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With the title:

Physical tests, hormonal and oxidative-stress related biomarkers in intermittent training of Taekwondo athletes

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DECLARATION

By submitting this dissertation electronically, I declare that the entire work contained therein is my own original work, that I am the owner of the copyright and that I have not previously in its entirety submitted it for obtaining any qualification.

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Musa Lewis MATHUNJWA

ABSTRACT

This thesis presents four studies. Study one aimed at identifying the anthropometric, physical and physiological characteristics of junior Taekwondo athletes required to achieve an international status in 25 males and 11 females aged 25.5±2.6 years. Body composition [percentage body fat (%BF), sum of skinfolds (SS)], flexibility (sit & reach, hip flexor (HF) and quadriceps flexibility (QF), lower extremity explosive power [vertical jump (Diff VJ)] and vertical jump relative power (R Power), muscle endurance (sit-ups and push-ups), muscular strength (handgrip right and left), hexagonal agility (HEX) and agility T-test, aerobic power (20 m bleep test (20MST) converted to maximum oxygen uptake (VO2max.). Significantly higher %BF and sum of skinfolds were recorded in junior female players. No differences in body mass, stature and body mass index (BMI) were found. Female athletes showed lower ($p<0.001$) results in push-ups compared to males. Maximal grip strength of both hands was higher ($p<0.05$) in males.

Study two investigated the effects of 4 weeks high-intensity intermittent Taekwondo (TKD) training program on body composition, physical fitness and performance of thirty-four (n=34) active TKD athletes of South African Zulu ancestry aged 20-26 years. The athletes were divided into control group (CG; n=10 male, n=7 female), performed interval TKD and strength training of lower intensity (70-75 % VO_{2max}), experimental group (EG; n=10 male, n=7 female) that performed a high-intensity intermittent TKD and strength training (85-95 % VO_{2max}). Body composition parameters: body mass, % body fat, sum of skinfolds, blood pressure (BP) and resting heart rate (RHR) flexibility, leg power, muscle strength and endurance, agility, VO_{2max} (20m bleep test) were measured. Data were analysed using *t*-test for independent samples and Z-score individual radar plots statistics for assessment of each athlete. After 4 weeks of training, athletes in the experimental group showed a significant reduction in body weight ($p<0.05$), BMI ($p<0.001$), systolic blood pressure (SBP) ($p<0.05$), resting heartrate (RHR) ($p<0.05$), SS ($p<0.05$), and fat % ($p<0.001$) and significant improvement ($p<0.001$) in flexibility, muscle strength, power, agility and VO_{2max}. In male controls, fat % was decreased ($p<0.05$), flexibility and VO_{2max} were increased ($p<0.05$). In female controls, only flexibility was improved ($p<0.05$).

Study three assessed the hormonal and biochemical responses of young male and female Taekwondo athletes during the 4 week high-intensity Taekwondo training. Twenty-eight (N=28) [16 males and 12 females] South African Taekwondo (TKD) athletes aged 20-26 years,

BMI=23.7±2.9 14 were subjected to 4 weeks TKD and strength training divided in two groups: experimental (n=8 male, n=6 female) performing high intensity intermittent (85-90% VO_2max) TKD training and a control group (n=8 males, n=6 females), performing interval TKD training of lower intensity (70-75% VO_2max). A structured Taekwondo tasks (sTT) test was conducted before and after the training period within the experimental group after 4 weeks of high intensity intermittent Taekwondo (HIITKD) training period, the post-sTT test total testosterone level was higher ($p<0.05$) by 21.7% compared to the pre-sTT test value. No differences between groups were found` in free testosterone, testosterone-binding globulin and cortisol. Post-sTT test cortisol/total testosterone (C/tT) ratio decreased by 13.3% in the experimental group and increased by 18.5% in controls ($p<0.05$) after the training period.

Study four assessed the haematological parameters in twenty-eight (N=28) [16 males and 12 females] South African Taekwondo (TKD) athletes aged 20-26years, BMI=23.7±2.9 14 subjected to 4 weeks of TKD training who were divided into two groups: experimental (n=8 male, n=6 female) performing high intensity intermittent (85-90% VO_2max) TKD training and a control group (n=8 males, n=6 females) performing interval TKD training of lower intensity (70-75% VO_2max). A structured Taekwondo tasks (sTT) test was conducted before and after the training period. Within the experimental group, after 4 weeks of high intensity intermittent Taekwondo (HIITKD) training period, the post-sTT test total testosterone level was higher ($p<0.05$) by 21.7% compared to the pre-sTT test value. No differences between groups were found in Haematocrit mean corpuscular volume (MCV), mean corpuscular haemaglobin (MCH), mean corpuscuclar haemaglobin concentration (MCHC), red distribution width (RDW), Platelets, Eosinophil and Basophil levels between experimental and control groups in the male and female athletes after the training period. RBC (L), Hb, Haematocrit, MCV, MCH, MCHC, RDW, and Lymphocyte levels increased significantly in experimental groups in both female and male TKD athletes.

Discussion

Intermittent physical events may produce great strength and muscle power demands on both upper and lower body with high anaerobic energy demand.

Conclusion. The findings of this study which were obtained from Taekwondo athletes of Zulu ancestry support the effectiveness of 4 weeks high intensity intermittent training in improving

body composition, cardiorespiratory response, blood hormone and physical performance that could contribute to improve health and enhanced combat skills of Taekwondo athletes.

Key words: Taekwondo, high-intensity training, intermittent exercise, physical fitness, hormonal responses, physiological response, haematological parameters.

LIST OF PUBLICATIONS

JOURNAL ARTICLES

1. **Mathunjwa M.L.,** S.C Mugandani., M, Ngcobo., T. Djarova-Daniels, and S. Ivanov. (2015). Physical, anthropometrical, and physiological profiles of experienced junior male and female South African Taekwondo athletes. *African Journal for Physical, Health Education, Recreation and Dance*, 21(4:2), 1402 - 1416.

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LIST OF ABBREVIATIONS

ABREVATIONS	FULL MEANING
ANOVA	Analysis of variance
BMI	Body mass index
B	Basophils
E	Eosinophils
Hb	Hemoglobin content
HCT	Hematocrit
HR	Heart rate (beats per minutes)
LCC	Leucocyte cell
LPC	Lymphocyte cells
MCH	Mean Corpuscular Hemoglobin
MCHC	Mean Corpuscular Hemoglobin Concentration
MCV	Mean Corpuscular Volume
NTP	Neutrophils
1RM	One repetition maximum
OS	Oxidative Stress
%HRmax	Percentage of maximum heart rate
PC	Platelet Count
RBC	Red blood cell
ROS	Reactive oxygen species
SD	Standard deviation
VO2max	Maximum oxygen uptake (ml/kg/min)
WBC	White blood cell
WTF	World Taekwondo Federation

CHAPTER 1
INTRODUCTION TO TAEKWONDO

1. INTRODUCTION

Taekwondo (TKD) is a Korean martial art sport that originated about some 1500 years ago. It was used as a way of life, hence, the strategies of warfare, self-defense and physical activity were at the center of this sport (Pons van Dijk *et al*., 2013). TKD is a strength-power sport requiring high levels of anaerobic and aerobic capabilities characterized by explosive movements mainly by the lower limbs of the body for successful performance (Ball, 2011; Campos *et al*., 2012). The sport has a specific nature of physical fitness that is demanding, discontinuous and explosive.

An estimate of over 140 countries globally participates in TKD, but only 120 nations are officially members of the World Taekwondo Federation (WTF: Kazemi *et al*., 2006). TKD became an Olympic sport, by firstly being a demonstration sport at the 1988 Seoul Olympics and thereafter, at the Barcelona Games in 1992. It was officially accepted as an Olympic combat sport since the year 2000 Sydney Olympics. TKD performances usually last under 2 minutes while active competitions consist of 3 rounds of 2 minutes of combat and a minute of rest period in between the rounds. It is a sport discipline in which opponents directly, deliberately and systematically confront each other in a dynamic combat environment (Kazemi *et al*., 2006). In competitions, the basics of the sport allows the participant to execute body kicks which are executed in high speed (on the safe guard), quick and powerful kicks as well as punches (on the torso), and kicking on the face (Kazemi *et al*., 2006). Kicks are allowed to the head, but it is an infringement to punch the face. A winner is determined by scoring more points or by winning on knockout when the opponent cannot continue with the fight.

The importance of TKD as a competitive sport in the Western society unlike, that the case in Korean society is that this kind of activity is mostly used to improve the chances of slowing down the ageing process and cognitive decline (Alzheimer's Association, 2009; Wolter and Studenski, 1996). Studies have shown that this type of physical activity improves cognitive speed, auditory and visual attention (Angevaren *et al*., 2008), and cognitive functioning (Colcombe and Kramer, 2003). It is well established that TKD, as a sport, has an impact on the improvement of cardiovascular fitness, thus reducing the incidence of stroke, diabetes, hypertension, and other cardiovascular diseases (Imayama *et al*., 2013; Mathunjwa *et al*., 2013). Furthermore, TKD stimulates the brain functioning by increasing the production and efficiency of neurotransmitters, and biochemical processes such as angiogenesis, synaptogenesis, and neurogenesis (McAuley *et al*., 2004). Angevaren and colleagues, (2008) reported a positive change in the aspects of cognitive function after improving aerobic fitness. Several martial arts including Tai Chi, semi-contact karate, and boxing have also reported similar effects (Toskovic *et al*., 2004). A recent study on TKD training showed that the sport is feasible and safe, producing a significant improvement in overall wellbeing (Pons van Dijk *et al*., 2013).

Several studies have yielded limited scientific information on anthropometric parameters and energy demand (Ball 2011; Kazemi, *et al*., 2010a; Kazemi *et al*., 2006), physiological profile (Kazemi Cassella, and Perri, 2009), mental development (Chiodo *et al*., 2011; Pieter, and Heijmans, 2000) with high technical and tactical proficiency (Bridge *et al*., 2011; Kazemi *et al*., 2010b) of TKD sport. Additionally, there is little or no information on gender differences regarding the impact of hormones as they relate to increased muscle performance between male and females in TKD (Toskovic, Blessing and Williford, 2002). The level of intensity in TKD as a combat sport is too high for long-term exercise performance, hence, the challenge is more on physical fitness. TKD requires strenuous exercises such as jumping, punching and kicking, together with a high degree of coordination and artistry on an 8 x 8 meters mat (Kazemi *et al*., 2010a)**.** Elevated anaerobic capacity, muscle resistance and strength, explosive power, flexibility and agility are the most important factors needed to achieve success in Taekwondo competitions are the hallmark of daily exercise training programme. Coaches use scientific assessment of these variables to make informed decisions for the selection of competent Taekwondo athletes. However, it remains to be determined the extent of physical capabilities, hormonal and oxidative stress biomarkers in screening TKD athletes as to enhance their trainability and their ability to perform at top levels.

More so, there is no comprehensive study investigating the changes in physical tests, hormonal and oxidative stress blood biomarkers in response to a specified duration of high intensity intermittent TKD training period in a group of healthy young professional TKD athletes. If effective, such TKD-based exercise programme, combined with aerobic interval training could provide significant insights into physiological profiles and improving training regimen and conditioning leading to better trained athletes.

1.1 PROBLEM STATEMENT

Taekwondo has never been assessed from the view point of energy metabolism of the aerobic and anaerobic contribution towards performance. To the best of the author's knowledge, this is the first investigation that comprehensively examine physical testing, hormone levels, oxidative-stress biomarkers and intermediary metabolites of TKD athletes in response to 4 weeks of intermittent Taekwondo training combined with aerobic training and strength conditioning. The analysis of the variables will have practical applications focused on the assessment of the athletes' individual profiles, monitoring the impact of training, avoiding fatigue and overtraining and improving the performance during Kyorugi and Poomsae competitions.

1.1.1 DELIMITATIONS

1. The study participants were recruited from the University of Zululand Taekwondo athletic club and were those who qualified for both the provincial and national teams of South Africa consisting of both males and females of all races.
2. Participants refrained from using antioxidants and other nutritional supplements or stimulants during the period of the study.
3. Participants were non-smokers or had refrained from smoking for more than 6 months.
4. Participating Taekwondo athletes had no orthopedic injury/disability that would have prevented them from participating and engaging in the 4 weeks high intensity Taekwondo training.

1.2 AIMS/OBJECTIVES

1.2.1 THE AIMS OF THIS STUDY WERE:

1. To design a very high intensity intermittent TKD training programme of short duration aimed at improving both aerobic and anaerobic capacity and strength of the South African TKD athletes.
2. To assess the changes recorded in physical performance tests, hormones, exercise-induced oxidative stress biomarkers, creatine kinase, lactate and glucose levels and haematological parameters, in response to taekwondo specific techniques, strength conditioning and the

impact of 4 weeks intermittent TKD training in South African athletes. (Anthropometric parameters?)

1.2.2 THE OBJECTIVES OF THIS STUDY WERE AS FOLLOWS:

1. To measure physical characteristics (explosive power, vertical jump, speed, agility, strength, and flexibility) related to the performance and fitness in response to intermittent TKD training.
2. To test physiological characteristics (blood pressure, body mass index (BMI), fat percent, and lean body mass) in response to intermittent TKD training.
3. To determine haematological parameters (RBC, WBC, haemoglobin and haematocrit) to assess and monitor the health status of South African athletes in responds to intermittent TKD training.
4. To determine the level of hormones (testosterone and cortisol), enzymatic biomarkers (C-reactive protein, uric acid and creatine kinase), and intermediary metabolites (glucose and lactate) in the blood of South African athletes exposed to intermittent TKD training.

1.3 INTENDED CONTRIBUTION TO THE BODY OF KNOWLEDGE

There are limited scientific studies on the impact of strenuous Taekwondo training on physical tests and physiological characteristics. Studies have been carried out in other countries, but these have been done on Caucasians and Asians and not in South African TKD athletes. Therefore, it was considered that this study would be helpful in the decision making process in selection and planning of training programs for the South African national TKD team. In contemporary sports practice, the optimization of the training regimen and training interventions are of greatest importance. More so, a complex approach made up of individual assessment of physical tests performance, physiological and biochemical variables can be developed for elite athletes thereby leading to a personalised training programme.

1.4 RESEARCH HYPOTHESIS

Very high intensity intermittent Taekwondo training of four weeks will significantly improve physical performance tests, physiological characteristics, anabolic/catabolic status, and exercise-induced oxidative stress biomarkers and creatine kinase response of South African TKD athletes.

1.4.1 THE NULL HYPOTHESES

There were no significant differences in physical performance tests, physiological characteristics, anabolic/catabolic status, and in the response to exercise-induced oxidative stress biomarkers and creatine kinase of South African TKD athletes subjected to four weeks intermittent Taekwondo training.

1.5 SCOPE OF THE STUDY

Elite Taekwondo require weeks, months and years of dedicated and intensive training to develop mental and physical preparation to enable success in winning local, national and international fights. Factors, especially the physiological and psychological attribute, which set this group apart from other athletes have not been clearly analyzed.

In chapter 2, a review of the literature exploring the different types of training was done on taekwondo sparring and poomsae, the tests of physical and physiological characteristics, hormonal responses to exercise, exercise-induced oxidative stress biomarkers as well as the enzymes and intermediary metabolites of taekwondo training is presented.

Chapter 3 presents the methodology of training which includes the summary of the practise of Taekwondo training protocol and selection for the South African Team, problem rational and experimental approach, pilot study, organisation of the research and experimental design. A full description of the procedures, testing instrument and protocols.

Chapter 4 presents the findings of the physical test, anthropometric and physiological profiles of junior experienced male and female South African athletes.

Chapter 5 presents the finding of the 4 weeks high intensity intermittent Taekwondo training intervention programme on body composition and physical fitness of University of Zululand athletes.

Chapter 6 presents the results of hormonal and biochemical responses to concurrent Taekwondo and resistance training in Taekwondo athletes.

Chapter 7 presents the study of oxidative stress related biomarkers and haematological parameters in male and female Taekwondo athletes.

Chapter eight concludes the study and proposes possible applications and future directions in the conditioning of Taekwondo in the field of sport sciences.

CHAPTER 2
REVIEW OF LITERATURE

2 TKD TRAINING AND AEROBIC / ANAEROBIC CAPACITY OF ATHLETES

Taekwondo techniques in Kyorugi (combat) and Poomsae (form) competitions vary in the use of feet (Tae), hands (Kwon) and way or method (do). In Kyorugi the competitors apply highly sophisticated techniques based on smooth body movements and quick targeted power strikes. Poomsae is a structural form of competition including the use of both hands and feet (Haddad *et al.*, 2012). The development of technical skills in TKD involves a specific criterion to meet the requirements of quality. TKD is a type of sport that involves intermittent exercise during training with both aerobic and anaerobic sequences, which requires quick recovery between its fast actions depending on the level of performance of the athletes in the match (Alizadeh *et al.*, 2010). The energy demands required high level of both aerobic and anaerobic physical fitness (Bouhlel *et al.*, 2006). Therefore, it is imperative to specifically consider intermittent types of exercises in the design and preparation of TKD training.

2.1 AEROBIC TRAINING

Aerobic training is a type of exercise that leads to increased oxygen consumption (VO_{2max}) in athletes, hence prolonged high intensity aerobic exercise may lend to increased production of reactive oxygen species. Taekwondo sport requires aerobic training during Kyorug and Poomsae to maintain the efforts in combat and contribute to effective recovery during periods of reduced effort or between fights. Fong and Ng (2011) indicated that TKD training enhances physical fitness and aerobic performance. The intensity of exercise stimulates the cardiovascular system above the aerobic threshold during typical TKD training (Bridge *et al.*, 2007; Toskovic *et al.*, 2002). Additionally, aerobic training may also contribute to the anaerobic threshold shift leading to a more effective clearance of lactate from the exercising muscles (Haddad *et al.*, 2012).

Furthermore, Bouhlel and colleagues, (2006) revealed that aerobic metabolism for elite TKD athletes correlates with heart rate (HR) responses and blood lactate concentrations during a 3 minutes specific exercise in TKD competitions.

The data about aerobic fitness measured by maximal oxygen uptake values (VO_2 max) of experienced TKD athletes compared to novices are quite contradictory. This was revealed by non-homogenous groups of participants (male and female) athletes with different fitness levels, implementing various training protocols (Bridge *et al*., 2007; Melhim, 2001; Heller *et al.*, 1998; Thompson and Vinueza, 1991).

A study by Melhim (2001) reported no significant change in VO_{2max} and HR before and after 8 weeks of TKD Poomsae training programme in experienced male athletes. More-so, an investigation of the effect of exercise and recovery HR in recreational TKD male practitioners, found significantly higher exercise heart rates (90-91% of HR max) in kicking and punching routines than repetitively performed Poomsae (80% of HR max) (Toskovic *et al*., 2002). Conversely, in experienced TKD athletes subjected to Kyorugi training including punches, kicks with elastic stretch bands, technical combinations and step sparring elicited exercise intensity ranging from 64.7 to 69.4% of HR max, whereas pad work and sparring drills induced higher exercise intensities (74.7 - 81.4% HR_{max}) (Bridge *et al*., 2007; ACSM, 2006). Yet, another study after a typical TKD training of 12 weeks during pre-competitive season divided in five intensity zones, ranging from the lowest 50-60 % HR to high 91-100% HR, a significant improvement of aerobic capacity level was established in the athletes (Haddad *et al*., 2012). It is well known that Poomsae and Kyorugi competition are performed at different levels of aerobic capacity and physical fitness of the participants. Kyorugi competitions more especially in the Olympic Games require higher aerobic capacity levels than Poomsae competition (Fong and Ng, 2011).

2.2 ANAEROBIC TRAINING

Anaerobic training comprises a large variety of sport activities (sprints, jumps and resistance exercise); an acute anaerobic exercise may result in the production of reactive oxygen species (Groussard, 2003). Studies have indicated that TKD competitions consist of very short periods of supramaximal exercise such as intermittent kicks, sprints, jumps, high-intensity movements that are frequently repeated during combat (Haddad *et al*., 2012: Ramel *et al*., 2004). In general, the TKD exercises are of short duration and they last from 10s to 3min (Matsushigue *et al.*, 2009; Bridge *et al*., 2007: Bouhlel *et al*., 2006). Many studies have provided evidence that fast attacking actions and defensive movements depend significantly on anaerobic pathways (Matsushigue *et al*, 2009; Bouhlel *et al*., 2006; Melhim, 2001; Heller *et al*., 1998).

Various combinations of high intensity bouts and short-term low intensity periods have been explored. Heller and colleaques (1998) revealed that TKD athletes in combats execute 3-5 seconds bouts of high intensity exercise alternated with low-intensity periods with working/recovery ratios ranging from 1:3 to 1:4 have a high demand on short-term anaerobic performance capacity, quicker recovery leading to a reduced fatigability during high-intensity of intermittent exercise.

Matsushigue and colleagues (2009) reported a 1:1 exercise to rest ratio with approximately 8 seconds for each period, and a 1:6 rest ratio after high intensity movement. This study suggested that creatine phosphate stores may be the main source of energy during the action phases of 1 - 5 seconds duration. The energy supply during the intervals between each two high intensity actions could be provided by aerobic metabolism**.** It was also noted that different intervals between rounds should be employed for each competitor during TKD competition. Interval training sessions with 8 seconds of high-intensity efforts and 8 seconds of rest or low-intensity efforts have been recommended to enable athletes to handle the metabolic and physiologic demands of combat.

2.3 TESTING OF PHYSICAL AND PHYSIOLOGICAL PARAMETERS OF TAEKWONDO ATHLETES

Muscle strength, power and speed are of significant importance for high level TKD performance. These characteristics are critical when performing explosive kicking, jumping and maintaining stances (Haddad *et al*., 2012).

Available literature on the effects of typical TKD training and resistance training are controversial. Some studies have reported an improvement in muscle strength (Toskovic *et al*., 2004; Heller *et al*., 1998), while significant correlations were found between the length of regular TKD training and the strength gained by knee muscles (Fong, Tsang, and Ng, 2013). On the other hand, Kim and colleagues (2011) demonstrated no positive correlation existed between TKD training when associated with muscle strength and endurance. However, few studies investigated the impact of resistant training effects, another study reported on enhanced striking force (Topal *et al*., 2011) and a detectable increase of kicking speed in a turning kick technique in athletes subjected to resistant training sessions for 4 weeks.

More-so, the impact of low intensity TKD training sessions on speed and agility of athletes performing a 50 m shuttle run was investigated (Fong and Ng, 2011), but failed to show any significant improvement on the whole. Comprehensive studies dealing with maximum grip force, low extremity explosive power, agility, speed and aerobic power were not found.

Added together, emphasis should be placed on high-intensity type of training based on very high-intensity specific TKD techniques interspersed with short low-to moderate-intensity movements; Relevant strength/power and sprint conditioning should also be implemented as an integral part of TKD training. Therefore, one of the major objectives of our study was to design a TKD training programme of short duration (4weeks) based on a combination of a very high intensity intermittent specific TKD actions and movement techniques and moderate to sub-maximal intervals of exercise training with the inclusion of targeted strength/power/sprint sessions leading to the improvement of both aerobic and anaerobic capacity as well as strength conditioning.

2.4 HORMONAL RESPONSES TO EXERCISE AND TAEKWONDO TRAINING

Numerous studies have shown that physical exercise of high intensity serves as a powerful stimulus influencing the circulating blood testosterone and cortisol levels in men (Cadore *et al*., 2009; Ahtiainen *et al*., 2005; Häkkinen and Pakarinen, 1995; Staron *et al*., 1994). Testosterone and cortisol have been considered as reliable markers of the endocrine response to competitive contact sport performance such as Taekwondo (Cormack *et al*., 2008, Elloumi *et al*., 2003, Passelergue *et al*., 1999).

Testosterone is the primary steroid hormone from the androgen group and its secretion is regulated by the hypothalamic–pituitary–gonadal axis (Loebel and Kraemer, 1998). Testosterone acts as an anabolic hormone contributing to muscle growth by increasing protein synthesis, decreasing protein degradation, and improving the strength-related performance of muscles (Crewther *et al*., 2006). Beaven, Cook, and Gill, (2008) showed that maximal levels of salivary testosterone detected in each individual are linked to increased gains in strength. The anabolic actions of testosterone stimulate the secretion of other anabolic hormones (e.g. growth hormone). Circulating testosterone is known to bind to serum proteins (95-98%) while a small amount (2-5%) remains unbound in circulation (free testosterone) (Crewther *et al*., 2006). Consequently, the unbound concentration levels reflected the available amount of testosterone available to target tissues.

Studies have shown that bioavailable free testosterone blood levels strongly correlated with salivary testosterone measurements (Morley *et al*., 2006: Sannikka *et al*., 1983: Shirtcliff *et al*., 2002). Salivary measurement without the invasive blood sampling is a preferable choice in sport practice for ascertaining the relationship between testosterone and strength-related performance (Crewther *et al*., 2011).

Kraemer et al, (2006) showed that increase in testosterone levels following resistance exercise is essential for muscular adaptation and muscle growth. It has also been shown that resistance training results in higher testosterone levels compared to aerobic training (Tremblay *et al*., 2004: Copeland *et al*., 2002). Resistant training of anaerobic glycolytic type has been found to be a more powerful and effective stimulus than aerobic training in the elevation of testosterone. The acute elevation of testosterone levels is feedback regulated by the luteinizing hormone (Fahrner and Hackney, 1998; Lu *et al*., 1997). Conversely, Izquierdo and colleagues (2006) demonstrated that prolonged strenuous physical exertion reduces testosterone levels by suppressing the secretion of gonadotropin-releasing hormone. However, short-term high-intensity exercise, on the other hand, increases circulating testosterone levels**.**

Cortisol is a steroid hormone, which is the main glucocorticoid responsible for catabolic processes. It is secreted from the adrenal cortex and is regulated via the hypothalamic–pituitary–adrenal (HPA) axis. Cortisol levels increase in response to various stressors such as physical exertion (Viru and Viru, 2004). More so, numerous factors associated with elevated cortisol levels include anxiety (Lader, 1983), depression (Gold *et al*., 1986) and intensive physical exercise (Stupnicki and Obmi'nski, 1992; O'Connor and Corrigan, 1987). The main function of cortisol is to stimulate gluconeogenesis and protein degradation (Viru and Viru, 2004) and to inhibit inflammatory process and immunity (Sapolsky, Romero, and Munck, 2000). The levels of cortisol are increased proportionally in response to exercise intensity, whereas, the secretion even though limited is dependent on exercise duration. It has been reported that an elevation of blood cortisol levels can occur when exercise intensity is above 60% maximal oxygen uptake (VO_{2max}) lasting for more than 20 minutes (Viru, 1992; Hill *et al*., 2008).

Additionally, there is a significant correlation between blood and salivary cortisol concentrations at rest (Lippi *et al*., 2009; Muramatsu and Yoshinori, 1994). It was also reported that the rise in cortisol level coincides with the onset of blood lactate accumulation (Port, 1991). Furthermore, it has been shown that post-exercise elevated blood and saliva lactate level are significantly associated with exercise intensity (Stupnicki *et al*., 1992; O'Connor and Corrigan, 1987), with peak power during 30 seconds Wingate test (Crewther *et al*., 2010) and competitive training matching (Moreira *et al*., 2009; Doan *et al*., 2007; Filaire *et al*.,1999).

It has been shown that the maximum cortisol concentration increase in blood occurred at about 20 min post-exercise (Acevedo *et al*., 2007), whereas, it was detected at about 30 min post-exercise in saliva (O'Connor and Corrigan, 1987; Moreira *et al*., 2011). Several studies have revealed that the cortisol changes in response to exercise are more pronounced in saliva compared to the blood (Lac *et al*., 1999; Stupnicki *et al*., 1992) and could provide a better measure of the dynamic hypothalamic–pituitary–adrenal axis activity in sport practice (Gozansky *et al*., 2005).

In elite rugby players, cortisol was found to be increased 30 mins post-match and displayed a clear pattern of significant elevation 24 hours post-match, while testosterone levels significantly decreased 24 hours post-match. In the same vein, testosterone/cortisol (T:C) ratio was significantly lower 30 min and 24 hours post-match compared to base values (McLellan *et al*., 2010). Martinez and colleagues (2010) reported some significant changes in cortisol and testosterone levels of professional basketball players with specific elevating and reducing patterns throughout competitions during the season. Stress and fatigue have been shown to generate an increase in adenocorticotropic hormone (ACTH) and cortisol, and a decrease in serum testosterone levels. The T:C ratio is an indicator of anabolic and catabolic balance and could be decreased by fatigue and overtraining. Ramson and colleagues (2009) showed that in rowers, exercise induced testosterone levels 30 mins post exercise was decreased during high volume training phases compared to the low volume training phases. Cortisol levels were also decreased 30 min post exercise during high training volume stages.

Furthermore, use of the T: C ratio which represents anabolic and catabolic hormonal profiles of athletes has implications for the design of relevant training programmes (McLellan *et al*., 2010).

Despite the advantages of non-invasive saliva collections, blood sampling could be considered a better choice due to variability of its use not only for testosterone and cortisol measurement but also for the determination of enzymes and important metabolites, as well as for long term storage for multiple genotyping of performance enhancing genes in athletes.

2.5 EXERCISE-INDUCED OXIDATIVE STRESS BIOMARKERS AND TAEKWONDO TRAINING

2.5.1 Oxidative stress

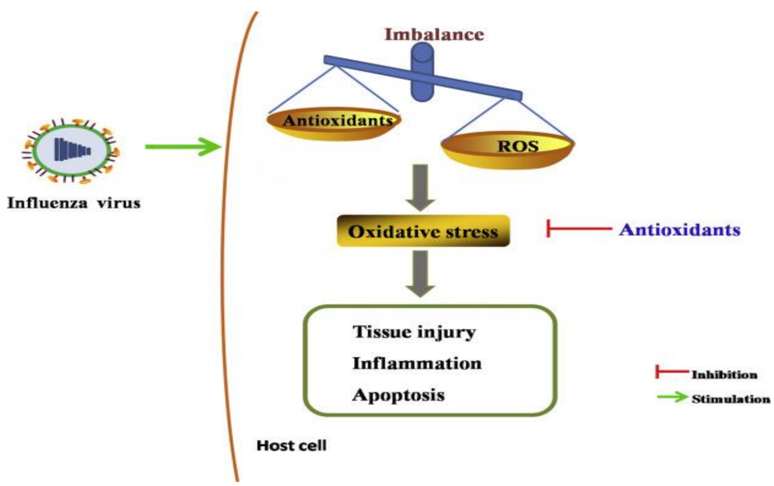

Fig 1. Despite an adequate antioxidant capacity, a marked increase in ROS production may overwhelm the antioxidant system (Opara *et al*., 2002).

Oxidative stress occurs when oxidation exceeds the antioxidant system in the body as a result of an imbalance between the two systems. The imbalance between reactive oxygen and nitrogen species (RONS) overwhelms the available antioxidant defenses of the body, which results in oxidative stress and tissue damage (Yoshikawa and Naito, 2002). The antioxidant system of the body consists of endogenous compounds such as uric acid, bilirubin, lactate, superoxide dismutase, catalase and glutathione peroxidase (Opara *et al*., 2002) while exogenous compounds include carotenoids, tocopherols, ascorbate and bioflavinoids supplied through diet (Urso and Clarkson, 2003; Watson *et al*., 2005).

2.5.2 URIC ACID

Uric acid (UA) is a metabolic by product found in blood from endogenous purine catabolism or from dietary source (Gonzalez *et al*., 2008; Chizyński and Rozycka, 2005). It can be excreted through the urine and from the gut with faeces. Abnormally high level of UA or hyperuriceamia results from high-purine food itake and alcohol consumption, lack of water, high protein meat intake and inactive lifestyle (Assob *et al*., 2014; Chizyński and Rozycka, 2005). Vaquero and colleagues (2013) and Luk and Simkin (2005) reported the prevalence of hyperuriceamia is increasing worldwide, with men having higher risk than women in all age groups (Li-ying *et al*., 2007). High concentrations of uric acid causes the deposition of the cartilage tissue resulting in a chemical disease known as gout, which presents as painful inflammation in the joints.

UA has potent biological antioxidant function with free-radical scavenging activities (Maxwell *et al*., 1997). However, elevations in UA can be detrimental to cardiovascular health (Feig *et al*., 2008). It has been established that hyperuricaemia and gout are associated with risk factors of cardiovascular disease such as obesity (Johnson, 2002)**,** metabolic syndrome (Masuo *et al*., 2003), diabetes (Nakanishi *et al*., 2003) and hypertension (Harris *et al*., 2010). Increasing prevalence of hyperuricaemia coupled with non-communicable diseases has been predicted to be major causes of morbidity and mortality in the next few years.

UA increases with the increase in the intensity of exercise causing oxidative stress and inflammation. It is well established that strenuous activity of either aerobic or resistance exercise results to oxidative stress (Michigan *et al*., 2011). Hyperuricemia is mostly produced in hot conditions, and the biochemical metabolites such as urea, ammonia and uric acid result from vigorous exercise (Huang *et al*., (2010). Peters and colleagues (1983) reported that high intensity ultramarathon runners exhibited a propensity for respiratory tract infection leading to low resting level of UA and immunoglobulin. For this reason, aerobic exercise was recommended to be performed between 20 to 60 mins, 3 times per week at intensities of 50 to 80% VO_2max in order to achieve cardiorespiratory fitness and maintain a healthy status in adults (ACSM, 2010).

Uric acid acts as a component of the innate antioxidant system. High uric acid concentrations found after submaximal and maximal exercise could be considered as an indicator of mobilization of tissue antioxidant stores into the plasma. Uric acid elevations can account for nearly one-third of the total plasma antioxidant capacity (Djarova *et al*., 2009).

2.5.3 C-REACTIVE PROTEIN (CRP)

C-Reactive Protein (CRP) is described as a protein that is synthesized by the liver in response to inflammation and forms part of the innate immune system (Mugandani *et al*., 2014). The presence of high level of CRP in the blood is an indication of inflammation in the body. A plethora of studies have pronounced CRP as the most sensitive inflammatory markers for predicting cardiovascular diseases (Kuo *et al*., 2007: Lamonte *et al*., 2002: Meyer *et al*., 2001).

More so, some studies have associated the increase of serum CRP levels with various coronary artery disease (CHD) risk, which can cause heart attack and stroke (Sampietro *et al*., 2004**;** Duprez *et al*., 2004; Cosin-Sales *et al*., 2003). Valiollah (2011) discovered a number of factors that can affect this biomarker. Inflammation and atherosclerosis in the body are caused by unhealthy diet, cigarette smoking, hypertension, hyperglycemia and infections (Tuzcu *et al*., 2005). An elevated level of CRP increases the risk of acute myocardial infarction, ischemic stroke and peripheral artery disease (Koening *et al*., 1999). Plasma CRP value less than 1.0mg/dL defines low CVD risk, while 1.0 - 3.0 mg/dL indicate moderate risk, and value above 3.0 mg/dL is a high risk inductor (Raitakari *et al*., 2005).

Furthermore, high level of CRP has been shown to be indicative of an inflammatory response, and it is extensively recognized that CVD is a chronic inflammatory disorder (Koenig, 2005; Lowenstein and Matsushita, 2004). Regular physical activity of moderate intensity can help individuals reduce the risk of high sensitivity CRP (Kuo *et al*., 2007; Church *et al*., 2002; Lamonte *et al*., 2002; Mattusch *et al*., 2000). Davis and colleagues (2007) revealed decrease in inflammation is indicative of a decrease in the risk of CVD. It has been shown that improving exercise capacity, fitness, and better diet lowers inflammation and CRP, as well as delays mortality (Blair *et al*., 1999). Church and colleagues (2010) investigated an aerobic intervention of 3-5 sessions per week of 60% - 80%VO_{2max} in a randomised control study and found an elevated CRP levels with 12% increase. Lakka and colleagues (2005) conducted a 20-week exercise intervention study and recorded a decrease in CRP levels after exercising for 50 minutes at 75% of maximum heart rate.

Although CRP was found to be elevated after heavy exertion, it has, however been, shown that the increase is delayed when compared to most cytokines (Nieman, 2012).

A 12-week exercise training program on CRP concentration produced positive results in healthy young and old people (Stewart *et al*., 2007). Thus, it is clear that serum CRP decreases with training in both old and young people. Studies have reported that CRP increased in a single long-term activity of marathon running (Meyer *et al*., 2001), or high-intensity anaerobic training (Hiller *et al*., 2003). CRP concentrations can also be raised after strenuous exercise when compared to the resting values (Siegel *et al*., 2001: Taylor *et al*., 1987). It has been found that CRP levels increased following an acute exercise when compared to baseline levels (Djarova *et al*., 2010). However, there are still the different types of physical activity/exercise that may impact this protein but still subject to be investigated. Moreover, no study has investigated the effect of strenuous physical activity in Taekwondo training on CRP blood levels. Therefore, this study seeks to investigate the association of intermittent Taekwondo training on CRP as a biomarker.

2.6 ENZYMES AND INTERMEDIARY METABOLITES AND TAEKWONDO TRAINING

2.6.1 ENZYMES

The changes in various serum enzymes such as liver enzymes (alanine aminotransaminase and aspartate aminotransferase), lactate dehydrogenase and creatine kinase have been investigated as markers of tissue damage established in response to oxidative stress-induced exercise (Djarova *et al*., 2009 and 2012; McKune *et al*., 2009). A study by Djarova and colleagues (2009) revealed no changes in these enzyme levels in athletes in response to 15 min submaximal test consisting of two bouts of 10 mins at intensity 60% VO_{2max} and of 5 min at 90% VO_{2max} intensity without an interval in between. Creatine kinase (CK) is an important biomarker of cardiac muscle and in skeletal muscle damage in contact sports such as soccer and rugby. McKune and colleagues (2009) demonstrated significantly elevated creatine kinase levels in male athletes of African origin compared to Caucasians in response to eccentric exercise (60 min downhill run on a treadmill at a speed eliciting 75% VO_{2max} intensity. Conversely Djarova and colleagues (2013) reported no changes in creatine kinase at rest during competitive season in female soccer players of African and Caucasian origin. However, in rugby players creatine kinase increased significantly post-match with peak values shown up to 24 hours after the match.

It has been hypothesized that, an increase in CK represents cellular necrosis and tissue damage after acute and chronic muscle injuries. Evidence from enzymatic assays has shown that CK increased with high intensity exercise in healthy participants, although with long duration of endurance training higher CK levels were also found (Brancaccio *et al*., 2007). The specific type of training that produces greater muscle damage over a period of time that can influence Taekwondo athletes performance is not known. It is also difficult to ascertain the exact source (brain heart or muscle) of CK when the enzyme is assayed from a blood sample.

2.6.2 GLUCOSE

Regular physical activity maintains insulin sensitivity and blood glucose level within the body. Furthermore, regular exercise has been found to provide a number of additional benefits, such as controlled weight, improved blood pressure and reduced risk of cardiovascular diseases (Mathunjwa *et al*., 2013; Yavari, 2008; Bassuk and Manson, 2005). Yavari (2008) reported that a single bout of physical exercise had an effect in insulin and improved the blood glucose that persisted over a period between 2-h to 48-h after cessation of exercise. Therefore, the impact of regular exercise lowers blood glucose levels and also efficiently assists insulin in its work towards achieving control of blood glucose.

A study by King and colleagues (1993) reported that exercise and insulin stimulate skeletal muscle glucose transport by increasing the activity and number of glucose transporters. Glucose is delivered into the muscles and is broken down through different pathways leading to the translocation of GLUT-4 to plasma membrane and transverse tubules from intracellular pools. With exercise, insulin is not readily released from the pancreas due to the lowered blood glucose levels. Moreover, moderate exercise decreases glucose levels in the body. Goodwin (2010) reported that vigorous exercise can cause the hormones epinephrine and glucagon to be released. These hormones act by stimulating the degradation of glycogen into glucose in the liver, resulting in an increase in blood glucose levels.

It is well known that exercising regularly may lead to an improvement in insulin sensitivity, glucose metabolism and an increase in the use of fat as a fuel during exercise (Holloszy and Coyle., 1984). Ritcher and colleagues (1982) reported that a single exercise session can alter glucose transport and insulin sensitivity in skeletal muscle of rats, subsequent studies confirmed these findings in humans (Heck *et al*., 2004). Al-Nawaiseh and colleagues (2013) found a decrease in blood sugar after performing a 30 min treadmill run at 75% VO_2max. The increased level of blood glucose resulted from an increased hepatic glycogenosis, decreased insulin levels during prolonged exercise.

2.6.3 LACTATE

Lactate is produced at any exercise intensity as a by-product of exercise, however, with the increase of the exercise intensity muscle cells produced more lactate and certainly it contributes to fatigue, muscle soreness and a potential decline in performance due to the production of hydrogen ions and lower pH. In terms of intensity, it is assumed that higher bouts of strenuous exercise can elicit an increased lactate production as compared to a lower bout of continuous low exercise intensity. At the outset of exercise, accumulation of lactic acid in the muscle occurs during, or immediately after, a short bout of high intensity exercise.

It has been suggested that the level of lactate increases in the skeletal muscle and blood with increase in exercise intensity and it is oxidized by moderate activity during recovery (Thiriet *et al*., 1993; Brookes, 1986). During high intensity exercise, when the rate of energy demand is high, lactate is produced at a very high rate within the muscle and is released into the blood resulting in higher blood lactate levels. The removal and production of lactate have been elucidated in the Cori and Krebs cycle (Robergs *et al*., 2004). It has been shown that excess hydrogen ions [H+] released during glucose degradation impede the muscle contraction during high intensity exercise (Cairns, 2006). High–intensity exercise lasting between 2-4 minutes produces intramuscular lactate and inhibits muscular contraction in the muscle cell lending to accumulation of [H+] through glycolysis during short term maximum exercise thereby contributing to fatigue (Cooper *et al*., 2002: Noakes, 2001).

During intense physical activity, the production of blood lactate and lactate accumulation in exercising muscle is known to be the major determinant of fatigue (Fitts, 2003: Weltman, 1995).

Lower blood lactate levels during submaximal and intense training have been observed due to overtraining (Fitts, 2003). Decreased levels of blood lactate reflected a reduction in anaerobic glycolytic capacity with a decreased muscle glycogen stores and impaired buffering capacity during physical activity (Fitts, 2003: Weltman, 1995). Mechanisms have been discussed in the control of lactate metabolism during short term high intensity exercise as it supported the view that the lactate production during exercise could be limited and the restricted availability of oxygen at the level of mitochondria have to be considered (Katz, 1990). Conversely, another mechanism based on experimental data showed that the lack of oxygen in the mitochondria did not occur. Hence, it was proposed that oxygen metabolism increases muscle lactate production and raises circulating levels, whereas anoxia causes the elevation of lactate production and severe lactic acidosis.

Studies have reported that training increases the rate of lactate clearance both in aerobically and anaerobically trained athletes compared to untrained individuals (Gollnick *et al*., 1986; McMillan, 1993; Pierce *et al*., 1978). More so, training was found to reduce lactate production with different exercise intensity. Stone et al. (1987) reported that untrained individuals normally reached the lactate threshold at about 60% of VO_2max intensity while trained individual were found to generate a higher blood lactate threshold at intensity ranging from 60% to 70% VO_{2max}. The lactate threshold of highly trained endurance athletes was found even above 80% VO_{2max} intensity. However, very few studies have explored the effect of high intensity intermittent training on lactate production and clearance even though specific training can help the body become more effective in lactate removal.

2.7 HAEMATOLOGICAL PARAMETERS

Blood plays important roles such as carrying oxygen, carbon dioxide, and other substances required by tissues (Edington and Edgerton, 2004). It consists of plasma, red blood cells (RBCs), white blood cells (WBCs) and platelets which are major constituents are red blood cells and water (Gaeini, 2001). Red blood cells and hemoglobin are responsible for transporting nutrients and oxygen to active tissues and excretory substances such as carbon dioxide from tissues for expulsion from the lungs. The RBC count, haemoglobin level and haematocrit are the most influential parameters used to measure oxygen carrying capacity to tissues and excretion potential of carbon dioxide (Gaeini, 2001).

Physical exercise leads to a substantial improvement in aerobic capacity and endurance. It also exerts physiological stress on the body while it encounters muscle soreness and damage after long duration and high intensity training (Thompson and Mcnaughton, 2001). Malm and Yu, (2012) reported that muscle damage normally occurred after high intensity or prolonged exercise initiating an inflammatory process leading to an increase in muscle damage markers in the blood. Variations of hematocrit with physical exercise have been indicated by numerous studies (Ghanbari-Niaki *et al.*, 2006; Clement and Asmundson, 1982; Fredrichson *et al.*, 1983; Moore *et al.*, 1993). A doubling of WBC counts after two bouts of exhausting exercise on bicycle ergometer has been reported (Field *et al*., 1991). Another study reported a three-fold rise in WBC counts after two sessions of intense rowing for six minutes in experienced rowers over two days (Nielsen *et al* 1996). Similarly, an increase in WBC counts following two bouts of intense endurance exercise at 75% VO_{2max} has been reported (Ronsen *et al*., 2002: Gleeson *et al*., 2007), whereas Robson-Ansley and Gleeson (2007) found no significant variation in WBC counts after three consecutive bouts of intense endurance exercise.

Boyajiev and colleagues (2000) reported that RBC counts of adolescent boys and girls significantly decreased after a submaximal exercise and the platelet count significantly increased following endurance exercise at different intensities (Ahmadizad *et al*., 2003). Similarly, a significant increase in WBC and platelet counts has been observed after a 24-hour ultra-marathon (Wu *et al*., 2004). Studies by Nikseresht *et al.* (2010) and Dressendorfer. (1991) found a significantly decreased in hemoglobin and mean corpuscular volume, with a significantly increased platelets and WBC counts after 90 minutes of soccer practice. The changes in RBC counts showed no significance (Karakoc *et al*., 2005; Ghanbariniaki *et al*., 2006; Dressendorfer 1991).

The haematological outcomes of physical exercise and training help trainers and athletes to pay extra attention to the effects of their training programs. Therefore, an investigation into hematological parameters will reveal important insights on the impact of training program on a variety of haematological parameters.

2.8 BLOOD PRESSURE

Blood pressure is defined as the force or pressure exerted by the blood on unit cross-sectional area of the blood vessel. Blood pressure is usually measured in millimeters of mercury (mmHg). The beating of the heart leads to two distinct pressures in the arteries, namely the systolic and diastolic blood pressures. Systolic blood pressure is the result of the constriction and forced emptying of the left ventricle of the heart into the aorta. The pressure within the arteries when the heart is between contractions is called the diastolic blood pressure (Waugh and Halligan, 2008). Blood pressure is usually expressed as systolic over diastolic blood pressure with the average normal value being 120/80 mmHg (ACSM, 2010). Angiotensin I converting enzyme (ACE) is a component of renin angiotensin system (RAS) which plays a role in regulating blood pressure through cascades of biochemical reactions. An increase in plasma ACE activity may increase blood pressure through increased production of angiotensin II, which is a result of cleavage of angiotensin I by ACE to form angiotensin II (Calo and Vona, 2008).

It has been revealed that various types of exercise may differently influence ROS production resulting in a reduced antioxidant defence capacity of the organism. The impact of exercise on oxidative stress in various sports has also been well documented, but little is known about exercise-induced stress when compared to aerobic and anaerobic modes of specific TKD techniques during training (Bloomer *et al*., 2005).

A study by Urgas (2012) dealing with the effects of high intensity interval training of 10 days on antioxidant status of elite Muay Thai athletes reported that malonylaldehyde levels were significantly elevated and catalase activity was reduced. It was suggested that free radical accumulation was increased in response to high intensity Muay Thai training, which is a combat sport of intermittent nature and very similar to Taekwondo, Karate, Boxing and Wrestling.

More so, physiological measurements, blood biomarkers, hormonal changes and physical tests have proven to be very important parameters in the assessment of physical performance. TKD exercise activities of intermittent TKD training are extremely dynamic in nature. Athletes perform explosive movements of high intensity followed by sub-maximal work. In TKD training during the short intervals between high intensity actions the aerobic metabolism is responsible for meeting the energy demands. Measurements of VO_{2max}, HR max and glucose levels are relevant indicators of aerobic metabolism. During high intensity explosive movements, the primary energy systems utilized are the anaerobic ATP-creatine phosphate and lactate systems.

Experimental data relating to the intermediary metabolites and enzyme changes in TKD athletes are scarce in the literature. No information on investigating testosterone, cortisol blood levels and anabolic-catabolic status of TKD athletes in response to Taekwondo training were found**.** Therefore, the enzyme creatine kinase, blood levels of lactate, testosterone/cortisol ratio would be reliable indicators of the involvement of anaerobic and aerobic metabolism. Physical test of TKD athletes, including endurance, explosive power, speed and agility have been conducted (Tabben *et al*., 2014), but further studies in this regard are warranted (Haddad *et al*., 2012).

Finally, it is obvious that experimental research is needed to address the gap and to better understand hormonal adjustments, exercise-induced oxidative stress biomarkers, creatine kinase, lactate, glucose and haematological changes in response to Taekwondo Kyorugi and Poomsae techniques and training.

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CHAPTER 3
RESEARCH METHODOLOGY

3 SUMMARY OF THE CURRENT PRACTICE OF TAEKWONDO TRAINING, PROBLEM RATIONALE AND EXPERIMENTAL APPROACH.

3.1 OVERVIEW OF THE CURRENT PRACTICE OF TAEKWONDO TRAINING PROTOCOL AND SELECTION FOR THE SOUTH AFRICAN NATIONAL TEAM

The athletes competing for the South African National team are divided into five weight categories which are also categorised on the basis gender. Training camps are planned throughout the year but specifically within the following periods.

December - January: The athletes are allowed to do their own training under minimum supervision from the coaches.

February – May: The athletes train with their respective teams from the different provinces of the country namely; KZN, North West, Limpopo, Gauteng, Northern Cape, Mpumalanga and the Eastern Cape. The basic training is done by the coaches to improve the physical fitness and technical skills of the athletes to meet the required criteria for grading and possible selection for the national team. The national coach visits and supervises the progress of the athletes. During this period, qualifications for grading are conducted on all the athletes.

May – July: Here, the training done by the provincial coaches is mainly focussed at improving technical skills in group training of moderate to high intensity training and sparing. The training includes Poomsae, demonstrations, breaking wooden plate, Kyorugi and grading to the next level of belt category. During this period, the athletes compete at provincial tournaments. The national coach again has to visit and supervise the performance at provincial levels. During this period, the athletes have to meet the criteria for the final call for selection to the National team. During the above-mentioned training period, there was no standardised programme but each coach uses his experience and skills in Taekwondo training to select the athletes. The coaches and the athletes are not on the same skill level hence, it may be very difficult for some to measure up to the national requirements and standards.

August – September: The selected athletes who meets the grading criteria and qualify are called to the National team training camp. Due to lack of resources the national camp is mostly organised for one week and very rarely for two weeks. The training schedule includes higher intensity workout loads and improving technical skills. After this training at national level the athletes are sent back to provincial coaches.

September- October: National and International level TKD competitions starts.

3.2 Problem Rationale and Experimental Approach

Analysis of TKD combats during competitions has shown that they consist of very short periods of intermittent high intensity movements which are frequently repeated. TKD training protocols of various duration have been tested and have provided data about the exercise intensity during typical TKD training of 12 weeks (Haddad *et al.*, 2012); maximal oxygen consumption after 8 weeks of Poomsae training (Melhim, 2001) and the rating of perceived exertion (PRE) during 4 weeks of TKD specific technical interval training (Haddad *et al.*, 2012). In contemporary TKD training leading experts have recommended the application of a variety of training, mixing physical and technical aspects of Taekwondo together. This would include specific TKD kicking techniques, while controlling training intensity such as inclusion of high intensity interval sessions (Matsushigue *et al.*, 2009). Furthermore, it should be emphasised that a complementary training should be aimed at improving muscle strength and explosive power of athletes, added to typical TKD training. Therefore, during high frequency TKD training, the adjunction of muscle strength training has to be further experimented (Haddad *et al.,* 2012).

The problem with the training of the provincial and national teams is that some of the selected athletes cannot meet all national criteria, hence, they fail to qualify for international competitions. It is obvious that there is a need to improve the training protocols at the provincial and national level. More so, only one available literature addresses the global need for unifying and improving teaching methods (Avramov, 2013) and creation of methodology for progressing through the technical degree grading. The above mentioned study was focussed and probed on young children and very young athletes. The implementation of this approach might take some years to bring the athletes to international level competitions.

The other approach is to introduce specially designed high intensity training protocols which could be implemented during the provincial and national teams training camp for a period of longer duration (4 weeks compared to 1-2 weeks) which was difficult to achieve due to financial restrains.

This study was designed to subject the University of Zululand, South African TKD athletes who could be selected for the KwaZulu Natal provincial and National teams to a very high intensity intermittent intervention Taekwondo training programme. This programme was combined with resistant strength training and components of endurance training. This programme was compared with a typical TKD training programme. The study was conducted at University of Zululand, South Africa, where all athletes were subjected to the same daily regime scheduled, the same environment to avoid the impact of other factors on the performance.

Physical testing was used to estimate the potential for performance improvement. Testosterone, Cortical and T/C ratio were recorded to reveal the anabolic catabolic metabolic interrelationships. Uric acid in blood is a marker of endogenous antioxidant capacity. The C-reactive protein is a biomarker of subclinical inflammation and oxidative stress. Creatine kinase reflects the muscle damage in response to high intensity exercise in contact sports like Taekwondo.

A structured Taekwondo techniques exercise test was designed to be employed at the beginning and the end of the 4 weeks training period to assess and compare the acute response and the recovery of the blood biomarkers in athletes.

Individual performance z-score radar plots charts based of the physical tests results were implemented to analyse and compare the effect of training on physical tests of each Taekwondo athlete. In addition, the individual z-score radar plots were used to compare the performance of the athletes in the same weight category; to compare and advise them during sparring; to advise the athletes during competition how to use their best performed technical skills against the other competitor (e.g. powerful kicks against the high agility of the opponent)

This is a modern approach towards the intensification of training in contemporary Taekwondo athletes focused also on the individualisation of the training practice protocols.

3.1.1 PILOT STUDY

Preliminary analysis of the current Taekwondo training practice was carried out by the researcher, who is the co-ordinator of KZN TKD provincial team. The summary is presented in Section 3.1

The need to design a very high intensity intermittent training was based on this preliminary analysis.

A pilot study on physical, anthropometrical and physiological profile of an experienced junior South African Taekwondo team was carried out. Some of the results obtained were presented at the 9th FIEP European Congress 7th International Scientific Congress "Sport, Stress, Adaptation" (Mathunjwa *et al*., 2014). Data were collected from 25 males and 11 females having average of 15.2±2.6years. Measurement consisted of body composition flexibility, quadriceps flexibility, lower extremity explosive power (vertical jump), muscular strength, agility and aerobic power.

3.2 ORGANISATION OF THE RESEARCH AND EXPERIMENTAL DESIGN

The research was carried out in four phases.

Phase One: Visits for supervision, analysis of training protocols, grading and performance at provincial tournaments of TKD athletes from three provinces (KZN, North West and Gauteng); January–July, 2014 and January–July, 2015.

Phase Two: Completion of the data analysis of physical, anthropometric and physiological characteristics of experienced junior male and female TKD athletes. In this phase, for the first time z-score statistics and z-score radar plot was used to assess individual performance. The athlete took part in sparring matches within their weight categories and the coefficients of performance were recorded and analysed (Avramov, 2013).

Phase three: Experiment study with TKD athletes recruited from the University of Zululand, South Africa. Data were collected from 34 male and female TKD athletes aged 20 -26 years. The athletes were divided into two groups: control (holders of green or lower belts) and experimental (holders of blue and senior belts) who had provincial, national and international experience.

Prior to the beginning of the study a full verbal and written description of all procedures and requirements of the study was given to all subjects. The participants signed an informed consent form. Ethical approval was sought from the South African Taekwondo Federation and the University of Zululand ethics committee. Behavioral and food intake restrictions were explained and activity record tables and questionnaires on personal details were given to the subjects before testing. All selected participants were included on a voluntary basis. Experimental protocols were conducted in accordance with Helsinki Declaration for Ethical Treatment of Human Subjects.

The research activities in Phase Three conducted in the following stages:

Stage 1: Anthropometric and physiological measurements and physical performance tests for both groups were carried out. Physical performance tests were analysed using individual Z-score radar plots. To assess the effect of both TKD training programmes for 4 weeks, a structured specific techniques TKD test of 20 min was designed. All athletes were subjected to this specific TKD test. Blood samples for biomarkers and hormones were taken by registered nurses at rest (pre-exercise) and 30 mins and post-exercise.

Stage 2: All TKD athletes from the University of Zululand participated in the 4 weeks training programme. The athletes of the experimental group were submitted to a very high intensity intermittent intervention training programme combined with strength training. The athletes from the control group were subjected to common modalities typical TKD training.

Stage 3: The athletes in each group participated in sparing matches within their categories. The performance was evaluated by three expert judges. The coefficients of intensity, success and point effectiveness of the kicks (Avramov, 2013) were recorded and analysed.

Phase Four: After the completion of the 4 weeks TKD training the athletes from the experimental and control groups had to participate again in all experimental procedures described in Phase Three (stage 1, Stage 2, Stage 3) -

The TKD intermittent training was implemented in order to improve the physical fitness, and to bring the athletes' abilities in combat during competition to a higher level. The subjects were instructed to refrain from participation in any other form of training during the testing and training period that might influence changes during the testing period. All participants were nonsmokers and non-users of ergogenic aids and medications known to affect cardio respiratory function during the study.

3.3 DESCRIPTION OF THE PROCEDURES

Experimental testing procedures were performed only in the mornings between 8-12 am. The procedures were scattered over a 2 week period of preparation and few days for testing before and after completion of the training programmes. Upon arrival at the laboratory, the researcher would explain and let participants read and sign an informed consent form (Appendix A).

A health screening interview with a medical doctor was conducted. Physical examination of all participants was carried out; blood pressure, and heart rate were recorded at rest. The exclusion criteria will include irregularities in HR and blood pressure, history of chronic diseases, current infection, use of antibiotics, and herbal, antioxidant or steroid containing supplements.

Sparring matches. Sparring matches were arranged within categories under the supervision of coaches and the assessment by expert judges. The following coefficients (Avramov, 2013) were recorded and calculated:

a) Coefficient of intensity of executed kicks in a TKD match (I_{round} or I_{match}):

I_{round} = number of kicks per round/ 120 sec or

I_{match} = number of kicks per match/360 sec

b) Coefficient of success of the kick (S)

S = number of kicks that score points/total amount of kicks of that type

c) Coefficient of point effectiveness of the kick (PE):

PE = number of points, scored with a specific kick/total amount of the kicks of that type

On the basic reason for acquiring data was that we could determine individually which kicks have a significant influence over the sport result in the match.

The description of the various tests that were performed follows:

Blood pressure measurements. Blood pressure were measured at rest using sphygmomanometer Microlife PPA 100 Plus (Microlife AG, 9435 Heerbrugg, Switzerland). The sphygmomanometer had an integrated stethoscope, and all measurements were performed automatically. Subjects were seated quietly for 5 minutes in a chair with back support, and both feet on the floor with their arm supported at heart level. The cuff was placed at the upper arm, and it was quickly inflating to 200 mmHg, and the pressure was gradually released. Blood pressure was taken, 1-minute rest was given, then a follow up reading was taken, after a further minute rest a 3rd reading was taken. The average blood pressure recorded was used (ACSM 2010).

Resting Heart Rate (HR): The resting heartbeat of the participants was recorded with a stethoscope at the morning of the day after the 5 minutes' rest at sitting and resting position. Measurements were taken by pressuring the radial artery on the left arm and counting the beats per minute using a stop watch for 60 second (ACSM 2010). The results were given as beats per minute.

Heart rate monitor: HR was recorded and expressed as a percentage of participant HR max. (ACSM 2010). Formulas such as 220 - age or 210 - (0.65 9Xage) were used as peak heart rate is unchanged with age. HRpeak was determined as the peak value reached and observed during training.

Anthropometric measurements.

Stature: The height measurement was recorded from the floor to the top of the head. The participants were measured barefoot on a floor surface that is even and firm. The participant stood straight upright, heels together, arms hanging down sides (in a tuck-in position). The heels, buttocks, upper back, and the head were in contact with the wall. The participants were instructed to look straight forward, take a deep breath, and stand as tall as possible (heels must not leave the ground). The stadiometer platform was dropped until it made contact with the top of the head. The results were recorded to the nearest 0.1 cm (ACSM 2010).

Mass: The participants were weighed without shoes wearing light clothes. The scale was calibrated to measure 0 before the participant stepped on. The participants were told to stand upright and evenly distribute the body weight between both feet, in the middle of the scale. Results were recorded to the nearest 0.5 kg (ACSM 2010).

Fat % - 6 site Skinfolds (ACSM 2010).

BMI: According to the ACSM (2010), to determine the subject's body mass index, the body mass (kg) were divided by the height in meters squared (kg.m-2).

3.4 PHYSICAL TESTING

Cardio respiratory fitness testing Bleep test (Aerobic power – Multi Stage Fitness Test (MSFT). This test measured a continuous running between two lines 20-meters apart in time to recorded beeps. The test was made up of 23 levels where each level lasts approximately one minute. Each level comprised a series of 20-meter shuttles where the starting speed was 8.5km/hr and increased by 0.5 km/hr at each level. On the tape a single beep indicates the end of a shuttle and 3 beeps indicated the start of the next level. The athletes score was the level and number of shuttles reached before he/she was unable to keep up with the CD recording. This score can be converted to a predicted VO2max equivalent value. The VO2max obtained in a MSFT is highly correlated (r= 0.92) with VO_{2max} levels obtained using the direct oxygen consumption test (Ramsbottom *et al*., 1988). The ICC for test-retest reliability and TEM for the multi-stage fitness test are reported as 0.90 and 3.1%, respectively (ACSM 2010).

Muscular strength (sit up test) The one minute sit up test was assessed for the strength of abdominal muscles and their ability to exert force to stabilize the trunk. The athletes lay supine with the hips and knees in 90 degree of flexion with arms crossed over the chest. Correct sit ups were ensured when the elbows touch the knees and the lower back touches the floor. The total number of sit ups completed over a period of one minutes was counted (ACSM 2010).

Muscular endurance testing (push-ups test) The maximum two minutes push-ups test was assessed for the endurance of the arms and shoulder girdle i.e. upper body muscular endurance. From a straight arm front leaning rest position, the performer was asked to lower the body until the chest touched the mat and then to push upwards to the straight arm support. The exercise continued for as many repetitions as possible without rest. The score was the number of correct push-ups executed (ACSM 2010).

Flexibility testing (sit and reach test). Trunk flexibility of subjects was measured through sit and reach test. During the test subjects sat on the floor and leaned the foot's sole to the test table in a straight way. Besides, the subject stretched out as possible as they can, bent body forward and the hands in front of the body without twisting the knees. In this position, at the farthest point waited 1-2 seconds without stretching forward or backward. The test was repeated two more times and the highest results were recorded.

Power (Vertical jump) The subjects jumped as high as they could with their hands on their waists bending with a quick movement. By using the results of the test of vertical jumping, the anaerobic power was calculated by using Lewis nomogram (given below):

$P= (\sqrt{4,9} \text{ xWeight}) \times \sqrt{d}$,

D = the result of vertical jumping by means of m.

Agility (hexagon). Agility was assessed by the hexagon test (secs) using a stop watch. A hexagon measuring 60cm on all sides at 120-degree angle was set up. At the start of the test, the athletes would stand inside the hexagon and then jump out and in with both legs on all sides of the hexagon, completing three cycles. The test was completed after the third cycle and the athletes had returned to the starting position (Raven *et al*., 1976).

Agility (T-Test). The T-Test was used to determine the agility of body trunk without loss of balance. The participants ran an equidistance of 10 meters in a T direction apart. Upon auditory signal, (whistle) the participant sprinted forward, laterally and back while touching the base of the marked distance. The participants repeated two timed trials and the best time was recorded.

Blood analysis. Overnight fasting blood was taken from the antecubal vein at the beginning and the end of the 4 weeks high intensity TKD training programme. Blood samples were taken by professional registered nurses 3 times during the study as follows: pre-exercise specific structured TKD test; 30 minutes and 24 hours post-exercise structured test. Blood was collected into both PAXgene (Qiagene, Germantown, MD), EDTA and serum tubes (Greiner-Bio One GmbH, Frickenhausen, Germany). Blood samples were centrifuged at 3000 rpm for 10 minutes at 20°C to separate serum from plasma. For later analysis the serum and plasma were stored at -80°C. The PAXgene tubes were handled according to the manufacturer’s instructions. Erythrocytes, hemoglobin, hematocrit, leukocytes, neutrophils, granulocytes, basophiles, glucose, lactate, uric acid, high sensitive CRP, creatine kinase, cortisol and testosterone were measured. The analysis of blood samples was done in an accredited South African laboratory (Lancet and Ampath) according to the international standards, as required for this kind of study to be comparable with the findings of other researchers.

3.5 HIGH INTENSITY INTERMITTENT TAEKWONDO TRAINING

3.5.1 EXERCISE INTENSITY.

The required intensity for all screened participants who meet the requirements to participate in acute bouts of Taekwondo training were calculated using their heart rate reserve in percentage (HRR). The participants were divided in two groups (control and experimental). Polar heart rate monitors were used to supervise the intensity of the exercise. All athletes participated in concurrent high intensity Taekwondo and resistance training 5 days weekly. The athletes of the experimental group exercised using the very high intensity intermittent training (Table 3.1). The athletes of the control group exercised using the common modalities typical interval TKD training combined with circuit strength training (Table 3.2). The difference between interval and intermittent training protocols should be emphasized. During typical interval training the short periods of exercise of high intensity were interspersed with rest or very slow moves. In our design of high intensity intermittent protocol, the very high intensity bouts (90-100% HRmax) were interspersed with lower intensity bouts (70-75% HRmax) (Table 3.2).

The goal of the design of the intermittent training protocol was to satisfy the demand of Taekwondo matches, including desired physical components of fitness such as strength, power, speed, competition-specific (cardiovascular) conditioning, and relevant technical and tactical aspects. Daily sessions were conducted in the mornings and afternoons with 8-10 hours separating each session. Each training session was observed and noted, and a diary of activities were recorded. HR data were downloaded using Polar precision software (version 4.0), and HRs for the training sessions were categorized and analyzed.

Training protocol

- All athletes participated in concurrent high intensity Taekwondo and resistance training 5 days weekly as follows:

- 60 % TKD training (fighting drills and tactics) – 5 morning sessions of 1.5hours
- 30 % strength training – 3-4 afternoon sessions of 30min
- 10% aerobic exercise – walking, jogging

Training program

All participants followed a Taekwondo training program for four weeks. As shown in Table 3.1, the training program for the experimental group included three components: warm up (TKD body movements together with dynamic stretching exercises to prepare the muscles and heart for action), workout (one-hour training program which involved both hands and feet Taekwondo techniques (blocks, punches and kicks) and cool down. Exercise intensity for intermittent training varied from 85- 100% HRmax during the 1st and 2nd week and 95-100% HRmax during the 3rd and 4th week. Intensities for the control group (Table 3.2), varied from 55-70% HRmax during the 1st and 2nd week and 70 -85% HRmax during 3rd and 4th week. Resistance training of full body exercises was performed for 30-45min, 3 times per week at the gym in the afternoon. The experimental group performed at higher levels of intensity and repetitions while the control group performed at lower levels of intensity and repetitions. Both groups had, 10 minutes of cool down and static stretching exercises. The Taekwondo training took place five times a week from Monday to Friday for 4 weeks.

Table 3.1: Taekwondo Training Programme Outline for the Experimental Group

Week	1-2	3-4
Training intensity %	85–95% of HRmax	90–100% of HRmax
Training frequency Borg RPE Scale	5 times a week 16-18	5 times a week 17-20
Warm up (20min)	Standardized Taekwondo warm-up (jogging, shuttle runs, cone drills) and dynamic stretches (neck, back, abdomen, leg, thigh, calf, ankle, wrist).	Standardized Taekwondo warm-up (jogging, shuttle runs, knee lift) and dynamic stretches (neck, back, abdomen, leg, thigh, calf, ankle, wrist).
Workout (60min)	Kicking target and technical exercises. Attacking and counter-attacking. Kicking drills executed continuously (Ap Dollyo Chagi, Dollyo Chagi, Ap Dollyo Chagi, Mom Dollyo) all done with alternating legs and arms.	Kicking target and technical exercises. Kicks executed continuously in various combinations, turning kicks, step fighting exercise. Step attacks with random counterattacks performed at the command of the coach/instructor.
Cool down (10min)	Static stretches (hold 10-15s twice). Neck, chest, triceps, upper back, abdomen, leg, thigh, calf, ankle, wrist, etc).	Static stretches (hold 10-15s twice). Chest, triceps, upper back, abdomen, hamstring, quards, thigh, calf, ankle, wrist).

HR_{max}-maximum heart rate, %- percentage, Reps – repetitions

Table 3.2: Taekwondo Training Programme Outline for the Control Group

Week	1-2	3-4
Training intensity %	60–70% of HRmax	70–85% of HRmax
Training frequency Borg RPE Scale	5 times a week 11-13	5 times a week 14-15
Warm up 20mins	Standardized Taekwondo warm-up (Taekwondo drills and dynamic stretches).	Standardized Taekwondo warm-up (Taekwondo drills and dynamic stretches).
Workout (60mins)	Kicking target and technical exercises. Attacking and counter-attacking. Kicking drills executed continuously (various kicks and blocks).	Kicking target and technical exercises. Kicks executed continuously in various combinations; direct, turn and twist kicks, including step fighting.
Cool down (5mins)	Static stretches (hold 10-15s twice). Neck, chest, triceps, upper back, abdomen, leg, thigh, calf, ankle, wrist.	Static stretches (hold 10-15s twice). Chest, triceps, upper back, abdomen, hamstring, quads, thigh, calf, ankle, wrist.

3.6 RESISTANCE TRAINING

The schedule of the resistance training is presented on Table 3.3 (control group) and Table 3.4 (experimental group). The difference between the two programme outline is in the number of sets and the number of repetitions. The goal of the resistance training was to improve the muscle strength and power of the upper body, trunk and lower body.

Table 3.3: Taekwondo Resistance Programme Outline for the Control Group

	Training (afternoon)		
Week 1	Weight training 12 reps for 2 sets 8 -10 reps (85-100%)	Resistance training (upper body- Power clean: push press, dumbbell raise. Lower body: Power snatch, squat, dead lift, leg curls, trunk and abdominal routine) 2 sets, 8- 10 Reps	4 sessions per week
Week 2	Weight training 12 reps for 2 sets 8 -10 reps (85-100% >)	Resistance training (upper body: Power clean, push press, dumbbell raise. Lower body: Power snatch, squat, dead lift, leg curls, trunk and abdominal routine) 2 sets, 8- 10 Reps	5 sessions per week
Week 3	Weight training 12 reps for 2 sets 8 -10 reps (85-100%)	Resistance training (Upper body: Incline bench press, lateral raises, triceps and biceps dumbbell, lower body: – squat, calf raises, dumbbell lunges and Trunk and abdominal routine) 3 sets, 8-10 Reps	5 sessions per week
Week 4	Weight training 12 reps for 2 sets 8 -10 reps (85-100%)	Resistance training (Upper body- incline bench press, lateral raises, triceps and biceps dumbbell, lower body – squat, calf raises, dumbbell lunges, trunk and abdominal routine) 3 sets, 8-10 Reps	5 sessions per week

Table 3.4: Taekwondo Resistance Training Programme for the Experimental Group

	Training (afternoon)		
Week 1	Weight training 12 reps for 4 sets, 10-15 Reps (85-100% of HRmax)	Resistance training (Upper body: Power clean, push press, dumbbell raise, Lower body-Power snatch, squat, dead lift, leg curls, trunk and abdominal routine) 4 sets, 10- 15 Reps.	5 sessions per week
Week 2	Weight training 12 reps for 4 sets, 10-15 Reps (85-100% of HRmax)	Resistance training (Upper body: Power clean, push press, dumbbell raise, Lower body: Power snatch, squat, dead lift, leg curls, trunk and abdominal routine) 4 sets, 10- 15 Reps.	5 sessions per week
Week 3	Weight training 12 reps for 4 sets, 10-15 Reps (95-100% of HRmax)	Resistance training (Upper body: incline bench press, lateral raises, triceps and biceps dumbbell, Lower body – squat, calf raises, dumbbell lunges, trunk and abdominal routine) 5 sets, 10-15 Reps	5 sessions per week
Week 4	Weight training 12 reps for 4 sets, 10-15 Reps (95-100% of HRmax)	Resistance training (Upper body- incline bench press, lateral raises, triceps and biceps dumbbell, lower body: squat, calf raises, dumbbell lunges, trunk and abdominal routine) 5 sets, 10-15 Reps	5 sessions per week

3.6.1 STRUCTURED TAEKWONDO TEST (sTT) DESIGN

The structured Taekwondo test is a technical workout of 20 minute duration, which consists of various kicks (Dollyo chagi montongo, Naeryo chagi, Parmbal dollyo chagi, Chirrugi, Mirro chagi, Nare chagi, Dwit chagi) performed at high intensity similar to the intensity of the TKD matches (Table 3.5).

Table 3.5: Structured Taekwondo Test (sTT)

Structured Taekwondo test (sTT) design		
Time Activity	**Intensity %**	**Tasks and Specific Techniques**
Dynamic Warm up & Static stretching (5 minutes)	60-80% HR_{max}	**Drills** (run through, leg swings, skipping, ankle bounces, jogging and shuttle run) **Circular kicks** (roundhouse kick and hook kick **Linear kicks** (side, axe, push and back kicks)
Workout (20 minutes)	One set (5minutes) at 75-85% HR_{max}	**Stepping back and forth in different positions on ready stance:** high-intensity Taekwondo movement (defense, attack and counter-attack) performed at the command of the coach.
	Two sets (5minutes by 16 reps each) 15 secs at 85-95% HR_{max} 5 sec at 65-75%HR_{max}	**Kicking techniques:** executing different techniques such as; Dollyo chagi montong, Naeryo chagi, Parambal dollyo chagi, Chirrugi, Mirro chagi, Nare chagi, Dwit chagi.

	One set (3minutes) at 70%HR_{max}	**Technical exercises**: continuous push- ups, sit- ups, burpes.
	One set (2minutes) at 100% HR_{max}	**Sparring drills:** Mini matches: sparring with an opponent from the same category.

3.1

3.7 DATA ANALYSIS

The data from this study were safely kept such that only the researcher and the supervisors had access to this information. Data collected were expressed as mean, plus or minus standard deviation. An analysis of variance (ANOVA) was used to determine if differences exist between and within the male and female groups of participants data at different time points, with the significance was set at $p < 0.05$. Due to the relatively small sample size, the statistical power of the study was calculated using two statistical power calculator: Alpha error level criterion set at 0.05 or 5% confidence level (i.e. 5% chance the null hypothesis to be rejected incorrectly) and beta criterion set at 0.80 - or 80% confidence level (i.e. 20% chance of accepting the null hypothesis incorrectly). The beta criterion level is chosen as a protection against this type of error. Additionally, individual performance Z-score radar plots were used to compare the physical test results before and after the 4 weeks period of training.

3.8 RESEARCH VARIABLES

3.8.1 DEPENDANT VARIABLES

- Physiological characteristics (blood pressure, heart rate, height, mass, fat %, lean body mass)
- Physical characteristics (cardiorespiratory fitness, explosive power, vertical jump, speed, agility, strength, flexibility
- Intermediary metabolites (lactate, glucose) and creatine kinase.
- Haematological parameters (RBC, WBC, Platelets)

- Uric Acid and C-reactive protein
- Testosterone, Cortisol and T:C ratio,

3.8.2 INDEPENDENT VARIABLES:

- Intermittent Taekwondo training
- Sparring matches

3.9 ETHICAL CONSIDERATIONS

Prior to this study, the University of Zululand Policies and Procedures on Research Ethics, as well as the Policies and Procedures on Managing and Preventing Acts of Plagiarism were read and contents understood by both the researcher and the participants.

The current study involved physical fitness testing procedures conducted on experienced junior TKD athletes. Prior to the study, permission was obtained (see appendix B) from the South African Taekwondo Federation (SATF) to test and collect data from their athletes; the participant's personal information was kept confidential. More so, the current study involves testing procedures for the assessment of body composition and physical characteristics of male and female TKD athletes from the University of Zululand. Therefore, ethical clearance certificate (certificate no UZREC 171110-030 RGD 2015/88) was obtained from the University of Zululand Research Ethics Committee after the submission of various letters of approval for the study.

The Taekwondo athletes wore chest-belt HR monitor (P Polar Vantage XL, Finland) and wrist receiver for collecting HR data during training.

Blood was drawn from an antecubital vein in front of the elbow by a qualified phlebotomist (Lancet Laboratories) using standard aseptic procedure which caused no harm but slight pain to the participant. Moreover, one doctor was present during the testing and training phases in case of an emergency.

3.10 METHOD A: TAEKWONDO ATHLETES AT PROVINCIAL LEVEL

3.10.1 PARTICIPANTS

Thirty-four (n = 34) active TKD practitioners (20 males and 14 females) aged 20 - 26 years volunteered for this study. Following an explanation of all procedures, risks and benefits, each participant expressly gave their informed consent to participate in the study. The participants were active members of the South African Taekwondo Federation. The athletes were divided into control and experimental groups. The control participants (10 males and 7 females) were those with green or lower belts and with provincial exposure in terms of TKD competitions. The experimental group (10 males and 7 females) had blue or senior belts and are qualified to represent their provincial clubs and to compete at international TKD championships. The two groups were subjected to both Taekwondo training and strength training. Measurement of the variables took place during the competition phase of the provincial selection. The study was conducted according to the Human Rights Declaration of Helsinki and approved by the South African Taekwondo Federation (SATF). Each athlete had a log book for recording their heart rate and were how to use the Borg Rating of Perceived Exertion (RPE) scale to keep records of performance each week.

3.11 METHOD B: TAEKWONDO ATHLETES AT NATIONAL LEVEL

3.11.1 PARTICIPANTS

Thirty-six junior Taekwondo athletes (24 males and 12 females) with a median age of 15.5±2.6 years voluntarily participated in the study. From this sample, 6 males and 2 females are internationally ranked fighters (African championships); 4 Korean championship participants; 4 male world championship participants; 8 males and 4 females Junior International Medalists and 10 other internationally ranked athletes who had participated in the Korean Ambassador’s Cup. The participants were members of the junior national South African Taekwondo team drawn from various provincial clubs. The inclusion criterion for participants in this study included a minimum of two years of competitive Taekwondo experience, and an average competitive experience of three years. After securing ethical clearance and prior to participation, all athletes received verbal and written explanations of the study procedures and its potential risks. Participation was voluntary and athletes could decide not to participate. Having decided to participate, each athlete then signed an informed consent form. The study was thereafter conducted according to the Declaration of Helsinki and approved by the South African Taekwondo Federation (SATF). More so, the participants were asked to refrain from any food intake for two hours before the measurements and to avoid caffeine, alcohol and strenuous exercise within 48 hours prior to the tests.

3.12 TESTING PROCEDURES

Before and subsequent to a 4-week Taekwondo training and strength programme, the following tests were administered: anthropometric measurements (stature, body mass, skinfolds); physical tests (flexibility, muscle strength and endurance, lower leg power and agility) and physiological measurements (SBP, DBP, RHR). The participants were familiarized with all procedures before the actual measurements were made. Proper technique of doing each test was explained and demonstrated. Thereafter, the tests were performed by participants altogether at the same time of the day.

3.13 ANTHROPOMETRIC MEASUREMENTS:

Body weight of individuals was measured in kilogram (kg) with participants wearing light clothes and standing bare footed on a digital scale (Kubota, Japan). Stature was measured using a stadiometer (La Fayette, IN, USA) with the participants standing upright with their heads in the Frankfort plane. Body mass index (BMI) was calculated as weight divided by height squared (kg/m^2). Six skinfolds (triceps, biceps, subscapular, thigh, calf and suprailiac) were measured using the Holtain T/W Skinfold Caliper, (Galaxy Informatics, Delhi, India).

3.13.1 PHYSICAL TESTS AND PHYSIOLOGICAL PERFORMANCE MEASUREMENTS

After sufficient warm-up and stretching the following tests were conducted:

1. Flexibility was measured in centimeters by the sit and reach (S&R) test using the La Fayette sit and reach box (Model 01285A: La Fayette, USA). The sit and reach test gauges the flexibility of the hamstrings and lower back muscles, with a reliability measure of 0.92 (Behm *et al.*, 2006). Athletes were instructed to sit with their knees extended on the floor against the box. With hands on top of each other and palms facing down, the athletes pushed the ruler forward as far as possible without jerky movements. The score in centimeters was the most distant point reached by the edge of the ruler in contact with the finger tips.

2. Agility was tested using the hexagon test and the T-Test.

a) In the hexagon test, a hexagon 60cm on all sides and 120 degree internal angles was set up. At the start of the test, the athletes stood inside the hexagon and jumped in and out with both legs on all sides of the hexagon, completing three cycles. The test was finished after the third cycle and the time taken to achieve this was measured in seconds using a Stop-watch. The purpose of the test was to see how quickly the leg can move while changing directions.

b) The T-Test was used to determine the agility of the body trunk without the loss of balance. It included forward, lateral and backward running. A running course in the form of a capital letter T was marked on the floor. The vertical and horizontal arms of the T were both 10 metres long, with the vertical arm made to form a junction at the mid-point of the horizontal arm. To begin the test, a participant was made to stand at the base of the vertical arm facing the horizontal arm. Upon an auditory signal (whistle), the participant sprinted forward, towards the horizontal line. At the junction the athlete shuffled to the left without crossing legs and facing the direction of the run. Upon reaching the end of the horizontal line on the left, the athlete shuffled laterally past the junction to the far end on the right. The athlete then shuffled laterally again towards the left for 5 meters to the junction of the two lines. From the junction the athlete ran backward passing the starting point at the base of the vertical line. For the purpose of this study, the participants performed this test twice (two-timed trials) and the faster time was recorded.

3. Muscular endurance was assessed by the one-minute sit-up and push – up tests (repetitions).

a) The one-minute sit-up test assessed the trunk and hip flexor muscular endurance. The athletes laid supine with the hips and knees in 90 degree of flexion with arms crossed over the chest. Correct sit-ups were ensured when the elbows touched the knees and the lower back touched the floor. The total number of sit-ups completed over a period of one minutes was counted (Sparling, 1997).

b) The one-minute push-up test assessed the endurance of the arms and shoulder girdle i.e. upper body muscular endurance. From a straight arm front leaning rest position, the performer was asked to lower the body until the chest touched the mat and then to push upwards to the straight arm support. The exercise was continued for as many repetitions as possible without rest. The score was the number of correct push-ups executed.

4. Maximal strength of both right and left hands of the participant were assessed using a Takei hand grip dynamometer (Takei, Kikikogyo, Japan). The test was performed in a standing position, arms in 90º flexion alongside the body. Then, participant was asked to squeeze the dynamometer with maximum isometric effort for a 5 second period. Three trials were made with a resting period of about 10-20 seconds between the efforts to minimize the effects of muscle fatigue. According to the American College of Sports Medicine (ACSM, 2000), the highest score was recorded.

5. Explosive leg power was measured by the vertical jump test using the Swift yardstick device (Swift Performance Equipment, Goonellabah, NSW, Australia), whole leg power was measured by a standing broad jump measured in centimetres.

a) The athletes reached with their dominant arm as high as they could against the vane style apparatus to measure the initial reach height. Using a counter-movement jump, the athletes jumped and reached as high as possible on the Vane style apparatus. The difference (Diff VJ) between the highest point touched and the initial reach height was recorded as the score in centimeters. The inta-class correlation coefficient (ICC) for test-retest reliability in vertical jump is 0.96 and 3.3%, respectively (Gabbett *et al*., 2009). The vertical jump anaerobic power was determined using Lewis nomogram (Sayer *et al*., 1999) and presented as relative power R in W/kg.

b) A tape measure was used (Stanley Power Locks, Tokyo, Japan) to measure the distance after jumping forward on a linoleum floor surface. Participants stood behind a starting line and were instructed to push off vigorously and jump as far as possible. The participant had to land with the feet together and stay upright. Two measurements were made and the best score was recorded to the nearest 0.1 cm from the distance between the toes at take-off and heels at landing nearest to the take-off spot. The reliability coefficient of the test is reported as 0.90 (Johnson and Nelson, 1986).

6. Aerobic power was measured using the multistage fitness test (MSFT). This test measured continuous running between two lines 20-meters apart in time to recorded beeps. The test was made up of 23 levels where each level lasts approximately one minute. Each level comprises a series of 20-meter shuttles where the starting speed is 8.5km/hr and increases by 0.5km/hr at each level. On the tape a single beep indicates the end of a shuttle and 3 beeps indicates the start of the

next level. The athletes' score is the level and number of shuttles reached before he/she is unable to keep up with the CD recording. The score was converted to a predicted VO_{2max} equivalent value (Gabbett *et al*., 2009). The VO_{2max} obtained in a MSFT is highly correlated (r= 0.92) with VO_{2max} levels obtained using the direct oxygen consumption test (Ramsbottom *et al*., 2009). The ICC for test-retest reliability and TEM for the multi-stage fitness test are reported as 0.90 and 3.1%, respectively (Leger *et al*., 1988).

3.13.2 BLOOD ANALYSIS

The blood was taken from the antecubal vein at the beginning and the end of the 4 weeks high intensity TKD training programme. Blood samples were taken from the participants by registered nurses at the pre- and post- structured TKD exercise stages. Blood was collected into both PAXgene (Qiagene, Germantown, MD), EDTA and serum tubes (Greiner-Bio One GmbH, Frickenhausen, Germany). Whole blood was centrifuged at 3000 rpm for 10 minutes at 20ºC to obtain separate fractions of plasma and serum. Thereafter, the blood analysis was carried out at the Lancet Laboratories situated within the premises of Richards Bay Hospital using standard hematological and pathological procedures according to international standards for international comparativeness.

The following tests were conducted;
Blood tests included; erythrocytes, hemoglobin, hematocrit, leukocytes, neutrophils, granulocytes, basophil, glucose, lactate, uric acid, high sensitive CRP, creatine kinase, cortisol and testosterone, white blood cell (WBC), red blood cell (RBC), mean cellular volume (MCV), mean cellular hemoglobin (MCH), mean cellular hemoglobin concentration (MCHC), red distribution width (RDW) determination.

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CHAPTER 4
PHYSIOLOGICAL PROFILES OF SOUTH AFRICAN TAEKWONDO ATHLETES

4 PHYSICAL, ANTHROPOMETRICAL, AND PHYSIOLOGICAL PROFILES OF EXPERIENCED JUNIOR MALE AND FEMALE SOUTH AFRICAN TAEKWONDO ATHLETES

4.1 INTRODUCTION

Taekwondo (TKD) is a Korean martial art sport that originated 1500 years ago. This combat sport was used as a way of life, a strategy for self-defense, physical fitness and warfare being the aspect of concern at that point in time (Pons van Dijk, Huijt & Lodder, 2013). Today, over 140 countries practice Taekwondo globally out of which 120 nations are officially members of the World Taekwondo Federation (WTF) (Kazemi *et al*., 2006).

Successful participants in combat sport like Karate, Judo, Boxing, and Taekwondo require high levels of technical, tactical, psychological, physical fitness and physiological characteristics. (Chiodo *et al.*, 2012). Taekwondo has unique technical actions and rules different from Kick Boxing and Karate, although they share the same competitive level and have similar techniques such as kicks and punches.

It is clear that scientific information on such characteristics helps coaches to enhance athletes' performance, determine weaknesses and correct them by designing specific training programmes for improvement (Zar *et al*., 2008). High level physical fitness training programme has been designed to suit the specific demands of Taekwondo (Bridge *et al*., 2007). Specific Taekwondo conditioning prepares the contestants to effectively manage their performance. The conditioning method requires improving both physiological demands of the competition and the physical competences of the participants (Yen Ke-tien, 2012). To date, there is no comprehensive study reporting on the physical and physiological profiles of young professional South African Taekwondo athletes. The purpose of this study was to investigate the anthropometric, physical, and physiological characteristics of junior South African Taekwondo athletes.

4.2 METHODS

4.2.1 PARTICIPANTS

Thirty-six junior Taekwondo athletes (24 males and 12 females) aged 15.5±2.6 years voluntarily participated in the study. The sample was made up of 6 males and 2 females internationally ranked fighters (African championships 1st to 3rd places), 4 Korean championship participants, 4 male world championship participants, 8 males and 4 females junior international medalists and 10 other internationally ranked athletes who had participated in the Korean Ambassador's Cup. The participants were members of the junior national South African Taekwondo team drawn from various provincial clubs. The inclusion criteria for participants in this study included minimum of two years of competitive Taekwondo experience, and an average competitive experience of three years. After securing ethical clearance and before participation, all athletes received verbal and written explanations of the procedures and potential risks. Participation was voluntary and athletes could decide not to participate. Having decided to participate, each athlete then signed an informed consent form. The study was conducted according to the Declaration of Helsinki and approved by the South African Taekwondo Federation (SATF).

4.2.2 STATISTICAL ANALYSIS

Statistical analyses were performed using IBM SPSS v. 20.0 (SPSS, Chicago, USA), Values from anthropometric, physical and physiological measurements and tests were expressed as mean ± SD. One-way analysis of variance (ANOVA), with a subsequent independent *t*-test was used to examine differences in physical and physiological characteristics among the Taekwondo athletes. The level of significance was set at $p \leq 0.05$.

Due to the relatively small sample size, the statistical power of the study was calculated using two statistical power calculators: Alpha error level criterion set at 0.05 or 5% confidence level and Beta criterion set at 0.80 or 80% confidence level (Zodplay, 2004). Z-criterion statistics (Marronna, Martony & Yohar, 2006) was applied for preparing computerised individual performance Z-score radar plots and used for comparison of the physical test results between athletes falling under the same category.

4.3 RESULTS AND COEFFICIENTS ANALYSIS

Physical characteristics of the Taekwondo athletes are presented in Table 4.1.

Male Taekwondo athletes tend to have slightly higher body mass and stature than females. No differences in BMI were noted. Statistically significantly higher body fat ($p<0.001$) and sum of skinfolds ($p<0.05$) were found in junior female athletes compared to males.

Table: 4.1 Physical characteristics of the South African Taekwondo male and female athletes (mean ± SD)

Variable	Males (n=25)	Females (n=11)
Body mass (kg)	53.3±13.4	51.8±10.7
Stature (cm)	163.0±13.4	157.1±9.1
BMI (kg/m^2)	20.0±7.5	20.9±1.3
%BF	16.8±6.0	26.7±2.8*
SUM 6sf (mm)	67.5±49.2	119.7±35.0**

* $p< 0.001$ ** $p< 0.05$; %BF: body fat percentage; SUM 6sf (mm): sum of 6 skinfold in millimeters

Physical tests and physical performance profiles of the junior Taekwondo athletes are shown in Table 4.1. Male athletes have significantly higher maximal oxygen uptake ($p < 0.001$), maximum grip force of both hands ($p < 0.05$) and higher ($p < 0.05$) upper body muscular endurance (push-ups). No significant differences were found in the following variables: BMI, body mass, stature, sit and reach, hip flexor flexibility, relative power, hexagon test, agility T-test and sit ups.

Table 4.2: Physical tests and physiological performance profiles of the South African Taekwondo male and female athletes (mean ± SD)

Variable	Males (n=25)	Female (n=11)
Sit & reach (cm)	40.1±7.9	42.6±6.4
Hip Flexor flexibility L(cm)	-11.2±7.9	-9.3±9.7
Hip Flexor flexibility R (cm)	10.7±8.1	7.6±9.7
Quadriceps flexibility L (cm)	59.8±9.4	59±10.3
Quadriceps flexibility R (cm)	59.7±12.1	62±9.5
Vertical jump height (cm)	49.0±14.0	41.5±7.3
Relative power R (W/kg)	15.1±2.8	14.0±1.2
Estimated Maximum oxygen uptake (ml/kg/min)	42.2±6.8	31.7±4.7 *
Hexagon test L (sec)	16.7±3.1	16.4±2.4
Hexagon test R (sec)	16.6±2.7	16.6±2.5
Agility T-test (sec)	12.6±1.2	14.2±1.4
Maximum grip force R(kg)	33.0±8.6	25.3±4.9 **
Maximum grip force L (kg)	32.9±8.7	24.6±5.2 **
Sit-ups (reps)	48.9±13.8	41.5±12.3
Push-ups (reps)	25.6±10.5	9.0±6.5 *

* $p < 0.05$ ** $p < 0.01$

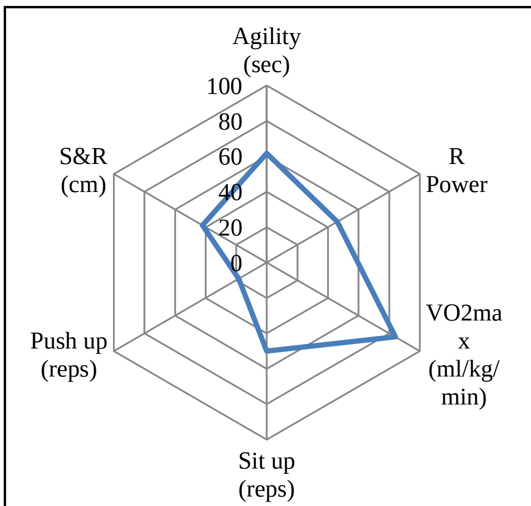
cm: centimeters, R: right, L: left, W: Watts, sec: seconds, reps: repetitions, kg: kilograms

Z-criterion statistics was used to design Z-score radar plots based on six fitness components (agility, R-power, VO_{2max}, sit up, push up and sit and reach) are relevant to success in taekwondo. These selected variables are very important in sustaining the athlete for the two minutes' fight during the three rounds of play and are fundamental for the strategy and tactics in the fight.

The results of the Z-score individual radar plots (in %) of two TKD male athletes of the same category are presented in Table 4.3 and Figures 4.1 and 4.2.

Table 4.3: Individual Z scores (in %) of two male Taekwondo athletes

		Agility (sec)	R Power	VO_{2max} (ml/kg/min)	Sit up (reps)	Push up (reps)	S&R (cm)
Z-score (in %)	M.P.	61.8	46	84	50	18.4	42.1
	N.D.	96.4	38.2	46	57.9	38.2	9.7



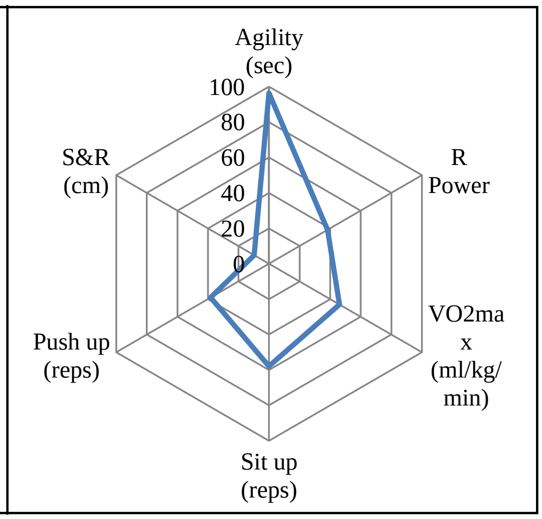


Figure 4.1: Z-score individual radar plots (in %) of male athlete M.P - 14yrs, 43.7 kg	**Figure 4.2:** Z-score individual radar plots (in %) of male athlete N.D - 16yrs, 43.8 kg

Analysis and practical implications of Z-score

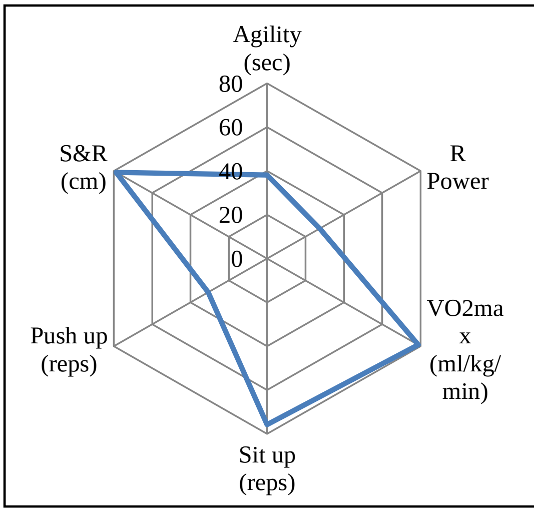
Athlete M.P. (Figure 4.1) showed a better flexibility, slightly higher anaerobic power and greater aerobic power. Based on these results, the athlete is likely to perform better than the opponent. The athlete would be technically and tactically advised to utilize his skills earlier in the first round with accuracy when kicking during attacking more especially towards the face. That would be a simple way of earning more effective points. M.P. might be able to fight more rounds because of his higher aerobic power, but his training should be focused on improving muscular endurance and agility.

Athlete N.D. (Figure 4.2) displayed greater level of agility and reasonable muscular endurance of the trunk and the upper body. He was able to fight more than 3-min rounds and probably 3-5 times in the same day. Due to his high agility the athlete will stand a good chance to avoid all the powerful long kicks from his opponent by quickly changing the direction and attacking. The player needs to commit the first round to save energy, by thinking on how to create fast moves during the fight and escape attacks from his slow but flexible opponent. The coach needs to emphasize on technique and tactic on fast counterattacking movements with this player against the opponent. Athlete N.D. has to know how to avoid the most effective kicks from the opponent, by analyzing his strategy. The strategy is to play to survive until the last round because his muscular endurance would be an advantage for longer fight period.

The results of the Z-score individual radar plots (in %) of two female TDK athletes of the same category are presented in Table 4.4 and Figure 4.3 and Figure 4.4.

Table 4.4: Individual Z-score (in%) of two Taekwondo female athletes.

		Agility (sec)	R Power	VO_{2max} (ml/kg/min)	Sit up (reps)	Push up (reps)	S&R (cm)
Z-score (in %)	C.J.	38.2	27.4	78.8	75.8	30.8	78.8
	S.C.	99.6	15.9	15.5	78.8	72.6	21.2



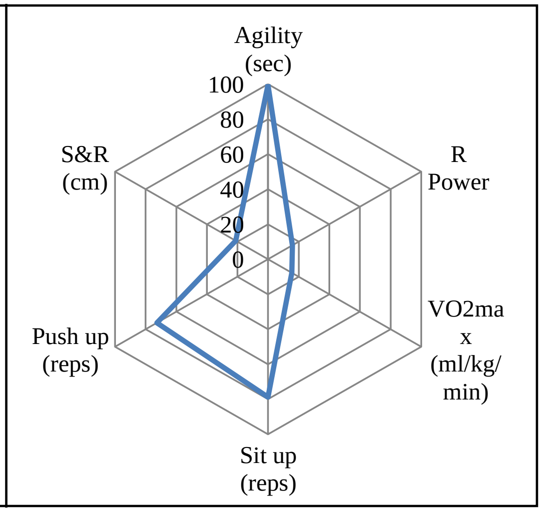


Figure 4.3: Z-score individual radar plots (in %) of female TKD athlete C.J. - 12 yrs, 34.5 kg	**Figure 4.4:** Z-score individual radar plots (in %) of female TDK athlete S.C. - 11 yrs, 36.6 kg

Analysis and practical implications of Z-score

Female athlete C.J. (Figure 4.3) showed a good trunk muscular endurance (assessed by sit-ups), flexibility, and greater aerobic power, but poor upper body muscular endurance and low power performance. The athlete needs to set her favourable pace to accumulate more points in the game. Technical and tactical advice would be to utilize her skills earlier in the first round. The advice from the coach would be to ensure that the athlete controls the game with consistent attacking to defeat the opponent's main characteristics - muscle endurance and agility. Strategically, the athlete has to use her flexibility and trunk muscle endurance to execute a wide range of defending and counterattacking kicks to frustrate the opponent. Athlete C.J. in her fight could be able to proceed to 2nd and 3rd round due to her high aerobic capacity and she could be able to play more than 2 times per day.

Female athlete S.C. (Figure 4.4) displayed higher level of agility, higher upper body muscle endurance (push-up), the same level of muscle trunk endurance, lesser explosive power (R-power) and very low aerobic power compared to C.J. She can avoid all strong flexible kicks from the opponent by using her very high agility to change directions and attack closely. The player needs to save energy in order to complete all rounds. The coach has to advise the athlete that each time she has the opportunity to collect points she should execute a quick sequence of fast kicks to be able to lead the fight. The greatest advantage for this athlete is her agility and she has to create more of these kicks to counteract the flexible but slow opponent C.J. Aerobic training sessions should be recommended to S.C.

4.4 ANALYSIS OF THE TECHNICAL INDICATORS IN A TAEKWONDO MATCH BASED

The purpose of this analysis was to establish specific indicators for the utilized techniques in a taekwondo match and to point out the directions of the development of the scoring techniques. In the course of the study, video analyses were used to identify the indicators of the utilized techniques and also to analyse the acquired data.

4.4.1 ANALYSIS OF THE RESULTS

Figure 4.5 Identifies the name of different kicks of Taekwondo athletes.

https://www.google.co.za/imgres?imgurl=https%3A%2F%2F67.media.tumblr.com%2Fe04dfc09349886a16372da24193cd86b%2Ftumblr_ob7gs1o5EY1udghf4o1_500.gif&imgrefurl=https%3A%2F%2Fwww.tumblr.com%2Ftagged%2Fwithshu&docid=2CZ88gvY2it0JM&tbnid=hYDOpGvpolmDlM%3A&w=490&h=238&bih=986&biw=1920&ved=0ahUKEwiQ2OCVnM_OAhWoIcAKHehdDT4QMwgnKAswCw&iact=mrc&uact=8

Table 4.5 Technical indicators in the Taekwondo matches of the 2015 South African National team selection.

Type of kicks	Number of kicks	Number of kicks on target	Number of points, scored	Coefficient of success	Point efficiency of the hit
Dollyo chagi momtong	63	38	41	60.3	65.07
Dollyo chagi with front leg	21	12	14	57.14	66.66
Naeryo chagi	10	2	2	20	20
Parrumbal dollyo chagi	10	3	4	3	40
Narre chagi	3	1	1	3.33	3.33
Chirrugi	3	1	2	3.33	66.66
Mirro chagi	2	0	0	0	0
Dwit chagi	22	5	6	22.72	27.27
Tiurige Turning back kick	11	2	2	18.18	18.18
Dollyo chagi olgul	9	2	4	22.22	44.44
Parrumbal dollyo chagi olgul	10	4	5	40	50
Dollyo chagi hagi	8	2	4	25	50
Dollyo chagi Narabam	10	2	3	30	20
TOTAL	182	74	88		

The types of kicks that were observed are shown in Table 4.5 above. There were 13 types of kicks identified, 1 type of punch, 2 types of penalties and their numerical indicators. Furthermore, a coefficient of success of the kicks and indicator of point effectiveness were identified. We investigated the number and type of the executed kicks for each round, the number of the points scored with each kick or punch and the coefficient of success of the kicks for each of the examined athletes. This coefficient represents the ratio between the numbers of kicks that scored a point towards the total amount of that type of kick. During the processing of the data it turned out that the "coefficient of success of the kick" is not a sufficient indicator of the win in every match. That is why we introduced the term "Point effectiveness of the kick", which represents the ratio between the numbers of points scored with a type of kick towards the total number of kicks of that type. The total amounts of executed kicks for the 8 reviewed match amounts to 182; the kicks and punches that have scored points are 74, and the points scored are 88.

4.5 DISCUSSION

The Taekwondo athletes who took part in this study were preparing for their provincial championship. The athletes were very close to their peak performance and the study was conducted a month preceding the championship. Most of the participants were national medallist, and some qualified to participate in the junior World Championship. Therefore, they were some of the best South African athletes in their categories at the time of data collection, and they could be considered as elite junior athletes. Knowledge of the physical and physiological profile of elite athletes in South African Taekwondo sport is important to determine the ability associated with high performance.

It is well known that TKD athletes regularly reduce their body mass to compete in their desirable, selected weight categories and to optimize their power to weight performance during combat (Tsai, Chou, Chang & Fang, 2011; Brito et al., 2012). The mean values of body mass and BMI recorded in the present study corroborate the values reported by previous studies and recommended to facilitate performance and maintain good health status (Rodriguez, DiMarco & Langley., 2009: Bridge, da Silva Santos, Chaabene, Pieter & Franchini, 2014). It had been found that high VO_{2max} in TDK athletes is related to a decrease in body fat percentage and an increase in lean body mass (Kazemi et al., 2006). According to the international Taekwondo norms body fat percentage has been reported to range between 11-14% and 19.5-24% for junior males and females respectively (Bridge, Jones & Drust, 2011). However, the data from the present study showed a higher proportion of body fat, which seems to be related to numerous factors such as diet, competition level, experience, sex and age.

Recent studies with the Wingate test have shown that medalist Taekwondo athletes rely on generation of high peak power in the lower limbs (Tornello, Capranica, Chiodo, Minganti & Tessitore, 2013; Bridge et al. 2014). Therefore, TKD athletes require high anaerobic power abilities to manage the energy requirements of the bouts effectively and excellently (Matsushigue, Hartmann & Franchini. 2009; Santos, Franchini & Lima-Silva 2011). The findings of these studies and our findings on leg relative power are in line with the work of Markovic, Vucetic and Cardinale, (2008) and Harris, (2014), who concluded that Taekwondo athletes depend on the anaerobic alactic power, and explosive leg power and strength. Compared to data on vertical jump reported by Ghorbanzadeh et al., 2011 and used as criteria for selection of national teams, our results from vertical jump test are higher by 10 cm in males and by 14 cm in females TKD athletes respectively. At present, much emphasis is placed on lower limb speed and power that needs to be significantly improved and which is necessary to generate the required sudden bursts, fast and powerful kicks in Taekwondo performance.

Aerobic fitness was considered previously of a lesser importance for Taekwondo competitive success (Harris, 2014). In fact, high reliance on aerobic power is needed to support and facilitate Taekwondo matches especially during recovery between successive bouts in tournaments (Bridge, McNaughton, Close & Drust, 2013; Campos et al., 2012). A powerful cardio-respiratory system is needed to sustain the metabolic demand. The level of cardiorespiratory fitness in Taekwondo differs in terms of competitions, success, experience, and weight category. Recent studies revealed that ideal values of VO_2max scores in junior female Taekwondo athletes were around 31- 41 ml/kg/min (Kim, Stebbins, Chai & Song, 2011), while ideal values for junior male Taekwondo athletes were 41- 49 ml/kg/min (Bridge et al., 2012). In combat sports (Taekwondo, Karate and Judo), while energy is generated predominantly through anaerobic pathways (alactic and lactic system) in the support of technical and tactical actions in combat, cardiorespiratory fitness is critical for recovery and the regeneration of energy during tournaments were athletes fight from one stage to the other (Chaabene, Hachana, Franchini, Mkaouer & Chamari, 2012). The cardiorespiratory fitness of the athletes in our study is therefore quite comparable with other international combat athletes. Thus, Taekwondo training should include exercise programmes that significantly improve aerobic metabolism to contribute to the athlete's ability to sustain the efforts for the total duration of the combat and sustain the number of matches' up-to the final round while recovering effectively during the rest periods.

Taekwondo athletes require submaximal muscular endurance to sustain repeated technical and tactical combat activities during competitions, which include kicking, punching, blocking, pushing and footwork (Moir, 2012). The sit-ups and push-up data gave insight into the muscular endurance of the athletes. There were few studies that examined push-ups for upper extremity and trunk muscular endurance of international Taekwondo athletes (Toskovic, Blessing & Williford, 2004; Markovic et al. 2005).

Some international studies reported that 60 seconds sit-ups test scores for TKD athletes' ranges between 52 -59 repetitions in males and 48-52 repetitions in females (Moir, 2012; Chiodo et al., 2012). In our study the mean sit-up for the male South African athletes were 48.9±13.8 repetitions which are close to the recommended range. However, the mean score for female athletes was 41.5±12.3 repetitions which was outside the reported range. In the present study South African female TKD players have shown low levels of muscle endurance. It is suggestive therefore that more upper and lower trunk muscle endurance conditioning needs to be done with the female South African Taekwondo athletes to improve their endurance compared to their male counterparts. Coaches and scientists are encouraged to study and determine the muscle groups which are relevant to the technical and tactical actions performed in fighting.

Flexibility plays a key role in taekwondo competition since it enables athletes to execute high kicks. Studies showed that female TKD athletes possess greater flexibility than their male counterparts (Toskovic, Blessing and Williford, 2004). It was noted that junior Taekwondo athletes produced lower sit and reach test scores than most seniors. Training adaptations and the technical demands of the sport produce higher flexibility scores (Kim, Stebbins, Chai & Song 2011). This could explain why the senior athletes who have been practicing the sport longer display higher flexibility scores than in juniors (Bridge et al., 2014). While there are a variety of tests which are used to test range of motion or flexibility in TKD athletes, the sit and reach test is the most widely used test in experienced TKD athletes. The other methods such as the front and side leg splits still need extensive research to determine their validity and reliability (Bridge et al., 2014). Markovic et al., (2005) obtained flexibility values of 56.6±5.2 cm in males and 54.8±4.5 cm in females, which are greater than scores from our study by 7.7 cm and 13.3 mm for males and females respectively. Therefore, the coaches have to consider introducing more stretching and flexibility exercises in their conditioning programmes. However, in the training of junior athletes these exercises should be chosen carefully to avoid injuries (Behm, et al., 2006).

To the best of our knowledge the introduction of Z-score radar plots based on the six most relevant variables (agility, explosive power, VO_{2max}, sit-up, push-up and flexibility) for assessment of the individual performance of TKD athletes was done for the first time in the present study. The analysis and interpretation of the individual Z-score was implemented in the current TKD practice to provide coaches with information relevant for designing personalised training programmes. It also enables coaches to give specific instructions to athletes during sparring matches and competitions.

The limitation of our study is the small number of participants, but at the time that was the total number of experienced and trained South African junior TKD athletes available for recruitment. Taekwondo is a very attractive sport and it is becoming more popular in South Africa and on the continent. Obviously, more experimental studies recruiting large number of athletes are needed.

4.6 CONCLUSIONS

The fitness variables are key components that contribute to performance and competence of Taekwondo athletes. These variables enable athletes to perform at their best.

The South African junior Taekwondo athletes exhibited: 1) High explosive leg power, but low levels of muscle trunk endurance and flexibility. 2) High body fat percentage 3) high aerobic capacity and high levels of agility. In general, the physical and the physiological profiles of the South African athletes are within the recommended ranges. These findings support the notion that a new approach focusing on strength and speed/power training combined with high intensity aerobic training has to be applied for further improvement. Regular physical testing and analysis of Z-score radar plots could be used to improve individual performance in Taekwondo.

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CHAPTER 5

TAEKWONDO TRAINING ON BODY COMPOSITION AND PHYSICAL FITNESS IN SOUTH AFRICAN TAEKWONDO ATHLETES

The contents of this chapter are currently under review for publication:

Musa L. Mathunjwa, Sam C. Mugandani, Abidemi P. Kappo. Svetoslav L. Ivanov. Tranyana G. Djarova-Daniels. (2016). Effect of 4 weeks high-intensity intermittent Taekwondo training on body composition and physical fitness in South African Taekwondo athletes of Zulu ancestry. *Currently under review.*

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Musa L. Mathunjwa, Sam C. Mugandani, Abidemi P. Kappo. Svetoslav L. Ivanov. Tranyana G. Djarova-Daniels. (2016). Effect of 4 weeks high-intensity intermittent Taekwondo training on body composition and physical fitness in Zulu descent, South African Taekwondo athletes. International Sports Science + Sports Medicine Conference. England, University of Newcastle. British Journal of Sports Medicine. *Br J Sports Med 2016;50:e4 doi:10.1136/bjsports-2016-096952.22*

5 EFFECT OF 4 WEEKS HIGH-INTENSITY INTERMITTENT TAEKWONDO TRAINING ON BODY COMPOSITION AND PHYSICAL FITNESS IN SOUTH AFRICAN TAEKWONDO ATHLETES OF ZULU ANCESTRY

5.1 INTRODUCTION

Sport participation in adolescence is one of the determinants for leading an active life during adulthood. Buckworth, Dishman, O'Connor, & Tomporowski (2013) have shown that being active during formative years influences the level of physical activity even later in life. Physical activity and sports like martial arts are effective in preventing health problems such as cardiovascular diseases, obesity and cancer (Mathunjwa *et al*., 2013; van Oostrom *et al*., 2012). Martial arts have several disciplines that develop the body, the mind and spiritual wellness to enhance physical, mental and spiritual well-being. Generally, the discipline of martial arts varies from soft execution (tai chi and yoga) to hard execution (karate and taekwondo) with complex movements and techniques (Gauchard *et al*., 2003). However, some martial arts like Taekwondo (TKD) have both elements.

Taekwondo (TKD) sport is renowned for its techniques such as kicking, blocking and punching as well as twisting, leaping, turning and jumping movements, including dynamic phases and powerful kicks that incorporate a variety of hand techniques for the purpose of attack or self-defense (Bridge *et al*., 2014; Hammami *et al*., 2013). TKD – was outlawed by the Korean and Japanese during World War II. However, after the war, the sport was unified to form a legal sport organisation. Since then, the sport became recognised globally (Kazemi *et al*., 2006).

Successively, TKD sport technically advanced into one of the frequently practiced martial arts sports worldwide with about 70 million participants in 180 countries (Fong and Ng. 2011).

TKD is characterized by basic techniques, forms or poomsae, self-defense and sparring or Kyrugi. Poomsae and Kyrugi require complex motor and functional skills, tactical excellence and high levels of fitness to excel (Cular *et al*., 2013; Melhim, 2001). International TKD athletes are categorised in different weight divisions for both male and female athletes to participate in poomsae and sparring. Poomsae is a structural form of group competition in which the participant simultaneously uses both hands and feet displaying various techniques (Haddad *et al*., 2014).

TKD athletes follow strict rules during sparring competitions and the rate of injuries is lower compared to other combative martial arts (Lystad, Graham & Poulos, 2015). The potential psychological (self-confidence, self-esteem and self-reliance) and physical benefits (fitness) of TKD training are to improve health and cognitive abilities of the athletes and to have better fighting strategy during fights. Therefore, it is suggested that TKD could be an ideal sport for improving the well-being of people from all walks of life.

It is quite clear that physical fitness is one of the main factors for TKD athlete's success. During fights TKD athletes perform numerous 3-5 sec bouts of high intensity exercise alternated with those of moderate-intensity, executing various defensive and offensive techniques (Kazemi, 2009). More studies are needed to establish the efficacy of various training programmes leading to the improvement of physical fitness and health in Taekwondo athletes. The purpose of this study was to investigate the changes in physical fitness variables following a high intensity intermittent taekwondo and resistance training programme on senior belt TKD athletes and of age-matched lower belt control group.

5.2 METHODOLOGY

5.2.1 PARTICIPANTS

Thirty-four (n = 34) active TKD athletes of Zulu ancestry (20 males and 14 females) aged 20-26 years volunteered for this study. Following an explanation of all procedures, risks and benefits each subject gave his/her informed consent to participate in the study. The participants were involved in Taekwondo training and were members of the South African Taekwondo Federation. The athletes were divided into control and experimental groups. The control group (10 males and 7 females) had green and lower belts with provincial exposure in terms of fighting. The experimental group (10 males and 7 females) had blue and senior belts and qualified to represent their provincial clubs and to compete at international championships. The two groups were subjected to both Taekwondo training and strength training. Measurement of the variables took place during the competition phase of the provincial selection. Ethical clearance was obtained from the University of Zululand, Faculty of Science and Agriculture Ethics Committee. The study was conducted according to the Human Rights Declaration of Helsinki and approved by the South African Taekwondo Federation (SATF). Each athlete had a Log book for recording heart rate and was taught how to use the Borg Rating of Perceived Exertion (RPE) scale to keep records of performance each week.

5.3 RESULTS AND COEFFICIENT

The results of the physical and physiological variables for the intervention and control groups of the 4-week high intensity intermittent Taekwondo training are presented in tables 5.1, 5.2, 5.3 and 5.4.

Table 5.1: Changes of physical characteristics in response to 4 weeks of high intensity training in experimental and control groups of male Taekwondo athletes. Values are presented as mean±SD

Parameters	Group	Before	After	Δ	% Δ
		Mean±SD	Mean± SD		
Weight (kg)	Experimental (n=10)	73.4±10.7	68.6±9.0[a]	4.8↓	6.5
	Control (n=10)	69.1± 13.5	68.0±11.9	1.1↓	-1.5
BMI (kg/m^2)	Experimental (n=10)	24.2±2.8	22.9±2.3[aa]	1.3↓	-5.3
	Control (n=10)	25.0±4.8	24.8±3.6[b]	0.2↓	-0.8
SBP (mmHg)	Experimental (n=10)	120.4±2.8	117.8±3.8[a]	2.6↓	-2.1
	Control (n=10)	118.7±5.8	119.9±4.1	1.2↑	1.0
DBP (mmHg)	Experimental (n=10)	80.6±6.3	78.2±4.7	2.4↓	2.9
	Control (n=10)	79.7±3.9	78.6±3.1	1.1↓	1.4
RHR (bpm)	Experimental (n=10)	70.8±2.7	69.5±3.9[a]	1.3↓	-1.8
	Control (n=10)	70.4±6.1	70.0±4.7	0.4↓	-0.5
SS (mm)	Experimental (n=10)	81.5±4.2	77.0±4.8[a]	4.5↓	-5.5
	Control (n=10)	81.6±5.8	80.1±5.5[b]	1.5↓	-2.5
Fat %	Experimental (n=10)	14.9±2.1	11.3±2.9 [a]	2.7↓	-18.1
	Control (n=10)	13.8±3.2	11.0±1.5[aa]	1.3↓	-9.1

BMI: body mass index, RHR: resting heat rate, bpm: beats per minutes, SBP, systolic blood pressure; DBP, diastolic blood pressure; SS, sum of skinfold; [a](p<0.05), [aa] (p<0.001) statistically significant between pre & post training, [b](p<0.05), bb(p<0.001) statistically significant between experimental & control group; SD, standard deviation; % Δ, percentage change, ↓decrease; ↑increase.

When comparing the experimental and control group before the beginning of the 4-week training period, we observed a significantly higher body weight ($p<0.001$), in the controls. No significant differences were observed between the experimental and control group in the other physiological variables. After the training period the experimental male athletes (Table 5.1) showed a significant reduction in body weight ($p<0.05$), BMI ($p<0.001$), SBP ($p<0.05$), RHR ($p<0.05$), SS ($p<0.05$), and percent body fat ($p<0.05$). No significant change was observed in DBP. With the control group, only the fat % showed a statistical significant decrease ($p<0.001$). No significant changes were observed in body weight, BMI, SBP, DBP, RHR and SS. When comparing the experimental and control group, we found a significantly higher decrease in BMI ($p<0.05$) and SS ($p<0.001$) in the experimental group.

Table 5.2: Changes of physical characteristics in response to 4-weeks of high intensity training in experimental and control group of female Taekwondo athletes

Parameters	**Group**	**Before**	**After**		
		Mean± SD	Mean± SD	Δ	% Δ
Weight (kg)	Experimental (n=7)	61.3±5.2	55.3±6.7[aa]	6.0↓	9.7
	Control (n=7)	69.5±5.1 [bb]	67.6±4.8[bb]	1.9↓	2.7
BMI (kg/m^2)	Experimental (n=7)	24.3±2.6	21.1±2.5[a]	3.2↓	13.2
	Control (n=7)	26.1±2.4	25.4±1.9[b]	0.7↓	2.7
SBP (mmHg)	Experimental (n=7)	121.5±1.8	118.5±1.8[a]	3.0↓	2.5
	Control (n=7)	120.9±4.6	121.5±2.7[b]	0.6↑	0.5
DBP (mmHg)	Experimental (n=7)	79.2±2.0	78.2±5.1	1.0↓	1.3
	Control (n=7)	79.0±0.5	77.7±3.2	1.3↓	1.6
RHR (bpm)	Experimental (n=7)	77.8±4.1	70.0±4.0[aa]	7.8↓	10.0
	Control (n=7)	77.7±3.1	74.0±2.5[b]	3.7↓	4.8
SS	Experimental (n=7)	89.5±2.3	85.8±3.4[a]	3.7↓	4.1
	Control (n=7)	86.7±3.9	85.8±3.8	0.9↑	1.0
Fat %	Experimental (n=7)	17.4±0.4	14.0±1.5[aa]	3.4↓	19.5
	Control (n=7)	16.3±1.8[b]	15.0±2.7	1.3↓	7.9

BMI: body mass index, RHR: resting heat rate, bpm: beats per minutes, SBP, systolic blood pressure; DBP, diastolic blood pressure; SS, sum of skinfold; Fat %- fat percentage; [a]($p<0.05$), [aa]($p<0.001$) statistically significant between pre & post training, [b]($p<0.05$), [bb]($p<0.001$) statistically significant between experiment & control group; SD, standard deviation; Δ change % Δ, percentage change ↓decrease; ↑increase.

Table 5.3: Changes in physical performance tests during the 4-week of high intensity training in experimental and control group of male Taekwondo athletes

Parameters	Group	Before	After	Δ	% Δ
		Mean± SD	Mean± SD		
Sit & Reach (cm)	Experimental (n=10)	47.6±5.5	54.2±5.8[aa]	6.6↑	13.9
	Control (n=7)	43.7±6.2[b]	46.6±6.3[bb]	2.9↑	6.6
Sit ups 60 s	Experimental (n=10)	45.2±7.0	53.1±6.1[aa]	7.9↑	17.5
	Control (n=7)	37.4±6.9[bb]	42.5±7.1[abb]	5.1↑	13.6
Push-ups 2mins	Experimental (n=10)	64.3±14.9	76.8±17.4[aa]	13.2↑	12.5
	Control (n=7)	38.9±17.1[bb]	41.3±11.4[bb]	2.4↑	6.2
Horizontal Jump (m)	Experimental (n=10)	1.9±0.3	2.3±0.3[aa]	0.4↑	21.1
	Control (n=7)	1.6±0.4[bb]	1.7±0.4[bb]	0.1	6.3
VO_{2max} (ml/kg/min)	Experimental (n=10)	48.5±2.1	52.5±2.8[aa]	4.0↑	8.2
	Control (n=7)	47.4±2.7[b]	49.7±3.4[abb]	2.3↑	4.8
T test (sec)	Experimental (n=10)	10.9±0.4	9.7±0.6[aa]	1.2↑	11.0
	Control (n=7)	11.6±0.8[b]	11.0±4.8[bb]	0.6↑	5.2

[a]*($p<0.05$),* [aa]*($p<0.001$) statistically significant change between pre & post training,* [b]*($p<0.05$),* [bb]*($p<0.001$) statistically significant between experiment and control group; SD, standard deviation; % Δ, percentage* ↓decrease; ↑increase.

Table 5.3 presents changes in physical performance in response to 4-weeks of high intensity taekwondo training in the experimental and control groups of male TKD athletes. When comparing the experimental and control group before the 4-week training, we observed significant differences, in sit & reach ($p<0.05$), sit ups ($p<0.001$), push-ups ($p<0.001$), horizontal jump ($p<0.001$), VO_{2max} ($p<0.05$) and T test ($p<0.05$) indicating better performance in the experimental group. After the training period the experimental male athletes improved significantly in the sit & reach, sit-ups and push-ups tests ($p<0.001$), horizontal jump ($p<0.05$), T-test ($p<0.001$) and VO_{2max} ($p<0.001$). On the other hand, the control group showed significant changes only in sit ups ($p<0.05$) and VO_{2max} ($p<0.05$) and no significant changes were observed in the other tests. All performance parameters improved significantly ($p<0.001$) in the experimental TKD athletes after 4 weeks of training compared to only two in the control group.

Table 5.4: Changes in physical performance tests in response to 4-week of high intensity training in experimental group of female taekwondo athletes

Parameters	**Group**	**Before**	**After**	Δ	% Δ
		Mean± SD	Mean± SD		
Sit & Reach (cm)	Experimental (N=10)	46.5±7.1	56.0±7.3[a]	9.5↑	20.4
	Control (N=7)	44.8±2	48.1±3.7[ab]	3.1↑	7.1
Sit ups 60 s	Experimental (N=10)	33.8±3.9	43.0±3.8[a]	9.2↑	27.2
	Control (N=7)	31.7±2.8	34.7±4.4[b]	3.0↑	9.4
Push-ups 2mins	Experimental (N=10)	40.7±11.7	54.3±13.8[a]	13.6↑	33.4
	Control (N=7)	42.8±9.2	47.2±9.9	4.4↑	10.3
Horizontal Jump (m)	Experimental (N=10)	1.4±0.0	1.6±0.1[a]	0.2↑	14.3
	Control (N=7)	1.4±0.1	1.5±0.1	0.1↑	5.1
VO_{2max} (ml/kg/min)	Experimental (N=10)	43.2±2.5	48.6±5.6[aa]	5.4↑	12.5
	Control (N=7)	45.6±4.1	47.5±4.5[b]	1.9↑	4.2
T test (sec)	Experimental (N=10)	12.3±1.0	10.9±0.9[aa]	1.4↓	11.4
	Control (N=7)	13.3±1.1	12.9±1.6[b]	0.4↑	3.0

[a]*(p<0.05),* [aa]*(p<0.001) statistically significant between pre & post training,* [b]*(p<0.05),* [bb]*(p<0.001) statistically significant between experimental and control group; SD, standard deviation; Δ change, % Δ, percentage change*; ↓decrease; ↑increase.

Changes in the physical performance test in response to 4 weeks of training in female athletes are shown in Table 5.4. No differences between the female experimental and control groups were found before the 4 weeks training period. After the training period the female athletes from the experimental group showed significant improvements in the sit & reach, sit ups, push-ups, horizontal jump, VO_{2max} ($p<0.05$) and in the T- test ($p<0.001$). In the control group a significant increase was observed only in the sit & reach test ($p<0.05$). When comparing both groups after training, the female experimental group showed statistically significant improvement ($p<0.05$) results in sit & reach, sit ups and T-test.

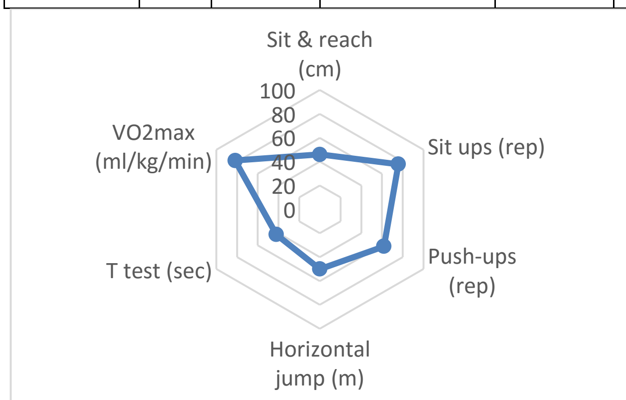
It should be noted that there were no injuries during the training programme. Injuries can be described as an incident where medics or paramedics were needed and which forced a participant to miss part of the training session.

Z-criterion statistics were used to design Z-score radar plots based on the selected components of physical fitness (sit & reach, sit-ups, push-ups, horizontal jump, T- test and VO_{2max}) which are important for the demands of Taekwondo performance. The individual responses were analysed and relevant changes could be implemented in the training practice to avoid overtraining effects on health and to focus on achieving top performance during upcoming Taekwondo tournaments.

The results of the Z-score individual radar plots (in %) of the experimental TKD male and female athletes before and after the training period are presented in Table 5.5, Figure 5.1 and 5.2 and Table 5.6, Figure 5.3 and 5.4 respectively.

Table 5.5: Individual Z-Score individual radar plot (in %) of a TKD male athlete NJ from the experimental group before and after 4-week TKD training

			Sit & reach (cm)	Sit ups (rep)	Push-ups (rep)	Horizontal jump (m)	T test (sec)	VO_{2max} (ml/kg/min)
Z-score (In %)	N.J.	Before	46	75.8	61.8	50	42.1	81.8
	N.J	After	65.5	94.5	88.5	69.2	50	85.6



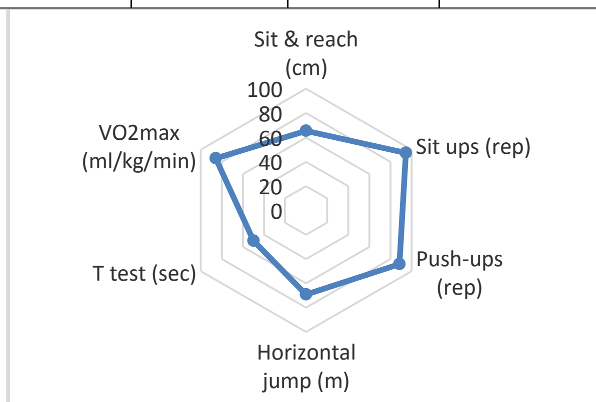


Figure 5.1: Z-score individual radar plots (in %) of male TKD athlete N.J - 26 yrs, 65 kg before 4 week high intensity training	**Figure 5.2:** Z-score individual radar plots (in %) of male TKD athlete N.J - 26 yrs, 63 kg after 4 week high intensity training

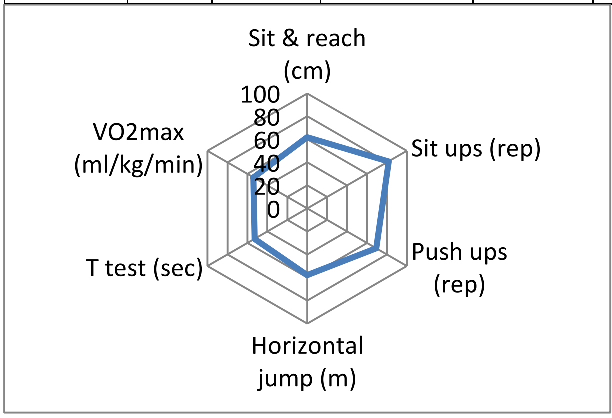
Analysis and practical implications of Z-scores

Athlete N.J [Figure 5.1], primarily showed low flexibility (sit & reach), average endurance (sit-ups) and strength (push-ups), but noticeably lower agility (agility) and average anaerobic capacity (horizontal jump). Based on these results, the athlete needs to improve his results in most of the test parameters in order to achieve better performance either in Kyrugi or Poomsae Taekwondo competition. Therefore, the athlete was tactically and technically advised during the training period to stretch frequently and regularly, to consider aerobic training and specific TKD techniques focused on anaerobic capacity, agility, and postural stability to avoid injuries and maintain good health status. After the 4 weeks' intervention programme, all parameters were improved.

Athlete N.J [Figure 5.2], after a consistent 4-week high intensity intermittent Taekwondo training, showed a considerable improvement in flexibility, good progress in agility and power and a marked increase in endurance and strength. However, only a slight improvement in VO_{2max} was noticed. The athlete is likely to display a high standard of performance during Taekwondo competitions. He could be near to excellence, compared to the previous performance before the programme.

Table 5.6: Individual Z-Score individual radar plot (in %) of a TKD female athlete NM from the experimental group before and after 4-weeks TKD training

			Sit & reach (cm)	Sit ups (rep)	Push-ups (rep)	Horizontal jump (m)	T test (sec)	VO_{2max} (ml/kg/min)
Z-score (In %)	N M	Before	61.8	81.6	69.2	58.0	52.9	54.0
	N M	After	72.6	97.1	88.5	69.2	61.8	69.2



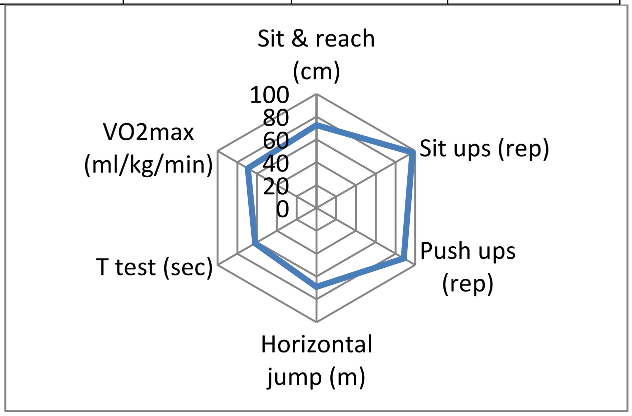


Figure 5.3: Z-score individual radar plots (in %) of female TKD athlete N.M. 19 yrs, 63 kg before the 4 week high intensity training	**Figure 5.4:** Z-score individual radar plots (in %) of female TKD athlete N.M. 19 yrs, 60 kg after the 4 week high intensity training

Analysis and practical implications of Z-score

Female athlete N.M [Figure 5.3] initially demonstrated low anaerobic power; reasonable flexibility, endurance and strength, with rather low agility. Based on these results, the athlete is not likely to perform well at higher standards of Taekwondo competitions. The athlete was tactically and technically advised to improve her flexibility and anaerobic power in order to meet competition standards.

Female athlete N.M [Figure 5.4] after the training period displayed considerable flexibility, higher muscle power (push-ups), substantial muscle trunk endurance (sit-up), improved explosive power (horizontal jump), and better agility than previously. She responded exceptionally well to the programme without any health problems. These results would lead the athlete to adapt better to the explosiveness of the game and a significant improvement of her performance during grading and competitions.

5.4 ANALYSIS OF THE TECHNICAL INDICATORS IN A TAEKWONDO MATCH

The purpose of this analysis was to establish specific indicators for the utilized techniques in a Taekwondo match and to point out the directions of the development of the scoring techniques. In the course of the study, video analyses was used to identify the indicators of the utilized techniques and to analyze the acquired data. The video recording of the matches was achieved using a “Samsung note 3” and the indicators were recorded on specially designed tables. For each round of the match we described the executed techniques, whether they scored a point and how many points they scored.

Figure 5.5. Identifies the name of different kicks of Taekwondo athletes.
(https://www.google.co.za/imgres?imgurl=https%3A%2F%2F67.media.tumblr.com%2Fe04dfc09349886a16372da24193cd86b%2Ftumblr_ob7gs1o5EY1udghf4o1_500.gif&imgrefurl=https%3A%2F%2Fwww.tumblr.com%2Ftagged%2Fwith-wushu&docid=2CZ88gvY2it0JM&tbnid=hYDOpGvpolmDlM%3A&w=490&h=238&bih=986&biw=1920&ved=0ahUKEwiQ2OCVnM_OAhWoIcAKHehdDT4QMwgnKAswCw&iact=mrc&uact=8)

Table 5.7: Technical indicators in the Taekwondo matches of the 2015 South African Provincial team selection

Type of kicks	Number of kicks	Number of kicks on target	Number of points, scored	Coefficient of success	Point efficiency of the hit
Dollyo chagi momtong	57	31	34	54.4	59.65
Dollyo chagi with front leg	17	9	11	52.94	64.71
Naeryo chagi	12	5	4	41.67	33.33
Parrumbal dollyo chagi	8	3	4	37.5	50
Narre chagi	4	1	1	25.0	25.0
Chirrugi	3	1	2	3.333	66.6667
Mirro chagi	2	0	0	0	0
Dwit chagi	25	5	6	20.0	24.0
Tiurige Turning back kick	10	2	2	20.0	20.0
Dollyo chagi olgul	9	2	4	22.222	44.444
Parrumbal dollyo chagi olgul	8	4	5	50	62.5
Dollyo chagi hagi	8	2	4	25	50
Dollyo chagi Narabam	10	2	3	30	20
TOTAL	173	67	80		

The types of kicks that were observed are shown in table 5.7 above. There were 13 types of kicks identified, 1 type of punch, 2 types of penalties and their numerical indicators. Furthermore, a coefficient of success of the kicks and indicator of point effectiveness were identified.

We investigated the number and type of the executed kicks for each round, the number of the points scored with each kick or punch and the coefficient of success of the kicks for each of the examined athletes. This coefficient represents the ratio between the numbers of kicks that scored a point towards the total amount of that type of kick. During the processing of the data it turned out that the "coefficient of success of the kick" is not a sufficient indicator of the win in every match. That is why we introduced the term "Point effectiveness of the kick", which represents the ratio between the numbers of points scored with a type of kick towards the total number of kicks of that type. The total amounts of executed kicks for the 8 reviewed match amounts to 84; the kicks and punches that have scored points are 67, and the points scored are 80.

5.5 DISCUSSION

The main findings of the study confirmed that a 4-week high-intensity Taekwondo training protocol reduced anthropometric parameters (body weight, percent body fat, sum of skinfolds), RHR and SBP and improved physical performance in both male and female athletes of the experimental group. However, no significant changes were observed in body mass, BMI, SS, BP, RHR, sit and reach, push-ups, horizontal jump and t-test in the control group, due to the lower intensity of the training.

To the best of our knowledge, this is the first study to examine the effects of a 4 week high-intensity, intermittent Taekwondo training, combined with strength training on physical and physiological parameters and on health in male and female Taekwondo athletes. It is north worthy that male Taekwondo athletes rarely utilize resistance training due to the demand of TKD on speed, while female Taekwondo athletes do not emphasise or commonly employ it. Studies conducted on other sports indicate that resistance training significantly improves muscular strength and power in male and female athletes (Fisher *et al*., 2011).

TKD athletes regularly reduce their body mass before competition in order to compete in their desired weight categories. Some studies in the recent past have revealed that body composition is key in distinguishing between elite and novice athletes and is highly associated with performance (Zemski Slater and Broad 2015; Stanforth *et al*., 2014). In the current study of a 4-week high-intensity Taekwondo training protocol, both percentage body fat and sum of skinfolds decreased significantly in the male experimental group by 18.1% and 5.5% respectively. The same was true for females with a decrease of 19.5% in percentage body fat and 4.1% in sum of skinfolds. The training proved to have a positive effect, with a significant reduction in percent body fat in both male and female athletes in the experimental groups than it does in the control groups. The reduction was in line with the elite international Taekwondo norms range between 14 % and 19.5 – 24% (Bridge, Jones and Drust 2011).

Flexibility is one of the specific components in defferential scoring in Taekwondo competition allowing athletes to score points by kicking the head. The use of lower extremity power is very important and contributes to score first golden or knockout points (Kim *et al*., 2015). TKD training routines place a great deal of importance in the improvement of flexibility for proficient performance and avoiding head injuries, thereby protecting the health status of the participants. Numerous studies have demonstrated that TKD practitioners are more flexible in their hamstrings and lower back muscles (Haddad *et al*., 2014; Bridge 2014; Markovia, 2005). Therefore, sufficient stretching exercises before and after the training were incorporated to augment the range of motion. In the current study, the difference in lower back and hamstring flexibility reached a significant increase in the experimental group but not in the control group. Female athletes demonstrated a higher range of flexibility scores than males, but only in the experimental group.

It has been shown that martial artists need maximal muscle strength/power and endurance to implement rapid and powerful movements during sparring by moving freely around an opponent while executing defensive and offensive techniques (Kazemi, 2009; Noorul, Pieter, and Erie, (2008) stated that possessing strong muscles is important for execution of explosive kicks, jumping and balancing techniques during TKD sparring. The high intensity intermittent training program of the current study improved these performance parameters significantly. Few studies have investigated the long term and short term effects of TKD training. Fong and Ng (2011) suggested that TKD training may have some beneficial effects on aerobic capacity, body composition (body fat) and flexibility. Fong, Tsang, Ng (2013) reported results showing that better knee joint repositioning is significantly correlated with sway velocity, improved isokinetic pique torque of quadriceps and hamstrings and single-leg stand balance rather than with knee muscle strength. On the other hand, Harris, 2014 reported that muscular strength and endurance are important components in TKD athletes at enhancing overall performance. The training protocol of the current study managed to achieve similar results in an even shorter time period. The results of our study support the findings of Harris, 2014 showing marked improvement of the limb and trunk muscular strength of elite TKD athletes in response to 4 weeks training mesocycle.

The training period of 4 weeks in the present study had a significant impact on strength and endurance in both male and female athletes of the experimental group and an increase in the control group. Therefore, our findings demonstrate that the combination of the high-intensity intermittent TKD training and resistance training contributed substantially to the improvement of core strength and endurance of TKD athletes contributing to their health and could play a major role in the enhancement of their combat performance.

TKD is predominantly considered as an aerobic/anaerobic sport due to the explosive movements which involves short bouts of fast, high-intensity kicking and punches. Bridge, 2014 reported that athletes' heart rate response during TKD competition exceeded the aerobic training threshold. Our current results revealed that there was a significant development of agility, power and cardiorespiratory endurance. Although fewer studies have examined the agility characteristics of Taekwondo athletes, our results are comparable to those reported in the previous studies of Bridge, 2014 and Haddad *et al*., 2014. In the current TKD training practices the importance of high aerobic fitness and the link between power training and improved jump tests results should be emphasized and might be considered as precursors of overall success in TKD competition (Harris 2015).

It is noteworthy to point that the design of our training was focused on applying concurrently very high-intensity Taekwondo training and resistance workouts. The design of the training was based on 60% Taekwondo (fighting drills and tactics), 30% strength training and 10% aerobic exercise (walking and jogging). This balanced approach might have provided the reason for the noticeable advancement in the performance and improved physical characteristics of the experimental group of Taekwondo athletes.

At present, the contemporary sport practice requires continuous assessment of the physical performance of each athlete and relevant adjustments should be applied accordingly. The importance of personalized training based on regular testing using Z-score individual radar plots allows the coaches to follow and assess the progress of each Taekwondo athlete during the different phases of the conditioning period through the year and before major championships.

5.6 CONCLUSION

The findings of this study support the effectiveness of the high-intensity intermittent training in Taekwondo athletes on improving body composition, cardio-respiratory response and physical characteristics. This type of training could be suggested and implemented in the training protocols of Taekwondo athletes when preparing for national and international competitions to enhance their fitness and combat performance.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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CHAPTER 6

HORMONAL AND BIOCHEMICAL RESPONSES TO CONCURRENT TAEKWONDO AND RESISTANCE TRAINING

6 HORMONAL AND BIOCHEMICAL RESPONSES TO CONCURRENT TAEKWONDO AND RESISTANCE TRAINING IN TAEKWONDO ATHLETES

6.1 INTRODUCTION

It is well-known that participation in sporting activities induces both acute and chronic metabolic changes through physical training and competition (Banfi *et al*., 2012). However, few studies are forthcoming on individual martial arts disciplines, especially Taekwondo (TKD), and how they affect acute endocrine responses and/or chronic endocrine adaptations (Pilz-Burstein *et al*., 2010; Shariat *et al*., 2017). This is especially important when attempting to objectively quantify the balance between training intensity and athlete tolerance (Pilz-Burstein *et al*., 2010). Ozen (2012) explained that high volume of exercise training places a significant stress on an individual, which could result in physiological maladaptation and other detrimental effects. Problematically, studies involving TKD athletes have generally been limited to the investigation of anthropometric and physiologic profiles/performance (Haddad *et al*., 2014; Hammami *et al*., 2013; Harris, 2014; Mathunjwa *et al*., 2015; Shariat *et al*., 2017).

The hormonal and physiological response to exercise is dependent on various factors such as frequency, intensity, duration and training status of an individual (Ozen *et al*., 2011). Until recently, the focus of many studies has been on the effects of resistance or endurance training on the responses and adaptations of male reproductive hormones (Shariat *et al*., 2015). Several studies have shown that physical exercise elicits a response in testosterone and cortisol levels in men (Cadore, 2009; Crewther *et al*., 2010; McCaulley *et al*., 2009; Smilios *et al*., 2003). Specifically, resistance training, dependent on the type of resistance training, intensity, number of sets, and type of muscle contraction, have been demonstrated to stimulate greater increase in testosterone levels when compared to aerobic training (Copeland, 2002; Kraemer, 2006; McCaulley *et al.*, 2009; Shaw, Shaw & Brown, 2015; Smilios, 2003).

However, many sports contain both endurance and resistance training elements and could potentially stimulate both an anabolic and catabolic hormonal response/adaptation (Ozen, 2012). TKD is one such intermittent sport in which the athletes have to train and compete at a variety of intensities, utilizing all of the energy systems (Haddad *et al*., 2014). The actions involved in TKD are characterized by periods of high levels of technical, tactical, psychological, physical fitness and physiological characteristics (Chiodo *et al*., 2012; Shariat *et al*., 2017). TKD techniques, such as kicking, blocking and punching involve high-intensity twisting, leaping, turning and jumping movements, and are interspersed with lower intensity actions, such as stepping and walking (Bridge *et al*., 2014; Hammami *et al*., 2013). Therefore, research is required to ascertain the hormonal and biochemical responses to Taekwondo training.

6.2 METHODOLOGY

6.2.1 PARTICIPANT

Twenty-eight (16 males and 12 females) South African TKD athletes aged between 20-26 years with BMI = 23.7±2.9 kg.m^{-2} volunteered for participation in the present study. Following sampling, in order to eliminate the physiological and hormonal influences accompanying gender which may compromise the findings of the study, athletes were grouped by gender and randomly assigned using a random numbers table to either and experimental (EXP) or control (CON) group ($Male_{exp}$: n=8 vs. $Male_{con}$: n=8; $Female_{exp}$: n = 6 vs. $Female_{con}$: n = 6). Written informed consent was obtained from the athletes following an explanation of the purpose of the study, measurement procedures and the possible adverse events that could be encountered during the study. The study was conducted according to the Human Rights Declaration of Helsinki and approved by the South African Taekwondo Federation (SATF). Ethical clearance to conduct this study was obtained from the Institutional Review Boards of the University of Zululand, Republic of South Africa.

6.2.2 PROCEDURE

6.2.2.1.1 Blood Variables

Blood samples were obtained pre- and post-experimentally by registered nurses from the antecubital vein following a 12-hour fast, collected into vacutainer tubes and stored at −80 C. Testosterone, cortisol, lactate, glucose, creatine phosphokinase (sCPK), uric acid and C-reactive protein (CRP) were analyzed using commercially available kits (Phoenix Peptides, Karlsruhe, Germany).

6.2.2.1.2 Concurrent Training Program

All athletes participated in a TKD test before and after a four-week concurrent TKD and resistance training (RT) program that consisted of a five-minute warm-up that entailed jogging, shuttle runs, cone drills and five minutes of dynamic whole-body stretching (Jeffrey *et al*., 2010). This was then followed by a one-hour TKD workout and each workout concluded with a five-minute cool-down entailing jogging and soft kicks and five-minutes of whole-body static stretching exercises (Jeffrey *et al*., 2010).

While both groups participated in the five-day weekly four-week training program, the control (CON) participated in a moderate-intensity one-hour TKD workout that involved both upper- and lower-body TKD techniques (blocks, punches and kicks) at a target training intensity of 55-70% maximum heart rate (HRmax) for weeks 1-2 and 70 -85% HR_{max} for weeks 3-4. Target HR ranges were monitored continuously using a HR monitor (Polar Electro, Kempele, Finland) during each session. The RT portion of the CON took place five times weekly for 30-45 min in the afternoon to limit the interference effect (Shaw, Shaw & Brown, 2009) and consisted of power cleans, push presses, dumbbell raises, power snatches, squats, deadlifts, leg curls, bench press, latissimus dorsi pulldowns, seated row, abdominal crosses, supine "bicycles" and spiderman plank crunches (Tuner, 2009). CON and RT exercises were conducted for four sets and 10-15 repetitions each (Hacket *et al*., 2018).

In turn, the high-intensity TKD portion of the experiment (EXP) four-week program also consisted of a one-hour TKD workout performed in the morning, but in contrast to the CON program, intensity was set at 85-100% HR_{max} for weeks 1-2 and 95-100% HR_{max} for weeks 3-4. In contrast to the CON, EXP RT exercises were conducted for five sets and 10-15 repetitions each (Hacket *et al*., 2018).

6.2.3 STATISTICAL ANALYSIS

All statistical analysis was performed using the SPSS for Windows software (version 20.0, SPSS Inc., Chicago, Illinois, USA). A one-way analysis of variance (ANOVA) and t-test were utilized to examine the differences in acute and chronic hormonal and biochemical responses to Taekwondo training. Data are presented as means ± standard deviation (SD). $P \leq 0.05$ were considered statistically significant in the interpretation of the results.

6.3 RESULTS

Prior to the four weeks of concurrent training, the measured hormone and biochemical values were found to be normal and within the acceptable clinical ranges for the conditions under which they were collected (KDIGO, 2012) (Table 6.1 and 6.2). In the $Male_{exp}$, total testosterone concentration and lactate were found to be significantly ($p<0.001$) greater in the post-TKD test compared to their pre-TKD test values after the four weeks of concurrent training. In addition, an observable significant ($p<0.01$) decrease in the C/T ratio was also found in the $Male_{exp}$ from pre- to post-TKD test following the four weeks of concurrent training. When comparing the $Male_{exp}$ and $Male_{con}$ following their respective four weeks of concurrent training, significant differences in total testosterone ($p<0.001$), free testosterone ($p<0.05$) and C/T ratio ($p<0.05$) were found. After the training period, the $Male_{exp}$ participants were found to have significantly improved in total testosterone ($p<0.001$), cortisol ($p<0.001$) and lactate ($p<0.001$). On the other hand, the $Male_{con}$ showed significant changes only in lactate ($p<0.001$). Creatine phosphokinase (S-CPK) levels were found to be significantly ($p<0.001$) lower after the four weeks of concurrent training.

Table 6.1: Hormonal and biochemical responses to concurrent Taekwondo and resistance training in male Taekwondo athletes

		Male experimental group ($Male_{exp}$) (n=8)		**Male control group ($Male_{con}$) (n=8)**	
		Pre-TKD test	**Post-TKD test**	**Pre-TKD test**	**Post-TKD test**
Total testosterone ($nmol.L^{-1}$)	**Before four weeks training**	30.4±4.5	36.9±6.9	24.4±6.0	30.1±14.9
	After four weeks training**	33.4.0±7.1	52.8±9.2[aa]	27.9±15.3	28.4±13.1[bb]
Testosterone binding globulin ($nmol.L^{-1}$)	**Before four weeks training***	52.8±14.7	47.8±13.2	50.0±16.7	48.9±19.2
	After four weeks training**	47.8±11.6	50.0±14.8	41.6±10.6	43.2±10.9

Free testosterone (pmol.L^{-1})	**Before four weeks training***	591.5±98.2	524.7±148.0	454.7±185.1[b]	529.7±185.1
	After four weeks training**	476.3±86.7	607.8±121.7	561.5±296.9[b]	567.0±255.7[b]
Cortisol (nmol.L^{-1})	**Before four weeks training***	280.7±68.5	307.8±80.8	296.3±67.2	334.7±60.1
	After four weeks training**	294.6±106.1	316.7±82.7 [aa]	257.8±32.0	301.7±76.5
C/T ratio	**Before four weeks training***	9.2±2.5	9.6±4.6	12.1±3.5	11.1±4.0
	After four weeks training**	10.5 ±7.7	5.9±5.4[a]	7.7±3.1	10.6±5.6[b]
Lactate (mmol.L^{-1})	**Before four weeks training***	1.6 ± 0.4	5.4 ± 3.7[aa]	1.8 ± 1.2	4.9 ± 1.7[aa]
	After four weeks training**	1.4 ± 0.5	7.9 ± 3.2[aa]	1.1 ± 0.5	6.4 ± 2.6[aa]
S-CPK (IU.L^{-1})	**Before four weeks training***	1032.1±637.9	959.1±678.9	660.3±440.2	594.5±466.2[aa]
	After four weeks training**	830.2±450	732±540	657.7±2310	621±3151[aa]
Uric Acid (nmol.L^{-1})	**Before four weeks training***	0.3±0.0	0.3±0.1	0.4±0.6[a]	0.6±0.1[aa]
	After four weeks training**	0.37±0.2	0.3±0.1	0.4±0.1[a]	0.4±0.1[a]

Data are presented as means±SD

nmol.L^{-1} : nanoMolar per litre; pmol.L^{-1}: picomole per litre ; C/T ratio: cortisol/testosterone ratio; S-CPK: creatine phosphokinase; IU.L^{-1}: International units per litre.

*Acute response to 20 minutes of structured taekwondo before four weeks of concurrent training; ** Acute response to 20 minutes of structured taekwondo after four weeks of concurrent training.

[a](p<0.05), [aa](p<0.001) statistically significant change between pre- & post-testing, [b](p<0.05), [bb](p<0.001) statistically significant between experiment and control group.

When comparing the Female$_{exp}$ and Female$_{con}$, following the four-week concurrent training, significant differences were observed in total testosterone (p<0.05), testosterone binding globulin (p<0.05) and cortisol (p<0.05). After the training period, the Female$_{exp}$ improved significantly in total testosterone (p<0.05), free testosterone (p<0.05), cortisol (p<0.05) and lactate (p<0.001). Female$_{exp}$ showed significant improvements in their S-CPK and uric acid (p<0.001). On the other hand, the Female$_{con}$ showed significant changes in free testosterone (p<0.05), C/T ratio (p<0.05) and lactate (p<0.001). After the training period, in the Female$_{con}$, a significant increase was also observed in S-CPK (p<0.001) and uric acid (p<0.05).

Table 6.2: Hormonal and biochemical responses to concurrent taekwondo and resistance training in female taekwondo athletes

		Male experimental group (Female$_{exp}$) (n=6)		**Male control group (Female$_{con}$) (n=6)**	
		Pre-TKD test	**Post-TKD test**	**Pre-TKD test**	**Post-TKD test**
Total testosterone (nmol.L^{-1})	**Before four weeks training**	0.8±0.4	1.0±0.4	0.8±4.4	0.8±4.4
	After four weeks training**	1.2±0.2	1.6±0.5[aa]	0.7±0.4	0.9±5.4[ab]
Testosterone binding globulin (**nmol.L^{-1}**)	**Before four weeks training***	59.9±14.7	56.5±13.2	49.2±16.7	47.9±19.2
	After four weeks training**	54.9±11.6	52.6±14.8	45.3±10.6	42.2±11.9[b]
Free testosterone (pmol.L^{-1})	**Before four weeks training***	7.5±2.4	8.0±2.6	11.6±6.1	10.8±11.6
	After four weeks training**	6.1±3.0	9.0±2.1[a]	8.3±8.1	10.2±6.2[a]

Cortisol (nmol.L^{-1})	**Before four weeks training***	280.7±68.5	307.8±80.8	296.3±67.2	334.7±60.1
	After four weeks training**	290.6±114.1	316.7±82.7[aa]	257.8±32.0[b]	301.7±76.5[b]
C/T ratio	**Before four weeks training***	9.4±2.5	11.0±4.6	13.3±5.5	13.5±5.3
	After four weeks training**	9.9±7.7	11.5±5.4[a]	9.7±4.1	11.5±7.6[a]
Lactate (mmol.L^{-1})	**Before four weeks training***	1.7±0.6	3.1±1.3 [a]	2.1±1.2	4.5±4.5 [ab]
	After four weeks training**	1.9±1.0	3.7±2.3 [aa]	1.4±2.5	4.3±2.5[aa]
S-CPK (IU.L^{-1})	**Before four weeks training***	342.5±186.3	348.3±175.5	342.5±454.1	371.8±469.2
	After four weeks training**	130.0±296.4[aa]	128.3±328.0[aa]	330.8±37.8	338.3±48.2
Uric Acid (nmol.L^{-1})	**Before four weeks training***	0.2±0.0	0.3±0.0[a]	0.2±0.1	0.2±0.1[b]
	After four weeks training**	0.3±0.7[a]	0.4±0.3[aa]	0.2±0.1[b]	0.2±019[bb]

Data are presented as means±SD nmol.L^{-1}: Nano molar per litre; pmol.L^{-1}: Picomole per litre; C/T ratio: cortisol/testosterone ratio; S-CPK: creatine phosphokinase; IU.L^{-1}: International units per litre

*Acute response to 20 minutes of structured taekwondo before four weeks of concurrent training; ** Acute response to 20 minutes of structured taekwondo after four weeks of concurrent training

[a](p<0.05), [aa](p<0.001) statistically significant change between pre- & post-testing, [b](p<0.05), [bb](p<0.001) statistically significant between experiment and control group

6.4 DISCUSSION AND CONCLUSION

The purpose of the study was to determine the hormonal and biochemical responses to concurrent Taekwondo and resistance training. In this regard, since the endocrine system and selected biochemical markers are known to play an important role in or indicate physiological adaptation to exercise (Alghadir *et al*., 2015; Shaw & Shaw, 2008), total testosterone (nmol.L-1), testosterone binding globulin (nmol.L-1), free testosterone (pmol.L-1), cortisol (nmol.L-1), C/T ratio, lactate (mmol.L-1), S-CPK (IU.L-1) and uric acid (nmol.L-1) were analysed pre- and post-experimentally following four weeks of TKD training.

Specifically, both anabolic (testosterone) and catabolic (cortisol) hormones have been suggested as being strong indicators of the exercise intensity and load. Following the four weeks of concurrent training, concomitant increases in total testosterone and decreases in cortisol were found in both the $Male_{exp}$ and $Female_{exp}$. Free testosterone was also found to be higher in the $Female_{exp}$ following the experimental period. This response of elevated testosterone levels as showed in the present study supports the results from a study by Benedini and colleagues (2012), in which ten karate athletes demonstrated increased testosterone levels following a period of training. In addition, this study is in agreement with the findings of Alghadir and co-workers (2015) in which athletes were also subjected to four weeks of aerobic training. Changes in the level of cortisol in this study confirm an acute increase in the total serum cortisol in response to an exercise protocol of high VO_{2max} and exercise intensity of more than 60% one-repetition maximum (1-RM), which has been observed in previous studies (Jezová & Vigaš, 1981; Sanavi & Kohanpour, 2013). In addition, Alghadir and co-workers (2015) reported that the magnitude of cortisol increases in response to a wide range of exercises higher than 60% maximal power in intensity and longer than 30 minutes duration. Support for this come from another study, which suggested that the higher the intensity and the longer the duration of exercise, the greater the hormonal response (de Souza *et al*., 2017). Moreover, the adrenal response is also stronger for intermittent anaerobic and aerobic exercise (Miłosz *et al*., 2017). In addition to the individual hormones as an indicator of adaption to exercise, Alghadir and colleagues (2015) and Pourvaghar *et al*. (2010) proposed that the ratio between anabolic and catabolic hormones could be used to determine the status of exercise readiness of individuals. As such, the cortisol/testosterone (C/T) ratio is commonly utilised as a sign of hemostatic balance between anabolic and catabolic states and thus an exercise adaptation index. In this study, both the $Male_{exp}$ and $Female_{exp}$ were found to have improved their C/T ratio. The range of C/T ratio values observed in this study is similar to that in previous studies (Alghadir *et al*., 2015; Elloumi *et al*., 2003; Hoogeveen & Zonderland, 1996; Maso *et al*., 2004).

In addition to selected endocrine indicators, such as testosterone and cortisol, selected biochemical markers are known to play an important role in or indicate physiological adaptation to exercise. Specifically, lactate is a biologically active molecule, which is an important indicator of the activation of glycolysis in skeletal muscle during exercise (Callaghan, 2004; Hur, 2014). The results of this study showed a significant 5.6- to 5.8-fold and 3.1-fold increase, respectively in lactate levels of the male and female athletes. This indicates that the male and female athletes could better improve contribution of glycolysis to energy demand and also tolerate lactate (Jabbour *et al.*, 2015). These results are consistent with the findings of previous studies (Conway *et al*., 2003), but contrary to others (Bell *et al*., 2000; Davis *et al*., 2007). This contrasting observation may be due to differences in various study design parameters such as sample size, type of test and duration of the tests used. Creatine phosphokinase (S-CPK) can be utilised as a gauge of the level of stress to skeletal muscle (Djarova *et al*., 2013). After the training period S-CPK levels were found to be lower in the $Male_{exp}$. Interestingly, the female group that participated in the moderate-intensity programme (i.e. $Female_{con}$) were found to have an increased S-CPK. Uric acid too is recognised as a stress biomarker. A significant increase in uric acid concentration in all groups after the Taekwondo and strength training was observed in both the experimental male and female groups (i.e. high-intensity groups). Since uric acid has been identified as a potential endogenous antioxidant, its elevation could be interpreted as an indicator of the mobilisation and maintenance of plasma antioxidant status needed during the recovery period after exercise (Margoms *et al*., 2007).

Intermittent physical events such as TKD may require greater strength and muscle power demands on both the upper- and lower-body with high anaerobic energy demands (Passelergue & Lac, 2012). The data from this study support the importance of monitoring hormonal and biochemical interactions in evaluating the effectiveness of different protocols and training responses (Passelergue & Lac, 2012), as well as the need to ensure that training programmes are of appropriate design (i.e. concurrent) and sufficient intensity and to promote optimal adaptation (66, Shaw & Krasilshchikov, 2009).

Conclusion

The monitoring of selected hormones and biochemical biomarkers is considered a reliable indicator for assessing not only the metabolic response to physical activity, but such measures can be useful in assessing the efficacy of exercise training. In this study, four weeks of concurrent

TKD and RT were demonstrated to stimulate enhanced an anabolic hormonal response and associated reduced muscle damage.

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CHAPTER 7

TAEKWONDO AND RESISTANCE TRAINING ON THE HEMATOLOGICAL PROFILES OF TAEKWONDO ATHLETES

7 EFFECTS OF 4 WEEKS TAEKWONDO TRAINING PROTOCOL ON THE HAEMATOLOGICAL PARAMETERS IN MALE AND FEMALE TAEKWONDO ATHLETES

7.1 INTRODUCTION

Competitive athletes involved in different intense physical activity during sporting events, performed under uncontrolled condition of both aerobic and anaerobic nature (Fisher-Wellman and colleagues, 2009). Intense training plays a major role in inducing oxidative stress and antioxidant. Few studies have investigated oxidative stress in response to high intensity aerobics and anaerobic training following sporting competitions (Bloomer and Smith, 2009; Shi *et al.*, 2007). Some studies also reported that acute and high level of physical activity resulted in tissue oxidative damaged thereby decreasing performance in athletes (Pepe *et al.,* 2009; Belviranli and Gokbel, 2006; Miyazaki *et al*., 2001).

Taekwondo (TKD) sport is a competitive contact sport that is intermittent in nature, similar to karate, boxing and wrestling where combatants fight against each other using rules of the game. The sport demonstrates a high level of both aerobic and anaerobic conditioning along with an ability to produce high muscle forces. The techniques of the sport as mentioned before are fast and powerful kicks, blocks and punches for the purpose of attack, count attack and defense (Kazemi *et al*., 2006).

TKD training consists of high intermittent physical activity and produces fast speed and muscle strength demands on both upper and lower body, with a high aerobic and anaerobic energy metabolism demand (Haddad *et al*., 2014; Bridge *et al.,* 2014).

Athletes are matched according to body weight. Therefore, they need to meet weight target to qualify for their event. Weight and nutrient management is needed not only to remain within a certain weight category for entry into competition but also to be physically strong and healthy (Haddad *et al*., 2014)**.**

The most common micronutrient deficiency of among Taekwondo athletes is iron. Iron is transported to the cell by transferrin receptor-mediated endocytic pathway, which allow the iron to be released from the transferrin into the cell (Schippinger *et al*., 2009). The membrane transferrin receptors are located on precursor cells of erythropoiesis in the bone marrow which is useful in the assessment of erythropoietic activities. In addition, to RBC morphology (mean corpuscular volume [MCV], mean cellular haemoglobin [MCH], and red distribution width [RDW]), monitoring of number of hypochromic red cells (low hemoglobin density [LHD]%) and reticulocyte hemoglobin content (IRF) are useful tools for monitoring functional iron deficiency, anemia or other health problems. Iron deficiency is a major cause of anemia in most athletes. The assessment of RBC, haemoglobin, mean corpuscular volume (MCV) and prevention of iron deficiency is very important for athletes to prevent anemia.

The main objective of this part of study was to investigate effects of 4 weeks Taekwondo training protocol on hematological parameters in male and female TKD athletes. Data obtained from such study should assist to strengthen the knowledge of Taekwondo coaches in the design of training programs, medical examinations schedule and dietary intake.

7.2 METHODS

7.2.1 PARTICIPANTS

Twenty-eight (16 males and 12 females) South African Taekwondo (TKD) athletes aged between 20 – 26 years with BMI = 23.7±2.9, were recruited for this study. The same experimental and control groups of health male and female TKD athletes, as previously described, were submitted to blood testing procedures. Blood samples were taken from the participant by registered nurses in vacutainers from antecubital vein at rest 30 min before and after performing structured TKD test structured TKD test of 20 minutes at the beginning and at the end of 4 weeks of high intensity intermittent TKD and Strength training. Blood tests such as red blood cells (RBC), haemoglobin (Hb), haematocrit, mean corpuscular volume (MCV), mean corpuscular haemaglobin (MCH), mean Corpuscular haemaglobin concentration (MCHC), red distribution width (RDW), platelets, leucocyte, neutrophil, lymphocyte, monocyte, eosinophil and basophil were all determined and analysed at the accredited laboratory at rest and post performing structured TKD test of 20 min at the beginning and at the end of a 4-week high intensity intermittent TKD and strength training programme. Student *t*-test was used for statistical analysis. The error probability of $p<0.05$ and was considered significant.

7.3 RESULTS

The data of the haematological parameters such as red blood cells (RBC), haemoglobin (Hb), haematocrit, mean corpuscular volume (MCV), mean corpuscular haemaglobin (MCH), mean Corpuscular haemaglobin concentration (MCHC), red distribution width (RDW), platelets, leucocyte, neutrophil, lymphocyte, monocyte, eosinophil and basophil measured before and after the 4 weeks high-intensity intermittent training for both males and females TKD athletes are shown in Table 7.1 and Table 7.2 respectively. The values of these haematological parameters were normal and within the acceptable clinical ranges for the conditions under which they were collected. No significant differences were observed in the mean values of RBC, haematocrit, MCV, MCH, RCW, NE, EO in the control group, male athletes (Table 7.1). Moreover, there were also no differences ($p>0.05$) in the mean values of RBC (L), Hb, Haematocrit, MCV, MCH, MCHC, RDW, platelets, leucocyte, neutrophil, lymphocyte, monocyte, eosinophil, basophil between experimental and control groups in the male athletes (Table 7.1). Nonetheless, the mean values of RBC, Hb, Hematocrit, MCH, RDW, LY and MO ($p<0.001$) and MCV, platelets, leucocyte, NE, EO ($p<0.05$) was significantly higher in the experimental group after a 4-week of high intensity intermittent Taekwondo and strength training in male athletes (Table 7.1).

Table 7.1: Serum blood counts before and in response to a 4 weeks high-intensity intermittent training in TKD male athletes.

Period		**Before 4 weeks of high intensity intermittent training**		**After 4 weeks of high intensity intermittent training**		
Blood sampling	**Group**	**Pre TKD test**	**Post TKD test**	**Pre TKD test**	**Post TKD test**	**Δ**
Red blood cells L/L	Experimental	4.0±0.3	4.9±0.4	5.0±0.4[a]	5.9±0.3[aa]	↑
	Control	5.1±0.1	5.3±0.1	4.9±0.2	5.5±0.4	↑NS
Hemoglobin (g/dL)	Experimental	14.4±0.7	14.6±0.7	15.5±0.5[a]	16.5±0.8[aa]	↑
	Control	14.0±0.7	14.6±0.5	14.8±0.9	15.5±0.8[b]	↑NS
Hematocrit (L/L)	Experimental	0.4±0.0	0.4±0.0	0.5±0.0[a]	0.6±0.1[aa]	↑
	Control	0.4±0.0	0.3±0.0	0.4±0.0	0.4±0.0	↑NS
MCV (fl)	Experimental	76.2±5.2	79.6±4.8	81.9±4.3	88.2±4.1[a]	↑

	Control	80.3±6.6	81.7±6.5	81.8±6.6	82.5±6.6	↑NS
MCH (pg)	Experimental	26.8±2.4	27.8±2.8	26.7±2.8	29.3±1.5^{a}	↑
	Control	28.5±2.7^{b}	28.7±2.8^{b}	28.4±2.8^{b}	28.5±2.8	↑NS
MCHC (g/dl)	Experimental	34.2±1.0	34.2±1.2	34.2±1.0	33.2±0.7	↓NS
	Control	34.5±0.9	34.6±0.9	34.7±0.8	32.5±2.5	↓NS
RDW (%)	Experimental	14.1±1.9	14.4±1.9	13.5±1.4	12.5±1.2^{aa}	↓
	Control	12.5±0.5	12.5±0.6	12.2±0.6	12.3±0.5	↓NS
Platelets (G/L)	Experimental	352±37.8	374±46.6^{aa}	331.4±37.8	339±67.8^{a}	↓
	Control	215.4±37.3^{b}	242±43.4^{b}	214.1±46.9^{b}	257.7±61.4^{ab}	↑
Leucocytes (G/L)	Experimental	6.5±2.1	7.8±2.4	6.0±1.8	7.9±2.2^{a}	↑
	Control	5.5±1.8	6.4±2.2	5.1±1.5	7.1±2.0^{a}	↑
Neutrophils (%)	Experimental	2.9±1.6	3.5±1.8^{a}	2.5±1.5	2.2±1.2^{a}	↓
	Control	2.5±1.1	2.9±1.3	2.9±1.3	2.8±1.5	↑ NS
Lymphocytes (%)	Experimental	1.8±0.9	2.0±0.8	1.8±0.6	3.3±1.1^{aa}	↑
	Control	2.0±0.2	3.1±0.9^{a}	2.4±0.4	3.5±1.1^{aa}	↑
Monocytes (%)	Experimental	0.5±0.2	0.4±0.2	0.5±0.7	0.6±0.7	↑NS
	Control	1.5±2.7^{b}	0.5±0.2^{aa}	0.4±0.1^{a}	0.5±0.2^{a}	↓
Eosinophils (%)	Experimental	0.6±0.7	0.7±0.7^{a}	0.6±0.7	0.7±0.7^{a}	↑
	Control	0.3±0.3	0.2±0.3^{a}	0.3±0.3	0.3±0.3	↑NS
Basophils (%)	Experimental	0.03±0.01	0.03±0.02	0.02±0.01 ^{b}	0.04±0.02	↑NS
	Control	0.02±0.00	0.02±0.00	0.01±0.00 ^{a}	0.03±0.01	↑NS

^{a}*(p<0.05),* ^{aa}*(p<0.001) statistically significant change between pre & post training,* ^{b}*(p<0.05),* ^{bb}*(p<0.001) statistically significant between experiment and control group; NN Not significant: SD, standard deviation; % Δ, percentage* ↓decrease; ↑increase; RDW-red distribution width; MCV-mean cellular volume; MCH-mean cellular hemoglobin; MCHC-mean cellular hemoglobin concentrate, values are expressed as mean± SD.

Table 7.2: Serum blood counts before and in response to a 4 weeks high-intensity intermittent training in Taekwondo female athletes.

Period		**Before 4 weeks of high intensity intermittent training**		**After 4 weeks of high intensity intermittent training**		
Blood sampling	**Group**	**Pre TKD test** **mean±SD**	**Post TKD test** **mean±SD**	**Pre TKD test** **mean±SD**	**Post TKD test** **mean±SD**	
RBC (L)	Experimental	4.1±0.1	5.0±0.1	4.9±0.3	6.3±0.5[aa]	↑
	Control	4.3±0.2	4.4±0.2	4.3±.8	4.8±1.0[b]	↑
Hemoglobin (g/dl)	Experimental	11.8±0.5	11.9±0.4	12.0±0.9	12.9±0.9[a]	↑
	Control	11.45±1.7	11.8±1.6	12.2±1.3[a]	12.2±1.0[a]	↑
Haematocrit (L/L)	Experimental	0.3±0.0	0.4±0.0	0.4±0.0	0.5±0.0[aa]	↑
	Control	0.3±0.0	0.3±0.0	0.4±0.0	0.4±0.0	↑NS
MCV (fl)	Experimental	85.9±3.8	86.6±3.6	86.9±3.6	88.2±4.5	↑NS
	Control	79.3±5.2	79.6±4.8	83.3±4.1[a]	83.8±4.1[b]	↑NS
MCH (pg)	Experimental	28.9±1.5	28.9±1.7	29.2±1.6	30.3±1.5[a]	↑
	Control	26.8±2.7	26.9±2.8	28.4±1.7	28.6±2.8	↑NS
MCHC (mmol/l)	Experimental	28.6±0.3	32.4±0.6	33.5±0.7	38.0±1.2[aa]	↑
	Control	33.8±1.3	35.5±1.5	34.2±1.0	35.5±0.7	↑NS
RDW (%)	Experimental	12.9±0.7	13.2±0.8	13.7±0.7	14.9±0.7[aa]	↑
	Control	14.1±1.9	14.4±1.9	13.4±1.4[a]	13.4±1.3	↓NS
Platelets (G/L)	Experimental	277.3±56.5	317.0±59.8	282.5±60.2	350.0±60.2[aa]	↑
	Control	353.0±46.6	374.0±43.8	331.4±37.9	350.0±67.8	↓NS
Leucocyte (G/L)	Experimental	4.5±1.3	6.5±2.5	5.6±1.6	7.2±1.7[aa]	↑
	Control	6.5±2.1	7.8±2.4[b]	6.0±1.8	7.4±2.2	↑
Neutrophils (%)	Experimental	2.1±0.6	2.7±0.9	2.6±1.4	3.0±1.0	↑NS
	Control	2.9±1.6	3.5±1.8	2.5±1.3	2.5±1.3	↓NS

Lymphocytes (%)	Experimental	2.5±0.2	3.1±0.9	2.4±0.4	3.5±1.1[aa]	↑
	Control	2.1±0.8	2.0±0.6	1.9±0.6	2.3±1.1	↑NS
Monocytes (%)	Experimental	0.4±0.2	0.4±0.2	0.5±0.2	0.6±0.3[a]	↑
	Control	0.4±0.1	0.5±0.2	0.4±0.1	0.5±0.2	↑NS
Eosinophils (%)	Experimental	0.2±0.2	0.2±0.2	0.03±0.0[a]	0.04±0.0[aa]	↓
	Control	0.6±0.7	0.6±0.7	0.6±0.6	0.7±0.6[b]	↑NS
Basophils (%)	Experimental	0.02±0.0	0.02±0.0	0.02±0.0	0.03±0.0	↑NS
	Control	0.03±0.0	0.03±0.0	0.02±0.03	0.02±0.0[a]	↓NS

[a](p<0.05), [aa](p<0.001) statistically significant change between pre & post training, [b](p<0.05), [bb](p<0.001) statistically significant between experiment and control group; SD, standard deviation; % Δ, percentage ↓decrease; ↑increase. MCV mean corpuscular volume; MCH: mean corpuscular hemoglobin; MCHC; RDW red cell distribution width

In Table 7.2 and Table 7.2, hematological parameters for females were measured at rest 30minutes pre and post performing structured TKD test of 20 minutes at the beginning and at the end of 4 weeks of high intensity intermittent TKD and strength training. No significant differences were found in the following variables; haematocrit, MCV, MCHC, RCW, Platelets, NE, MO, EO and Basophils in female athletes in the control group after training. There were also no differences (p>0.05) in Hb, MCH, MCHC, RDW, platelets, leucocyte, neutrophil, lymphocyte, monocyte, basophil between experimental and control groups in the female athletes after training. Statistical significantly higher values for RBC, hematocrit, RDW, leucocyte, lymphocytes and eosinophil for Hb, MCH, platelets, NE and MO were found in the experimental group after a 4 week period of high intensity intermittent taekwondo and strength training.

7.4 DISCUSSION

The objective of the present study was to evaluate the effect of a 4 week high-intensity intermittent Taekwondo and strength training program on oxidative stress and haematological markers in male and female TKD athletes. It has been shown that taekwondo and strength training induces significant changes in most of the oxidative stress and haematological markers studied. We observed that most of the parameters increased significantly after the TKD and strength training program in both male and females in experimental groups. Some improvements witnessed in the control group were non-significant due to the low intensity training program. Contrary to the findings of this study, the haematological parameters of elite soccer players diminished significantly after 45 days of regular training (Marija *et al.*, 2014). The decrease in Hb, Ht, RBC, WBC count, neutrophils and platelets counts might be an indicator of heavy effort, as shown in heavy aerobics sports such as cycling (Schumacher *et al*., 2002).

The values of haematological parameters observed in this study were within the range of normal haematological values**.** Numerous studies indicated that changes in haematological parameters could induce intense training regimes such as endurance or strength training (Di Santolo *et al*., 2008; Dopsaj *et al*., 2008; Schumacher *et al*., 2000; Banfi *et al*., 2012). Athletes who predominately require energy from aerobic training were found to have large value of haematological parameters that provide information about cell volume and the haemoglobin that they contain. Schumacher et al. (2000) indicated that plasma volume multiplication affects the disparity in the number of red blood cells and haemoglobin. Parameters such as RBC, MCV, MCH, MCHC, platelets and lymphocytes were found to be higher in female than in male indicating accelerated erythropoiesis. In female athletes, low ferritin values indicate that participation in intense exercise results in risk for iron storage depletion.

The results of the present study demonstrated that some of the parameters (MCV, MCH, Neutrophils, Lymphocytes, basophils) analysed were unaffected compared to the pre training values. Significant ($p<0.001$) changes were observed in red blood cell, Hb, haematocrit, mean cellular volume, red cell distribution width, in both male and female experimental group while the control group had a significant ($p<0.05$) change in hemoglobin and red cell distribution width (see Table 7.1 and Table 7.2). This finding is consistent with previous reports and is acceptable since these variables are sensitive to pathological states such as overtraining and factors for controlling diseases (Abidi, 2007). A study showed changes in red blood cells as a chronic adaptation to training in cyclists (Shumacher *et al.*, 2002).

The changes have been attributed to factors such as haemodilution, a disproportion between hematopoiesis and intrascular hemolysis and iron reduction (Shumacher *et al.*, 2002). These findings agree with those reports by Martinovic and Dopsaj, (2011) who observed an increase in red blood cell count. The present results suggest that Taekwondo with strength training has the potential to severely affect red blood cell count and related measures. Regardless of being a fully contact nature of the sport, the impact in Taekwondo fights is less pronounced than it is in a contact sport like boxing and wrestling which is heavily traumatic during combat. This could be the fact of the more amplified impact in boxing than in TKD for the changes in red blood cell parameters in TKD athletes.

With respect to white blood cell count, there were significant changes observed after the 4 weeks high intermittent TKD and strength training. It is well established that inflammation is a protective process that includes blood cells and tissue proteins in response to injury, infection, trauma and immune response (O'Toole *et al.,* 1999). The increase in leukocyte, lymphocyte, monocytes, eosinophil and basophil responses observed in the two groups can be therefore viewed as normal (see Table 7.1 and Table 7.2).

Platelets were increased in the experimental female TKD athletes and reduced in the control group while a reduction was observed in the male experimental group with an increase in the control group. A study by Costa Rosa and colleagues, (2002) confirmed that a decrease in these cells of 30% to 50% below baseline levels may occur after vigorous exercise. The results are in line with the male experimental group after the 4 weeks high intermittent TKD and strength training with a 10% decrease. Franchini et al. (2009) reported that inflammation is directly related to the fight intensity of the Brazilian Jiu-Jitsu (BJJ) and the fight may increase the total number of eosinophils. Based on the results of Costa Rosa and colleagues, it is recommended that the leukocyte, lymphocyte, monocytes, eosinophil, and basophil values obtained during the TKD and strength training is related to the release of neutrophils from peripheral tissues into the bloodstream. The data substantiate these results as the TKD and strength training induced increases in monocytes. Similarly, to the present findings, an increase in lymphocyte values was observed after TKD competitions.

Oliveira and colleagues established that high intensity exercise produces changes in concentration, ratio and function of leukocytes, affecting Natural Killer cells, polymorphonuclear and immunoglobulin. Studies have shown that these changes attributed to the state of stress generated by the effort and metabolites that are related to adrenaline, cortisol, and catecholamines which generate immune suppressive effect (Bachur *et al.*, 2008; Costa Rosa and Vaisberg, 2002).

Overtraining intensify the chain of reactions which limit what may or may not be healthy in physical exercise. Lymphocytes are susceptible to cortisol and lead to a decrease in their concentration of intense effort. In the present study, there was significantly higher ($p<0.001$) lymphocytes in both male and female in the experimental group (see Table 7.1 and & 7.2). The concentration of lymphocyte population is proportional to the intensity of training.

A review of literature on changes in oxidative stress markers and haematological parameters following Taekwondo and strength training indicates a lack of information in this area. For this reason, we therefore investigated the oxidative status and haematological parameters of Taekwondo athletes in response to a 4 weeks high intermittent taekwondo and strength training.

Currently, there is limited information regarding oxidative stress and haematological parameters in TKD athletes. It was shown that Taekwondo and strength training induces significant changes in most of the markers studied.

7.5 CONCLUSION

This was the first study analysing the effect of a 4 week high-intensity intermittent taekwondo and strength training program on oxidative stress and haematological markers performed by male and female TKD athletes of Zulu Ancestry. The results indicate that Taekwondo with strength training is able to promote significant changes in immune function without significant changes in MCHC measures. In addition, several biochemical markers related to the high stress induced by high intensity exercise were also found to have an effect during the competitive effort.

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CHAPTER 8
OUTCOMES AND CONCLUSIONS

8 OUTCOMES AND CONCLUSIONS

The fitness variables are key components that contribute to performance and competence of Taekwondo athletes. These variables enable athletes to perform at their best. The South African junior Taekwondo athletes exhibited: 1) High explosive leg power, but low levels of muscle trunk endurance and flexibility. 2) High body fat percentage 3) high aerobic capacity and high levels of agility. In general, the physical and the physiological profiles of the South African athletes were within the recommended range. Z-score radar plots based on the six most relevant variables (agility, explosive power, VO2max, sit-up, push-up and flexibility) were introduced for the first time in the assessment of the performance of each athlete. These findings support the proposal that a new approach, focusing on strength and speed/power training combined with high intensity aerobic training has to be applied for further improvement. Regular physical testing and analysis of Z-score radar plots could be used to improve individual performance in Taekwondo.

The high intensity intermittent Taekwondo training protocol combined with strength/resistance training was developed and implemented to uplift the training efficiency of young male and female TKD athletes. The findings of this study support the effectiveness of the high-intensity intermittent training in Taekwondo athletes on improving body composition, cardio-respiratory response and physical characteristics. This type of training could be suggested and implemented in the training protocols of Taekwondo athletes when preparing for national and international competitions to enhance their fitness and combat performance.

Intermittent physical exercise may produce great strength and muscle power demands on both upper and lower body with high energy demand and simultaneously could lead to changes in both anabolic and catabolic hormones. The data for this study support the importance of monitoring testosterone, cortisol interactions, C/T ratio, lactate and oxidative biomarkres for assessment of training intensity and effectiveness of training programmes. Our results were based on the response of the athletes to structured TKD test after the end of the training period showed higher blood testosterone, decreased C/T ratio and lower creatine phosphokinase levels. These findings suggest that 4 weeks of high intensity intermittent Taekwondo training protocol combined with resistance training led to anabolic type hormonal response and reduced oxidative muscle damage in young South African Taekwondo athletes.

The changes of most haematological parameters were found within the acceptable clinical reference ranges. The observed variations in red blood cells and the white blood cells counts after 4 weeks of training display relevant insight into the response of the body to high intensity intermittent TKD and strength physical exercise. The accumulated knowledge could help coaches and athletes to avoid the adverse effects of overtraining and potential infections.

The high intermittent intensity TKD training protocol with concurrent strength resistance training could be recommended in sport practice on the basis of overall analysis indicating favourable metabolic response and simultaneous development of power and specific Taekwondo fitness required for the combat matches.

8.1 FUTURE RESEARCH

The most important fact that this study reveals is the need for greater research in male and female Taekwondo athletes in order to provide more contributions in similar studies and to consequently make stronger conclusions about biomarkers in male and female Taekwondo athletes. With these stronger conclusions, there would be the possibility to establish male and female Taekwondo athletes reference values or even normal ranges which can then be used to make comparisons between evaluated baseline values and the concluded "normal" values for this population. Generally, the new established reference range for these male and female athletes could then not only be compared to the general population, including non-athletes, but it would also provide male and female Taekwondo athletes specific ranges which can be used for further monitoring. These ranges would allow and support the detection of out-of-norm baseline measurements and therewith related illness, overtraining and inflammation or muscle weakness. Based on the lack of studies in this area of research, only a very small amount of biomarkers could be considered for evaluation. To make future studies helpful and supportive requires the advancement in research for the physiological component and that many more biomarkers have to be looked at. Because of insufficient research on electrolytes and minerals for example, both had to be neglected for this study. Despite the limited research with which our findings can be compared, the results from this investigation could provide information for future research in this population and possibly for an establishment of specific sport nutrition guidelines.

8.2 IMPLICATIONS FOR ATHLETES, COACHES, AND SPORT FITNESS PROFESSIONALS

This study detects several tendencies of selected biomarker group means for male and female field Taekwondo athletes. Whereas iron, white blood cell count and especially haemoglobin tend to lie either towards or beneath the lower limit of the reference range assigned to the general population, CK and cortisol have a tendency to be higher in these athletes when compared to the general population. The testosterone value seems to be very similar and within the general population range, however still tending towards the upper limit. These prevailed mean values reinforce the importance of close observation of athletes throughout the season. The high cortisol and low white blood cells values indicate the importance of sufficient rest for the athletes. Whereas intense and frequent practice is essential to bring the athletes to the next level of performance, it is especially important for the long run to provide them with sufficient rest and time for recovery in order to be able to maintain and improve performance. As mentioned earlier that these athletes, based on their lower white blood cell count, are more susceptible to illness. It is essential for them to let their body recover from previous practice sessions and games. Also, the aspect of illness and infection, in the long run, importance of appropriate nutrition, adequate amounts of vitamins for the athletes.

For coaches, sports nutritionists and athletic trainers is essential to make sure female athletes have adequate amounts of vitamins to help support their immune system in order to counteract the high cortisol and low white blood cell values. For this good reason, it is also essential to educate the athletes about the importance of iron in their diet for their performance and to make sure they incorporate iron rich foods or if required iron supplements in their diet to help prevent extremely low iron stores and haemoglobin presence. Similar to cortisol, generally elevated CK and lactic acid values are natural occurrences in elite athletes. These “natural occurrences” however, have to be closely observed since they could quickly, if not treated carefully with adequate rest, inhibit the athletes’ performance. It is essential to monitor/observe these values in order to detect possible enzyme activity disturbances or initial stages of overtraining. Overall, this study’s findings call for close observation and if possible frequent monitoring of the athletes in order to early on detect iron deficiencies, possible muscle weakness and initial signs of inadequate recovery early on. Moreover, it calls for education and consideration of the importance of vitamin and iron supplementation to allow the athletes to perform to their maximum potential. Even though it is recommended that nutritional needs are generally met through a well-balanced diet, this can be very difficult and in some cases almost impossible for athletes, through which supplementation becomes a great way to meet these needs of athletes with altered nutritional needs.

8.3 LIMITATIONS

There were several identified limitations in the present study. The participant in the study were male and female university level students, so the results may not be generalizable to other populations including children, adults etc. However, the chosen population for the main study was those between 20-26yrs engaged in Taekwondo training. The reason for selecting this particular sample was informed on the basis that this study exposes individuals to a very high intensity intermittent training. The recruitment of limited number of highly experienced TKD South African athletes was another limitation in this study. The cohort of active South African TKD athletes consists of 40-50 individuals and not all of them qualify for the National team. The inexperienced TKD athlete's volunteers had to be used as a control group and required attention, because they were not being exposed to a very high intensity intermittent TKD training due to the risk factors related to the technical, metabolic and metabolic demands of the TKD sessions. The last practical limitation was that the participants did not wear correctly the chest-belt heart rate monitor during training, resulting in discontinuous recording by the wrist receiver.

Additionally, the study was comprised of 34 subjects, which is a relatively small number. The small sample size limits the statistical power and the possibility of observing more statistical differences. The small sample size was comparable to similar studies investigating both Oxidative stress in high interval training program.

8.4 APPENDIX A: ETHICAL APPROVAL

PARTICIPANT INFORMED CONSENT

INFORMED CONSENT DECLARATION
(Participant)

Project Title: **PHYSICAL TESTS, HORMONAL AND OXIDATIVE-STRESS RELATED BIOMARKERS IN INTERMITTENT TAEKWONDO TRAINING**

Musa Mathunjwa (***name of researcher/person administering the research instrument)*** from the Department of **Biokinetics and Sports Science**, University of Zululand has requested my permission to participate in the above-mentioned research project.

The nature and the purpose of the research project and of this informed consent declaration have been explained to me in a language that I understand.

I am aware that:

1. The purpose of the research project is to **assess changes in Physical tests, hormonal and oxidative stress related biomarkers in intermittent training of taekwondo athletes.**

2. The University of Zululand has given ethical clearance to this research project and I have seen/ may request to see the clearance certificate.

By participating in this research project I will be contributing towards

- The benefits of participating in this study are: **My participation will make a contribution to further understanding of hormonal (testosterone and cortisol), oxidative stress biomarkers (C-reactive protein and uric acid), creatine kinase and intermediary metabolites (glucose and lactate), in response to intermittent taekwondo training.**

- **I will receive information on my physical fitness (explosive power, (vertical jump), speed, agility, strength and flexibility in relation to performance and fitness) and physiological characteristics (blood pressure, body mass index (BMI), Fat %, and lean body mass)** (***state expected value or benefits to society or individuals that will arise from the research***)

3. I will participate in the project by **performing explosive power, vertical jump, speed, agility, strength and flexibility in relation to performance and fitness.**

- I will be required to test my physiological characteristics: height and weight blood pressure, body mass index (BMI), Fat %, and lean body mass body fat assessed. This will be performed a week before the actual intermittent training.

- **I will be required to provide blood to determine hormones (testosterone and cortisol), biomarkers (C-reactive protein and uric acid), creatine kinase and intermediary metabolites (glucose and lactate) in blood to assess the effects of TKD techniques and training).** (***state full details of what the participant will be doing***)

4. My participation is entirely voluntary and should I at any stage wish to withdraw from participating further, I may do so without any negative consequences.
5. I will not be compensated for participating in the research, but my out-of-pocket expenses will be reimbursed. (***Should there be compensation, provide details***)
6. There may be risks associated with my participation in the project. I am aware that
   a. the following risks are associated with my participation: **The may be some minor discomfort associated with the venepuncture and usually go away shortly after the tests are done. In addition, spasm of the blood vessel and/or minor bruising could occur.** (***state full details of risks associated with the participation***)
   b. the following steps have been taken to prevent the risks: **The blood will be drawn from an anticubital vein in front of my elbow by a qualified phlebotomist (Lancet Laboratories) using standard aseptic procedures**.
   c. there is a 0.001% chance of the risks materialising
7. The researcher intends publishing the research results in the form of **scientific articles**. However, confidentiality and anonymity of records will be maintained and that my name and identity will not be revealed to anyone who has not been involved in the conduct of the research.
8. I will ~~not receive feedback/will~~ receive feedback in the form of **my physical fitness (explosive power, (vertical jump), speed, agility, strength and flexibility in relation to performance and fitness) and physiological characteristics (blood pressure, body mass index (BMI), Fat %, and lean body mass)** regarding the results obtained during the study.

- Any further questions that I might have concerning the research or my participation will be answered by Trayana G Djarova-Daniels PhD (082 619 289); Svetoslav L Ivanov, PhD (359-2-8703340) and Musa Mathunjwa, PhD candidate (0796297857) (*provide name and contact details*)

9. By signing this informed consent declaration, I am not waiving any legal claims, rights or remedies.
10. A copy of this informed consent declaration will be given to me, and the original will be kept on record.

I, ……………………………………………………………………… have read the above information / confirm that the above information has been explained to me in a language that I understand and I am aware of this document's contents. I have asked all questions that I wished to ask and these have been answered to my satisfaction. I fully understand what is expected of me during the research.

I have not been pressurised in any way and I voluntarily agree to participate in the above-mentioned project.

………………………………….	…………………………………
Participant's signature	**Date**
………………………………….	…………………………………
Researcher's signature	**Date**

8.5 APPENDIX B: APPROVAL LETTER FROM THE SOUTH AFRICAN TAEKWONDO FEDERATION

South African Taekwondo Federation

Recognized by the South African Sports and Recreation, South African Sports Confederation and Olympic committee, the World Taekwondo Federation and the Kukkiwon.

To whom it may concern

PhD study entitled: Physical test, hormonal and oxidative stress biomarkers in intermittent training of taekwondo athletes.

This letter serves to grant the researchers of the above mentioned topic the permission to use our national team athletes for their research study. After reserving the PhD research proposal for Mr Musa L Mathunjwa one of the Kwazulu-Natal`s Taekwondo coordinator and a student at the University of Zululand. The South African Taekwondo Federation (SATF) is pleased to inform the candidate together with his supervisors Prof. T. Djarova-Daniels and Prof. L. Svetoslav Ivanov that they will be allowed to have access to a group of twenty-five national team athletes to conduct their study.

The federation is looking forward to assist them achieve their goals in this scientific endeavour which is frame within the ethics protocols of research. We also request the feedback after the study not only for records purpose, but for our own improvement as well.

For any further clarification, do not hesitate to conduct us.

Yours Sincerely

....

Godfrey Mokoboto (072 396 5430)

President

8.6 APPENDIX C: PRELIMINARY FORMS AND CONSENT DOCUMENTATION

DEPARTMENT OF BIOKINETICS AND SPORTS SCIENCE

UNIVERSITY OF ZULULAND

YOUR HELP NEEDED!

DO YOU FIT THE FOLLOWING CRITERIA?

- NATIONAL TEAM
- NON SMOKER
- AGE 15 – 25
- HEALTH
- ACTIVITY FACTOR (VERY HARD TAEKWONDO TRAINING SIX SEVEN DAYS PER WEEK)

WOULD YOU LIKE TO:

- BE PART OF A SCIENTIFIC STUDY – CONTRIBUTING TO RESEARCH**?**

CAN YOU COMMIT TO:

- 4x WEEKLY SESSIONS OF 60-90MINS DURATION EACH?
- CONTINUE YOUR SESSIONS FOR 1 MONTH (4WEEKS)

DON'T HESITATE! CONTACT MUSA LEWIS MATHUNJWA ON 0738955897 OR EMAIL mlmathunjwa@gmail.com NOW!

8.7 APPENDIX D: INCLUSION CRITERIA, INFORMATION AND PRE SCREENING

PHYSICAL TESTS, HORMONAL AND OXIDATIVE-STRESS RELATED BIOMARKERS IN INTERMITTENT TRAINING OF TAEKWONDO TRAINING

RESEARCH PARTICIPANTS: INFORMATION SHEET

Thank you for agreeing to participate in this research programme. The research programme is on physical test, hormonal and oxidative stress biomarkers in response to high intensity intermittent training of taekwondo athletes over a period of a 4-week.

It will be a mutually beneficial time for those who are successfully selected to participate in the study. You are expected to commence with the testing as well as taekwondo intermittent training, in two separate groups, one group will be control group which will be subjected to taekwondo training and circuit training and the other group will also do taekwondo training as well as resistance training. The training will take place in the High Perfomance Centre at University of Pretoria, and the researchers will gather data during the ongoing programme. In the preliminary session, we are going to conduct several assessments and establish that you are health and fit enough to commence with the programme. Prof Dr. Djarova Daniels will be present to ensure your safety prior to undertaking the research.

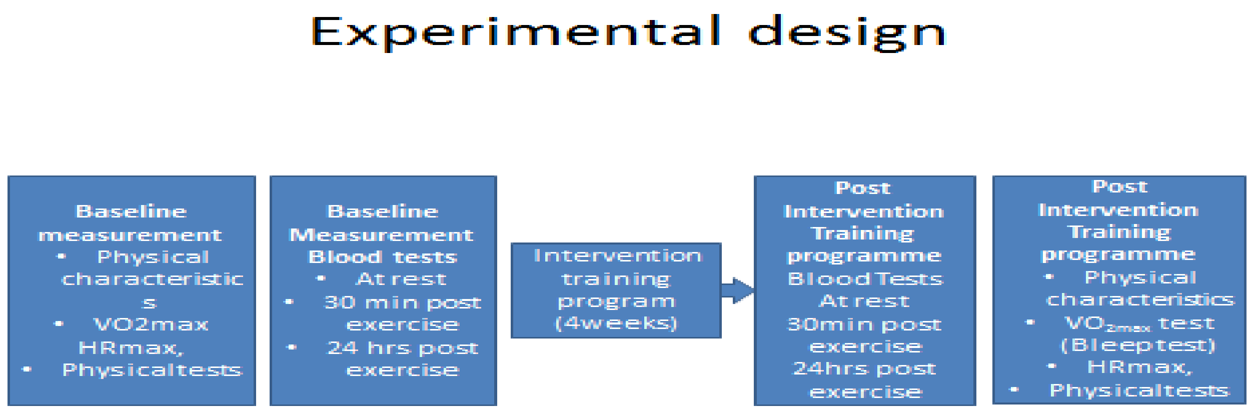
Physical tests will be done by sport scientist and all blood samples will be done by qualified Nursing Sisters, at an accredited laboratory (Lancent) Please note that blood tests as well as the physical test will be paid by the researcher’s funds.

After the initial tests, we will commence with the first sessions. We are going to supply you with Consent forms to complete with information pertaining your health and lifestyle history. Please note that the information that will be gathered is treated with great confidentiality, and is coded for use. Your name will not be mentioned or identified in the presentation of results. The information will be use within 2years after your participation and it will be used by the researchers only. The results of the study will be published in recognised SAPSE international journals if accepted.

Your training sessions will be supervised at all times. The researcher together with the national team coach will equally distribute you in either a control group (Taekwondo and circuit training) or the focused group (Taekwondo and resistance group). The sessions will take place in the High Performance Centre, making use of standard commercially available gym equipment as well as free core training equipment that will get you very active, learn, strong and fit. You will be expected to attend five sessions weekly, of 90minutes duration each including morning and evening. You will encounter different postgraduate trainers alternating in the circuit and strength training.

You may occasionally encounter different supervisors, all of whom will be postgraduate students of the Department. All will have been properly briefed by the principal researcher. You are encouraged to ask questions at any time, and to contact the principal researcher at any time should you have any comment or query.

At different interval two times at initial training and another two times after the four week training, measurements will be taken. These will be as follows.



The researcher will only share the results with you after completion of the four-week training so that you don't have to influence the results obtained initially. Nevertheless, once the 4-week period is over, you will receive all your results in a hard copy for your records. The researcher will discuss the results with your coaches and that will help you in the area that you need improvement.

Please do not hesitate to contact the research team at any stage you need clarity and questions would be welcomed.

Musa Mathunjwa
Researcher
0738955897
mlmathunjwa@gmail.com

Supervisor
Prof T Djarova
Tel: 0826192939

8.8 APPENDIX E: MEDICAL HISTORY (PLEASE PLACE AN X WHERE APPROPRIATE)

Do you have, or have you been previously diagnosed with any of the following?

	NO	YES	UNSURE
1.1 Sports injuries (within the past five years) Comment:			
1.2 Motor Vehicle Accident related injuries			
1.3 Heart problems			
1.4 High blood pressure			
1.5 Diabetes			
1.6 Asthma or pulmonary diseases			
1.7 Epilepsy			
1.8 Chronic Medication			
1.9 Arthritis or Osteoporosis			
1.10 Family history of heart, lung, metabolic disease, stroke, sudden death. Comment			
1.11 Cancer			
1.12 Rheumatic fever			
1.13 Lower back pain			
1.14 Pregnancy			
1.15 Depression			
1.16 Stress			

Is there any other reason, not mentioned above, why you cannot follow a vigorous exercise programme or undergo an exercise test? Y/N

If you answered yes on any of the abovementioned questions, please specify below.

____

BASED ON THE INFORMATION PROVIDED, WE RESERVE THE RIGHT TO EXCLUDE YOU FROM THE CURRENT RESEARCH PROJECT, BASED ON THE REQUIREMENTS WHICH POTENTIAL SUBJECTS MUST FULFIL, AND FOR MEDICAL SAFETY.

I,________________(Full name) do confirm that the information here provided is complete an is correct.

__________________________ ____________________

Signed (Subject) Date

___________________________ _____________________

Singed (Researcher) Date

8.9 APPENDIX F: ANTHROPOMETRIC AND BODY COMPOSITION MEASURES

ANTHROPOMETRIC AND BODY COMPOSITION MEASURES				
Tester:		Date of test:		
Name:		Surname:		
Test number		1		
Weight		2	3	4
Height				kg
BMI				cm
SKIN FOLDS				Kg/m^2
		Triceps		
Suprailiac				mm
Subscap				mm
Calf				mm
Abdominal				mm
Thigh				mm
Total				mm
Fat%				mm
		PHYSICAL TESTS		
2mins Push ups				
Vertical jump				
VO_{2max}				
Sit & reach				
Hexagonal				
T-test				
		HORMONAL TEST		
Cortisol				
Testosterone				
		BIOMARKERS		
Oxidative stress				
Blood lactate				
Uric acid				
C-reactive protein				
Creatine kinase				
Enzymes				
		HAEMATOLOGICAL PARAMETERS		
Hemoglobin				
White blood cell				
Red blood cell				
Platelets				

8.10 APPENDIX G: PARTICIPATING SCREENING

Department of Biokinetics and Sport Science, University of Zululand

PhD Research Project: Principal Researcher: Mr Musa Lewis Mathunjwa

	Exercise group attendance register															
Name	Week 1				Week 2				Week 3				Week 4			
1																
2																
3																
4																
5																
6																
7																
8																
9																
10																
11																
12																
13																
14																
15																
16																
17																

8.11 APPENDIX H: ANALYSIS OF THE RESULTS

Table 1. Technical indicators in the Taekwondo matches of the 2015 South African National team selection

TYPE OF HIT Type of kicks	NUMBER OF HIT	NUMBER OF HITS THAT HAVE SCORED A POINT	NUMBER OF POINTS, SCORED WITH THAT HIT	COEFFICIENT OF SUCCESS	% FROM THE TOTAL AMOUNT OF HITS	POINT EFFICIENCY OF THE HIT
Dollyo chagi momtong						
Dollyo chagi with front leg						
Naeryo chagi						
Parrumbal dollyo chagi						
Narre chagi						
Chirrugi						
Mirro chagi						
Dwit chagi						
Tiurige Turning back kick						
Dollyo chagi olgul						
Parrumbal dollyo chagi olgul						
Dollyo chagi hagi						
Dollyo chagi Narabam						
TOTAL						