSM recommendations for quantity and quality of exercise for the development of cardiovascular fitness in healthy individuals (American College of Sports Medicine, 1998). According to the ACSM, a training intensity of 50% of VO2 max is considered to be the minimum threshold for cardiovascular exercise. In this study, all of the participants achieved and exceeded the recommended stimulus for effective initiation of cardiovascular adaptations and conditioning as expressed by the percentage of VO2 max (50 – 85%). The observed
exercise intensity during this study averaged 85.9% of VO2 max and was therefore above the recommended training zone.

Similarly, the Olympic style Tae Kwon Do match resulted in significant increases in exercise HR (Figure 4). On the basis of the exercise HR responses, all participants achieved the recommended stimulus for effective initiation of cardiovascular adaptations and conditioning as prescribed by the ACSM (60-90% maximal heart rate). The mean HR response during this study (94.7% of HR max) was well above the threshold (60%) for the cardiovascular training effect and therefore was within the recommended cardiovascular training zone.

Limitations

Probably the most significant limitation of the study is that participants had to perform their fighting bouts while wearing the portable gas exchange telemetry device. It is possible that this may have altered the dynamics and kinematics of the movement in a way that could affect their physiological response. For example, a definite limitation was the restriction the non-monitored subject had on kicking the face. Although such restriction ensured both the safety of the participant and the device, during a real Tae Kwon Do game both participants are free to kick the face. Moreover, the fact that a strike to the face is awarded with an additional point makes such restriction even more critical. For example, since winning was one of the objectives for both of the participants, not having the right to score a double point on the face may have caused an unfair advantage for the monitored subject who was the only one allowed to strike the face.
Also, the subjects were asked to play as normally as they would during an actual competition. However, this could not be controlled by the researcher. Nonetheless, mean RPE after the third round was significantly greater than the first round (18.4 + 1.81 vs 14.4 + 2.29, \( p < 0.05 \)) suggesting that participants followed the instructions and their effort increased from round to round.

The fact that participants were aware that they only had to compete once per day may have caused them to push themselves harder during the match. If participants knew that they had to compete more times during the same day, results may have been different.

Small sample size limits the ability to generalize from the results of the study. Fitness and conditioning level, preferred strategy (offensive or defensive), extent that subjects were matched with competitors of similar performance level, and other factors may all affect physiologic outcomes, and these effects may have magnified the mean responses with the small sample size.

Although the environment and atmosphere in which the matches took place were designed to give the impression and feeling of a real competition, several parameters were lacking. Firstly, despite the fact that an audience was present during the day the matches took place, the number was very small (10-15 spectators) and not representative of the number of the spectators during a real competition. Also, although one judge was utilized in order to count the points and provide the players with feedback, three judges are used during a real Olympic Tae Kwon Do match.

Despite the above-mentioned limitations, procedures were taken to minimize their deleterious effects. A certified referee, a time keeper, and a judge were used to create a
more realistic, competitive environment. The referee underwent all the formal procedures typically used in competition before initiation of each match making sure that participants were ready. The limited audience was encouraged to cheer and motivate the participants adding to the effort of having an atmosphere as realistic as possible.

**Practical Applications**

By conducting the study out of the lab and in the actual setting, a more realistic environment was created which hopefully provided more valid results. The design was chosen because to the author’s knowledge no research has studied the physiological responses of Olympic style Tae Kwon Do players during competition using a portable metabolic device. No other study has utilized this device for such a high impact sport.

An additional benefit of the design is it provides an approach that every Tae Kwon Do coach or enthusiast uses everyday for training purposes. Therefore, the design has high external validity because each athlete’s ultimate goal is to develop those characteristics that will maximize his performance during the match. Because of the design used, it is believed that the results have training implications for Olympic style Tae Kwon Do athletes. Tae Kwon Do coaches and athletes, by knowing the physiological responses imposed by competition, can more suitably match their training programs to develop and maximize their performance. The results clearly indicate the importance of aerobic power. Consequently, athletes and coaches might include greater emphasis on sport specific aerobic training via drills and sparring in order to optimize training. Secondly, the large blood lactate levels indicate the importance of muscular endurance. Lastly, although the difference in body temperature in a single match is not large, in
multiple matches and in training sessions adequate fluid replacement is probably important.
Chapter Seven

Summary, Conclusions, and Recommendations

The purpose of this study was to examine the physiological demands of a match play in Olympic style Tae Kwon Do. Physiological assessment included measurement of oxygen uptake (VO₂), heart rate (HR), blood lactate concentration (BL), rating of perceived exertion (RPE), and body temperature. The assessment of these variables provided information to profile the acute physiological responses to a match.

Subjects were seven black belt Olympic style Tae Kwon Do athletes between the ages of 19 and 27 years. VO₂ max was estimated from a 1.5 mile run test. Subjects engaged into a three round-three minutes per round Olympic style Tae Kwon Do competitive match in which they were asked to perform as they would during a real competition. To facilitate a competitive environment, one referee, one judge, and 10-15 spectators were incorporated during each match.

Across the three rounds, no physiologic differences existed for VO₂, HR, BL, body temperature and the number of kicks performed. However, RPE after the end of the third round was significantly greater than after the end of the first round. The mean VO₂ value for the match was 38.8 ± 3.46 ml/kg/min which corresponded to 85.9 % of VO₂ max. Mean heart rate was 185.9 ± 7.40 bpm which was equivalent to 94.7% of HRmax. Mean match blood lactate values were 14.46 ± 4.17 whereas mean RPE was 16.62 ± 1.68. Mean body temperature was 99.02 ± 0.96 degrees Fahrenheit and rose about 0.4 degrees Fahrenheit after each round. Mean kicking frequency was 27.02 ± 6.78 kicks corresponding to 8.9 kicks every minute.
Body fat estimated from the 3 skinfolds according to the Jackson and Pollock equation revealed an average body fat of 10.9 ± 3.74% indicating that these competitive Olympic style Tae Kwon Do participants are lean. This percentage of body fat was similar to the 12.7 ± 3.6% in experienced Tae Kwon Do athletes reported by Toskovic, Blessing and Williford (2002) but higher than the 8.1% and 8.4% of body fat in elite kickboxers and wrestlers reported by Terbizan and Seljevoldt (1996) and Zabukovec and Tiidus (1995), respectively.

In conclusion, Olympic style Tae Kwon Do competition taxes both the aerobic and anaerobic energy systems. The mean VO2 value for the match was 38.8 ± 3.46 which corresponded to 85.9% of VO2 max. Mean BL of 14.46 ± 4.17 was significantly correlated with mean RPE (r = 0.71) indicating an extensive involvement of anaerobic glycolysis suggesting that both aerobic and anaerobic training is needed for this sport.

Recommendations for further research in the area of Olympic style Tae Kwon Do include an additional investigation of the same variables utilizing more subjects. Assessing VO2 max via treadmill testing may not provide the highest values for Olympic style Tae Kwon Do athletes, so a sport-specific protocol maybe more accurate. In addition, a more controlled pre-game meal with exact nutritional guidelines before the match would ensure more control over results in some physiologic variables.
References


Appendix A

Informed Consent Form
THE ADULT CONSENT FORM

PHYSIOLOGICAL PROFILE OF OLYMPIC STYLE TAE KWON DO MATCH

INVITATION

You are invited to participate in this research study. The following information is provided to help you make an informed decision whether or not to participate. If you have any questions, please do not hesitate to ask.

WHY ARE YOU BEING ASKED TO BE IN THIS RESEARCH STUDY?

You are asked to participate in this study because you are between the ages of 19-35 years and have a rank of black belt in Olympic style Tae Kwon Do. You may participate if you are free from any known cardiovascular or metabolic diseases and any musculoskeletal injuries.

WHAT IS THE REASON FOR DOING THIS RESEARCH STUDY?

The purpose of this study is to determine to what extent and how energy systems are used for Olympic style Tae Kwon Do performance during a real Olympic style Tae Kwon Do match.

WHAT WILL BE DONE DURING THIS RESEARCH STUDY?

You will be asked to make a total of three visits to the Exercise Physiology Lab, Rock Climbing Room and Indoor Track facility at the University of Nebraska at Omaha. You will be asked to play a three minute per round-three round Olympic style Tae Kwon Do match twice over several days. The matches will be conducted at the UNO Rock Climbing Room and designed, in the same way as real Olympic style Tae Kwon Do matches including one minute rest between the first and second rounds and between second and third rounds.

During the first visit you will participate in the preliminary testing at the UNO Exercise Physiology Lab and Indoor Track facility. After filling out a medical history questionnaire and measuring your height and weight, skinfold thickness
will be measured at three sites of your body to estimate your body fatness. Then you will be asked to engage in a 1.5 mile run to estimate your baseline maximal aerobic power. The duration of the visit will be about 45 minutes.

During the second or third visit you will be randomly assigned to the role of 'monitored' or 'non-monitored' subject. Your role as the 'monitored' subject will be to wear a breathing mask and portable recording device during the (simulated) Olympic style Tae Kwon Do match. The breathing mask will be fixed on your face using four straps attached to the mask and the portable metabolic device will be stabilized on your back and covered with an elastic wrap and also with the chest protector itself. This portable device will measure the amount of oxygen your body uses every 10 seconds which provides information about your energy expenditure during the match. The match will consist of three rounds, each round being three minutes long, with one minute rest periods between the first and second, and between the second and third rounds. In the other match you will be assigned the role of 'non-monitored' subject.

Your responsibilities as 'monitored' and 'non-monitored' subject will be the same. In both situations you will be instructed to mimic real competition as much as possible. The kicking techniques and the attacking or defensive tactics that will be used during the match are absolutely your personal choice and decision. However, as a 'non-monitored' subject you will be instructed not to kick to the head of the 'monitored' subject. This will ensure increased safety for both the portable device and the "monitored" subject that will be wearing it.

You will be required to rest at least 24 hours between matches to allow for adequate recovery. If you will not be assigned as a 'monitored' subject you will still be asked to engage in a three minute per round-three round Tae Kwon Do match but with out having to wear the breathing mask and the portable metabolic device while playing. The duration of this visit will be about 45 minutes.

In advance, you will be asked to avoid having high intensity and/or volume of physical activities within 24 hours before the participation. Also, you will be asked not to eat for four hours prior to each testing to minimize stomach upset. You will also be asked to stay well hydrated the day before and the day of the match.

Prior to the start and during the one minute rest periods of each match blood lactate will be assessed via a finger stick blood draw. One drop of blood will be needed for each blood lactate assessment. You will be taken through a warm up and cool down before and after the match. For the warm-up you will be required to do 10 minutes of light aerobic activity at a self-selected pace (walking, or running). For the second part of the warm-up you will perform 5 minutes of
stretching the major muscles that will be involved during the match. You will then be given the amount of rest corresponding to the rest interval between each round of the match.

During the one minute intervals between the first and second rounds and between second and third rounds your rating of perceived exertion (RPE) and body temperature will be measured.

After completion of each match you will have another finger stick blood draw to measure the blood lactate content and another rating of perceived exertion (RPE) and body temperature will be measured. Then, you will be asked to complete a questionnaire indicating the amount of effort and intensity you experienced during the match. Then, 5 minutes of light walking followed by 5 minutes of stretching will be performed where you will be lead through a stretching routine where every major muscle group used in the training session will be stretched.

WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS YOU COULD EXPERIENCE DURING THIS RESEARCH STUDY?

Possible risks associated with an Olympic style Tae Kwon Do match include injuries to the muscles, ligaments, tendons, and joints to the body, ankle sprains, head blows, concussions, contusions, disorders of the heart rhythm, and very rare instances of heart attack, stroke, or even death. Possible risks and discomforts associated with a blood draw include pain and infection. It is possible that other rare side effects could occur which are not described in this consent form. It is also possible that you could have a side effect that has not occurred before.

Finger stick:
There may be minor pain associated with the needle stick. There is also a chance of bruising, fainting and a slight possibility of infection.

Warm up:
There may be a slight increase in body temperature, sweating and heart rate elevation due to initiation of activity.

Running on the track:
There may be some minor ankle and/or knee joint discomfort associated with the type of the floor surface and the reaction forces it produces.

Wearing the portable metabolic device:
There may be some discomfort associated with carrying the portable metabolic device during the match. However, there is a very limited possibility of facial lacerations or injury during the game as you will be instructed not to strike or kick to the head. Also, the portable metabolic device will be stabilized on your back.
and covered with a rubber band and also with the chest protector itself. Kicking the back of the subject is restricted by the rules of the game. However, the chest protector extends all the way to your back for safety purposes.

Kicking or striking the device:
Facial lacerations, bruises and/or bleeding may occur in the rare incident of an accidental kick or strike to the device.

WHAT ARE THE POSSIBLE BENEFITS TO YOU?

You will be informed of the level of blood lactate and oxygen uptake an Olympic style Tae Kwon Do match produced. Further, you will be informed on how difficult you and others perceived an Olympic style Tae Kwon Do match to be and what your body temperature and heart rate were. This information may be useful in terms of developing a sport specific exercise program that meets your exact physiological requirements during an Olympic style Tae Kwon Do match.

WHAT ARE THE POSSIBLE BENEFITS TO SOCIETY?

Society may benefit by learning more about how an Olympic Tae Kwon Do match affects perception of effort, as well as cardiorespiratory and blood lactate responses. Information from this study may be helpful in providing insight of proper sport specific conditioning based on the actual demands of the sport. Knowledge of the sport-specific physiology may improve how fitness coaches plan the conditioning of Olympic style Tae Kwon Do athletes.

WHAT ARE THE ALTERNATIVES TO PARTICIPATION?

The alternative to participation in this study is not to participate.

WHAT ARE YOUR FINANCIAL OBLIGATIONS?

You will not incur any financial obligations as a result of participating in this study.

WHAT ARE YOUR FINANCIAL COMPENSATIONS?

You will not receive financial compensation for participating in this study.

WHAT SHOULD YOU DO IN CASE OF AN EMERGENCY?

Your safety is the major concern of every member of the research team. If you are injured or have a medical problem as a result of being in this study, you
should immediately contact one of the people listed at the end of this consent form. Immediate emergency medical treatment for this injury will be available at the Nebraska Medical Center. There will be no charge to you for this care provided you have followed all instructions and medical advice and done nothing to cause or contribute to the injury. The costs for any other medical problems unrelated to this research study are your responsibility. There are no plans to provide payment for things like lost wages, disability or discomfort. Agreeing to this does not mean you have given up any of your legal rights.

HOW WILL INFORMATION ABOUT YOU BE PROTECTED?

You have rights regarding the privacy of your medical information collected before and during this research. This medical information, called "protected health information" (PHI), includes demographic information (like your address and birth date), the results of your exercise tests, as well as your medical history. You have the right to limit use and sharing of your PHI, and you have the right to see your exercise records and know who else is seeing them.

By signing this consent form, you are allowing the research team to have access to your PHI. The research team includes the investigators listed on this consent form and other personnel involved in this specific study at UNO.

Your PHI will be used only for the purpose(s) described in the section "What is the reason for doing this research study"?

Your PHI will be shared, as necessary, with the Institutional Review Board (IRB) and with any person or agency required by law. You are also allowing the research team to share your PHI with other people or groups listed below. All of these persons or groups are obligated to protect your PHI.

You are authorizing us to use and disclose your PHI for as long as the research study is being conducted. You may cancel this authorization to use and share your PHI at any time by contacting the principal investigator in writing. If you cancel this authorization, you may no longer participate in this research. If you cancel this authorization, use or sharing of future PHI will be stopped. The PHI which has already been collected may still be used.

The information from this study may be published in scientific journals or presented at scientific meetings but your identity will be kept strictly confidential.
WHAT ARE YOUR RIGHTS AS A RESEARCH SUBJECT?

You have rights as a research subject. These rights have been explained in this consent form and in "The Rights of Research Subjects" that you have been given. If you have any questions concerning your rights, talk to the investigator or call the Institutional Review Board (IRB), telephone (402) 559-6463.

WHAT WILL HAPPEN IF YOU DECIDE NOT TO BE IN THIS RESEARCH STUDY?

You can decide not to be in this research study. Deciding not to be in this research study will not affect your medical care or your relationship with the investigator, the University of Nebraska at Omaha or the Nebraska Medical Center. Your doctor will still take care of you and you will not lose any benefits to which you are entitled. If any new information develops during the course of this study that may affect your willingness to continue participating, you will be informed immediately.

WHAT WILL HAPPEN IF YOU DECIDE TO STOP PARTICIPATING ONCE YOU START?

You can stop being in this research study ("withdraw") at any time before, during, or after the study begins. Deciding to withdraw will otherwise not affect your care or your relationship with the investigator, the University of Nebraska at Omaha or the Nebraska Medical Center. You will not lose any benefits to which you are entitled.

DOCUMENTATION ON INFORMED CONSENT

YOU ARE FREELY MAKING A DECISION WHETHER TO BE IN THIS RESEARCH STUDY. SIGNING THIS FORM MEANS THAT (1) YOU HAVE READ AND UNDERSTOOD THIS CONSENT FORM, (2) YOU HAVE HAD THE CONSENT FORM EXPLAINED TO YOU, (3) YOU HAVE HAD YOUR QUESTIONS ANSWERED, AND (4) YOU HAVE DECIDED TO BE IN THE RESEARCH STUDY.

IF YOU HAVE ANY QUESTIONS DURING THE STUDY, YOU SHOULD TALK TO ONE OF THE INVESTIGATORS LISTED BELOW. YOU WILL BE GIVEN A COPY OF THIS CONSENT FORM TO KEEP.

Signature of Subject: Date: Time:
IRB#: 028-05-FB

MY SIGNATURE AS WITNESS CERTIFIES THAT THE PARTICIPANT SIGNED THIS CONSENT FORM IN MY PRESENCE AS HIS VOLUNTARY ACT AND DEED.

Signature of Witness: Date: Time:

I CERTIFY THAT ALL THE ELEMENTS OF INFORMED CONSENT DESCRIBED ON THIS CONSENT FORM HAVE BEEN FULLY EXPLAINED TO THE PARTICIPANT. IN MY JUDGEMENT, THE PARTICIPANT IS VOLUNTARILY AND KNOWLEDGEABLY GIVING INFORMED CONSENT AND POSSESESSES THE LEGAL CAPACITY TO GIVE INFORMED CONSENT TO PARTICIPATE IN THIS RESEARCH.

Signature of Investigator: Date: Time:

MY SIGNATURE CERTIFIES THAT I HAVE AUTHORIZED THE INVESTIGATOR SIGNING ABOVE TO DOCUMENT THE OBTAINMENT OF INFORMED CONSENT, AND HE/SHE HAS THE NECESSARY CLINICAL EXPERTISE, AND SUFFICIENT KNOWLEDGE ABOUT THE PROTOCOL AND IRB CONSENT REQUIREMENTS TO DOCUMENT OBTAINMENT OF CONSENT. IN MY JUDGEMENT, VALID INFORMED CONSENT HAS BEEN OBTAINED FROM THIS SUBJECT.

Signature of PI: Date: Time:

AUTHORIZED STUDY PERSONNEL

Principal Investigator

Georgios C. Korellis; BS
Graduate Student, School of HPER
University of Nebraska at Omaha
Day/Night Phone: 402-208-0476

Secondary Investigator

Kris Berg, EdD
Professor, School of HPER
University of Nebraska at Omaha
Phone: 402-554-2670
IRB#: 028-05-FB

Richard Latin, PhD Professor, School of HPER
University of Nebraska at Omaha
Phone: 402-554-2670

William Vincent, BS
Graduate Student, School of HPER
University of Nebraska at Omaha
Phone: 402-554-3221

Kenji Narazaki, BS
Graduate Student, School of HPER
University of Nebraska at Omaha
Phone: 402-554-3221

Chris Sjoberg, BS
Graduate Student, School of HPER
University of Nebraska at Omaha
Phone: 402-554-3221
Appendix B

Medical Questionnaire
Medical History Form

Date: ________________ Age: ________________
Name: __________________ Sex: ________________
Address: __________________ Weight (lbs.): __________
Employment: __________________ Height (inch): __________
Address: __________________
Phone: ____________________ (home)
Phone: ____________________ (work)
Name of Personal Physician: __________________
Address: __________________

Have you been hospitalized within the last two years? ________________
If yes, please explain:
___________________________________________________________
___________________________________________________________
___________________________________________________________

Check the following which have occurred in your past medical history:
Heart Attack __________ Epilepsy __________
High Blood Pressure __________ Asthma __________
Chest Discomfort __________ Emphysema __________
ECG Abnormality __________ Bronchitis __________
Stroke __________ Shortness of Breath __________
Obesity __________ Lightheadedness or
Unexplained Weight Gain __________ Fainting __________
or Loss __________ Heat Illness __________
Diabetes __________ Allergy __________
Arthritis, Bursitis, Gout __________ Other (explain) __________
or Joint Inflammation __________
List any medication(s) you are presently taking and condition(s) being treated.

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

List and describe any condition you have which may affect your ability to participate in strenuous physical activity.

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

Any family history of: (check if yes and indicate age of occurrence)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Age of Occurrence</th>
<th>Who (mother, father, sibling aunt, uncle, grandparents)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Death before age 60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heart disease</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High blood pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diabetes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stroke</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obesity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asthma</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emphysema</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Weight History (lbs.)
- High-school graduation: __________ One year ago __________
- Now: __________ Maximum ever __________
  When? __________

Smoking History
- Ever?: __________ Now?: __________
- What?: __________ How often?: __________
Physical Activity History
Describe any physical activities that you have participated in during the last 12 months.

<table>
<thead>
<tr>
<th>Activity involvement</th>
<th># of days</th>
<th># of minutes</th>
<th># of weeks or months</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Describe any physical activities that you have participated in during the last 6 weeks.

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix C

Borg Scale
Borg's 6-20 point scale for ratings of perceived exertion

6
7 Very, Very Light
8
9 Very Light
10
11 Fairly Light
12
13 Somewhat Hard
14
15 Hard
16
17 Very Hard
18
19 Very, Very Hard
20
Appendix D

Post-Match Questionnaire
POST-MATCH QUESTIONNAIRE

The following questionnaire intends to assess the effort and the motivation you showed during the match you have just participated in. Please try to answer each question as honestly and as accurately as possible. There are no correct or incorrect answers. The accuracy of each response will help provide a more meaningful and complete interpretation of your performance.

Please circle a number on each question that best describes your answer.

1. How close was your performance effort during this match to real competition?
   1) Far less than a real competition
   2) Less than a real competition
   3) The same as a real competition
   4) More than a real competition
   5) Far more than a real competition

2. What was the tactical strategy you followed during this match?
   1) Very defensive
   2) Defensive
   3) Balanced attacking and defending
   4) Attacking
   5) Very attacking

3. What is the typical strategy you follow during an actual competition?
   1) Very defensive
   2) Defensive
   3) Balanced attacking and defending
   4) Attacking
   5) Very attacking

4. How important was winning this match to you?
   1) Not important
   2) Somewhat important
   3) Important
   4) Very important
   5) Extremely important
5. How much energy did you expend during the match you just completed?

1) Much less than a real competition
2) Somewhat less than a real competition
3) The same as in a real competition
4) Somewhat more than in a real competition
5) Much more than in a real competition.