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DETERMINATION OF AEROBIC AND ANAEROBIC POWER IN ELITE TAEKWONDO ATHLETES THROUGH A SPORT SPECIFIC TEST

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Dedicatória

Em memória do meu saudoso pai.

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A work of this kind is a great personal challenge, which is only achieved with the collaboration and partnership of several people and institutions. I would like to thank, without particularizing, all the people without whom the realization of this thesis would be an impossible task.

Resumo

Atualmente, o taekwondo moderno na vertente desportiva, exige um elevado nível no volume e na intensidade de treino quase permanente ao longo da época desportiva. Os testes de avaliação física específicos da modalidade permitem monitorizar o estado de treino do atleta, dando orientações específicas para o desenvolvimento do treino, para além de se constituírem como indicadores com reconhecida potencialidade na prevenção e deteção do sobretreino. Acontece que as avaliações físicas dos atletas de taekwondo são geralmente suportadas em testes de baixa especificidade no que se refere ao gesto técnico e às características do esforço em treino e competição. Assim, o propósito central desta tese foi determinar a validade concorrente de dois protocolos de avaliação da aptidão física aeróbia e anaeróbia em atletas de taekwondo.

A amostra foi constituída por 17 sujeitos do género masculino com idades iguais ou superior a 17 anos, todos atletas da seleção Portuguesa de taekwondo. A técnica *Bandal Chagui* foi a selecionada para integrar ambos os protocolos de avaliação física, sendo executada contra um saco de boxe. Recorreu-se ao teste de vai-e-vem de 20m e ao teste Wingate de 30 segundos, como testes critério aos protocolos aeróbio e anaeróbio, respetivamente.

O teste específico aeróbio baseou-se no teste progressivo de esforço máximo proposto por Sant'Ana e colaboradores, tendo sido avaliado o consumo máximo de oxigénio ($VO_{2max.}$). O teste específico anaeróbio baseou-se num protocolo com a duração de 30 segundos, onde os atletas tiveram que realizar o maior número de pontapés (*Bandal Chagui*) possíveis e com a máxima força contra o saco de boxe. A força de impacto da técnica *Bandal Chagui* foi avaliada em ambos os protocolos através de um sensor piezoeléctrico.

Das principais conclusões, destacamos: (i) a correlação entre os dois testes aeróbios; (ii) o modelo apresentado para estimar o VO_{2max} com o teste específico explica 74% da variabilidade observada do $VO_{2max;}$ (iii) o teste específico anaeróbio tem um nível de concordância elevado com o teste Wingate conferindo especificidade na avaliação da aptidão anaeróbia.

Palavras-chave

Taekwondo; Avaliação aeróbia; Avaliação Anaeróbia; Overtraining; Testes Específicos

Abstract

Currently, the modern taekwondo in the sporting competitive side requires a high volume and almost constant training intensity throughout the sports season. The specific physical assessment test mode can monitor the athlete's training status, giving specific guidance for the development of training, in addition to being an indicator of recognized potential for the prevention and detection of overtraining. It turns out that taekwondo athletes are subjected to physical evaluations with nonspecific tests, without any transfer to the form to the technical gesture level, and also in respect of the effort characteristic during training and competition. Thus, the primary purpose of this thesis was to determine the concurrent validity of using two assessment protocols of aerobic and anaerobic fitness in taekwondo athletes.

A sample consisted of 17 male subjects older than 17 years from the Portuguese taekwondo national team participated in this study. The *Bandal Chagui* technique was selected to integrate both physical assessment protocols running against a punching bag. The 20m shuttle run test and the Wingate 30-second protocol test were both used as a criterion for aerobic and anaerobic evaluation, respectively.

The aerobic-specific test was based on the progressive test of maximum effort proposed by Sant´Ana and collaborators, having been rated the maximal oxygen uptake (VO_{2max}). The anaerobic-specific test was based on a protocol for 30 seconds, where the athletes had to perform the maximum number of kicks (*Bandal Chagui*) and with maximum force against a punching bag. The impact force of *Bandal Chagui* technique was evaluated in both protocols through a piezoelectric sensor.

Here are some of the key findings: (i) There was a correlation between the two aerobic tests; (ii) The model presented for estimating VO_{2max} with a specific test explains 74% of the observed variability in VO_{2max}; (iii) The anaerobic-specific test had a level of agreement with the Wingate test, conferring specificity for the evaluation of anaerobic fitness.

Keywords

Taekwondo; Aerobic evaluation; Anaerobic evaluation; Overtraining; Specific tests

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List of Abbreviations

AC	Anaerobic capacity
ACTH	Adrenocorticotropic
BCAA´S	Branched chain amino acids
CMJ	Counter Movement Jump
DALDA	Daily Analysis of life Demands of Athletes
FI	Fatigue index
GH	Grow hormone
Gln	Glutamine
Glu	Glutamate
HR	Heart rate
HRV	Heart rate variability
IgA	Immunoglobulin A
MAP	Mean anaerobic power
MKIF	Maximum kicking impact force
NC	Natural Killer cells
PP	Peak power
RH	Releasing hormone
RMAP	Relative mean anaerobic power
RPE	Ratings of perceived exertion
RPP	Relative peak power
RQ	Respiratory quotient
SRT	Shuttle Run Test
TE	Time to exhaustion
TQR	Total quality recovery
TSAT	Taekwondo Specific anaerobic Test
TST	Taekwondo specific test
URTI	Upper respiratory tract infections
WAnT	Wingate Test
WTF	World Taekwondo Federation

Chapter 1:

General Introduction

Given that the main purposes of this thesis are addressed in the research chapter, this brief introduction will firstly report on the physiological pattern of taekwondo as a combat sport and martial art. Secondly, our approach is to explain the need for specific protocols to assess physical fitness in taekwondo athletes at the expense of the most used generalist protocols. We also refer to the need for the prevention and detection of overtraining syndrome. Then, we present the main aims of this research and the structure of this thesis.

Background

Competitive sports require athletes, beyond their natural talent, to have optimal physical and mental capacities. Through training, coaches and athletes must adapt to and cope with all sport-specific demands in a manner that avoids exhaustion (Grantham, 2006). To deal with this concern, the coach makes the decision of selecting the best training load but also the most efficient recovery process, making it possible to reach the limits of human performance. However, the complexity of this task relies heavily on the dynamic nature of the athlete's individual trainability (on some endogenous factors – age, gender, morphology, training experience – and some of exogenous factors – nutrition, social support).

It is a rather thankless task because there are no strict strategies to measure the individual capacity of response or the athlete's adaptation to exercise/training. We can always use questionnaires, diaries, physiological parameters, or even direct observation (Borresen & Lambert, 2009) to track the physiological adaptations to training. However, it always involves having a set of standardized and validated instruments to explain the changes over time. The need for an evidence base that supports physiological assessments of athletes started to be matched by exponential growth in the last 30 years in clinical exercise physiology and medical health-related applications of exercise assessment (Winter et al., 2007). Martial arts and combat sports are no exception. We have witnessed in the last decade an exponential increase in scientific publications about combat sports and also the creation of research associations and organizations to promote and spread academic studies.

Like most sports, combat sports also had their beginnings in the late nineteenth century. In England, it was boxing that represented the combat sports, and the introduction of this modality in the Olympic games, especially between 1945 and 1991, opened the doors for other ones (Franchini & Del Vecchio, 2011). According to the same authors, the percentage of medals from the combat sports in the modern Olympic Games has always had an upward direction. It is estimated that 25% of the total awarded medals at the 2012 London Olympics Games came from combat sports.

Taekwondo has been included in this batch of combat sports since its recognition as an Olympic sport at the 2000 Sydney Olympic Games. Nowadays, Taekwondo has been practiced in over 140 countries around the world, and 120 nations are official members of its principal organization, the World Taekwondo Federation (WTF). Like martial arts, Taekwondo in Korea emerged as a means of self-defense that mainly uses the hands and feet for both defense and attack. The word “Taekwondo” means “Tae,” “kicking,” “Kwon,” “fisting,” and “Do,” a “way to do” (Kim, 1998). As competitive sports are widely recognized by their many leg techniques, run at high speed (Kim, 2002).

After the 2004 Olympics Games in Athens, the electronic body protectors were included; Taekwondo started to arouse the interest of not only practitioners and supporters but also several enterprises interested in the production, validation, and commercialization of these electronic vests (Del Vecchio et al., 2011). The body protector can register up to five techniques per second, showing the instantaneous power of each technique, which enables one to set minimum impact power to obtain a valid score. The introduction of this technology has led to increased attention to the athlete’s preparation for the competition, namely strength, power, and aerobic and anaerobic exercise capacity.

Regarding temporal structure, the Taekwondo match/fight lasts for three rounds of two minutes with a minute between each round. This indicates that the biological responses such as the function of the effort: pause ratio from Taekwondo athletes in a competition fall into the organization from 1:3 to 1:4 (Heller et al., 1998) and 1:6 to 1:9 (Matsushigue et al., 2009). In Table 1, we can get an overview of the physical demands of some martial arts, including Taekwondo. One can note that high demands are placed upon both aerobic and anaerobic metabolism during competitive bouts (Bridge et al., 2009). This suggests that coaches need to structure Taekwondo training sessions based not only on the technical and tactical needs of practitioners but also in a manner that enables sufficient cardiovascular conditioning for the competition (Bridge et al., 2007).

The study of Marcovic et al. (2005) sought to assess the fitness profile of elite Croatian female taekwondo athletes and to determine which physical, physiological, and motor characteristics best differentiate the successful from the less successful fighters. The results suggested that the performance of female taekwondo athletes primarily depends on the anaerobic alactic power, explosive power expressed in the stretch-shortening cycle movements, agility, and aerobic power. Ball et al. (2011) also suggested that elite taekwondo athletes need high levels of explosive power and anaerobic capacity; these characteristics (among others that determine athletic performance such as psychological and emotional parameters) can have a positive impact in highlighting the most promising athletes (Keogh, 1999).

Table 1- Physical requirements for different Martial Arts.

Martial Arts	Aerobic Level	Anaerobic Level	Flexibility	Muscular Strength	Muscular Power
Aikido	Low	Low	Moderate	Moderate	Low
Jujitsu	Low	Low	Moderate	Moderate	Moderate
Judo	High	High	Moderate	High	High
Karaté	High	High	High	Moderate	High
Kung Fu	High	High	High	Moderate	High
Muay Thai	High	Moderate	Moderate	Moderate	High
Taekwondo	**High**	**High**	**High**	**Moderate**	**High**

Source: Cochran (2001).

Although muscle power is not dependent on aerobic capacity, the athletes' aerobic fitness becomes essential, particularly during intervals of rounds or throughout the competition (when athletes perform consecutive fights). Indeed, Glaister et al. (2006) found that, in 20 sets of 5 seconds with rest intervals between sets of 10-30 seconds, the aerobic system was required for recovery; however, there is evidence to suggest that aerobic processes are also involved in ATP resynthesis during all-out, high-intensity exercise, suggesting that even for activities considered to be anaerobic in nature, there is significant involvement of the aerobic system in energy production (Nunan, 2006). Figure 1 shows the contribution of the energy systems during an exercise concerning the practice time. It can be seen that both the anaerobic and glycolytic (aerobic) systems are preponderant in taekwondo competition, with requirements ranging from 30 to 120 seconds.

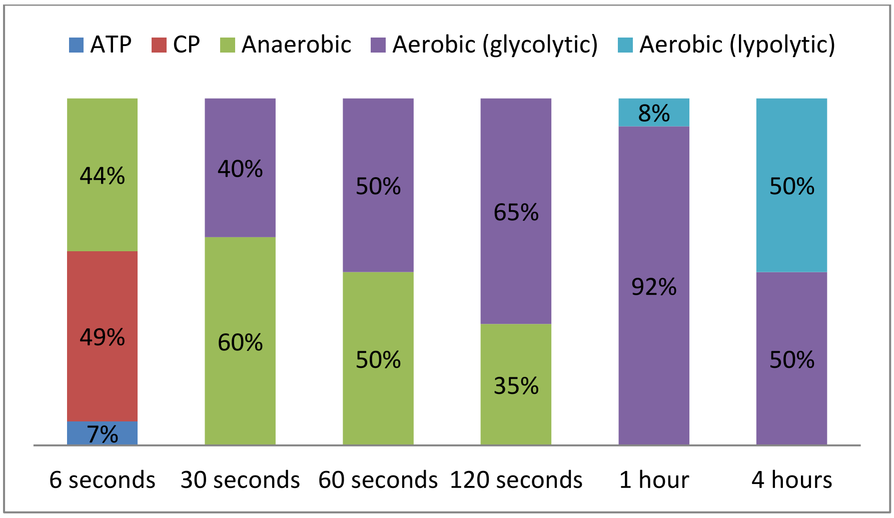

Figure 1: Energy systems and their contribution during the exercise. Adapted from Hawley et al (1998) in Peak Performance (2009).

In a review article, Harris (2014) presented some keys points about the physical and physiological profiles of taekwondo athletes, identifying that: a) elite taekwondo athletes possess a high anaerobic fitness base, yet aerobic fitness may be a precursor to overall success in taekwondo given the high work to rest ratios of the sport; b) elastic resistance training can potentially augment strength and power adaptations as an additional training method integrated with standard strength and power training protocols; and c) there is a causal link between power training, jump height, and success among elite taekwondo athletes. This key points derived from studies consider what the current training practices in taekwondo are, i.e. the training approach on the development of strength, muscle power, agility, flexibility, aerobic, and anaerobic fitness.

Nevertheless, not many studies have measured the aerobic and the anaerobic components using specific protocols for taekwondo. In fact, the literature often refers to the same nonspecific tests: for anaerobic assessment, the ‘Wingate test’ (WAnT) is used (Matsushigue et al. 2009; Sadowski et al. 2012); for explosive power, the ‘Counter Movement Jump’ (CMJ) is used (Casolino et al., 2012; Harris, 2014; Sant´Ana et al., 2014); and for aerobic endurance, a continuous progressive treadmill test (Marcovic et al., 2005), a test on the cycle ergometer (Heller et al., 1998), or even the ‘Shuttle Run Test’ (SRT) is used (Butios & Tasika, 2007).

Despite obtaining anomalous data, the scientific community recognizes the importance of assessing the physiological status of taekwondo athletes accurately through sports-specific protocols to improve the data validity, hence their application in both research and practice (Bridge et al., 2014). Also, it has been proposed that more specific movement training might improve strength adaptations to a greater degree (Jakubiak & Saunders, 2008) and further promote specific metabolic demands (Bridge et al., 2014).

When considering the specificity of this sport (intermittent, high-intensity maneuvers interspersed with either rest or low-intensity activity), with the energy systems and their contribution as well as the type of multiple planning periodization (with competitions spread year around) we can realize that it is a hard task to develop high levels of fitness to excel in taekwondo. The effects of intense training, with characteristics of high-intensity interval training that are normal in taekwondo training and competition, are fairly rapid on physiology and performance. Without careful monitoring, quick plateau effects are seen as well (Seiler & Tønnessen, 2009). An appropriate periodization strategy with specific and suitable protocols may be useful in screening misfit fatigue states that may lead to overtraining and staleness (Stone et al., 1999a; Stone et al., 1999b).

Unfortunately, little empirical evidence exists on both issues mentioned earlier, i.e., periodization strategies and specific protocols for physiological evaluation of taekwondo athletes. In the following chapter we will explore this issue.

Statement of the problem

There seems to be a consensus among researchers, coaches, and even athletes regarding the importance of sport-specific aerobic and anaerobic endurance to improve performance in taekwondo. There are many different parameters that can be used to monitor training load and subsequent fatigue. According to Halson (2014, s141), "both external and internal loads have merit for understanding the athlete's training load; a combination of both may be important for training monitoring". Examples of external load in taekwondo would be the mean power output of the kick performed during the taekwondo-specific test (Sant'Ana et al., 2014) or other measures of neuromuscular function such as the countermovement/squat jump (Chiodo et al., 2011). Regarding the internal load, the variables most referred in the literature are heart rate, maximum oxygen consumption (VO_{2max}), and lactate concentration (Heller et al., 1998; Lin, 2000; Melhim, 2001) or mean kicking time (Sant´Ana et a.l, 2014) when we are referring to psychomotor speed (Halson, 2014).

Thompson (1991) and Pieter (1991) recorded VO_{2max} values for national and international-level athletes ranging between 44.0 ml/kg/min to 55.8 ml/kg/min. In a study conducted by Heller et al. (1998), the VO_{2max} was 57.0 ml/kg/min for Spanish international taekwondo athletes and 53.8 ml/kg/min for Czech international athletes. According to Pieter (1991), athletes with VO_{2max} between 65.0 ml/kg/min and 55.0 ml/kg/min—men and women, respectively, from the Korean team—have a better chance of winning Olympic medals. Consequently, several researchers have recommended using the VO_{2max} to evaluate the aerobic fitness of athletes from anaerobic sports, encouraging endurance training (Bouhlela et al., 2006; Cooke et al., 1997).

However, this need carries a significant challenge – to measure oxygen consumption or to improve aerobic fitness, specific types of assessments and workouts are required. Typically, either the treadmill or cycle ergometer has been used by coaches and researchers for VO_{2max} testing. None of these tests or exercises reproduce the mechanical movements of this martial art, so we cannot reliably get the true fitness or training status of athletes.

The same limitation occurs when the goal is an anaerobic assessment. In fact, the Wingate test is placed as the most popular assessment within the scientific community for peak anaerobic power, anaerobic fatigue, and total anaerobic capacity (Laurent et al., 2007). Despite its widespread use, and considered not to be a sport-specific test for taekwondo, Cetin et al. (2009) used the Wingate test to assess anaerobic capacity and power in taekwondo athletes; Lin et al. (2008) used the cycle ergometer to assess anaerobic capacity while not specifically using the Wingate protocol.

This fault has been detected by numerous researchers, resulting in the need to create specific protocols that mimic the technical moves of martial arts and combat sports. Nunan (2006) developed an aerobic-specific test for karate practitioners; Almansba et al. (2007) drew up and validated a specific test as closely as possible to the real effort in judo competition to assess the state of physical performance of judo athletes; Santos et al., (2010) also in judo, developed an individual and specific test to determine the anaerobic-aerobic transition zone in competitive judokas; Sant´Ana et al. (2009) investigated the possibility of predicting the anaerobic threshold from a taekwondo-specific test. The same author (2014) proposed a method for evaluating the anaerobic power and capacity during a specific taekwondo test. These approaches are critical steps towards predicting performance and accurate monitoring of the training loads, allowing a better understanding of each athlete's tolerance to the effort.

Nevertheless, precise information on global competitive taekwondo sports performance is lacking. By 'performance' we mean the optimal biological state of training, commonly called overreaching. The difficulty of differentiating between overreaching and the overtraining syndrome is well known because of the multifactorial aspects that are involved in overtraining syndrome. Nevertheless, there really is scientific consensus on one symptom regarding the overtraining syndrome: the unexplainable decrease in performance (Mackinnon, 2000). Indeed, athletes suffering from overtraining syndrome usually can start a regular training sequence at their normal capacities, but they are not capable of completing the training load. Detecting this decline in physical performance involves having a set of standardized and validated instruments (as well as access to individual baseline data) for the changes over time to be explained. Halson (2004) states that, in general, time-to-fatigue tests are more likely to show greater changes in exercise capacity as a result of overreaching and overtraining syndrome than incremental exercise tests. Beyond that, time-to-fatigue tests allow for the evaluation of substrate kinetics, hormonal response, and the possibility of setting specific intensities and durations for the collection of sub-maximal results.

Research aims

In the previous subsection, a major design emerged—the need to develop specific tests for assessing taekwondo performance, particularly for the physiological/aerobic and anaerobic components. Its relevance is justified not only by the importance of monitoring the athlete adaptive responses to the rigorous demands of training but also as the primary overtraining syndrome indicator. Aiming to contribute to the state of the art of this scientific domain, this thesis has the following broad objectives:

1) to provide a narrative review of the overtraining syndrome;
2) to estimate maximum oxygen consumption using a specific test for taekwondo, relating oxygen uptake to the energy produced in a strike leg technique (*Bandal Chagui*);
3) to estimate the power and anaerobic capacity as well as the resistance to fatigue using specific taekwondo technical gestures (*Bandal Chagui*).

Monitoring sports performance involves having a set of standardized and validated instruments that can explain the changes over time. The individual baseline data and the need for highly standardized conditions are the most frequent problems and represent a limitation for the use of performing tests; however, if the tests are easy to use, with minimum requirements of assessment tools, then coaches and athletes will have a strong ally for success. That would be our most significant contribution.

Thesis organization

This thesis follows the Scandinavian model and comprises a collection of published manuscripts, which will be organized as follows: The first part of the thesis (chapter 1) has the overview, including the problem definition and the objectives. The second chapter discusses the concept of overtraining and its multifactorial aspect, emphasizing the importance of specific physical assessment tests in the detection and prevention of this state. The following two chapters (3 and 4) are the result of the empirical research: chapter 3 analyses the assessment of aerobic fitness through a taekwondo-specific test, and chapter 4 presents the taekwondo-specific anaerobic test. For each of these sections, the whole intervention process, methodology, and discussion of results will be presented independently. The fifth part (chapter 5) has the final analysis of the results and also provides the final conclusions, the practical applications of the research, the thesis limitations, and suggestions for future research.

References

Almansba, R., Franchini, E. & Sterkowicz, S. (2007). An Uchi-komi with load, a physiological approach of new special judo test proposal. *Science and Sports, 22*, 216-223.

Ball, N., Nolan, E. & Wheelere, K. (2011). Anthropometrical, physiological, and tracked power profiles of elite taekwondo athletes 9 weeks before the Olympic competition phase. *The Journal of Strength and Conditioning Research*, 25, 2752-2763. doi:10.1519/JSC.Ob013e31820d90f.

Borresen, J. & Lambert M. (2009). The quantification of training load, the training response and the effect on performance. *Sports Medicine, 39(9)*, 779-795.

Bouhela, E., Jouinia, A., Gmadaa, N., Nefzib, A., Ben Abdallahb, K. & Tabkan, Z. (2006). Heart rate and blood lactate responses during Taekwondo training and competition. *Science and Sports, 21*, 285-290.

Bridge, C. A., Jones, M. A., Hitchen, P. & Sanchez, X. (2007). Heart rate responses to Taekwondo training in experienced practitioners. *The Journal of Strength and Conditioning Research*, *21(3)*, 718-723.

Bridge, C. A., Jones, M. A. & Drust, B. (2009). Physiological Responses and perceived exertion during international Taekwondo competition. *International Journal of Sports Physiology and Performance, Human Kinetics, 4,* 485-493.

Bridge, C. A, Santos, J. F. S., Chaabène, H., Pieter, W. & Franchini, E. (2014). Physical and physiological profiles of taekwondo athletes, Review article. *Sports Medicine, 44,* 713-733.

Butios, S. & Tasika, N. (2007). Changes in heart rate and blood lactate concentration as intensity parameters during simulated Taekwondo competition. *The Journal of Sports Medicine and Physical Fitness, 47,* 179–185.

Casolino, E., Cortis, C., Lupo, C., Chiodo, S., Minganti, C, Capranica, L. (2012). Physiological versus psychological evaluation in taekwondo elite athletes. *International Jornal of Sports Physiology and Performance*, 7(4), 322-331.

Cetin, C., Kececi, A. D., Erdogan, A. & Baydar, M. L. (2009). Influence of custom-made mouth guards on strength, speed and anaerobic performance of taekwondo athletes. *Dental Traumatology, 25(3)*, 272-276.

Chiodo, S., Tessitore, A., Cortis, C., Lupo, C., Ammendolia, A., Iona, T. & Capranica, L. (2011). Effects of official Taekwondo competitions on all-out performances of elite athletes. *The Journal of Strength and Conditioning Research*, *25,* 334–339.

Cooke, S. R., Patersen, S. R. & Quinney, H. A. (1997). The influence of maximal aerobic power on recovery of skeletal muscle following aerobic exercise. *European Journal of Physiology, 75,* 512-519.Consulted at http://link.springer.com/article/10.1007/s004210050197 in 19-01-2014.

Cochran, S. (2001). Complete Conditioning for Martial Arts. Edited by Kim Thoren and John Wentworth: *Human Kinetics*, 2-3.

Del Vecchio, F. B., Franchini, E., Del Vecchio, A. H. M. & Pieter W. (2011). Energy absorbed by electronic body protectors from kicks in a Taekwondo competition. *Biology of Sport, 25,* 75-78.

Franchini, E. & Del Vecchio, F. B. (2011). Estudos em modalidades esportivas de combate: estado da arte. *Revista Brasileira de Educação Física e Esporte, 25*, 67-81.

Glaister, M., Stone, M. H., Stewart, A. M., Hughes, M. G. & Moir, G. L. (2006). Aerobic and anaerobic correlates of multiple sprint cycling performance. *The Journal of Strength and Conditioning Research, 20(4),*792-798.

Grantham, N. (2006).Injury Prevention: Want to know the key to training success? Plenty of R&R. *Peak Performance, 232,* 1-4.

Halson S., Jeukendrup A., (2004). Does overtraining exists?: An analysis of overreaching and overtraining research. Sports Medicine, 34, 967-981.

Halson, S. L. (2014). Monitoring training load to understand fatigue in athletes. *Sports Medicine,* 44(2), 139-147.

Harris, D. M. (2014). A review of the physiological and current training practices with a practical application of a four-week training mesocycle. *Journal of Australian Strength and Conditioning, 22(2),* 96-109.

Heller, J., Peic, T., Dlouha, R., Kohlikova, E., Melichna, J. & Novakova, H.(1998). Physiological profiles of male and female Taekwondo (ITF) black belts. *Journal of Sports Science, 16(3),* 243-249.

Jakubiak, N. & Saunders, D. H. (2008). The feasibility and efficacy of elastic resistance training for improving the velocity of the olympic taekwondo turning kick. *The Journal of Strength and Conditioning Research, 22*, 1194-1197.

Keogh, J. (1999). The use of physical fitness scores and anthropometry data to predict selection in an elite under 18 Australian Rules football team. *Journal of Science and Medicine in Sport, 2(2)*, 125-133.

Kim, K. P. (1998). A study on development upon the age and globalization of Korea Taekwondo. *Korea University Sports Science*, 7, 21-38.

Kim, Y. (2002). Effect of practice on pattern changes: Round house kick in taekwondo. Thesis for the degree of Master of Science in the Texas Christian University.

Laurent JR, C. M., Meyers, M. C., Robinson, C. A. & Green, J.M. (2007). Cross-validation of the 20-versus 30-s Wingate anaerobic test. *European Journal of Applied Physiology, 100(6),* 645-651.

Lin, Z. P. & Cynthia, E. R. (2008). The study of physiological factors and performance in welterweight Taekwondo athletes. *The Sports Journal*, ISSN: 1543-9518.

Lin, G. Y.& Kuo, Y. A. (2000). Maximum oxygen uptake, blood lactate and serum LDH activity of Taekwondo athletes before and after competition. *China Sports Technology,* 36 (1).

Mackinnon L. (2000). Overtraining effects on immunity and performance in athletes. Immunology and Cell Biology, 78, 502-509.

Marcovic, G., Mišigoj-Duraković, M. & Trninić, S. (2005). Fitness profile of elite Croatian female taekwondo athletes. *Collegium Antropologicum, 29(1)*, 93-99.

Matsushigue, K. A., Hartmann, K. & Franchini, E. (2009). Taekwondo: physiological responses and match analysis. *The Journal of Strength and Conditioning Research, 23(4)*, 1112-1117.

Melhim, A. F. (2001). Aerobic and anaerobic power responses to the practice of Taekwon-do. *British Journal of Sports Medicine. 35(4),* 231-234.

Nunan, D. (2006). Development of a sports specific aerobic capacity test for karate – a pilot study. *Journal of Sports Science and Medicine,* 47-53.

Pieter, W. (1991). Performance Characteristics of Elite Taekwondo Athletes. *Korean Journal of Sports Sciences,3,* 94-117.

Sant´Ana, J., Silva, J. F. & Guglielmo, L.G.A. (2009). Variáveis fisiológicas identificadas em teste progressivo específico para Taekwondo. *Motriz, Rio Claro, 15(3),* 611-620.

Sant´Ana, J., Diefenthaeler, F., Dal Pupo, J., Detanico, D., Guglielmo, L.A. & Santos, S. G. (2014). Anaerobic evaluation of taekwondo athletes. *International SportMed Journal, 15(4),* 492-499.

Santos, L., González, V., Iscar, M., Brime, J. I., Fernandez-Rio, J., Egocheaga, J., Rodríguez, B. & Montoliu, M. A. (2010). A new individual and specific test to determine the aerobic-anaerobic transition zone (Santos Test) in competitive judokas. *The Journal of Strength and Conditioning Research, 24(9*), 2419-2428.

Sadowski, J., Gierczuk, D., Miller, J. & Cieśliński, I. (2012). Success factors in elite WTF taekwondo competitors. *Archives of Budo – Science of Martial Arts, 8(3)*, 141-146.

Seiler, S. & Tønnessen, E. (2009). Intervals, thresholds, and long slow distance: the role of intensity and duration in endurance training. *Sportscience, 13,* 32-53.

Stone, M. H., O'Bryant, H. S., Schilling, B. K, Johnson, R. L., Pierce, K. C., Haff, G. G., Koch, A. J. & Stone, M. (1999a). Periodization: effects of manipulating volume and intensity. Part 1. *Strength & Conditioning Journal 21(2),* 56-62.

Stone, M. H., O'Bryant, H. S., Schilling, B. K., Johnson, R. L., Pierce, K. C., Haff, G. G., Koch, A.J. & Stone, M. (1999b). Periodization: effects of manipulating volume and intensity. Part 2. *Strength & Conditioning Journal, 21(3),* 54-60.

Thompson, W. R. & Vinueza, C. (1991). Physiologic profile of Tae Kwon Do black belts. *Sports Medicine Training and Rehabilitation, 3,* 49–53.

Toskovic, N. N., Blessing, D. & Williford, H. N. (2002). The effect of experience and gender on cardiovascular and metabolic responses with dynamic taekwondo exercise. *The Journal of Strength Conditioning Research, 16(2),* 278-285.

Winter, E.M., Jones, A.M., Davison, R.C.R., Bromley, P.D., Mercer, T.H. (2007). Sport and Exercise Physiology Testing Guidelines: Sport and Exercise Sciences Guide.

Chapter 2:

Training over the edge - understanding the overtraining syndrome

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Summary

Owing to the huge media coverage of sport it is not enough - for athletes - just to participate. The current pursuit of sports titles in all circumstances, social, economic and cultural, can make athletes break barriers regarding the intensity and amount of training, without giving due consideration to something as important as the workout recovery. Neglecting this dynamic training load and recovery numerous times over periods of one or more sports seasons can lead to a state of mal-adaptation called overtraining syndrome, and as such, compromise the ability of an athlete´s performance and, subsequently, a sports career. In this review, we intend to address the concepts and terminology concerning this syndrome, indicating the lines of research currently underlying this problem. The literature does not mention a single instrument capable of detecting a state of overtraining or of differentiating it from a state resulting from an optimal load stimulus which, when associated with a good recuperation period, enables the athlete to benefit from the super compensation, just as in the case of overreaching. There are several markers - immunological, physiological, hematological, hormonal and psychological factors - that can help diagnose the overtraining syndrome, but these isolated markers are of little use to determine a state of overtraining. Only taken together and through a process of exclusion of disease that can “mask” overtraining can it be diagnosed. Preventing is the key to avoiding the overtraining syndrome, and the first step to that end is to understand the fundamental principles of progressive workload, then understand the significance of recovery. Through this, reading the response of individual adaptation to training and relating it to the athlete’s performance, using the tools that at the moment seem to be the most appropriate (such as questionnaires, daily training, monitoring physiological parameters, direct observation and performance tests to track the specific results of the intervention that is being applied or submitted to the athletes), is a good strategy, since the decline in performance appears, (with other associated disturbances like non-training stressors) to be a common denominator in the scientific literature when the state of the overtraining syndrome is referred.

Key words: Overtraining, overreaching, recovery, training load, sports performance.

Introduction

Top-level sport inevitably requires a rigorous training and control regimen and therefore lies with the coach the decision of selecting the best training load. However, the complexity of this task results from the dynamic nature of the athlete’s individual trainability. Thus, the capacity to adapt to successive training loads during a defined period - translated into improved performance – depends on some endogenous (age, gender, morphology, training experience, etc.) and exogenous factors (nutrition, social support, etc.). As such, the adaptation capacity varies over time, inclusively facing the same applied load.

Providing training loads that are effective in improving performance is not new for sports coaches. Unfortunately, the common acceptance of the classical theory of training does not converge to the requirements of the modern high-level sport. Here, the amount of volume and training intensity imposed on athletes today has grown to the point of no return. Moreover, this wild scheme of training can become dubious in its true effectiveness, beyond to the possible deleterious effects on the athlete’s physical and mental integrity. So, nowadays, consider a proper recovery for the current demands of training load and competition, became a primary concern.

Successful training must involve overload; however, the combination of excessive overload plus inadequate recovery must be avoided. As a consequence of a disrupted balance between training stress and recovery, the athletes may experience acute feelings of fatigue, changes in mood state, staleness and even decreases in overall performance. If no other explanation for this observed changes can be found, the state of overtraining may be diagnosed - overtraining syndrome.

While many athletes and coaches unaware this phenomenon, its high prevalence in the top-level sport have gradually been highlighted. Therefore, the purpose of this chapter is to deepen the knowledge about overtraining, bringing actual scientific data to help coaches and athletes to recognize but particularly to avoid and overcame the overtraining syndrome. The following issues will be discussed: (i) misconception of overtraining terminology (overtraining, overtraining syndrome, overreaching); (ii) understanding the multifactorial etiology; (iii) the assessment of overtraining (monitoring performance, immunological, hematological, hormonal and psychological parameters); (iv) prevention and treatment of the overtraining syndrome.

Misconception of overtraining terminology

The definition of the term overtraining has considerably conflicting viewpoints. Researchers have used too many terms in different ways to describe both processes and outcomes associated with overtraining. Indeed, there has been confusion “about whether overtraining may have positive or negative aftereffects; about whether it should be considered a process, an outcome, or both; about whether various aspects of overtraining are causes or consequences; and about the varied usage of terms in the fields associated with overtraining" (Richardson, Anderson & Morris, 2008, p. 6). The difficulty of having a standardized diagnosis helps this misconception, demonstrating that this issue needs further investigation.

The competitive sports requires an athlete, beyond their natural talent, have their physical and mental capacity at an optimal level and this can only happen through the training process. Through training, coaches and athletes must adapt to and cope with all demands, in a manner to avoid exhaustion (Grantham, 2006). With this concern, which must be based not only on training loads but also in the recovery process, it may be possible to reach the limits of human performance. Sometimes (more often that we would like), by carelessness or lack of knowledge, that ceiling is exceeded resulting in a state of chronic fatigue and a decrease of physical performance (Gleeson, 2002). The same author identifies this state as overtraining, adding that "it is also a situation defined by excessive training, characterized by long-lasting fatigue and worsening of competitive performance with further attempts to improve physical condition" (p. 32). Indeed, overtraining is an imbalance between training/competition and recovery with atypical cellular adaptations and responses (Steinacker & Lehmann, 2002). Therefore, the state of overtraining is characterized by the inability to recover properly after successive training sessions (Kuipers, 1998). That's why the feeling of fatigue persists even after a regular rest period and leads to an emotional, physical and behavioral changes. This accumulation of training and non-training stress results in a long-term decrement in performance capacity (Kreider et al., 1998). However, besides performance incompetence, many other clinical problems may arise as a result of overtraining; including sports injuries, infections or mood disturbances (Steinacker & Lehmann, 2002.) Moreover, stress factors not caused by training such as monotony, intra and interpersonal conflicts, can exacerbate the risk of resulting in overtraining (Lehmann et al., 1997). That's why the term overtraining seems insufficient to describe what was going on with athletes in their everyday battles to balance stressors with recoveries (Richardson, Anderson, & Morris, 2008).

With effect, quite a few authors (Hooper & Mackinnon, 1995; O'Toole, 1998, Steinacker, & Lehmann, 2002) have provided a definition that describes overtraining as a process and also an outcome (i.e., overtraining syndrome). The term overtraining seems appropriate to label the process, whereas overtraining syndrome is an outcome, representing the end state of nonadaptation that results from overtraining (Hooper & Mackinnon, 1995). By using the expression 'syndrome,' the emphasis is placed on a multifactorial etiology, recognizing that exercise (training) is not necessarily the only cause of this phenomenon (Meeusen, Duclos, Gleeson, & Rietjens, 2005).

Israel (1976), says that the overtraining can be classified into two categories: the parasympathetic and sympathetic. The sympathetic form or the classic overtraining is characterized by increase sympathetic nervous system activity at rest. The sympathetic nervous system causes changes to the basic functions of the body, making easily the motor response to acute stress or physical activity. It occurs more frequently in athletes that rely primarily on anaerobic metabolism (lactic and alactic) to supply their muscle energetic demands. The parasympathetic overtraining form is characterized by the predominance of parasympathetic tone at rest and during exercise and is observed with greater frequency in endurance athletes.

Lehmann, Foster, Gastmann, Keizer & Steinacker (1999) distinguished overtraining by time frame (i.e., short- or long-term overtraining). The short-term overtraining is presented as a common part of athletic training, which leads to a so-called state of overreaching. This positive state "is characterized by transient underperformance, which is reversible within short-term recovery period" (p. 2). Therefore, in search of peak performance, the state of overreaching seems to be a regular part of athletic training in which restoration of performance capacity usually take one or two weeks and can be rewarded by an increase in performance ability. On the other hand, when overreaching is too profound or is extended for too long (i.e., long-term overtraining) the athlete runs the risk of a resulting overtraining syndrome.

Nederhof, Lemmink, Visscher, Meeusen & Mulder (2006) described the overtraining process occurring in three progressive stages: (i) Functional overreaching; (ii) Non-functional overreaching and; (iii) Overtraining syndrome. According to this author, functional overreaching occurs as a result of the heavy training process, where there is a momentary decrease in performance, however, this reduction is reversible in a short time if we consider an appropriate recovery plan. The functional overreaching occurs after several days of intense training and is associated with muscle fatigue or peripheral and, according to Lehman, Foster & Keul (1993), can be defined as pre-overtraining. Many coaches use training camps to increase the training load (intensity and volume) so that athletes are subjected to a stimulus that creates the functional overreaching. Promoting the so-called super - compensation period, usually, enable the athlete to reach higher performance levels.

Non-functional overreaching or extreme overreaching, can occur if the athlete neglecting the balance between training and recovery, typically, situations where the training load is markedly heavy during recovery periods; when the athlete drops down to a low level of performance and energy are not restored after a planned short-term recovery period; and when the impact of the non-training stressors in life are underestimate (Saunders, 2009; Meeusen et al., 2006). Non-functional overreaching is, therefore, a quite severe level of fatigue where athletes can experience the first signs and symptoms of prolonged training distress such as performance decrements, psychological disturbance (decreased vigor, increased fatigue) and hormonal disorder.

Recovery happens if athletes refrain from training for a few weeks (or even months). At this stage, the action of the coach is very important because realizing that the athlete is in a non-functional overreaching state, may delay the next training session. Facing such performance decrease, an anxious coach may even increase training load, contributing to the deterioration of the non-functional overreaching state, that is, a deeper level of fatigue, impairing the capacity for regeneration and recovery of the body. If this tune persists, may lead to overtraining syndrome.

Despite the importance of correct terminology, many coaches and athletes unaware this phenomenon whereas their main object of interest are sports performance. Thus, sports scientist should focus on distinguishing and monitor positive from negative training adaptation to get always positive results and avoid damaging the athlete health (Richardson et al., 2008).

Table 2 represents the overload training progression (referring to the fatigue level, recovery time and level of performance) and, in a way, summarizes and demonstrates how thin is the line between overtraining and overreaching.

Table 2. Overload training progression.

Process	**Training (overload)**		**Intensified Training**	→
Outcome	Acute fatigue	Functional overreaching (short-term overreaching)	Non-functional overreaching (extreme overreaching)	Overtraining syndrome
Fatigue level	Ordinary	Moderate	Moderate-severe	Severe
Recovery time	Day(s)	Days to Weeks	Weeks to Months	Months …
Performance	Increase	Temporary performance decrement (e.g., training camp)	Stagnation Decrease	Decrease

Notes: based on Saunders (2009) and Meeusen et al. (2006).

By this time, we can say that overtraining syndrome often can be accompanied by several biochemical, physiological, psychological and hormonal changes, and some common manifestation is chronic muscle pain, joint pain, mood, and personality changes, elevated resting heart rate, and of course, decreased performance (Gleeson, 2002). The difficulty of knowing whether and an athlete is in a state of peak fitness or if he is at the beginning of a decline in performance due to overtraining is very complex, especially regard to the physiological and biochemical factors (Meeusen et al., 2006, p.5). Moreover, overtraining signs and symptoms vary from individual to individual, are non-specific, anecdotal and numerous. These symptoms can also be confused with other clinical disturbances, and many times, the chronic fatigue syndrome and clinical depression are the most confoundable factors.

Understanding the multifactorial etiology

The progress of knowledge in this area has been delayed because there are few prospective scientific types of research and lack of well-controlled studies about individual responses to overload training (Halson & Jeukendrup, 2004). This lack of studies happens because is not ethical to “overtrain” an athlete. Thus, identifying possible events that trigger or initiate overtraining (imbalance between load and recovery, training monotony, the exaggerated number of competitions, glycogen deficiency, infections, emotional demands – affective and professional) is, perhaps, a rational study design, although cannot fully explain the entire mechanism of overload training. Since the phenomena involved in overtraining and recovery are clearly multifactorial, qualitative descriptive case studies can also assist in understanding the complex relationships involved (Botterill & Wilson, 2002). It could be useful to conduct research looking into many variables as possible; nevertheless, it is not an easy task in understanding problems in a holistic way.

The physiopathology of overtraining syndrome ranges from muscle soreness and weakness, cytokine actions, moods swings, hormonal and hematological changes, psychological depression and nutritional problems, but the number of symptoms reported by overtrained athletes is very large, more than 200 (Fry et al., 1991).

Table 3 shows, the physiological and psychological symptoms that are most commonly associated with a clinical diagnosis of overtraining (base on Gleeson, 2002).

Table 3- Common reported physiological and psychological changes associated with overtraining.

Symptoms
Underperformance
Muscle weakness
Chronic fatigue
Sore muscles
Increased perceived exertion during exercise
Reduced motivation
Sleep disturbance
Increased early morning or sleeping heart rate
Altered mood states (e.g. low scores for vigor; increase scores for fatigue and depression)
Loss of appetite
Gastrointestinal disturbance
Recurrent infections

Notes: based on Gleeson (2002).

To understand the etiology of overtraining syndrome seek first to exclude some organic diseases or infections and other nutritional factors (negative energy balance, insufficient carbohydrates and proteins intake, iron and magnesium deficiency). Despite the existence of several hypotheses about the causes of overtraining syndrome, there seem to be also some consensus. Situations that can trigger overtraining syndrome are the imbalance between training and load and recovery, excess competition, the monotony of training, emotional issues. Other less mentioned causes, relies on exercise heat stress and training at altitude (Meeusen, 2006), but the scientific evidence to support or refute these hypotheses are scarce, and the diagnosis is reached when you cannot identify and justify the cause of such symptoms.

In the following subsections, we point some main reasons that seem to trigger overtraining. What we need to retain, is that the etiology of overtraining syndrome varies from individual to individual, depending a lot on your state (physical and psychological) and stressors factors that are put upon it. Nevertheless, high-intensity training and too little regeneration (recovery) is always the starting point.

Variations of the hypothalamic-pituitary-adrenal axis

Lehmann et al., (1993) introduced the concept that hypothalamic function reflects the state of overreaching or overtraining syndrome because the hypothalamus integrates many of the stressors. The same author in 1998 suggested that a regulation disorder at the hypothalamus-pituitary might be the central disorder in overtraining syndrome.

Increased training loads, as well as other stresses, can influence the neuroendocrine system in a chronic way. The endocrine system acts to promote the adaptation to the stimulus (load or other life stressors) through the activation of the autonomic nervous system. These actions result in changes in blood catecholamine, glucocorticoid, testosterone levels (Cunha et al., 2006), adrenocorticotrophin (ACTH), cortisol and prolactin (Gleeson, 2002).

In response to stress, greater quantities of hormones are released by changing the sensitivity of specific receptors for these hormones, and tissues became less responsive to its action. Some authors (Fry et al., 1991; Lehmann et al., 1998) refers that the negative feedbacks responses reduce sympathetic drive and down –regulation of anterior pituitary gland receptors for hypothalamic releasing factors (corticotrophin) and/or inhibition of pituitary hormone pulse generators could result in a decreased pituitary hormone - ACTH; growth hormone; follicle stimulating hormone, (FSH); luteinizing hormone, (LH)- in response to stress. This and a down-regulation of receptors for ACTH on the cells of the adrenal cortex could result in a decreased release of cortisol in response to stress.

In a normal training state, with high loads and other life stressors, there is a decrease in the adrenal responsiveness; this decrease is compensated by an increase in the pituitary release of ACTH. In an early stage of overtraining, we still record a decrease in the adrenal responsiveness to ACTH, but at this time it is not compensated, and a decrease in cortisol response will be verified. A more advanced state of overtraining continues to show a reduction of the ACTH release by the pituitary, a decrease in sympathetic activity and a decreased sensitivity to catecholamine's (adrenaline and noradrenaline). Those catecholamine´s and cortisol, are responsible to redistribute metabolic fuels, maintain blood glucose and enhance the responsiveness of the cardiovascular system. Repeated exposure to stress can change the responsiveness, through alterations in neurotransmitter and receptors functions, impairing the behavioral adaptations.

Imbalance of circulating amino acids

During exercise, there may be a decrease in circulating amino acids (including the branched chain - BCAA´s, isoleucine, leucine, and valine) due to oxidation in skeletal muscle to ATP production, while there is the formation of an aromatic amino acid, tryptophan, that binds to albumin in the blood.

Free fatty acids may also be oxidized to form ATP (when the muscle and liver glycogen is depleted), and because they are not soluble, they also circulate in the blood bound to albumin. Consequently, there will be a competition for that link - albumin-tryptophan and albumin- free fatty acids (Petibois, Cazola, Poortmans & Deleris, 2002).

Tryptophan is the serotonin precursor. As 90% of tryptophan is bound to albumin, and the 10% remaining is free in the blood, the freer fatty acids bound to albumin, a greater amount of free tryptophan will exist. Tryptophan also competes with BCAA's to pass the blood brain barrier.

During physical activity there is a decrease in BCAA's circulating and a greater concentration of tryptophan than BCAA's will take place, thus, tryptophan will have the preference to pass to the brain, and that can result in fatigue of cerebral origin (Budgett, 1998). In the brain, tryptophan acts as a neurotransmitter (5HT), and the level of changes in that neurotransmitter can provoke overtraining symptoms (see figure 2), causing central fatigue, loss of appetite, affecting sleeping, and even inhibiting the release of factors from the hypothalamus that control pituitary hormones (Rang, 1987, cited by Budget, 1998).

The Glutamine, a nonessential amino acid synthesized by isoleucine and valine, very abundant in skeletal muscle, also seems to play a role in the overtraining syndrome. Glutamine can be used for hepatic gluconeogenesis, and its main target is the kidneys, where it is used in maintaining the pH balance (Rowbottom, Goodman & Morton, 1995). A negative arteriovenous difference in plasma glutamine concentration occurs during prolonged exercise (Graham, 1995) and some evidence shows that this concentration of amino acid is higher in slow-twitch fibers compared with fast-twitch fibers. Long-duration exercise, with aerobic characteristics and in periods of intense training, the concentration of glutamine rises, decreasing during the recovery period.

Since the white blood cells (lymphocytes in particular) cannot synthesize glutamine for energy, being dependent on syntheses and release by skeletal muscles the decrease in glutamine cause a muscle acidosis (cannot do the buffering of hydrogen ions) and provoke a decline in the immune response, especially in overtraining (Gleeson, 2008). Indeed, plasma glutamine has been suggested to be a potential cause of the exercise-induced immune impairment and increased susceptibility to infection in athletes and therefore, as a possible indicator of excessive training stress. However, not all studies have found a fall during periods of increased training and overtraining (Walsh, Blannin, Robson & Gleeson, 1998).

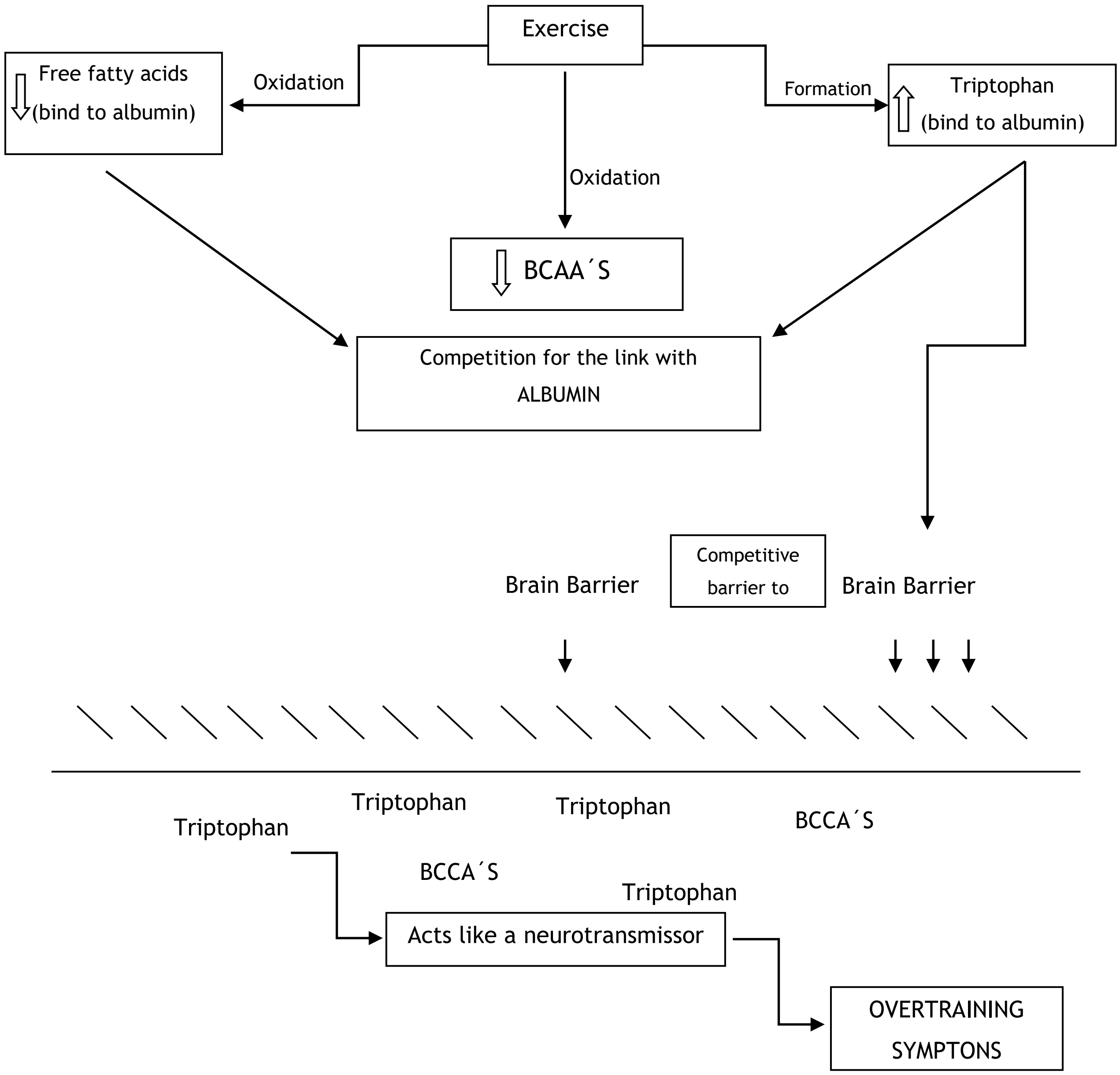

Figure 2: The imbalance of circulating amino acids during exercise leeds to a competition between BCAA´s and Tryptophan to pass the blood brain barrier. The result of this process can be the central fatigue.

Cytokine and inflammation

Cytokines have also been linked to overtraining as these appear to be mediators of this syndrome, a situation justified by the activation of monocytes to produce and release inflammatory cytokines such as IL-1b, IL-6, and TNF-α. Repetitive exercise, high volume, and inadequate rest generate a high inflammatory response, which can cause micro-trauma in joints, muscles and connective tissue (Mackinnon, 2000). These cytokines would then initiate a ‘whole-body’ response, involving chronic systemic inflammation, ‘sickness behavior,' suppressed immune function and mood state changes. It has also been suggested that cytokines may activate the hypothalamic-pituitary-adrenal axis, and therefore, may underlie the neuroendocrine changes observed in overtrained athletes.

With overtraining there are also increases in the plasma concentrations of others substances that are known to influence leukocyte functions (besides the ones that already were pronounced) like the inflammatory cytokines (Mackinnon, 1998b quoted in Gleeson, 2002). It appears that the high release of pro-inflammatory cytokines (interleukins 1, 2 and 6, interferon α, tumor necrosis alfa and protein c-reactive) triggered by the systemic inflammation process – due to excessive training – acts on the central nervous system, changing the hormonal balance. Cytokines also activate the sympathetic nervous system, while suppressing the activity of hypothalamic-pituitary-gonad, and thus responsible for the observed changes in blood concentrations of gonadal hormones and catecholamines, which are present in a state of overtraining athletes (Rogero, Mendes, & Tirapegui, 2005).

The assessment of overtraining

At present, it still is a very hard task to differentiate acute fatigue and decreased performance resulting from isolated training sessions from any overtraining progression states (Halson & Jeukendrup 2004). Additionally, it is also complicated to identify a specific marker that can register the difference between the states of overtraining and overreaching.

Acoording to Meeusen, Nederhof, Buyse, Roelands, Shutter and Piacentini (2010), a keyword in the detection and recognition of the overtraining syndrome may be the prolonged inability to adapt, not only to the level of aspects of athletic performance, but also in relation to other regulatory mechanisms, such as biological mechanisms, hormonal and neurochemicals. The marker of choice for detecting overtraining syndrome should address the following two criteria: (i) the marker should be sensitive to training load and, preferably, should not be affected by other factors such as diet; (ii) changes in the marker value should occur before reaching the state of overtraining syndrome, and responses due to the acute exercise should be possible to distinguish in relation to chronic responses. As this marker would be extremely useful for coaches and athletes, a criterion of easy applicability and low cost also is a point to be fulfilled (Meuseen, 2006), however, so far, the literature does not identify any marker that has all these requirements.

The mechanisms that are consistently documented to occur with overtraining and together may provide significant support to expose the overtraining syndrome include the list below. (Mackinnon, 2000, p. 503):

- Performance decrements;
- Reduce ability to performance high-intensity exercise;
- Persistent high fatigue ratings;
- Decreased maximal heart rate;
- Changes in blood lactate variables, such as the blood lactate threshold or blood lactate concentration at maximal exercise;
- Neuroendocrine changes, such as reduced nocturnal excretion of norepinephrine (Nep);
- Changes in athletes self-reported indicators of “wellbeing” such as fatigue and quality of sleep.

Prevention is an important point in this thematic, therefore, a very well structured planning train is necessary, where coaches and athletes can register and track all adaptations to short and long term training.

Monitoring Performance

Identify the prevalence of overtraining is difficult because it requires a long-term monitoring of several athletes from different sports, and on the other hand, the coaches have a great reluctance to identify athletes who are overtrained, but some studies indicate that about 7 % to 20% of athletes in specific individuals active phase of his sports life may have symptoms of overtraining (Hooper, 1993, 1995; Raglin, 1994).

The type of sport most likely to cause overtraining appears to be the endurance modes, where the very intense training volume is more present than those where the strength is the predominant capacity. But in sports, like judo and weightlifting can also occur overtraining symptoms (Callister, Fleck & Dudley, 1990).

Meeusen (2006, citing Budget, 2000; Lehmann, 1999 and Urhausen, 1995) refer that athletes suffering from overtraining syndrome, normally can start a regular training sequence at their usual capacities, but they are not capable of completing the training load, so, as mentioned before, one very good indicator is the unexplainable decrease in performance. Of course, it is clear that the type of tests should be sport-specific. How to apply it is still involved in academic discussions: maximal or incremental test? Halson (2004) refers that in general, time to fatigue test are more likely to show greater changes in exercise capacity as a result of overreaching and overtraining syndrome than incremental exercise tests, beyond that, allows the evaluation of substrate kinetics, hormonal response and the possibility of setting specific intensities and durations for the collection of sub-maximal results.

Meeusen et al. (2010), used a two-bout maximal exercise protocol to objectively and immediately make a distinction between non-functional overreaching and overtraining syndrome in underperforming athletes who were diagnosed with suspicion of non-functional overreaching or overtraining syndrome. With this protocol, they measured physical performance and stress-induced hormonal reactions. The protocol was applied to 4 hours of the interval, obtaining the following main results: the maximal blood lactate was lower in overtraining syndrome subjects, compared with the non-functional overreaching subjects while resting concentrations of cortisol, adrenocorticotrophic hormone (ACTH) and prolactin (PRL) concentrations were higher. However, the sensitivity of these measures was low. Both, ACTH and PRL had a higher reaction in the second bout in non-functional overreaching athletes compared with the overtraining syndrome and showed the highest sensitivity for making that distinction. This study suggests that using a two-bout maximal exercise protocol can be useful to detect non-functional overreaching and overtraining syndrome in an early stage. The authors used the cycle ergometer and the treadmill, obviously, depending on the specific type of athlete/sport to be tested, proving that the specificity of the test may be sensitive not only to variation in performance but also in the variation of other parameters that may be associated with the overtraining syndrome.

Monitoring sports performance involves having a set of standardized and validated instruments, for the changes over time can be explained. However, there are no ways to measure the individual capacity of response or the athlete’s adaptation to exercise/training. For such task we can always use questionnaires, diaries, monitoring physiological parameters or even use direct observation (Borresen & Lambert, 2009) to track the physiological adaptations of training. The individual baseline data and the need for high standardized conditions are the most frequent problems and represent a limitation for the use of performing the test as a detector of overtraining syndrome.

Monitoring Heart Rate

Heart rate (HR) appears as one a preferable indicator for the evaluation of training load response and physical fitness. In addition to HR responses to exercise, research has recently focused on heart rate variability (HRV). HRV is an index of interbeat intervals; the higher the HRV, the higher the cardiovascular autonomic responsiveness (Bosquet et al., 2008), which also means an increase in vagal (parasympathetic) tone about the sympathetic activity (Uusitalo et al., 2000). It seems that trained individual have higher HRV than untrained individuals. As enunciated in the following texts, both HR and HRV could potentially play a role in the prevention and detection of overtraining (Achten & Jeukendrup, 2003).

Training stress interferes with the autonomic nervous system and therefore with HR. According to Fry et al., (1991), this influence may be one of the reasons why HR is considered an indicator of overreaching and overtraining syndrome. However, the effects of overreaching on submaximal HR are controversial, with some studies showing decreased rates and others no difference. Maximal HR appears to be decreased in almost all 'overreaching' studies, but concerning the HRV, it appears that in overreaching or overtraining there is no differences (Achten & Jeukendrup, 2003) or the ones are very inconsistent (Uusitalo et al., 2000).

Meeusen et al. (2006) underlined the study of Halson et al. (2005), in which they sought to understand the influence of increased training intensity for seven days (overreaching) on HRV. The results showed a significant effect on HRV values when the intensity of training was intensified. This suggests an increase in the relative contribution of parasympathetic to sympathetic nervous system activity.

In a meta-analysis developed by Bosquet et al. (2008), overreaching resulted in a small decrease in the HR measured during submaximal and maximal exercise, together with a small increase in the cardiovascular autonomic balance at rest. The decrease in HR in a submaximal effort was more evident during a long-term increase in training load, suggesting that this marker cannot be used as valid short-term fatigue indicator; it probably suits better for long-term fatigue. The results also show that maximum HR can also be a possible indicator of overtraining syndrome, functional overreaching, and non-functional overreaching because it was the only variable that changes with increased training load during short and long term periods. The overall effect size showed only a small increase in resting HR, suggesting that it cannot be a valid indicator of overtraining syndrome or both states of overreaching. Although, the results also show a moderate increase in resting HR after short term interventions (2 weeks) of increasing training load, no alterations when the intervention was longer than two weeks. According to the authors, the increasing in resting HR suggests that this indicator can be used as a valid marker of short-term fatigue, probably for functional overreaching, but not for a long-term intervention of increasing load (possibly nonfunctional overreaching or overtraining syndrome). Another variable widely used in training is the heart-rate recovery. Bosquet et al. (2008) found no data/studies supported by experimental data that would enable them to make considerations about this parameter, noting that any conclusion about the validity of post-exercise HR recovery as a marker of functional overreaching, non-functional overreaching, and overtraining syndrome will be hazardous.

The meta-analysis results are primarily statistical, and in this context Bosquet et al. reported that the moderate amplitude of the alterations found in their research limits the clinical usefulness, as this difference may be justified with the day-to-day variability. Consequently, the correct interpretation of HR or HRV fluctuations during the training process requires the comparison of these markers with other objective signs and symptoms of functional overreaching, non-functional overreaching, and overtraining syndrome. Indeed, HR or HRV alone does not provide consistent results due to the difficulty of standardized procedures. Moreover, it seems that it is also difficult to distinguish between changes in physiological measures resulting from functional overreaching, non-functional overreaching and overtraining syndrome (Meeusen et al., 2006).

Immunological Parameters

The immune system composed of several white cells seems to be affected by exercise. For instance, leukocytes, whose change in number and its functions are closely correlated with being active. According to Mackinnen (1998b, quoted by Gleeson, 2002) in intense and repeated exercises bouts there is a decreased in the leukocytes ability, suspecting that the change in plasma concentration of hormones such as adrenaline, cortisol, growth hormone and b-endorphin is considered the neuroendocrine cause that leads to immunosuppression induced by exercise (Niemann, 1997).The falls in blood concentration of glutamine as seen before, also seems to be implicated in causing immunosuppression associated with heavy training.

One situation that is often reported with increased training intensity and with overreaching and overtraining syndrome is the risk of upper respiratory tract infections (URTI) (Niemann, 1997; Mackinnon, 2000; Meeusen et al., 2006), but it has been suggested that the predisposition increase of high-performance athletes to URTI is not necessary accompanied by a state of overreaching or overtraining syndrome; URTI can be the consequence of an intense workout.

In a study using swimmers submitted to intensified training for 4 weeks, it was found that the high rate of URTI among athletes who have not reached a state of overreaching was a protective factor since, in a way, forced them to reduce the training loads for some time, allowed sufficient rest to prevent overreaching (Jonsdottir et al. in IV International Symposium Exercise and Immunology, 1999 quoted by Mackinnen, 2000). When trying to support the theory that overtraining alone is associated with increased risk of URTI, the studies are inconclusive, but there are good evidence that when the training is truly intense (beyond the limits of an individual athlete capacities and before the presence of some monotony in training), the risk of URTI is increased, suspecting that the overtraining syndrome and URTI may result from a common denominator - excessive training load and insufficient recovery time.

How intense training causes an immunosuppression has several explanations. The question of increasing the duration and degree of “open window” is a trigger to induce overtraining syndrome and to infections. On the other hand, when an athlete is subjected to prolonged exercise, there is an increase in neutrophils (bone marrow) and if that training continues to occur over extended time for weeks and/or months, the bone marrow can deplete the ability to neutrophils release, particularly those who have reached a mature state. This decreased a number of neutrophils in overtrained athletes might also predispose athletes to infections.

During the recovery period after a workout, the number of neutrophils increases, however, the number of lymphocytes decreases, and the ratio neutrophil/lymphocyte seems to be a good indicator of stress induced by exercise, and also for the recovery capacity (Nieman, 1998). The normal values of this ratio usually take 6-9 hours after exercise to be replaced, but if it is a prolonged and intense training, the same ratio can be elevated for 24 hours after exercise (Gleeson, 2002).

The same author also claims that using the indicator given by an expression of CD45RO+ over the CD4+ cells, can identify overtrained athletes with high sensitivity and specificity. CD45RO+ and CD4+ cells are subsets of T lymphocytes, changing both with exercise or training. CD45RO cells are markers of T-memory cells and T-cells activators. Therefore, an expression of CD45RO on T-cells may be only an indicator of the presence of an acute infection, which may be a possible cause of underperformance (Meeusen et al., 2006).

Another changing in the leukocytes function with intense training is the ratio CD4+/CD8+ (helper/suppressor). This ratio under conditions of intense training falls, but it seems not be different enough in overtrained athletes when compared with healthy or well-trained athletes (Gleeson et al., 2005). Regarding the number and functions of natural killer cells (NK, CD16*/CD56*) the percentage and number are normal in athletes, although their cytotoxic activity at rest may be higher in athletes than in non-athletes (Nieman, 1995, cited by Mackinnon, 2000). Nieman and coworkers in Suzui et al. (2004) reported that NK cell cytolytic activity was greater in marathon runners, rowers, and active elderly than in untrained individuals, although there were no intergroup differences in NK cell count. Such results suggest that chronic exercise increases cytotoxicity per NK cell. On the other hand, many studies have failed to establish positive relationships between NK cell cytolytic activity and chronic exercise (Boas et al., 1996; Shepard, 1997; Shepard & Shek, 1999, cited by Suzui et al., 2004). Acute exercise temporarily increases NK cytolytic activity (Gleeson, 2002) but decreases after exercise, usually for no more than a few hours (Suzui et al., 2004).

Natural killer cells cytotoxic activity have been shown to increases in the training load in already well-trained athletes, however, it is not possible to identify differences between overtraining and healthy athletes (Verde, Thomas & Shepard, 1992). Mackinnon says that in terms of functionality and number of NK is not possible, yet, to distinguish a state of overtraining and overreaching, but during periods of intense training the number of NK cells may decrease: a military study found that for 10 days of intense workout (running) the number of CD56* cells decreased more than 40%, and these values remained low for 5 days of light training for recovery (Fry et al., 1992).

In another study whose reference is direct to the number of NK and cytotoxic activity, it is reported that both conditions (number and activity) after an intense workout plan for four weeks in swimmers are lower. A special feature of this intervention is that athletes who reported these results are not achieved during the four weeks a state of overreaching (Gedge, Mackinnon & Hooper, 1997).

For competitive athletes who often train twice a day is possible that the number of NK cells and their function need more time to recover, since it is reported that intense and prolonged training sessions have a transient response of suppression of cytotoxic activity of NK cells, which may take at least 6 hours, and perhaps can reach 12 hours to normal activity (Nieman et al., 1995, Mackinnon et al., 1997 as cited in Mackinnon, 2000). That downregulates of Nk function, seem to support the "open window" theory, whereby some athletes become susceptible to upper respiratory infections (URTI) for a brief period after heavy exercise (Pedersen and Ullum, 1994, as cited in Suzui et al., 2004).

Another important parameter of the immune system is the concentration of immunoglobulin A (IgA), which also constitutes a barrier to infectious agents in the body, particularly against pathogens that cause URTI. IgA is found in external secretions (e.g., mucous, saliva, tears), and with intensified training, it seems that the concentration of IgA falls, continuing low after several hours in the recovery period (Nieman, 1997). Some studies documented a negative relationship between salivary IgA and the concentration and occurrence of URTI: for example, lower IgA levels early in the training season have been correlated with the number of URTI episodes throughout the season (Mackinnon, 2000).

Low levels of IgA have been reported in overtrained athletes (Mackinnon, 1996, as cited in Gleeson, 2002) demonstrating that monitoring salivary IgA may be useful in indicating overtraining, although the inter-individual variation in salivary IgA is quite large.

It seems that the immunity system is fairly sensitive to intense training, and it is not possible to distinguish those alterations (mainly in functions and not in numbers) from the well-trained stage (overreaching) and a maladaptation state (overtraining). Like for all stress parameters that we have referred to, is important to establish a reference/normal value for the each athlete. Given the biological variability, comparing values between individuals seem not a sufficiently reliable method. Moreover, testing immunological markers for overtraining, despite being wrapped up in the lengthy and costly process, the data presented in the scientific literature are inconsistent, which leads us to use and analyze these markers with relative care.

Hematological Parameters

The values of hematological parameters are affected by some factors even in apparently healthy populations. These factors include age, sex, ethnic background, social, nutritional and environmental factors, and it has been shown in several studies that some of the hematological parameters exhibit considerable variations at different periods of life (El-Hazmi & Warsy, 2001). For the overtraining syndrome and overreaching, a variety of responses to the increased training load has been studied in an attempt to achieve a reliable indicator for those two states.

Mackinnon et al. (1997, as quoted by Silva, 2006) refer that the hematocrit tends to decrease with overtraining in swimmers after two and four weeks of gradually increasing the training volume. In the same study, some red blood cells also decreased with overtraining after four weeks of increased training volume. The reduction was about 8-12%, very similar to the decline in magnitude to the concentration of hemoglobin in amounts of 5-9%. Likewise, according to Silva, (2006) others authors (Newhouse and Clement, 1988; Smith, 1995) also reported a reduction concentration of red blood cells and hemoglobin after high-intensity training.

The concentration of plasma glutamine has been suggested as a possible indicator of excessive training stress (Rowbottom et al., 1995, as cited by Meeusen et al., 2006; Rowbottom et al., 1996, as cited in Gleeson, 2002). During periods of high demand of immune system an increased production of glutamine is observed, but during prolonged period of training, glutamine levels fall - the same don´t happen in short, and intense training bouts – the same decrease of glutamine can also be seen during the existence of physical trauma, burns, inflammations and infections (Walsh et al., 1998; Gleeson, 2002).

Because of these changes in glutamine levels and also because of its relationship with the immune system, it has been associated this amino acid with the overtraining. Parry-Byllings et al. (1992, as quoted by Halson, 2004), reported a lower plasma glutamine concentrations in 40 athletes diagnosed as overtrained when compared with controls; the same study reported lower increased glutamate levels in overtrained athletes. Smith and Norris (2000), in an attempt to track the training tolerance through the glutamine and glutamate concentrations found changes in the plasma glutamine/glutamate ratio (Gln/Glu) suggesting this ratio as a predictor of overreaching or overtraining in athletes. They also observed an elevated plasma glutamate and hence a reduced Gln/Glu ratio in athletes who were classified as overtrained. However, no studies have investigated changes in glutamine, glutamate, and reported concurrent performance measures during a period of intensified training that has resulted in overreaching (Halson et al., 2003)

Although not all studies have found a fall during periods of increased training and overtraining. Plasma glutamine may provide a useful biochemical marker of overtraining, but since plasma glutamine level is influenced by short term exercise, nutritional status, diet, infection and physical trauma, it is important that standardized evaluations of these parameters are taken into account (Walsh et al., 1998; Gleeson, 2002).

Another marker that also seems to help to detect overtraining is urea. Urea is an end product of the degradation of nitrogenous or protein materials. Measurements recorded in the field as a component of the training program represents the concentration of serum urea (can be regarded as equal to plasma), i.e., balance of urea synthesized in the liver and urea excreted renally (Hartmann & Mester, 2000), briefly, the extent of protein degradation can be very helpful to the coach. An increase in exercise can promote an increase in serum urea value, but the conclusion of catabolic/metabolic activity does not automatically result from such elevated values. If those increased values are associated with a reduced exercise tolerance after a long phase of the intensive physical effort, the possibility of a catabolic/metabolic activity or insufficient exercise tolerance becomes much more likely (Hartmann & Mester, 2000). According to the same investigators, it is only appropriate to mention a catabolic/metabolic activity when serum urea levels are elevated for 2-3 days. If the levels remain high for more than 3 to 5 days, it may be suspect a massive loss of protein.

In Halson et al. (2003) study, plasma urea concentration tended to be slightly elevated during an intense training period, and also declined to pre-intensive training levels after recovery, which means that elevation is temporary, and the concentration of urea is markedly influenced by the recent diary protein intake, so serum urea hardly fulfills a reliable indicator for the onset of overtraining (Gleeson, 2002).

Another parameter very associated with muscle function is the creatine kinase, an enzyme present in the blood when the muscle cell membranes are damaged as a result of an intense muscle contraction, and that is often used as an indicator of muscle damage (Diaz, Ruiz, Hoyos, Zubero, Gravina, Gil & Irazusta, 2010). One consequence of the high level of creatine kinase in plasma is the temporary decline in athletic performance, probably caused by muscle aches, muscle stiffness, decreased the range of motion, changes in lactate concentrations, loss of strength and decrease in the maximum dynamic power (Jones, Newham, Round & Tolfree, 1986). Although Gleeson (2002) noted that the eccentric work does not cause large increases in creatine kinase activity in highly trained athletes, yet, athletes experience muscle aches. The same author, quoting O´Reilly et al. (1997), also notes that once installed elevated creatine kinase levels in the body, the resynthesis of muscle glycogen become impaired, resulting in a performance decrease.

Halson et al. (2003) found that plasma creatine kinase activity was significantly elevated during the intensive training period, and also returned to baseline levels during recovery. Regarding the activity of creatine kinase, it seems that the characteristics of the effort, intensity, and volume, are both important since they have an influence on the reduction of high-energy phosphate in the muscle cell. Creatine kinase seems to have higher concentrations in men than in women, probably due to the influence of sex hormones (Hartmann & Mester, 2000), which makes females more inclined to muscle disruption than males (Clarkson & Hubal, 2012).

There is another peculiarity of creatine kinase, which is the inter and intra-individual variability. As mentioned by Hartman and Mester (2000), there are athletes who have low levels of creatine kinase at rest, others a mean value and there are still those who have high values when compared with normal values. In this study, athletes who had chronic low values of creatine kinase have demonstrated a lower variability, whereas those with chronically higher values exhibited considerable variability of this parameter. This information becomes important for the coach since he can better tailor training schemes to a more individualized intervention.

As noted for serum urea, increases in creatine kinase concentrations at rest when measured under standardized conditions, can provide a set of information concerning an elevated muscle and /or metabolic strain, but they are not suitable to indicate an overreaching or overtraining state (Urhausen et al., 1998a, as cited by Meeusen et al., 2006).

Another proposed marker of overtraining is a paradoxical decrease in plasma lactate levels in submaximal and maximal exercise. While lower lactate levels during submaximal exercise generally indicate improved endurance capacity (Foster et al., 1988; Jacobs, 1986 as cited by Jeukendrup & Hesselink, 1994), paradoxically, lower lactate levels in maximal exercise have been linked to overtraining (Jeukendrup et al., 1992; Lehmann, 1988 as cited by Jeukendrup & Hesselink, 1994). This has been explained by low muscle glycogen levels, a decreased catecholamine response to exercise or decreased muscle tissue responsiveness to the effects of catecholamine's (Jeukendrup et al., 1992, as cited by Gleeson, 2002).

Associate ratings of perceived exertion with lactate values seems to be a possible way to distinguish the state of training with overtraining. This is supported by the explanation that for a given exercise intensity, a decrease in blood lactate concentration is accompanied by an increase in rating of perceived exertion during overtraining, while ratings of perceived exertion remains unchanged or decreases when the athlete is tested during intensive training (Snyder et al., 1993, as cited by Bosquet et al., 2000). So, the blood lactate /rating of perceived exertion quotient would be expected to decrease with overtraining, but stay relatively the same with intensive training. This theory seems to be true in overreaching athletes but never has been tested with overtraining athletes.

Bosquet et al. (2000) in a study with the objective of determine if it is possible to disassociate the changes in the lactate curve brought about by training and overtraining, with the hypotheses that overtraining would result in a decrease in the blood lactate /ratings of perceived exertion quotient after an overtraining period and a 2 weeks recovery period. The study showed that rating of perceived exertion does not provide useful information for detecting overtraining during an incremental test. Therefore, the proposed ratio is not a better marker for overtraining than blood lactate alone.

Another interesting fact was that the authors noted that the right shift of the curve of lactate was accompanied by a decrease in the peak blood lactate when there was a decrease in a performance capacity, which remained after the two recovery weeks when athletes were in overtraining, but not when they were in overreaching. Following this observation, Bosquet et al. (2008) propose to retain a decrease in the peak blood lactate as a marker of overtraining in events of long duration and repeating its measurement after a sufficient period of rest to make the distinction with overreaching.

Beyond what already mentioned, the literature presents some limitations to lactate being a marker for overtraining - lactate differences are sometimes subtle (lying within the measuring error of the apparatus) and depend on the modes of the used exercise test; and there are no lactate changes reported in strength athletes (Meeusen et al., 2006).

Hormonal Parameters

Halson et al. (2000, cited by Urhausen et al., 1998) reported that in overtraining endurance athletes there were no significant changes in cortisol (normal vs. overtrained athletes) when subjects were examined before and during a state of short-term overtraining. However, maximal cortisol response appears to be reduced during overtraining. Compared to testosterone, some studies are contradictory. Urhausen referring to Flynn et al. (1994), indicates that after intensive training, a decrease in testosterone levels may be found, which can also coincide with a decrease in performance capacity. Vervoorn et al. (1991, as cited by Halson & Jeukendrup, 2004) obtained the same decrease in testosterone concentrations; however, no significant loss of performance was obtained.

The ratio testosterone/cortisol is referred in some studies as a marker of the anabolic-catabolic balance, which can be a tool for the diagnosis of overtraining syndrome (Adlercreutz et al., 1986, as cited by Urhausen & Kindermann, 2002). Cortisol and testosterone are both released in response to high intensity (>60% maximal oxygen uptake, VO_{2max}) aerobic and anaerobic exercise and is believed that this ratio decreases about the intensity and duration of training. Moreover, it seems to be an indicator of the positive and negative effects of training due to the opposing effects that hormones have on growth, protein synthesis and muscle metabolism (Kreider et al., 1998, as cited in Halson & Jeukendrup, 2004). This ratio only indicates the actual physiological strain of training and cannot be used for diagnosis of overreaching or overtraining syndrome (Meeusen, 2005, Urhausen et al., 1995; Meeusen et al., 2004) because the ratio has been shown to remain unchanged in overreached athletes; although, a decrease ratio has been reported in athletes who show no performance decrements after intensive training (Vervoorn et al., 1991, as cited by Halson & Jeukendrup, 2004).

The decrease in nocturnal urinary excretion of catecholamine’s has been suggested as a sign of an advanced state of overtraining syndrome, in overtraining athletes, and has also been interpreted as low intrinsic sympathetic activity (Lehmann et al., 1992, Mackinnon et al., 1997, as cited by Urhausen & Kindermann, 2002). This excretion appears to be lower than normal in overtrained athletes (Foster & Lehmann, 1999, as cited by Gleeson, 2002) indicating a negative correlation with fatigue ratings. Catecholamine levels in urine and plasma can reflect the activity of the sympathetic nervous system and can, therefore, examine the possibility of parasympathetic-sympathetic imbalance or autonomic imbalance (Halson et al., 2003).

Lehmann et al., (1997) reported that athletes after submitting an intensive ergometer training, revealed 60% higher pituitary adrenocorticotropic hormone (ACTH) release to corticotrophin releasing hormone, which was also followed by a decrease of about 25% of adrenal cortisol release. Barron et al., (1985, as cited by Gleeson, 2002) have also presented evidence of an adrenocortical deficiency in athletes suffering from overtraining syndrome. They found that growth hormone, prolactin and ACTH responses to insulin-induced hypoglycemia (a potent stimulus to sympathetic nervous activity) were lower in a small group of overtrained athletes compared with healthy well-trained controls. Urhausen et al. (1998, as cited by Halson & Jeukendrup, 2004), reported lower resting ACTH levels and lower exercise-induced ACTH release in overreached athletes. A reduced maximal plasma growth hormone (GH) concentration was also reported.

In order to protect the target organs of inadequate or pathological loads during the process of overtraining, the body has several adaptations, and one that appears to prevent a catabolic state is a slight increase in pituitary sensitivity to GHRH (increased release of GH), which is more anabolic (Lehmann et al., 1993). This also happened in response to the unchanged testosterone/cortisol ratio.

About the limitations for the use of hormonal markers to identify overtraining, the baseline data also appears a problem to avoid; it is needed to have a baseline measure to allow the comparisons among different stages/periods for the same athlete. Moreover, nutrients through the food intake can change the concentration of some hormones at rest and in response to exercise (Meeusen et al., 2006). The same author also highlighted that the concentrations of blood hormone are linked with the sample conditions, i.e., conservation and the assay variability.

Psychological Parameters

It becomes clear to us the multifactorial etiology of the overtraining process - several methods using physiological markers, hematological or immunological parameters have been used. However, Shepard & Shek (1994) highlighted that the psychological evaluation is an easier and less expensive to detect the overtraining syndrome. In fact, there is a general agreement that the overtraining syndrome is characterized by psychological disturbances and negative affective states (Hooper et al., 1997, as cited by Halson & Jeukendrup, 2004).

O´Connor (1998, as cited by Kentta & Hassmén, 1998) identify four advantages for using psychological markers: i) Psychological changes are more reliable, i.e. mood shifts coincide with increases and decreases in training and are also highly replicable; ii) Some mood states are highly sensitive to increases in the training load (changes in these states occur early on and have large effects) while others are more sensitive to the staleness (overtraining) syndrome; iii) Variations in measures of mood often correlate with those of physiological markers, and iv) The titration of training loads based on mood responses to overtraining appears to have good potential for preventing overtraining. On the other end, psychological testing may reveal early-warning signs more readily than the various physiological or immunological markers (Kenta & Hassmén, 1998).

The great advantage of psychometric instruments is the quick availability of information (Kellmann, 2002, as cited by Meeusen et al., 2006), therefore, some questionnaires such has the “Profile of Mood State” (POMS) (Morgan et al., 1988; Raglin et al., 1994; O´Connor, 1997; O´Connor et al., 1989; Rietjens et al., 2005, as cited by Meeusen et al., 2006) the “Recovery – Stress Questionnaire” (RestQ-Sport) (Kellmann, 2002), the “Daily Analysis of Life Demands of Athletes” (DALDA) (Halson et al., 2002), and the “Self-condition Scale” (Urhausen et al., 1998b) have been used to monitor psychological parameters in athletes. Although these questionnaires give a set of information that can predict a state of overreaching or overtraining syndrome, the results should not be interpreted without an association of decreased performance measurements.

It has been said that sometimes there is a confusion between burnout and overtraining, where the first is a sequel to the second. In psychological terms, it is necessary to treat the two situations differently, once an athlete burnout has their motivation levels far below, and this is a central issue of burnout. Overtrained athletes may be highly motivated at the point of increasing their levels of training/load to try to reverse the decline in performance.

The limitations of the use of questionnaires to assess psychological parameters/mood changes were described in the “ECSS Position Statement Task Force” (Meeusen et al., 2006): the application of the questionnaires must be in a well-standardized conditions to avoid different in mood; the timing is also important for example, normally during the day the mood in the morning, afternoon, and evening changes. Also in this parameter the measures of an individual must be compared with baseline data and the questionnaire as an instrument must detect the influenced in the results of other psychological parameters independently of moods state.

Prevention and treatment of overtraining syndrome

Scientific research in the field of sports science has been keen on getting a set of effective strategies that promote physical recovery, indicating that talent is not enough to ensure success in sports. The concept that body needs a recovery time to adapt to a load of training and competition is not new. However, athletes and coaches often rely on the empiricism to act at this stage of training.

Before one can develop a recovery strategy, it must define what kind of fatigue we want to reverse. Because fatigue is a multifactorial condition, the type of stimulus-induced will define the forms of fatigue that may manifest itself (Gleeson, 2002). The issue focuses on the occasion (the shortest amount of time) that a new load of training or competition can be applied, causing the athlete benefits from the previous load. This requires that the same athlete is subjected to a recovering method at the point of fatigue that allows having a recovery time of the stimulus that was submitted, avoiding overtraining and all its negative repercussions on athletic and sports performance.

Avoiding / preventing is the primary measure in the fight against the overtraining syndrome. Uusitalo (2001) refers that because there is still a huge difficulty in diagnosing the overtraining syndrome and distinguish it from a state of overreaching, it is best to prevent that overtraining happen, and the first step is to understand the fundamental principles of progressive load before of understanding the significance of recovery (Grantham, 2006, p. 1-2):

- Training is designed progressively to overload body systems and stores;
- If the training stress is insufficient to overload the body´s capabilities, no adaptations will occur;
- If the workload is too great (progressed too quickly, performed too often without adequate rest), then fatigue follows and subsequent performance will be reduced;
- Work alone is not enough to produce the best results; it takes time to adapt to training stress;
- Trainers have to encourage adaptation to training: it is important to plan recovery activities that reduce residual fatigue;
- The sooner the recovery from fatigue, and fresher when to undertake a training session, the better the chance of improving.

Figure 3 (based on Grantham, 2006) shows the principle of progressive overload, where it enters a recovery strategy in the fatigue point where it will decrease the length of time it will take to recover from training.

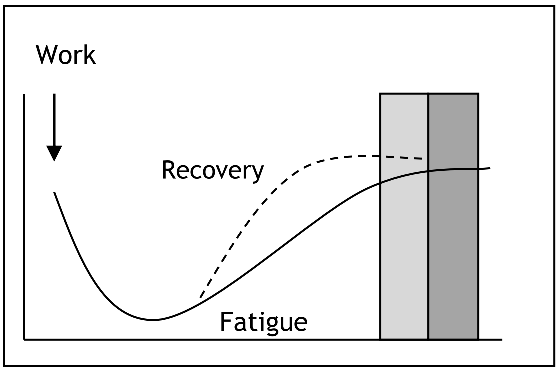

Figure 3: Progressive overload (based on Grantham, 2006).

As in Grantham manuscript (2006), the broken line represents the gain in the recovery time, and the light gray shaded area, the opportunity window to applied another training/competitive load, which will be sooner than if it hadn't been a training unit for recovery.

To achieve the situation described above is necessary to have a training plan, based on periodicity. Periodicity means that loads are given in an appropriate stimulus, followed by periods of recovery. This will also decrease the monotony of training (Uusitalo, 2001) and allow taper. The taper is a type of reduced training, which is implemented to maintain fitness and skill levels. The taper cannot be considered detraining and is needed to reduce the residual effects of fatigue resulting from training, and peak performance will occur at a point where fitness and fatigue differences are maximized (Banister & Calvert, 1980**)**.

Training and recovery must be in the balance to prevent non-functional overreaching and overtraining syndrome, and for that, it is very important that coaches and athletes make the registration of the load applied in practice/training session and total week training using a training log.

The four methods, most frequently used to monitor training and prevent overtraining are retrospective questionnaires, training diaries, physiological screening and the direct observational method (Hopkins, 1991, as cited in Meeusen et al., 2005). Also the psychological screening of athletes (Berglund & Safstrom, 1994; Hooper et al., 1995; Hooper & McKinnon, 1995; McKenzie 1999, Raglin et al., 1991; Urhausen et al., 1998b; Morgan et al., 1988; Kellmann, 2002; Steinacker et al., 2002, all cited by Meeusen et al., 2005) and the Ratings of Perceived Exertion (RPE) (Acevedo et al., 1994; Callister et al., 1990; Foster et al., 1996; Foster, 1998; Hooper et al., 1995; Hooper & McKinnon 1995,; Kentta & Hassmen 1998; Snyder et al., 1993, all cited by Meeusen et al., 2006) have received more and more attention nowadays.

In order to have a rigorous training program (and training records), Foster et al. (1996, 1998, as cited by Meeusen, 2006), proposed the training load as the product of the subjective intensity of a training session using 'session RPE' and the total duration of the training session expressed in minutes. If these parameters are summated on a weekly base, it is called the total training load of an individual. The 'session RPE' has been shown to be related to the mean percentage heart rate reserve during an exercise session and to the percentage of a training session during which the heart rate is in blood lactate derived heart rate training zones. With this method of monitoring training, they have demonstrated the utility of evaluating experimental alterations in training and have successfully related training load to its performance. But, as training load is clearly not the only parameters that influence an overtraining syndrome, the same investigators additionally to the weekly training load, daily mean training load, as well as the standard deviation of training load, were calculated during each week. The daily mean divided by the standard deviation was defined as the monotony.

The product of the weekly training load and monotony was calculated as strain. The incidence of simple illness and the injury was noted and plotted together with the indices of training load, monotony, and strain. They noted the correspondence between spikes in the indices of training and subsequent illness or injury which allowed an optimal explanation for illnesses.

Kentta and Hassmé (1998), attest that there are many methods used to measure the training process but few with which to match the recovery process against it. One such framework for this is referred to as the total quality recovery (TQR) process. By using a TQR scale, structured around the scale developed for ratings of perceived exertion (RPE), the recovery process can be monitored and matched against the breakdown (training) process (TQR versus RPE). The TQR scale emphasizes both the athlete's perception of recovery and the importance of active measures to improve the recovery process. Furthermore, directing attention to psychophysiological cues serves the same purpose as in RPE, i.e. increasing self-awareness, as opposed to relying on physiological cues alone.

The TQR has a correspondence with the RPE and is divided into two subscales, one more subjective (perception) and other more objectives (action). The idea is to integrate quantitative and qualitative aspects of the overtraining syndrome, to speed up the recovery process with interventions and strategies that are optimized for one particular stimulus.

To best overcome and prevent the overtraining is necessary to take into consideration that the more intense the training, the greater the breakdown. High-intensity training, therefore, demands higher quality recovery than low-intensity training. Consequently, high-intensity training also demands a longer recovery period than low-intensity training. The athlete undertaking high-intensity training would, therefore, benefit from high-quality recovery more than an athlete undertaking low-intensity training (Kentta & Hassmén, 1998) and the whole process of recovery depends on, among other factors (gender, age, level of experience, weather) of the energy system used. Bompa and Cornacchia (1998), recommend the following recovery time (see table 4).

Terjing and Hood (1988, cited by Bompa & Cornacchia, 1998), reported that to overcome the effects of short-term overtraining, the sessions should be discontinued for 3-5 days. After this rest period, the training should be lowered, alternating one day of training and one day of rest. If the overtraining is more severe and the initial rest period is longer, then each week of rest will require at least two weeks of training to reach the prior fitness state.

Table 4: Suggested recovery time after intense training.

Recovery process	**Recovery time**
ATP/CP restoration	3-5 minutes
Restoration of muscle glycogen: - After prolonged exercise - After intermittent exercise (weight training)	 10-48 hours 24 hours
Renewal of blood and muscle lactic acid	1-2 hours
Restoration of enzymes and vitamins	24 hours
Recovery of strength training of high intensity (super metabolic compensation and CNS)	2-3 days
Payment of alactic O_2 debt	5 minutes
Payment of the lactic debt.	30-60 minutes

It is important to take notice about the type of training effort because this is what will determine which forms of fatigue an athlete will experience (Calder, 1996, as cited by Grantham, 2006, p.2). The next table (table 5) illustrates the various types of fatigue.

Following the previous table, it seems to be an order in which recovery strategies should be applied. Grantham (2006) called it “The recovery pyramid,” which comprises four levels, namely:

- Level 1 (base) – covers the rest (passive and active), sleep and nutrition (refueling and rehydration);
- Level 2 – covers periodisation (training changes), reactive programming, cool down, stretching);
- Level 3 – encompasses pool recovery work, compression skins, ice baths, massage, contrast bathing;
- Level 4 – is responsible for strategies that involve psychological/environmental (flotation tanks, etc.), omega wave, integrated approach with individual focus.

The list is not exhaustive, and strategies at levels 3 and 4 should not form part of the equation until and unless the basic (levels 1 and 2) has already an established regime; first we should look for the simple intervention, sleep, nutrition, and training.

The repair of damage muscle tissue is in the category of short-term overtraining, requiring 5-7days to complete the process, while the total regeneration of muscle tissue takes approximately 20 days (Ebbing & Clarkson, 1989, as cited by Bompa & Cornacchia, 1998). The recovery of muscle damage in the acute phase is best treated with ice, elevation, compression and passive and active rest, depending on the degree of injury. After three days we can begin to introduce other methods of therapy such as massage. Alternate hot and cold can also be an effective way to decrease the stiffness associated with muscle damage caused by exercise (Cornheim, 1988, as cited by Bompa & Cornacchia, 1998; Prentice, 1990, Bompa & Cornacchia, 1998).

Table 5: Type of fatigue and how they occur (based on Grantham, 2006).

Type of fatigue	Occurs as a result of …
Metabolic (energy stores)	- high volume training - repeated workloads - aerobic/anaerobic conditions - multiple training sessions throughout the day
Tissue damage	- plyometrics - eccentric loading - contact sports
Neurological (peripheral nervous system)	- high-intensity work - resistance training (strength and power development) - speed work - skill sessions and the introduction of new training techniques
Psychological (central nervous system and emotional fatigue)	- training monotony - lifestyle issues - heavy game/competition/training periods - pressure plays (training simulating match conditions - new training techniques
Environmental	- hot and cold environmental - travel (local, national, international) - time differences - competitions

The diet has a direct connection with the overtraining because it can be an important factor in the recovery of muscle tissue. Carbohydrates are essential to maintaining muscle glycogen levels during intense training and become crucial in intense high-volume workouts because the glycogen is the primary source of stored energy in the muscles being used. After exercise, in the first 30 min, there is a window of opportunity to replenish muscle glycogen, this window is caused by the insulin-like effect of exercise which lasts for some time after exercise. If this time is spent on the consumption of carbohydrates, the replacement will happen much faster than if the intake of carbohydrates happens later. This action is sufficient to prevent the non-functional overreaching and give to the athlete the opportunity to get the most out of the training, as showing in figure 4 (based on Saunders, 2009).

The effects of protein intake seem to add some benefits in the recovery process, especially when it is mixed with carbohydrates, however, there is no consensus regarding the role that protein play in the overtraining. Some studies have shown faster rates of muscle glycogen replenishment when carbohydrate-protein is consumed immediately following endurance exercise, compared to carbohydrate alone; a better protein balance, increasing protein synthesis and decreased protein breakdown; improvements in some muscle damage markers, resulting in lower blood creatine kinase, less muscle soreness and improve muscle function. But not all studies have shown significant improvements in subsequent performance following carbohydrate-protein intake. However, the positive effects of protein seem to appear more regularly in the studies that provide the more demanding training/recovery periods. So, it also seems that the longer and harder are the training, the more important the details of the recovery nutrition, including the inclusion of protein, become.

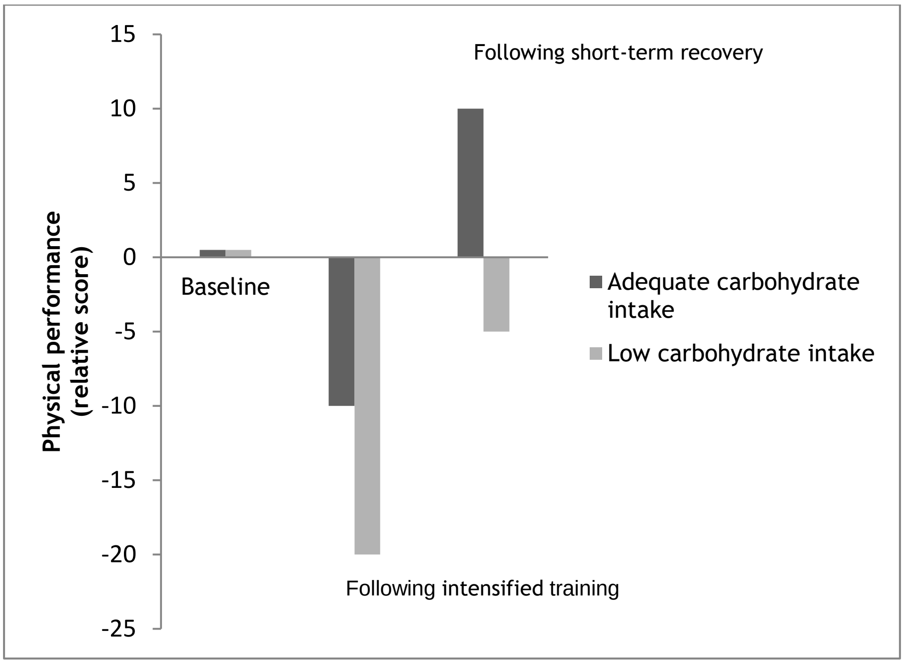

Figure 4: Effects of carbohydrate intake during intensified training (based on Saunders, 2009).

Conclusion

The overtraining is a challenge for coaches, athletes, and researchers, since there isn't, yet, a valid and reliable instrument for diagnosing it. This syndrome is wrapped in a set of situations that can lead to a difficult, time consuming and tricky diagnosis. So far the best possible diagnosis is by the exclusion of diseases that can mask the overtraining.

The targets for diagnostic markers are lacking, although some such as heart rate variability, the perception of mood changes and feelings/self-awareness of the athletes is a promising diagnostic tool. Until further studies reveal more information and reliable indicators, confirming the effectiveness of physiotherapists and psychotherapists interventions as a treatment, prevention is still the best cure.

References

Achten, J. & Jeukendrup, A. (2003). Heart rate monitoring: applications and limitations. *Sports Medicine, 33*, 517-538.

Banister, E. W. & Calvert, T. W. (1980). Planning for future performance: implications for long-term training. *Canadian Journal of Applied Sports Sciences, 5,* 170-176.

Bompa, T. & Cornacchia, L. (1998). Serious strength training. São Paulo: Phorte Editora.

Borresen, J. & Lambert M. (2009). The quantification of training load, the training response and the effect on performance. *Sports Medicine, 39(9),* 779-795.

Bosquet, L., Merkani, S., Arvisais, D. & Aubert A.G. (2008). Is heart rate a convenient tool to monitor over-reaching? A systematic review of the literature. *British Journal of Sports Medicine, 42,* 709-714.

Botterill, C. & Wilson, C. (2002). Overtraining: Emotional and interdisciplinary dimensions. In M. Kellmann (Ed.), Enhancing recovery: Preventing underperformance in athletes (pp.143-160). *Champaign. IL: Human Kinetics.*

Budgett, R. (1998). Fatigue and underperformance in athletes: the overtraining syndrome. *British Journal of Sports Medicine, 32*, 107-110.

Callister, R., Callister, R. J., Fleck, S. & Dudley, G. (1990). Physiological and performance responses to overtraining in elite judo athletes. *Medicine and Science in Sports and Exercise, 22(6),* 816-824.

Cunha, S., Ribeiro J. & Oliveira A. (2006). Overtraining: theories, diagnosis, and markers (Review article). *Revista Brasileira de Medicina Esportiva, 12(5),* 297-302.

Clarkson P. M., & Hubal M. J. (2012). Exercise-induced muscle damage in humans," American Journal of Physical Medicine and Rehabilitation, 81(11), S52–S69.

Diaz, E., Ruiz F., Hoyos I., Zubero J., Gravina L., Gil, J. & Irazusta, J. (2010). Cell damage, antioxidant status, and cortisol levels related to nutrition in ski mountaineering during a two-day race. *Journal of Sports Science and Medicine, 9*, 338-346.

El-Hazmi, M. A. F. & Warsy, A. S. (2001). Normal reference values for hematological parameters, red cell indices, HB A2 and HB F from early childhood through adolescence in studies. *Annals of Saudi Medicine, 21(3,4),* 165-169.

Fry, R., Morton A., Crawford, G. & Keast, D. (1992). Cell numbers and in vitro responses of leukocytes and lymphocyte subpopulations following maximal exercise and interval training sessions of different intensities. *European Journal of Applied Physiology, 64,* 218-227.

Fry, R., Morton A. & Keast, D. (1991). Overtraining in athletes: un update. *Sports Medicine, 12,* 21-65.

Gedge, V., Mackinnon, L. & Hooper, S. (1997). Effects of 4-wk intensified training on natural killer (NK) cells in competitive swimmers. *Journal of Medicine Sciences Sports and Exercise, 29,* S158.

Gleeson, M. (2002). Biochemical and immunological markers of overtraining. *Journal of Sports Sciences and Medicine, 2,* 31-41.

Gleeson, M. & Bishop, N.C. (2005). The T cell and NK cell immune response to exercise. *Annals of Transplantation*, 10(4), 43-48.

Gleeson, M. (2008). Dosing efficacy of glutamine supplementation in human exercise and sports training. *Journal of Nutrition, Supplement,* 2045S - 2049S

Graham, T. E., Rush, J. W. E. & Maclean, D. A. (1995). Skeletal muscle amino acid metabolism and ammonia production during exercise. In: Hargreaves M., editor. *Exercise Metabolism. Champaign (IL) Human Kinetics*, 133-177.

Grantham, N. (2006). Injury Prevention: Want to know the key to training success? Plenty of R&R. *Peak Performance, 232,* 1-4.

Halson, S.L., Bridge, M.W., Meeusen, R., Busschaert, B., Gleeson, M., Jones, D.A. & Jeukendrup, E. (2002). Time course of performance changes and fatigue markers during intensified training in trained cyclists. *Journal of Applied Physiology*, 93(3), 947-956.

Halson, S., Lancaster, G., Jeukendrup, A. & Gleeson, M. (2003). Immunological Responses to overreaching in cyclists. *Journal of Medicine and Sciences in Sports and Exercise, 35(5),* 854-861.

Halson, S. & Jeukendrup, A. (2004). Does overtraining exists?: An analysis of overreaching and overtraining research. *Sports Medicine, 34*, 967-981.

Hartmann, U. & Mester, J. (2000). Training and overtraining markers in selected sports events. *Journal of Medicine and Sciences in Sports and Exercise, 32(1),* 209-215.

Hooper, S. L., & Mackinnon, L. T. (1995). Monitoring is overtraining in athletes. Sports Medicine, 20, 321-327.

Hooper, S. L., Mackinnon, L. T., Gordon, R. D. & Bachmann A.W. (1993). Hormonal response of elite swimmers to overtraining. *Journal of Medicine and Sciences in Sports and Exercise,* 25, 741-747.

Israel, S. (1976). Problems of overtraining from an internal medical and performance physiological standpoint. *Medicine in Sports, 16*, 1-12.

Jeukendrup, A. & Hesselink, M.(1994). Overtraining – what do lactate curves tell us? *British Journal of Sports Medicine, 28(4),* 239-240.

Jones, D. A., Newham, D. J., Round, J.M. & Tolfree, S. E. J. (1986). Experimental human muscle damage: morphological changes in relation to other indices of damage. *Journal of Physiology, 375*, 435-448.

Kellmann, M. (2002). Enhancing recovery: Preventing underperformance in athletes. Human Kinetics.

Kentta, G. & Hassmén, P. (1998). Overtraining and recovery. A conceptual model. *Sports Medicine, 26(1),* 1-16.

Kuipers, H. (1998). Training and overtraining: an introduction. *Journal of Medicine and Sciences in Sports and Exercise, 30(7),* 1137-1139.

Kreider, R. B., Fry, A. C. & O´Toole, M. L.(1998). Overtraining in sport. *Champaign: Human Kinetics.*

Lehmann, M., Foster, C., Dickhuth, H. & Gastmann, U. (1998). Autonomic imbalance hypothesis and overtraining syndrome. *Journal of Medicine and Sciences in Sports and Exercise 30,* 1140-1145.

Lehmann, M., Foster, C., Keul, J. (1993). Overtraining in endurance athletes: a brief review. *Journal of Medicine and Sciences in Sports and Exercise, 25,* 854-862.

Lehmann, M. J., Lormes, W., Opitz-Gress, A., Steinacker, J. M., Netzer, N., Foster, C. & Gastmann, U. (1997). Training and overtraining: an overview and experimental results in endurance sports (Review Article). *Journal of Sports Medicine and Physical Fitness, 37,* 7-17.

Mackinnon, L. (2000). Overtraining effects on immunity and performance in athletes. Immunology *and Cell Biology, 78*, 502-509.

Marshall, J. (2008). Making weight – do boxers really need to dehydrate? *Peak Performance, 268,* 1-4.

Meeusen, R., Duclos, M., Gleeson, M. & Rietjens, G. (2006). Prevention, diagnosis, and treatment of overtraining syndrome (Review -ECSS Position Statement "Task Force"), 1-30.

Meuseen, R., Nederhof, E., Buyse, L., Roelands, G., Shutter, G. & Piacentini, M. (2010). Diagnosing overtraining in athletes using the two-bout exercise protocol. *British Journal of Sports Medicine, 44,* 642-648.

Nederhof, E., Lemmink, K., Visscher, C., Meeusen, R. & Mulder, T. (2006). Psychomotor Speed: Possibly a New Marker for Overtraining Syndrome (Abst.). *Sports Medicine, 36(10),* 817-828.

Newhouse, I.J. & Clemen, D.B. (1988). Iron status in athletes. *Sports Medicine*, 5(6), 337-352.

Nieman, D. (1997). Immune response to heavy exertion. *Journal of Applied Physiology, 82(5),* 1385-1397.

Nieman, D. (1998). Influence of carbohydrate on the immune response to intensive, prolonged exercise. *Exercise Immunology Review, 4,* 64-76.

Ohtani, M., Sugita, M. & Maruyama, K. (2006). Amino acid mixture improves training efficiency in athletes. *Journal of Nutrition,* Supplement, 538s-543s.

O'Toole, M. L. (1998). Overreaching and overtraining in endurance athletes. In R. B. Kreider, A. C. Fry, & M. L. O' Toole (Eds.*), Overtraining in sport (*pp. 3-18). Champaign, IL: Human Kinetics.

Petibois, C., Cazola, G., Poortmans, J. & Deleris, G. (2002). Biochemical aspects of overtraining in endurance sports: a review. *Sports Medicine, 32*, 867-878.

Raglin, R. S. & Morgan, W. P. (1994). Development of a scale for use in monitoring training-induced distress in athletes. *International Journal of Sports Medicine, 15*, 84-88.

Richardson, S. O., Andersen, M. B. & Morris, T. (2008). Overtraining athletes: personal journeys in sport. *Champaign, IL: Human Kinetics.*

Rogero, M. M., Mendes, R. R. & Tirapegui, J. (2005). Aspectos Neuroendocrinos e Nutricionais em atletas com overtraining. *Arquivo Brasileiro de Endocrinologia e Metabolismo, 49(3),* 359-368.

Rowbottom, D., Goodman, C., Morton A. (1995). The hematological, biochemical and immunological profile of athletes suffering from the overtraining syndrome. *European Journal of Applied Physiology, 70,* 502-509.

Saunders, M. (2009). Recovery nutrition: why it´s a potent weapon against overtraining. *Peak Performance,* 276, 1-4.

Shepard, R. J. & Shek, P. N. (1994). Potential impact of physical activity and sport on the immune system: a brief review. *Britsh Journal of Sports Medicine,* 28, 347-355.

Silva, A., Santiago, V. & Gobatto C. (2006). Understanding overtraining in sports: from definition to treatment. *Revista Portuguesa de Ciências do Desporto, 6(2),* 229-238.

Small, E. (2002). Chronic musculoskeletal pain in young athletes. *Pediatric Clinical North American,* 49, 655-662.

Smith, D. J. & Norris, S. R. (2000). Changes in glutamine and glutamate concentrations for tracking training tolerance. *Medicine and Science in Sports and Exercise*, 32(3), 684-689.

Steinaker, J. M., & Lehmann, M. (2002). Clinical findings and mechanisms of stress and recovery: preventing underperformance in athletes (pp. 103-118). *Champaign, IL: Human Kinetics.*

Suzui, M., Takeshi, K., Kimura, H., Takeda, K., Yagita, H., Okumura, K., Shek, P.N. & Shepard R.J. (2004). Natural killer cell lytic activity and CD56^{dim} and CD56^{bright} cell distributions during and after intensive training. *Journal of Applied Physiology, 96*, 2167-2173.

Urhausen, A. & Kindermann, W. (2002). Diagnosis of Overtraining.What Tools Do We Have? *Sports Medicine, 32(2),* 95-102.

Uusitalo, A.(2001). Overtraining. Making a difficult diagnosis and implementing target treatment. *The Physician and Sportsmedicine, 29*, 35-50.

Uusitalo, A. L., Uusitalo, A. J. & Rusko, H. (2000). Heart rate and blood pressure variability during heavy training and overtraining in the female athlete. *International Journal of Sports Medicine, 21*, 45-53.

Verde, T., Thomas, S. & Shephard, R. J. (1992). Potential markers of heavy training in highly trained endurance runners. *British Journal of Sports Medicine, 26*, 167-175.

Walsh, N., Blannin, A., Robson, P. & Gleeson, M. (1998). Glutamine, exercise, and immune function: links and possible mechanisms. *Sports Medicine, 26,* 177-191.

Chapter 3:

Determination of aerobic power through a specific test for taekwondo - a predictive equation model

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Determination of aerobic power through a specific test for taekwondo - a predictive equation model

Abstract

Our aim was to verify the concurrent validity of a maximal taekwondo specific test (TST) to predict VO_{2max} through an explanatory model. Seventeen elite male taekwondo athletes (age: 17.59 ± 4.34 years; body height: 172 ± 6.5 cm; body mass: 61.3 ± 8.7 kg) performed two graded maximal exercise tests on different days: a 20 m multistage shuttle run test (SRT) and an incremental TST. We recorded test time, VO_{2max}, ventilation, a heart rate and time to exhaustion. Significant differences were found between observed and estimated VO_{2max} values [F (2, 16) = 5.77, $p < 0.01$]; posthoc subgroup analysis revealed the existence of significant differences ($p = 0.04$) between the estimated VO_{2max} value in the SRT and the observed value recorded in the TST (58.4 ± 6.4 ml/kg/min and 52.6 ± 5.2 ml/kg/min, respectively). Our analysis also revealed a moderate correlation between both testing protocols regarding VO_{2max} (r = 0.70; $p = 0.005$), test time (r = 0.77; $p = 0.02$) and ventilation (r = 0.69; $p = 0.03$). There was no proportional bias in the mean difference (t = -1.04; $p = 0.313$), and there was a level of agreement between both tests. An equation/model was used to estimate VO_{2max} during the TST based on the mean heart rate, test time, body height and mass, which explained 74.3% of the observed VO_{2max} variability. A moderate correlation was found between the observed and predicted VO_{2max} values in the taekwondo TST (r = 0.74, $p = 0.001$). Our results suggest that an incremental specific test estimates VO_{2max} of elite taekwondo athletes with acceptable concurrent validity.

Keywords: Aerobic Assessment; Martial Arts; Mechanical Specificity; Validity.

Introduction

Taekwondo has emerged as an international martial art of self-defense that uses mainly hands and feet for both defense and attack. As a sport, regarding temporal structure, the match/fight lasts for three rounds of two minutes with one minute rest period between each round. Like most combat sports, it is characterized as an intermittent acyclic activity, where short and intense movement bouts (moments of fighting) alternate with low-intensity periods (pauses) (Matsushigue et al., 2009; Nunan, 2006).

Although different post-match blood lactate concentrations can be found in the literature on this sports discipline (due to different types of competition), a glycolytic metabolism is unlikely to be the predominant energy source during competition (Nunan, 2006). In fact, MedØ and Tabata (1989) had already published that the contribution of energy from aerobic pathways is as high as 40% during 30 s maximal workout, and 50% during 1 min of maximal work. Elite taekwondo athletes show an average ratio between the duration of exercise and rest ranging from 1:3 to 1:4 in both male and female athletes (Heller et al., 1998). In national and international level athletes, it is estimated that actions are intense for 3-5 s before periods of low intensity, causing heart rate (HR) responses near maximum effort (99% maximum HR) and blood lactate concentrations close to 11.4 $\text{mmol}\cdot\text{L}^{-1}$ and 10.2 $\text{mmol}\cdot\text{L}^{-1}$, respectively (Bridge et al., 2009).

These assumptions support the fact that high demands are placed upon both the aerobic and anaerobic metabolism during taekwondo matches. Muscle power produced in a fight does not depend on aerobic capacity. However, aerobic capacity becomes essential in the intervals of rounds, or even in combat, when athletes perform more than once during a competition day, and to aid the recovery process, particularly in the removal of lactic acid. Glaister et al. (2006) found that in 20 sets of 5 s of high-intensity exercise with rest intervals between sets lasting 10-30 s, the aerobic system was required for recovery and was also involved in ATP resynthesis.Like Nunan (2006), this suggests that even for activities considered to be anaerobic in nature, there was significant involvement of the aerobic system to energy production.

In this sense, coaches should structure taekwondo training sessions based not only on the technical and tactical needs of athletes but also in a manner that enables sufficient cardiovascular conditioning for competition (Bridge et al., 2007). Some authors have already reported quite high VO_{2max} values in national and international level taekwondo athletes that ranged between 44.0 and 55.8 ml/kg/min (Thompson and Vinueza, 1991; Pieter, 1991). In a study conducted by Heller et al. (1998), average VO_{2max} was 57.0 and 53.8 ml/kg/min for Spanish and Czech international taekwondo athletes, respectively. Cooke et al. (1997) stated that athletes with VO_{2max} close to 55.0 and 65.0 ml/kg/min (women and men, respectively) were in a better position to win an Olympic medal. These authors recommended intensive aerobic training to optimize athletes' aerobic conditioning, using VO_{2max} as an indicator of cardiovascular fitness and aerobic endurance.

However, this presents a major challenge as to measure oxygen uptake or improve aerobic fitness in taekwondo athletes, specific types of assessments and workouts are required. The literature offers several laboratory tests to assess VO_{2max} using cycle ergometers or treadmills. None of these modes of exercise reproduces technical movements of this martial art, so as to develop a closer representation of the fitness/training status of the athletes (Bridge et al., 2014). The same inconsistency seems applicable to running field tests. To our knowledge, only one study (Sant´Ana et al., 2009) intended to assess physiological responses of taekwondo athletes using a specific testing protocol by performing the *Bandal Chagui* technique, the most commonly used kick during competition (Lee, 1996). However, this study did not estimate VO_{2max} and only sought to predict the anaerobic threshold from the HR deflection point.

The main purpose of this study was to verify the concurrent validity of a maximal taekwondo specific test to predict VO_{2max}. To this end, we compared the acute metabolic responses of elite taekwondo athletes when performing a 20 m multistage shuttle run test (SRT) (Léger and Lambert, 1982; Léger et al., 1988) and a taekwondo specific test (TST). Additionally, we performed an explanatory model of VO_2 uptake (during the TST) associated with a predictive equation.

Material and Methods

Subjects

A convenience sample of 17 elite male athletes (age 17.59 ± 4.34 years; body height 172 cm ± 6.5 cm; body mass 61.3 kg ± 8.7 kg) recruited from the taekwondo Portuguese national team was used in this exploratory research. According to the characterization survey, all subjects were high-level junior and senior taekwondo athletes with more than five years of experience (black belts) that trained 8.7 ± 1.4 sessions per week. The athlete's federal license was also verified to attest the absence of any impediment to the practice of taekwondo.

The athletes were invited for two consecutive internship weekends for testing. This period coincided with the competitive phase of the season to ensure that all athletes would be in a state of good overall performance.

All subjects and their parents (for those under-18-years-old) were informed in advance about the procedures of the study and asked to sign a term of consent that had been approved by the University of Beira Interior, Portugal; the study was carried out according to the Declaration of Helsinki.

Anthropometric measures

The anthropometric assessment was carried out according to the International Working Group of Kinanthropometry methodology (Ross and Marfell-Jones, 1991). To evaluate body height (m), a stadiometer (SECA, model 225, Hamburg, Germany) with a range scale of 0.10 cm was used. Body mass and body fat were assessed using a Tanita body composition analyzer (model TBF-200, Tanita Corporation of America, Inc. Arlington Heights, IL). These variables were assessed before any physical performance test. Subjects were tested barefoot while wearing shorts and t-shirts.

Assessment of maximal **aerobic power**

The SRT, a popular field test, was used as a predictor of aerobic power (Léger and Lambert, 1982). The test, as described by Léger et al. (1988), involves running between two lines set 20 m apart. The pace was dictated by emitting recorded tones at prescribed intervals. The initial running velocity was 8.5 $km \cdot h^{-1}$ for the first minute, which increased by 0.5 $km \cdot h^{-1}$ every minute after that. The individual test score was established according to the number of 20 m shuttle runs completed before reaching volitional exhaustion or failure to be within 3 m of the end lines on two consecutive tones. The Léger prediction equation from Léger et al. (1988) was used for the indirect calculation of VO_{2max}.

The athletes were also submitted to a progressive TST (Sant´Ana et al., 2009) of approximately 15 min long, starting with a frequency of 6 *Bandal Chagui* techniques during the first 100 s. The time between following techniques is constant at each stage; as it progresses to the next stage, this interval becomes shorter; an additional increment of four techniques on each new stage occurs and a steady decline over time in the following stages.

According to Sant'Ana et al. (2009), during the exercise protocol, the athletes should be "stepping," and the techniques should be performed alternately (lower limbs) starting with the right leg (the left leg forward at the start of the test). Each kick was executed at a predefined individual height (between the navel and nipples, previously marked in the striking bag). As suggested by the authors, the following criteria were also used to determine the end of the test: (i) the subject failed to track the frequency of kicks (determined by a beep); (ii) the subject did not reach the previously stipulated height; (iii) voluntary exhaustion. Additionally, an extra criterion was applied, i.e. a decrease in kicking force to less than 60% of the maximum previously recorded value. Thus, the athletes' muscle force was formerly evaluated by performing the *Bandal Chagui* technique on the bag with_a striking shield (Mega-Strike, IMPTEC, United Kingdom). A single piezo sensor (LDT4-028K/L, Measurement Specialties Incorporation) located in the center of the shield was used to assess the *Bandal Chagui* absolute force expressed in units ranging between 0 and 255. Subjects were encouraged to exert their maximal force in three trials. The rest intervals between the consecutive measurements lasted 3 min.

In both the SRT and TST protocols, the ventilatory pattern [(VO_{2max}, expiratory ventilation (VE), time to exhaustion (TE), time to achieve VO_{2max}, respiratory quotient (RQ)] was assessed with a portable gas analyser device (Cosmed® K4b2, Roma, Italy) (Duffield et al., 2004). The expired gasses were collected breath-by-breath and then averaged for 15 s intervals (Aisbett and Rossignol, 2003). Subsequently, the average values for each minute were calculated (McCann and Adams, 2002). Time delay and the reference air calibration of the device was performed before each test using a gas sample with 16% O_2 concentration and 5% CO_2 concentration. The flow meter was also calibrated before each test with a 3000 ml syringe according to the manufacturer's recommendation. The HR was continuously monitored (Polar T31 coded^{TM} transmitter). The criteria for establishing peak VO_{2max} adopted from Howley et al. (1995) were as follows: a respiratory quotient greater than 1.15; the estimated maximum HR (220-age) attained during the test and no VO_2 increase in the last minute of the test.

Procedures

In the 48 hours before testing, subjects were instructed to refrain from any physical activity. Before baseline tests, each subject was familiarized with all testing procedures. During this familiarization session, all athletes were counseled on proper exercise technique, as well as stretching and an appropriate warm up.

During the first testing weekend, data collection started with anthropometric measurements, followed by the evaluation of absolute force (leg strikes in the boxing bag) just after 10 min of a specific warm up. Approximately 60 min later, all athletes performed the SRT (Léger and Lambert, 1982) with direct metabolic measurement using the Cosmed $K4b^2$ system (Rome, Italy)

On the second testing weekend, all athletes performed the TST just after 10 min of a specific warm up with the applied Cosmed $K4b^2$ system. The test consisted of performing a turning kick in a striking bag with a force sensor at a gradual pace over the following protocol levels indicated using a sound stimulus or a "beep."

All tests were conducted in an indoor sports facility (temperature 19-21ºC) by two experienced sports science researchers.

Statistical Analysis

All data were analyzed using SPSS 20.0 (Chicago, IL). Standard statistical methods were used for the calculation of means and standard deviations. The Kolmogorov-Smirnov test was used to verify the normal distribution of variables.

Pearson and Spearman (for HR from VO_{2max} TST, RQ and SRT) product-moment correlation coefficients were used to verify the association between dependent (VO_2 uptake) and independent variables (HR, kick absolute power measured in units, total number of executed techniques and test duration) and also between common variables measured during the TST and the SRT with direct metabolic measurements (time to achieve VO_{2max}; HR at VO_{2max}; test duration, maximum HR; RQ and VE). A t-test for paired measures was applied to compare the mean values obtained in both testing conditions (SRT and TST).

The Levene's test was used to assess variance homogeneity. The coefficient of variation (represented by the mean squared error as a percentage of the overall mean) was also calculated to compare the degree of variation between both testing protocols using the ANOVA Levene's F test to verify the existence of differences.

We also constructed a 95% confidence interval for the observed VO_{2max}. The extent to which the TST and SRT produced the same VO_{2max} values, using the strength of relation as well as the extent of agreement, was examined by the Bland-Altman graphics using linear regression analysis to verify if there was a significant bias.

A one-way repeated measures ANOVA was also used to assess any differences in the observed and estimated VO_{2max} values and also to detect differences among the *Bandal Chagui* absolute power over the ten stages of the TST. The Tukey's test was used for posthoc analysis when the F-ratio was significant. To establish statistical significance, a $p \leq 0.05$ criterion was used.

IBM Amos v20 software was used to apply structural equation modeling (SEM) in the univariate multiple regression models adjusted for obtaining maximum VO_2 uptake in the TST. The existence of outliers was assessed by the square Mahalanobis distance (D^2) and the normality of variables was assessed by asymmetry coefficients (Sk) and kurtosis (Ku) uni- and multivariate analysis. No variable had values of Sk and ku that indicated a severe violation of the normal distribution [$|Sk|<3$ and $|Ku| <10$].

Results

Table 6 shows the results (mean values ± standard deviation) for all recorded variables in both testing protocols. One can note significant differences between both tests concerning the time to achieve VO_{2max} (p=0.03).

Table 6: Oxygen uptake (VO_2), heart rate (HR), respiratory quotient (RQ) and minute ventilation (VE) (l/min) in both testing conditions (mean ± standard deviation, n=9).

	SRT	**TST**	**P-value**
VO_{2max} (ml/kg/min)	52.2±6.5	57.4±7.8	0.11
Time to achieve VO_{2max} (s)	521.6±130.4	440.9±78.7	0.03
HR at VO_{2max} (beat/min)	190.6±15.8	189.6±8.0	0.34
Test time (s)	609.4±133.9	562.9±72.0	0.16
Final HR (beats/min)	195.1±8.7	196.4±3.7	0.13
RQ	1.02±0.08	0.99±0.06	0.38
VE (l/min)	79.2±14.1	80.4±6.8	0.76

Our analysis also revealed a moderate correlation between both testing protocols regarding VO_{2max} (r=0.70; *p*=0.005), test time (r=0.77; *p*=0.02) and VE (r=0.69; *p*=0.03).

The TST and SRT coefficients of variation (CV) were 9.9% and 11.0%, respectively. Through the ANOVA Levene´s F test, no significant differences were found in the CV (F=0.17; *p*=0.72).

We are 95% confident that the mean observed for VO_2 uptake through the TST was between 55.3 and 61.5 ml/kg/min. The point estimate was 58.4 ml/kg/min, with a margin of error of 3.1 ml/kg/min.

There were significant differences between the observed and estimated VO_{2max} values [F(2,16)=5.77, *p*<0.01]; posthoc subgroup analysis revealed the existence of significant differences (*p*=0.04) between the estimated VO_{2max} value in the SRT (52.6±5.2 ml/kg/min) and the observed value recorded in the TST (58.4±6.4 ml/kg/min). No significant differences were found between the predicted and observed VO_{2max} values in the SRT.

Figure 5 shows the Bland-Altman graphs and table 7 shows the Bland-Altman fit differences.

The mean difference between the TST and SRT was significantly different from zero (*p*=0.002). We performed a linear regression model to see if there was a trend towards a bias; given the t score (t=-1.04; *p*=0.313); there was no proportional bias, and it seemed there was a level of agreement between both tests. We assumed that no trend existed for data above or below the mean of the difference score of the two tests.

Our results also showed a non-significant increasing trend for the HR and VO_2 uptake and a non-significant declining trend for the *Bandal Chagui* absolute force over time in the TST.

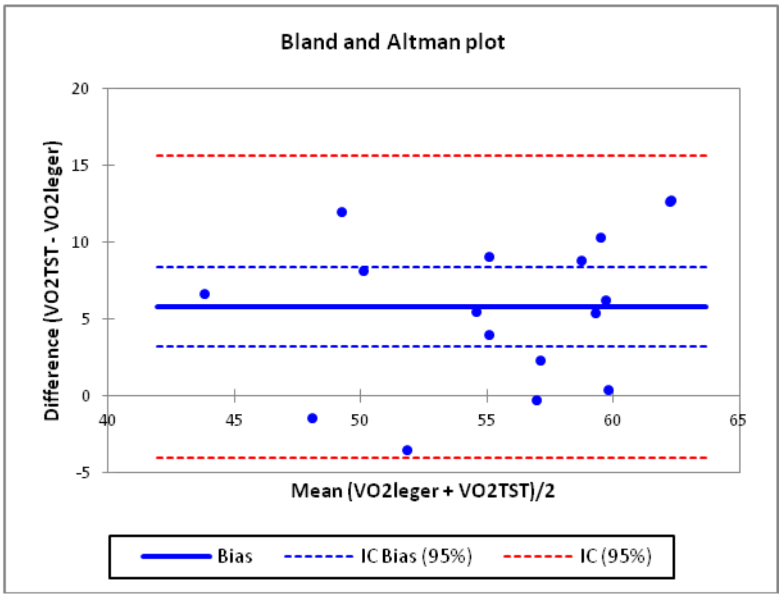

Figure 5: Bland-Altman graphs are comparing VO_2 uptake values obtained by the TST and SRT (Léger). The solid blue line represents the mean of the difference (5.8 ml/kg/min). The dashed red line represents the upper and lower limits for 95% confidence, 15.3 and -3.7, respectively.

Table 7: Bland-Altman fit differences.

Variable	Estimate	95% CI		SE
Mean difference	5.802352941	3.386436303	to 8.218269579	1.145084273
95% Lower LoA	-3.719507101	-7.927444074	to 0.488429873	1.994457249
95% Upper LoA	15.324212983	11.116276010	to 19.532149956	1.994457249
SD	4.858181128	-	-	-

Multiple linear regression was used to model the relationship between explanatory variables during the TST and VO_2 uptake by fitting a linear equation to the observed data. No outliers were found, and data analysis proceeded. The adjusted model included four independent variables (mean HR, body height, TST time and the test time multiplied by body mass), which together explained 74.3% of the overall variability. All of the following paths were statistically significant:

- Body Height→VO_{2max}($\beta_{VO2max.Body\ Height}$ = 0.45, $p<0.001$);
- Mean_TST_HR→VO_{2max}($\beta_{VO2max.mean\_TST\_HR}$ = -0.37, $p<0.003$);
- TST_Time→VO_{2max}($\beta_{VO2max.TST\_Time}$ = 0.55, $p<0.001$);
- TST_Time*Body Mass→VO_{2max}($\beta_{VO2max.TST\_Time*Body\ Mass}$ = -0.33, $p<0.01$);

The correlation between the predictors was not significant (mean_HR↔ TST_time, r=0.04, *p*=0.86; mean_HR↔ TST_time*body mass, r=0.06, *p*=0.82).

Figure 6 presents the standardized model with the model estimates of regression coefficients and variability that explained O_2 uptake.

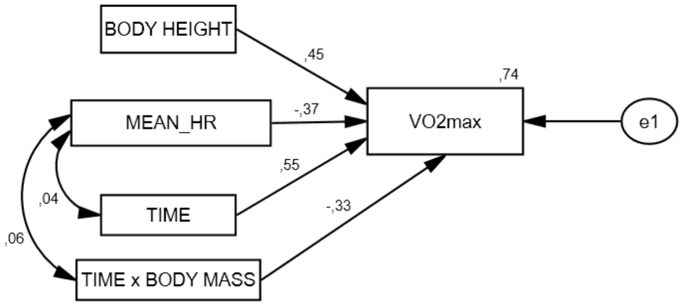

Figure 6: Multiple linear regression model between VO_{2max}, mean HR, body height, test time and test time*body mass in 17 elite Taekwondo athletes. Standardized estimates. Values represent (from left to right) correlations between predictors, standardized regression weights, and squared multiple correlations.

To use this model with one equation, we must consider the values of non-standardized coefficients (Figure 7), where we obtain:

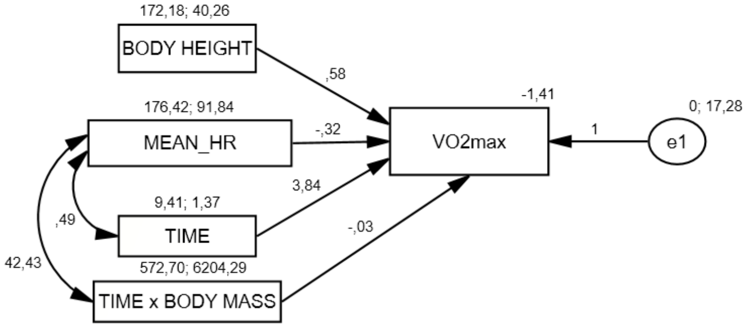

Figure 7: Multiple linear regression model between VO_{2max}, mean HR, body height, test time and test time*body mass in 17 elite Taekwondo athletes. Non-standardized estimates. Values represent (from left to right) covariance, means, and variances, regression weights, intercept and variance of e1.

The mathematical equation that best described the relationship between VO_{2max}, mean HR, body height, TST time and test time multiplied by body mass in the TST was as follows:

$$VO_{2max} = - 1.4 + 0.58 \text{ (body height)} - 0.32 \text{ (meanHR)} + 3.84 \text{ (time)} - 0.03\text{(time*body mass)} \quad (1)$$

A moderate correlation coefficient was found between the observed (58.4 ml/kg/min) and predicted (60.9 ml/kg/min) VO_{2max} values in the TST ($r=0.74$, $p= 0.001$; Cohens´s d of -0.45).

Discussion

The purpose of this study was to assess the aerobic power of taekwondo athletes using an incremental test with high mechanical specificity. Our aim was also to establish an explanatory model of VO_2 uptake related with a predictive equation.

Our primary findings showed a similarity between the observed and estimated VO_{2max} during the SRT, which reinforced the reliability of the Léger equation (Cunningham et al., 1994; Paliczaka et al. 1997). However, this appeared to differ from the results presented by Cetin et al. (2005), who reported underestimation of approximately 16% between the observed and estimated VO_{2max} during the SRT in elite Turkish taekwondo athletes. The fact that these authors examined a joint sample of men and women may explain this difference.

We also showed that both protocols (SRT and TST) elicited comparable observed VO_{2max} values (and also VE, HR, and RQ). This might appear to be a negative finding as it provides some evidence that a non-specific protocol was a valid method of VO_{2max} determination in taekwondo athletes. In our opinion, the SRT was useful for its intended application but fairly insensitive to predict VO_{2max} in elite taekwondo athletes, particularly when using the Léger predictive equation. This was the reason why Cetin et al. (2005) developed a regression equation to improve the accuracy of VO_{2max} estimations from the SRT (Bridge et al., 2014). In fact, the Léger predictive equation underestimated VO_{2max} by 10% (52.6 ml/kg/min *vs.* 58.4 ml/kg/min, $p=0.04$) compared to the observed VO_{2max} values during the TST. Concerning the results obtained in the TST, it should be emphasized that these values fell within the range shown by several studies (between 44 and 63 ml/kg/min) (Bridge et al., 2014; Cetin et al., 2005).

A Bland and Altman plot were used not as analysis, but rather to check the assumptions necessary for validation of the limit of agreement. The points on the plot scattered all over a chart, above and below zero, which suggested that there was no consistent bias of one approach versus the other. This led us to conclude that the plot showed no relationship between discrepancy and the level of measurement so that the limit of agreement was valid. In fact, the limit of agreement also estimated an interval of -3.7 to 15.3, which indicated that the TST may measure as much as 3.7 ml/kg/min below and 15.3 ml/kg/min above the SRT (on average the TST measured the VO_2 variable over 5.8 ml/kg/min to the SRT). This difference was due to the specificity of the technical gesture: running versus kicking.

Furthermore, significant differences were noted between both tests concerning the time to achieve VO_{2max} ($p=0.03$). The mechanisms inducing physiological differences between different exercise modes are not largely understood. Nevertheless, our data seemed in line with other studies (Caputo and Denadai, 2006; Millet et al., 2009) that already showed that exercise mode (e.g., running versus cycling) affected the time to achieve VO_{2max} without influencing maximal exercise time. The physiological differences at submaximal intensities were not addressed in our study. This can be considered a limitation, which otherwise could have shown more physiological dissimilarities between running, cycling, and kicking. In fact, running and cycling involve isotonic contractions while kicking is a complex motor task characterized by the large force exerted in a short period (Falcó and Estevan, 2014). Since VO_2 is highly specific to the exercise modality (Millet et al., 2009), given skill can significantly affect motor unit recruitment patterns and as a consequence different technique efficiency (Machado et al., 2010).

For didactic reasons, performing factors of modern-day taekwondo are commonly categorized into those related to tactical and technical efficiency and those related to the physical and physiological demands of competition (Bouhlel et al., 2006). However, heavily dependent relationships are expected to occur between factors. For example, the athlete's ability to generate and sustain power output (using both concentric and 'stretch shortening cycle' muscle actions of the lower limbs) may be important to support the technical and tactical actions in competition (Bridge et al., 2014). In fact, muscle force seems to be a good predictor of endurance performance in several other sporting disciplines such as running and swimming (Hawley and Noakes, 1992). Thus, if muscle force output has a substantial influence on oxygen uptake, and because intermittent exercises place the accent of stress at the peripheral level (neuromuscular, vascular and metabolic) (Falcó and Estevan, 2014), specialized tests in taekwondo should consider the muscular force characteristic of athletes. However, we failed to identify a significant relationship between muscle force output and VO_{2max} during the TST. For that reason, the adjusted model (structural equation modeling) of VO_{2max} uptake based on force output was not significant. We presume that this lack of correlation was due to the low sensitivity of the Piezo sensor used, particularly when the technique was not performed exactly in the center of the shield, which can induce some inter-individual variability on the output scores. Nevertheless, mean force values did not change significantly over the TST, which also reflected the commitment of athletes towards the exercise protocol.

We must also keep in mind that a given theoretical model can be appropriate to explain the relational structure of data but can never prove that such a model is unique; it only shows that the theoretical framework envisaged is appropriate for the data observed, not excluding other theoretical models (Marôco, 2014). Further studies should, therefore, provide a model where the force output could be part of the predictive VO_{2max} equation. Since the TST is an incremental test to be carried out until reaching volitional exhaustion, the number of completed levels/stages represented by the test time was considered in the final model as a predictor variable. Future studies may also consider reporting muscular force in relation to sex, age and weight categories (Bridge et al., 2014); the quotient between body height and force in absolute terms and scaled relatively to lean body mass or height may be important data for researchers and coaches (Pieter & Bercades, 2010).

Notwithstanding the relevance of the present results, this study has some limitations. In particular, the small sample size and its heterogeneity. Taekwondo competitors are usually divided by age, belt, body mass and gender. Our study sample, despite being composed of only elite male athletes (black belts), presents some variability in weight classes. This could have resulted in the exclusion of certain variables in the predictive model (e.g., the mean power output), leading to only 74% of the overall variability in oxygen uptake. A larger and more homogenous group would lead to more accurate variable estimates, although the results when compared between the predicted and observed TST VO_{2max} had a small to moderate effect size, demonstrating that the differences were insufficient to have a practical impact.

Despite the limitations, this study has some significant merits. An effort was made to assess the aerobic power of taekwondo athletes through a specific test that better represented the mechanical actions and metabolic demands of taekwondo competition. This study also established one equation for predicting VO_{2max} that coaches can use during the training process, without the need to apply a generic laboratory or nonspecific field test. The TST is a non-invasive test, simple to operate in training and cost efficient together with being valid, i.e. the taekwondo athlete is more likely to respond to this specific test positively as they can identify the techniques with their sports. This presents a great advantage in practice terms and also should encourage researchers to obtain a specific and standardized aerobic assessment protocol.

Conclusion

In summary, the TST had a moderate correlation with the SRT and a relative level of agreement showing that the use of a generalized predictive equation (Léger) can underestimate VO_2 uptake in elite taekwondo athletes. The TST protocol with equation (1), which includes such variables as body height, test time, the interaction between test time, body mass and mean heart rate, can be used to estimate VO_{2max} in taekwondo athletes.

References

Aisbett, B. & Le Rossignol, P. (2003). Estimating the total energy demand for supra-maximal exercise using the VO2-power regression from a incremental exercise test. *Journal of Science and Medicine in Sport,* 6(3), 343-347.

Bouhlel, E., Jouini, A., Gmada, N., Nefzi, A., Ben Abdallah, K. & Tabka, Z. (2006). Heart rate and blood lactate responses during taekwondo training and competition. *Science and Sports*, *21,* 285–90.

Bridge, C. A., Jones, M. A. & Drust, B. (2009). Physiological Responses and perceived exertion during international taekwondo competition. *International Journal of Sports Physiology and Performance*, *4*, 485-493.

Bridge, C. A., Jones, M. A., Hitchen, P. & Sanchez, X. (2007). Heart rate responses to taekwondo training in experienced practioners. *Journal of Strength and Conditioning Research, 21(3)*, 718-723.

Bridge, C. A, Santos, J. F. S., Chaabène, H., Pieter, W. & Franchini, E. (2014). Physical and physiological profiles of taekwondo athletes, Review article. *Sports Medicine, 44,* 713-733.

Caputo, F. & Denadai, B. S. (2006). Exercise mode affects the time to achieve VO_{2max} without influencing maximal exercise time at the intensity associated with VO_{2max} in triathletes. *International Journal of Sports and Medicine*, *27(10)*, 798-803.

Cetin, C., Karatosun, H., Baydar, M. L. & Cosarcan, K. (2005). A regression equation to predict true maximal oxygen consumption of taekwondo athletes using a field test. *Saudi Medical Journal, 26(5),* 848-850.

Cooke, S. R., Patersen, S. R. & Quinney, H. A. (1997). The influence of maximal aerobic power on recovery of skeletal muscle following aerobic exercise. *European Journal of Physiology*, *75*, 512-519.

Cunningham, L. N., Cama, G., Cilia, G. & Bazzano, O. (1994). Relationship of VO_{2max} with the 1-mile run and 20 meter shuttle run test with youth aged11 to 14 years. *Medicine and Science in Sports and Exercise, 26(5),* 8209.

Duffield, R., Dawson, B., Pinnington, H. C. & Wong, P. (2004). Accuracy and reliability of a Cosmed K_4b^2 portable gas analysis system. *Journal of Science and Medicine in Sport, 7(1)*, 11-22.

Falcó, C. & Estevan, I. (2014). Biomechanics in Taekwondo: practical applications. In: *Performance optimization in Taekwondo: from laboratory to field*. ed. OMICS Group eBooks. Foster City, CA, 1-23.

Glaister, M., Stone, M. H., Stewart, A. M., Hughes, M. G. & Moir, G. L. (2006). Aerobic and anaerobic correlates of multiple sprint cycling performance. *Journal of Strength and Conditioning Research*, *20(4),* 792-798.

Hawley, J. A. & Noakes, T. D. (1992). Peak power output predicts maximal oxygen uptake and performance time in trained cyclists. *European Journal of Applied Physiology, 65,* 79-83.

Heller, J., Peic, T., Dlouha, R., Kohlikova, E., Melichna, J. & Novakova, H. (1998). Physiological profiles of male and female Taekwondo (ITF) black belts. *Journal of Sports Sciences, 16(3),* 243-249.

Howley, E. T., Bassett Jr, D. R. & Welch, H. G. (1995). Criteria for maximal oxygen uptake: review and commentary. *Medicine and Science in Sports and Exercise, 27(9),* 1292-1301.

Lee, K. M. (1996). *Tae Kwon Do, techniques and training.* New York, NY: Sterling Publishing Comp.

Léger, L. A. & Lambert, J. (1982). A maximal multistage 20-m shuttle run test to predict VO_{2max}. *European Journal of Applied Physiology, 49,* 01-12.

Léger, L. A, Mercier, D., Gadoury, C. & Lambert, J. (1988). The multistage 20-meter shuttle run test for aerobic fitness. *Journal of Sports Sciences, 6,* 93-101.

Machado, S. M., Osório, R. A., Silva, N. S. & Magini, M. (2010). Biomechanical analysis of the muscular power of martial arts athletes. *Medical and Biological Engineering and Computing*, *48*, 573-577.

Marôco, J. (2014). Structural equation modelling – theoretical foundations, software and aplications. Pero Pinheiro (2nd Edition) ReportNumber.

Matsushigue, K.A., Hartmann, K. & Franchini, E. (2009). Taekwondo: physiological responses and match analysis. *Journal of Strength and Conditioning Research, 23(4),* 1112-1117.

McCann, D. J. & Adams, W. C. (2002). A dimensional paradigm for identifying the size-independent cost of walking. *Medicine and Science in Sports and Exercise*, *34(6*), 1009-1017.

MedbØ, J. I. & Tabata, I. (1989). Relative importance of aerobic and anaerobic energy release during short-lasting exhausting bicycle exercise. *Journal of Applied Physiology*, *67,* 1881-1886.

Millet, G. P., Vleck, V. E. & Bentley, D. J. (2009). Physiological differences between cycling and running: lessons from triathletes. *Sports Medicine*, *39(3),* 179-206.

Nunan, D. (2006). Development of a sports specific aerobic capacity test for karate – a pilot study. *Journal of Sports Science and Medicine,* 47-53.

Paliczaka, V. J., Nichols, A. K. & Boreham, C. A. (1987). A multi-stage shuttle run as a predictor of running performance and maximal oxygen uptake in adults. *British Journal of Sports and Medicine, 21(4),* 163-165.

Pieter W. (1991). Performance characteristics of elite Taekwondo athletes. *Korean Journal of Sport Science, 3*, 94-117.

Pieter, W. & Bercades, L. (2010). Strength and power in filipino varsity taekwondo. *Ido Movement for Culture – Journal of Martial Arts Anthropology*, *10,* 67–72.

Ross, W. D. & Marfell-Jones, M. J. (1991). Kinanthropometry. In: *Physiological testing of the high-performance athlete*. Champaign, Illinois: Human Kinetics Books, 22-29.

Sant´Ana, J, Silva, J. F. & Guglielmo, L. G. A. (2009). Physiological variables identified in progressive specific test for taekwondo.. *Motriz, Rio Claro*, *15(3),* 611-620.

Thompson, W. R. & Vinueza, C. (1991). Physiologic profile of Tae Kwon Do black belts. *Research in Sports Medicine*, *3,* 49–53.

Chapter 4:

Anaerobic fitness assessment in taekwondo athletes – a new perspective

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Chapter 4:

Anaerobic fitness assessment in taekwondo athletes – a new perspective

Abstract

We intend to determine the concurrent validity of a taekwondo specific anaerobic test (TSAT) to assess anaerobic fitness in taekwondo athletes. Seventeen elite male subjects (17.59 ± 4.34 years of age; 1.72 m ± .07 m in height; 61.3 kg ± 8.7 kg in weight and 15.6% ± 8.5% in body fat) performed a TSAT, which consisted of kicking a punching bag for 30 seconds. The standard test was the Wingate Anaerobic Test.Two trials were made for both tests and the agreement between both was tested. The variables analyzed and compared were: peak power; relative peak power; mean anaerobic power; relative mean anaerobic power; fatigue index and anaerobic capacity. The number of kicks performed in the TSAT protocol and the maximum height of the counter movement jump (CMJ) was also registered. Trial I and II had significant ICC results in all variables (*P* = .000) ranged between 0.56 and 0.97. Both protocols were significantly correlated (r = 0.55 to 0.88; P = .000 to .05). CMJ strongly correlated with the number of techniques (r=0.59; *P* = .013) and the mean power (r = 0.56; *P* = .019) of the TSAT. The variables between the two methods correlate and are consistent, except for the anaerobic capacity that although correlated, is not consistent with constant bias, P = 0.001; CI]-705.1;-370.2[. TSAT has a level of agreement with the Wingate and assigns specificity in the evaluation of these variables.

Keywords: Anaerobic Power, Anaerobic Capacity, Taekwondo, Specific Test, Wingate Test.

Introduction

As a martial arts and Olympic sports, taekwondo performance relies on short bursts of intense exercise in which the phosphagen system (also called the ATP-PC system) is the predominant energy system used to resynthesize ATP (Bouhlel et al., 2006; Matsushigue et al., 2009). Under the World Taekwondo Federation and Olympic rules, competitions consist of three semi-continuous contact rounds with two minutes each and with one minute of rest in between. Among the wide variety of techniques used in competition, all performed with extreme velocity, the kicks to the head, spinning and jumping kicks and the roundhouse kicks are frequently used. It is a sport that requires high levels of strength and anaerobic capacity (Matsushigue et al., 2009). Therefore, the lower limb muscle power is a variable of interest to evaluate the muscular mechanical characteristic of taekwondo practitioners. The literature (Olsen and Hopkins, 2003; Ravier et al., 2004; Sant´Ana et al., 2014) refers the counter movement jump (CMJ) as a protocol that serves this goal since this test has a movement pattern similar to that of the martial arts movements. Sant´Ana et al. (2014) found significant correlations between CMJ and kicks frequency, while Olsen and Hopkins (2003) link CMJ and similar movements with the enhancement of speed movements. Ravier et al. (2004) conclude that karate performance depends on explosive strength.

Taekwondo players elicit near maximal heart rate (HR) responses (90 % HR peak) and high lactate concentrations (7.0–12.2mmol/l), which infer that high demands are imposed upon both aerobic and anaerobic metabolism during the matches (Bridge et al., 2009; Heller et al., 1998). Hence, the assessment of anaerobic performance can provide the coach with valuable information about these athletes' fitness status as well as allowing them to monitor improvement through training (Inbar et al, 1996). Individuals with improved anaerobic power are capable of generating energy at a high rate, which delays the onset of muscle fatigue and enables the continuation of high-intensity exercises (Heller et al., 1998).

Currently, one of the tests used to assess the anaerobic performance of overall athletes is the Wingate anaerobic cycle test (WAnT) (Bar-Or, 1987) including taekwondo athletes (Lin et al., 2006; Melhim, 2001). Bridge et al. (2014) in a review article about physical profiles of taekwondo athletes, presented several studies in which the lower body Wingate anaerobic test performance was used as an instrument to measure anaerobic power. The same authors also claim that WAnT constitutes the most common method of assessing anaerobic peak power and capacity of taekwondo competitors. In that review, relative peak power for senior males has been reported with values ranging 8.4-14.7W/kg. Concerning the mean anaerobic power, investigators reported that there is limited data available, with values for males ranging between 6.6-9.2 W/kg. These values allow a favorable comparison with those produced by athletes in other intense short-duration events that elicit demands from the ATP/PC system (Aziz et al. 2002; Zupan et al., 2009). The easy application, replication, and scientific acceptance are factors underlying the widespread use of this laboratory test. In taekwondo, the use of this popular test made it possible to confirm that the intense anaerobic nature of this combat sport and the ability of the lower limbs to generate high peak power may be essential in competition (Bridge et al., 2014).

However, there are physiological and biomechanical differences between pedaling and "kicking." As Falcó and Estevan (2014) testify, running and cycling involve isotonic contractions while kicking is a complex motor task characterized by large forces exerted in a short period. Consequently, according to Bridge et al. (2014), there is a need for specificity of the testing protocol, of specialized fitness tests that better reflect the mechanical actions, activity patterns and metabolic demands of the sport in a way to improve the validity of data and its application in research and training/competition.

Recently, Santana et al. (2014) recognize the WAnT limitations about their ecological validity in taekwondo. The authors proposed a new method for anaerobic assessment, specific to this sport using the *Bandal Chagui* kicking task over the 30s. Ten subjects were asked to perform the largest number of techniques against a punching bag. The number of kicking cycles (time interval between two consecutive kicks with the same leg) was significantly correlated with a peak blood lactate concentration (P = 0.04; r =.65) and the counter movement jump (CMJ) performance (P = 0.03; r =.70). A drop in kicking cycles' time and impact magnitude during the last 20% of kicking cycles was also found when compared to the initial 20% kicking cycles (P = 0.01). However, no evaluation criterion of the anaerobic capacity was used (laboratory evaluation of power and anaerobic capacity) to validate this specific test for taekwondo, which made it impossible to understand the estimated level of this test to foretell the values obtained in the reference test. TSAT should evaluate the ideal observation model (anaerobic capacity) which theoretically must be related to WAnT. Thus, the correlation between the results of the laboratory test (WAnT) with the results evaluated in the field test (TSAT) has not been assessed as suggested by Bland and Altman (1986).

Therefore, the aim of this study is to provide valid evidence to support the effectiveness of a taekwondo specific anaerobic test (TSAT) to assess anaerobic power and anaerobic capacity in athletes. It was hypothesized that: i) WAnT underestimates the anaerobic performance of taekwondo players; ii) the limit of agreement (LoA) between variables for both test protocols are in a range that allows the use of the two measurement methods interchangeably.

Materials and Methods

This is a concurrent validity study with the purpose to provide evidence to support the effectiveness of a TSAT to assess the anaerobic fitness of taekwondo athletes. A concurrent validation model was applied in the form of a statistical correlation between the TSAT and the criterion data obtained during the WAnT.

Subjects

Seventeen male elite subjects (age 17.59 ± 4.34; body height 1.72m ± .07m; body mass 61.3kg ± 8.7kg and body fat 11.9 ± 5.7 %s) of the Portuguese taekwondo national team participated in this study. According to the characterization survey, all subjects were high-level junior and senior taekwondo athletes over five years of experience (black belts) and trained 8.7 ± 1.4 sessions per week. Each athlete's federal license was also verified to confirm the absence of any impediment to the practice of taekwondo.

All subjects and the parents (of under-18-year-old subjects) were informed in advance about the procedures and asked to sign a term of consent that had been approved by the University of Beira Interior and carried out according to the Helsinki Declaration.

Anthropometric measures

The anthropometric assessment was carried out according to the International Working Group of Kinanthropometry methodology (Ross & Marfell-Jones, 1991). To evaluate height (m) we used a stadiometer (SECA, model 225, Germany) with a range scale of 0.10 cm. Weight and body fat were assessed using a Tanita body composition analyzer (model TBF-200, Tanita Corporation of America, Inc. Arlington Heights, IL).

Maximum kicking impact force and power

The maximum kicking impact force was evaluated by performing the *Bandal chagui* technique (roundhouse kick) to a boxing bag. This technique is a turning kick and happens to be the most commonly used kick during competition (Lee, 1996).

The impact force of the kick was measured using a *piezo* sensor (LDT4-028K/L, Measurement Specialties Incorporation) built-in into a striking shield (Mega-Strike, IMPTEC, United Kingdom). The result is expressed in units ranging between 0 and 255. * Subjects were encouraged to exert their maximal force in three trials. The rest intervals between the consecutive measurements lasted 3 minutes. The maximum, value was chosen for analysis. These units, resulting from the impact force are determined by the degree of deformation of the sensor; its corresponding value in SI units is not known or disclosed by the manufacturer. Therefore, it was necessary to establish a relationship between the force of impact registered by the *piezo* sensor and the corresponding kicking power in an SI unit (in *watts*,). For that purpose, a 3D motion tracking technology (Xsens, MTi 1-series) was used to analyze body movement to determine the peak kicking power of each athlete. Seventeen sensors were placed throughout the entire body, particularly in lower limbs in precise locations (hip, knee, and ankle). Each sensor consists of a small gyroscope, an accelerometer and a magnetometer in its interior.

The MVN Studio Pro software was used to treat the data enabling its use in Visual 3D software, in a way that allowed defining the segment to be analyzed through the Compute Model-BasedTool.
The option to calculate the power was set up, and then the segment of interest (ankle) and the reference segment (leg) were defined. For this calculation, power was the result of the multiplication between the angular velocity (rad/s) and the moment of inertia.

Counter movement jump

The Optojump Next System (Microgate, SARL, Italy) was used to access maximum height in CMJ test, (Bosco (1994).

Wingate Anaerobic 30 Cycle Test

The WAnT was performed by all participants for determining anaerobic power and capacity using a cycle ergometer (Monark, Ergomedic 939E, Vansbro, Sweden). Reliability and validity information for the WAnT have been reported across some studies (e.g., Bar-Or et al., 1987; Nicklin et al., 1990)

The performance indices are peak power (PP), mean anaerobic power (MAP), anaerobic fatigue or fatigue index (FI) and anaerobic capacity (AC). Peak power is the highest mechanical power elicited from the test taken as the average power over any 5 seconds' period, usually the first 5 seconds. Mean anaerobic power is the average power maintained throughout the six segments of 5 seconds. Fatigue index is the amount of the decline in power during the test expressed as a percentage of peak power (Inbar et al., 1996) and anaerobic capacity is recorded over the entire 30 seconds of the test (Zupan, 2015) and an average is measured.

Taekwondo Specific Anaerobic Test (TSAT)

The TSAT consists of performing the *Bandal Chagui* technique for 30 seconds at maximum speed and power against a boxing bag with a striking shield, using both legs alternately. Before testing, the boxing bag was set for each athlete´s optimal kicking height and distance to target (strike shield center). A single *piezo* sensor (LDT4-028K/L, Measurement Specialties Incorporation), located in the center of the striking shield was used to assess the impact force demonstrated in each kick, expressed in units ranging between 0 and 255.

During the TSAT, the amount of performed techniques was recorded, as well as the kicking impact force, in units. These units were then converted to *watts* based on a conversion factor that was previously calculated during the maximum kicking impact force and power test. Consequently, the following variables were calculated as follows:

(i) Peak Power Output (PP) observed during the first five seconds of TSAT:

$$\text{PP (watts)} = \frac{mean\ bandal\ chagui\ force\ in\ the\ first\ 5\ secs\ x\ number\ of\ tecniques\ in\ the\ first\ 5\ secs}{time(5\ secs)} \quad (2)$$

(ii) Relative Peak Power Output (RPP), concerning body weight:

$$\text{RPP (watts/kg body weight)} = \frac{PP}{Body\ weight}$$

(iii) Mean Anaerobic Power (MAP):

$$\text{MAP (watts)} = \frac{mean\ power\ of\ tehcniques\ for\ 30\ secs\ x\ total\ number\ of\ techniques\ in\ 30\ secs}{time\ (30\ secs)}$$

(iv) Relative Mean Anaerobic Power (RMAP), concerning body weight:

$$\text{RMAP (watts/kg body weight)} = \frac{MAP}{Body\ weight}$$

(v) Fatigue índex (FI):

$$\text{FI (\%)} = \frac{highest\ 5 \sec PP - lowest\ 5 \sec PP}{higest\ 5 \sec PP} \times 100$$

(vi) Anaerobic Capacity (AC):

$$\text{AC (watts)} = \sum of\ each\ 5 \sec PP$$

Procedures

Participants were tested on four sessions (days) for two consecutive weekends. All athletes had regularly been competing, exhibiting, at the time of this study, a good overall performance.

In the 48 hours before the first session, subjects were instructed to refrain from physical activity and underwent one familiarization session. During this session, all athletes were counseled on proper exercise technique, as well as stretching and appropriate warm up to prevent the large gains that tend to occur as the subjects learn the testing procedure and also to verify the protocol acceptance and applicability to this group.

The first data collection, session 1, included the anthropometric measures, the kicking impact force (leg strike on the boxing bag) and the WAnT. Session 2 (at the same hour of the day on the following day) included the CMJ and the TSAT. Also, all the procedures (except the anthropometric evaluation) were repeated the following weekend (sessions three an 4) for reliability measurement. During this period and up to 48 hours before session 3, participants were instructed to maintain their normal diet and training patterns.

Before testing, the participants were asked to perform 15 minutes of standardized warm-up consisting of running, dynamic joint mobility exercises and eight submaximal jumps. Before the WAnT, each subject performed a 5 minutes warm-up period on a cycle ergometer (Monark, Ergomedic 939E, Vansbro, Sweden). Static stretching exercises were also performed at the end of the sessions. All tests were conducted in an indoor facility to avoid weather changes during the pre- and post-test sessions (at a temperature of 19-21ºC).

The data collection started with the measurement of weight and height and body mass percentage. Subjects were tested while wearing shorts and t-shirts (shoes were removed). After the participants had carried the warm up, in a random order, they began the tests. The maximum kicking impact force (MKIF) test was the first, after the boxing bag having been previously adjusted according to the body height of each athlete (the center of the shield was placed in height between the navel and nipples)

After one hour, the WAnT was performed. Prior to testing, the seat height was adjusted individually for all athletes in order to find a knee flexion angle of fewer than 5 degrees when the leg was fully extended. The load was the result of multiplying the athlete's body weight by a constant (0.075 kg per kg/body (Jackson, 1980). The test consisted of cycling, i.e. the athlete tried to keep the number of revolutions as high as possible in an attempt to complete the highest number of revolutions per 30 seconds.

As mentioned before, each subject was allowed a warm-up period on another cycle ergometer (Monark, Ergomedic 939E, Vansbro, Sweden) at a self-selected cadence (at 50 *Watts*) including two sprints, each lasting 3 seconds at the end of the third and fifth minutes (Beneke et al., 2002). The test began with the start command, which released the resistance. Verbal support was given during the entire test and after finishing the participant continued pedaling for three minutes, with a very light load to avoid dizziness and syncope due to testing.

On the second day of evaluation, at the same time of the day, after the standardized warm up, the counter movement jump (CMJ) was performed; wherein each athlete performed 3 trials with 3 minutes in between for each attempt. The maximum height expressed in centimeters (cm) was considered for analysis. After one hour, the taekwondo specific anaerobic test (TSAT) was accomplished- trial I. The re-test, trial II, for WAnT and for TSAT, took place one week later, in the same order.

Statistical Analysis

All data were analyzed using SPSS 20.0 (Chicago, IL). Standard statistical methods were used for the calculation of means and standard deviations. The Shapiro-Wilk test was used to verify the normal distribution of variables. A t-test for paired measures was applied to compare the mean values obtained in both test situations (WAnT and TSAT) and to verify any difference between WAnT and TSAT test and re-test, correlated by intra-class correlation coefficients (ICC). Also, the strike shield reliability was measured through the internal correlation coefficient. Pearson product-moment correlation coefficients were used to verify the association among all variables between WAnT and TSAT, and between CMJ and TSAT.

The effect size was evaluated through Cohen´s d. The extent to which WAnT and TSAT produced the same values, using the strength of relation as well as the extent of agreement, was examined by the Bland-Altman graphics, using XLSTAT Addinsoft^{TM}. For quantitative analysis, it was deemed that the values projected by TSAT would be correct if at least 80% of the dots were inside the limits of agreement To establish statistical significance, a $P \leq 0.05$ criterion was used.

Results

Through 3D analysis, we verify that each unit charged by the striking shield is equivalent to 3.93 *watts*. Therefore we register that the mean value of the Bandal Chagui impact force is 418 ± 85.1*Watts*. Figure 8 represents the output of two Bandal Chagui impacts. The gray shadow shows the standard deviation of the athlete's data while the line is the average of all athletes' data.

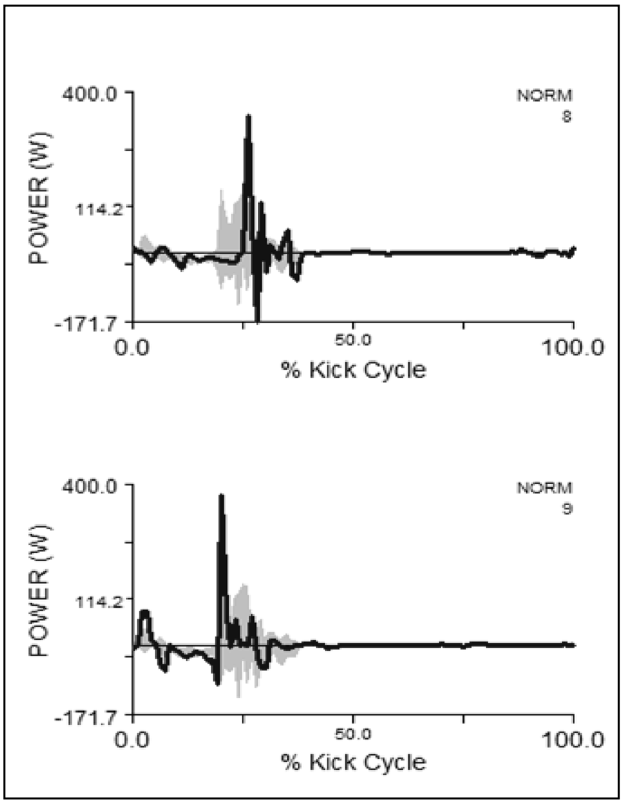

Figure 8: 2D plots from segment power scalar – right foot.

Table 8 shows the mean values (± standard deviation) for all recorded variables in both test and re-test during the WAnT and the TSAT.

Table 8: Mean values (± SD) of performance variables measured during the test and re-test of both the WAnT and the TSAT (n=17).

	Variables	**Trial 1**	**Trial 2**	**Cohen´s d**	**t-test**	***p*-value**	**ICC** (95% IC)	***p*-value**
WINGATE	PP(W)	575.5(88.7)	663.8(89.3)	1.1	-8.871	.000	0.75 (-.16-.94)	.000
	RPP(W/Kg)	9.3(1.1)	10.7(1.3)	1.0	-8.781	.000	0.66 (-.18-.91)	.000
	MAP(W)	386.2(71.9)	470.6(75.1)	1.2	-9.782	.000	0.70 (-.15-.93)	.000
	RMAP(W/Kg)	6.2(0.9)	7.6(0.9)	1.2	-9.936	.000	0.56 (-.15-.87)	.000
	FI(%)	36.8(9.7)	36.9(7.1)	-----	-.133	.895	0.95 (.87-.98)	.000
	AC (W)	2449(431,8)	2529(427.7)	0.32	-2.637	.018	0.97 (.89-.99)	.000
TEAKWONDO TEST	PP(W)	558.5(127.7)	599.9(119.3)	0.27	-2.225	.041	0.87 (.62-.96)	.000
	RPP(W/Kg)	8.9(1.6)	9.7(1.6)	0.28	-2.265	.038	0.80 (.42-.93)	.000
	MAP(W)	371.4(69.7)	414.9(86.3)	0.46	-3.756	.002	0.83 (.23-.95)	.000
	RMAP(W/Kg)	6.0(1.2)	6.7(1.4)	0.47	-3.781	.002	0.84 (.25-.95)	.000
	FI(%)	37.4(7.2)	37.7(5.9)	-----	-.34	.757	0.86 (.60-.95)	.000
	AC (W)	1911(310,5)	1958(354.7)	-----	-1.220	.250	0.93 (.84-.98)	.000
	Nº Techniques	73.3(7.2)	73.4(6.8)	-----	-.223	.826	0.99 (.98-.99)	.000

PP- peak power; RPP – relative peak power; MAP-mean anaerobic power; RMAP – relative mean power; FI – fatigue index; AC – anaerobic capacity; Nº TECHNIQUES – number of the total bandal chagui´s in 30 seconds. Statistically significance, *p* <.05.

Towards trial II we observed a trend for higher values in both protocols, especially in WAnT protocol.

The test-retest reliability was assessed with the mean values of every variable which paired trial I with trial II using the intra-class correlation coefficient (ICC), ranging from all measures between 0.56 and 0.97 (P = .000) in the WAnT and between 0.89 and 0.99 (P = .000) in the TSAT. In WAnT, in what concerns the FI variable, from trial I to trial II, there were no differences (P =.895; ICC = 0.95). For the remaining variables, there was a difference with a large effect size (from 1.0 to 1.4).

In the TSAT, the differences in the trial I and II had an effect size ranged between small and medium (0.33-0.55) for PP, RPP, MAP, and RMAP. We observed a trend towards trial II for higher values in all measure variables, although, for FI, AC and number of techniques the difference wasn´t statistically proved, P = .757; P = .240; P = .826, respectively. A significant correlation between CMJ performance and the number of techniques (r = 0.59; *P* =.013) and the MAP (r = 0.56; P =.019) was registered in the TSAT.

The reliability for the striking shield had an internal correlation coefficient of 0.87. One can note in table 9 that variables in WAnT and TSAT were significantly correlated, FI being the strongest correlation (P =.000, r =.88). Results also show a trend for higher values in WAnT (table 8). However, only the AC variable demonstrates being statistically different *(*P = .000), with a large Cohen´s d, 0.85 (table 9).

Table 9: Results of paired sample t-test, correlations and Cohen´s effect size, between the Wingate Anaerobic Test (30 seconds, WAnT) and the Taekwondo Specific Anaerobic test (TSAT) (n=17).

	Correlation	p-value	t-test	p-value	Cohen´s d
PP (W)	0.64	.006	.719	.482	-----
RPP (W/Kg)	0.55	.05	.808	.431	------
MAP (W)	0.65	.004	1.033	.317	------
RMAP (W/Kg)	0.62	.008	.857	.404	-----
FI (%)	0.88	.000	-.533	.602	-----
AC (W)	0.66	.004	6.808	.000	0.85

PP- peak power; RPP – relative peak power; MAP-mean anaerobic power; RMAP – relative mean power; FI – fatigue index; AC – anaerobic capacity. Statistically significance, $p < .05$.

In the Bland-Altman analysis, we checked if the mean of the differences between the results of the two methods were different from zero (0). According to our data, only the anaerobic capacity variable showed a significant difference, P = 0.0001; CI [-705.1;-370.2].

Using a scatterplot graphic, figure 9, we compared the reference test (WAnt) with TSAT and we can observe that for the PP, RPP, MAP, RMAP and FI the data are on both sides of the identity line and are not distant from it, which means that both methods/tests (WAnT and TSAT) provide us with similar consistent outcomes.. The TSAT seems to underestimate the AC variable values, once the data is under the identity line.

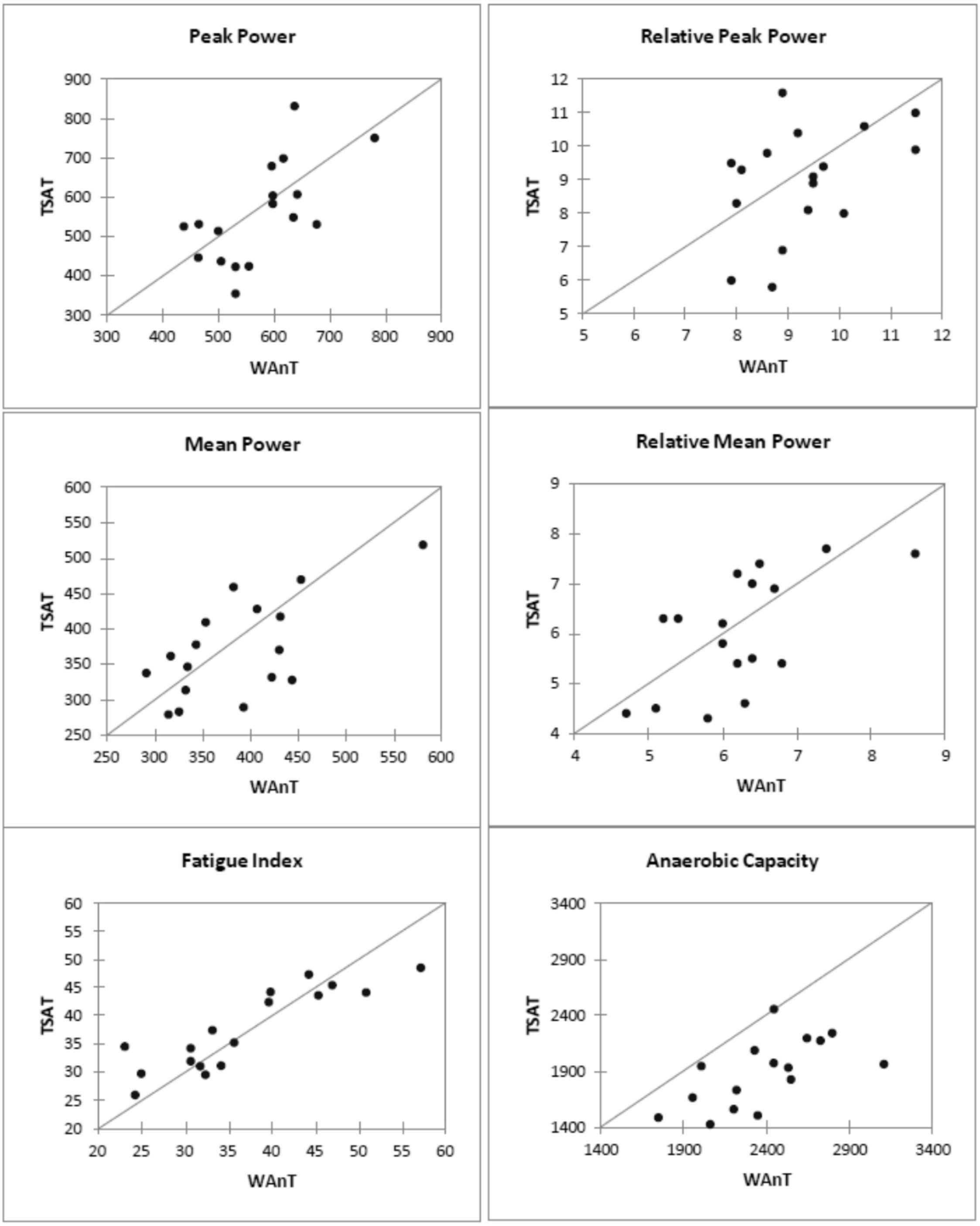

Figure 9: Scatter plot graphics for variables measured by WAnT and TSAT.

In the Bland-Altman plot graphic, figure 10, we can infer the following: for PP the bias is -17.1, with a 95% CI of [-67.7;33.4], the limit of agreement (LoA) is [-210.1;175.8]; for RPP the bias is the value of -0.3 with a 95% CI [-1.1;0.4], the LoA is [-3.3;2.7]; for MAP, there is a bias of -14.7 with a 95% CI of [-45.0;15.5] and LoA of [-130.2;100.7]; for RMAP the bias is -0.2 with a 95% CI of [-0.6;0.3] and a LoA [-0.2;0.7]; concerning FI and AC, there is a bias of 0.6 and -537.6, a 95% CI of [-1.8;3.0] and [-705.0;-370.1] and a LoA of [-8.7;9.2] and [-1175,9;100.7], respectively. Summing up, the 95% CI of bias for the first five variables includes the zero (0) value. This can confirm that the risk of concluding that WAnT and TSAT are different when they are not is high and should be avoided. The LoA suggests that any difference between the two measures should lie in this CI, and allows understanding that at least 80% of dots are within this limits.

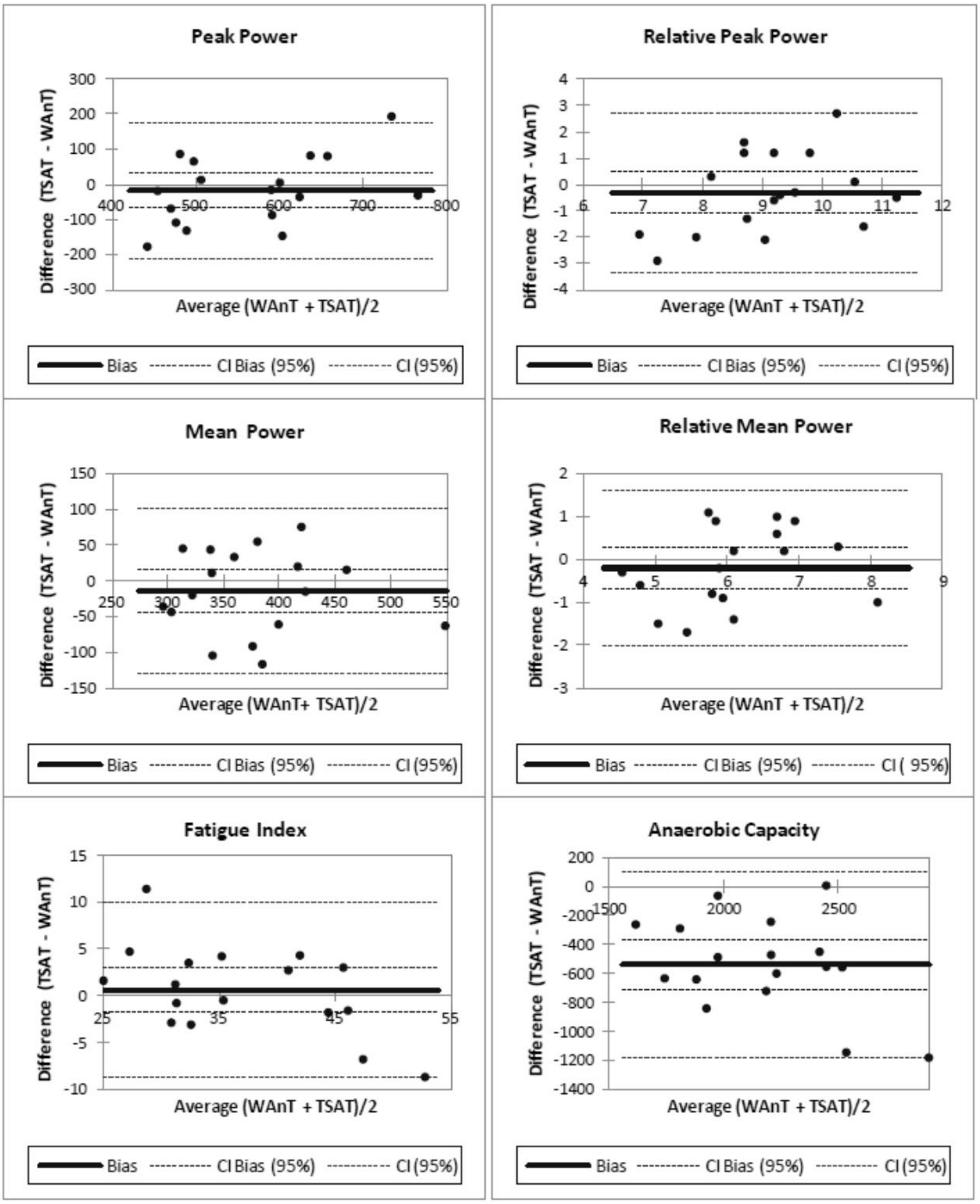

Figure 10: Bland-Altman fit differences from the variables measured by WAnT and TSAT.

Discussion

The intent of this study was to evaluate the concurrent validity of TSAT using the WAnT as a gold standard test and to verify how far the TSAT gives results that are similar to WAnT in an elite male taekwondo subjects.

Performing a technique with speed and strength are two important criteria for taekwondo competition (Roosen, 2006). Several studies have attempted to assess the kick impact force using measurement systems whose results are presented in Newtons (O´Sullivan et al, 2009; Falco et al., 2011) others in Kilogram-force (Chiu et al., 2007) or in joules (Del Vechio et al., 2011) and also in gravity acceleration units (g) (Sant´Ana et al., 2014). Moreover, the electronic body protector used in official taekwondo matches records the impact in joules. Del Vecchio et al., (2011) presented data from the energy absorbed by the electronic body protector during taekwondo official competitions and states that the energy values recorded ranges from 211 ± 34 joules in junior <51kg athletes to 262 ± 49 joules in senior 67-78kg athletes. In this study, we used the watts measurement system to quantify the *Bandal chagui* impact because we wanted to correlate the impact forces with the WAnT results and because the Mega Strike device measures the impact of a hit in units patented by the manufacturer. We verify that the *Bandal chagui* technique can produce in average an impact force of 418 ± 85.1Watts. Assuming the relationship between joules and watts by the following formula, Joules= Watts x seconds, and considering the work of Matsushigue et al. (2009), which refers *Bandal chagu*i speed values in order of 0.31 seconds, we realize that the electronic body protector delivers higher values than those recorded in this study (680 watts vs. 418 watts). There must be several reasons for this underestimation in the presented work, and from our point of view, it is clear that the difference is explained by how the impacts are assessed, the material used, contact time, and other factors.

For the WAnT evaluation, all participants were instructed about the proper methods, although, a difference in the trial I and trial II was registered. Barfield et al. (2002) reported a systematic change in peak power (14%) and mean power (5%) between two trials in WAnT, when there is not a good familiarization with the evaluation test. In our study, for WAnT, the differences are 15% for peak power and 21% for mean power. During the sports seasons, all participants are evaluated with WAnT, and even so, it is evident that any technical gesture unspecific to the sport performed in WAnT protocol can act as lack of familiarization, which in a way can explain the differences between trial I and II. This question became apparent when we recorded differences of 7% and 11% for the same variables, peak power and mean power respectively, between trial I and II for the TSAT protocol, both with an ICC above 0.83 and a small to medium effect size, suggesting that these differences in practice will not have a big impact.

Several studies have been conducted on the validity, reliability and/or replication of the 30 seconds Wingate test protocol (Beneke et al., 2002; Denadai et al., 1997). Additionally, Bridge et al. (2014) in a review article reported 864.6 ± 246.2 w (peak power); 11.8 ± 2.0

w/kg (relative peak power); 671.2 ± 151.3 w (mean power) and 9.2 ± 1.2 w/kg (relative mean power) for an international US male elite taekwondo sample. Heller et al. (1998) reported values of 14.7 ± 1.3 w/kg (relative peak power); 344 ± 26.4 J/kg (anaerobic capacity) and a 42.2 ± 7.3% (anaerobic fatigue) in a sample of elite male and female taekwondo subjects. When considering our findings in WAnT we reported results in some variables lower than those considered in the literature, such as the peak power, relative peak power, and anaerobic capacity. The lower values can explain the value presented in FI, i.e., installed fatigue was also shorter, resulting in a lower FI.

There is a notorious difference in anaerobic capacity (about 22%) between both tests. Despite the reliability of the mega strike shield presenting a good ICC, the power decline in the techniques throughout the TSAT is evident. We suppose that this decline is partly due to the reduction of energy sources, including ATP, PC, muscle glycogen and accumulation of H^+ and inorganic phosphate (Pi) (Fitts, 2008), but it may also be due to the striking shield not having the same sensitivity throughout. As declines in physical performance can be associated with reductions in technical skill performance (Fitts, 2008; Radman et al., 2015) a decrease in technical aim for the most sensitive part of the shield may have occurred, presenting, in our view, a difference in values to the AC variables between the two tests. This observation can also justify the FI behavior when compared with the Sant´Ana et al. (2014), although the values between WAnT and TSAT were very similar, they seem to be higher than 27.69% in the Sant´Ana study.

Sant´Ana et al. (2014) justified the lower values of the taekwondo anaerobic test, in FI variable, when compared with other authors using the WAnT, due to the fact that in the WAnT there is a constant load for the technical gesture (cycling) while in taekwondo specific tests, there is a brief pause between the kicks which somehow allows for recovery, causing a lower drop in performance. In this study, assuming the feature mentioned above, and to justify the similarity of values in the FI variable, we would rather assume that the similar values between the two tests are due to a specific technical gesture that imposes physiological dissimilarities between cycling and kicking. Cycling involves isotonic contractions while kicking is a complex motor task characterized by large forces exerted in a short period (Falcó and Estevan, 2014) and therefore, there is a central and peripheral specific adaptation. The specific gesture also allows the athletes to synchronize better the various phases of the kick skills they use, thus saving energy in carrying out the test. On the other hand, this ability to synchronize also allows the athlete a larger fiber recruitment to mobilize a larger muscle mass in a greater angular velocity and this, eventually, results in more force applied (DelVecchio et al., 2011) corresponding to increased energy consumption.

We suggested that the correlation between the mean power and number of techniques in the TSAT with CMJ is supported by the stretch-shortening cycle. When performing the *Bandal chagui* there is a knee flexion before a leg extension (when the foot hits the bag), a movement that mimics the one performed in the CMJ test. With this association, we can understand that the ability to perform the TSAT, particularly regarding the number of techniques and the average value of the impact force, depends on the maximal muscular power production by the knee extensors, a finding also described by Sant´Ana et al (2014).

We obtained results contrary to our first hypothesis, WAnT underestimates the anaerobic performance of male taekwondo o athletes, due to, in our perspective, factors related to impact measurement; nevertheless, the same results show the existence of a significant correlation, which suggests that both protocols have the ability to evaluate an identical variable. Additionally, there is no proportional bias in all variables (except for AC), which leads us to mention that there is a level of agreement between both tests and that confirms our second hypothesis. The level of agreement is higher after normalization (peak power and mean anaerobic power) according to the body weight (Falcó et al., 2013). For the anaerobic capacity variable, the first assumption is that the two methods on this variable do not consistently provide similar measures because there is a level of disagreement that may include important practical discrepancies up to 537.6 watts. In fact we have a correlated and inconsistent measure at a constant bias; however, this bias does not render TSAT meritless to assess anaerobic capacity. In this particular case, to evaluate AC we could use the value of the AC plus the bias, as an estimate of the anaerobic capacity from TSAT. It should also be added that these results are in position to assume the TSAT validation: a) there are no differences between the tests (mean data) with the exception of AC variable; b) the Bland and Altman analysis allows for realization that PP and FI have one dot each beyond the limits of agreement, while the other variables have all the dots within those limits. So, the cut-off value of at least 80% of plots within the LoA was accomplished for all variables of TSAT protocol.

We discussed earlier the sensor sensitivity issue that may have caused this constant bias. This constitutes a limitation for this study and should be further investigated through complementary experiments with an improved power assessment tool, capable of retaining a minimum level of measurement accuracy that guarantees that every major portion of the strike shield surface must include a sufficient number of sensors to ensure recording of every possible type and magnitude of hit on it.

Our findings have been limited to a group of elite male athletes. Further approaches are needed to confirm if TSAT protocol is appropriate for assessing other athletes in different levels of training, of different ages and especially in female athletes.

Conclusions

It was hypothesized that WAnT underestimates the anaerobic performance of taekwondo players. In fact, the results showed the opposite, especially regarding the AC variable; due to a decrease of motor acuity in performing the *Bandal* C*hagui* with onset fatigue, the techniques began to be carried out in areas farther from the center of the shield/sensor, with lower impact values than the force applied. Our results also have shown that TSAT has a level of agreement with the WAnT, especially in the variables PP, RPP, MAP, RMAP, and FI. Therefore the protocol attaches great specificity in assessing the anaerobic fitness of taekwondo athletes. The importance of muscular power in the TSAT is significant when there is a relation between CMJ and mean power, CMJ and the number of techniques.

An important point in this work was to quantitatively measure the performance effort, providing a set of equations with a clearly practical impact on the training/anaerobic evaluation process of taekwondo athletes.

References

Aziz, A. R., Tan, B., & Teh, K. C. (2002). Physiological responses during matches and profile of elite pencak silat exponents. *Journal of Sports and Sciences in Medicine,1,* 147-155.

Barfield, J. P., Sells, P. D., Rowe, D. A., & Hannigan-Down, K. (2002). Practice effect of the wingate anaerobic test. *Journal of Strength and Conditioning Research, 16*, 472-473.

Bar-Or, O. (1987).The Wingate anaerobic test: An update on methodology, reliability and validity. *Sports Medicine, 50*, 273-282.

Beneke, R., Pollmann, C., Bleif, I., Leitäuser, R. M., & Hü Tler, M. (2002). How anaerobic is the wingate anaerobic test for humans*?, European Journal of Applied Physiology, 87*, 388–392.

Bland, J. M., & Altman, D. G. (1986). Statistical methods for assessing agreement between two methods of clinical measurement*, Lancet,* 1, 307-310

Boehlel, E., Jouini, A., Gmada, N., Abdallah, K.B.,& Tabka, Z. (2006). Heart rate and blood lactate responses during taekwondo training and competition. *Science and Sports, 21*, 285-290.

Bosco, C. (1994). La valoracion de la fuerza con el test de Bosco. Paidotribo, Barcelona, Spain.

Bridge, C. A., Jones, M. A., & Drust, B. (2009). Physiological responses and perceived exertion during international taekwondo competition. *International Journal of Sports Physiology and Performance,4,* 485–93.

Bridge,C. A., Santos, J.F. S., Chaabène,H., Pieter, W., & Franchini, E. (2014). Physical and Physiological Profiles of taekwondo Athletes. *Sports Medicine, 44,* 713-733, doi: 10.1007/s40279-014-0159-9.

Chiu, P. H., Wang, H. H., & Chen, Y. C. (2007). Designing a measurement system for taekwondo training. *Poster Session 1/Sport. Poster 138, S619. Institute of Sports Equipment Technology, TPEC,* Taipei, Taiwan.

Del Vecchio, F. B, Franchini, E., Del Vecchio, A. H. M., & Pieter, W. (2011). Energy absorbed kicks in a taekwondo competition. *Biology in Sports, 28*, 75-78.

Denedai, B., Gugliemo, L. G. A., & Denedai, M. L. D. (1997). Validade do teste de wingate para a avaliação da performance em corridas de 50 e 200 metros. *Motriz, 3 (2),* 89-94.

Falcó, C., Estevan, I., Solves, O., & Molina-García, J. (2011). Capacity to create impact forces and execution time according to weight category in taekwondo. *Revista de Ciencias del Deporte, 7(suppl.),* 23-29.

Falcó, C., Molina-García, J., Àlvarez, O., & Estevan, I. (2013). Effects of target distance on select biomechanical parameters on tae kwon do roundhouse kick. *Sport Biomechanics, 12*, 1-8.

Falcó C., & Estevan, I. (2014). Biomechanics in taekwondo: practical applications. *In Performance optimization in taekwondo: from laboratory to field, ed. OMICS Group eBooks.* Foster City, CA, 1-23.

Fitts R.,H. (2008). The cross bridge cycle and skeletal muscle fatigue. *Journal of Applied Physiology, 104,* 551-558.

Heller, J., Perici, T., Dlouhç, R., Kohlíkovç, E., Melichna, J., & Novoçkovç, H. (1998). Physiological profiles of male and female taekwondo (ITF) black belts. *Journal of Sports Sciences, 16,* 243-249.

Inbar O., Bar-Or, O., & Skinner, J. S. (1996) The wingate anaerobic test. *Human Kinetics,* Champaign, Ill.

Jackson,A. S., Pollock, M. L., & Ward, A. (1980). Generalized equations for predicting body density of women. *Medicine and Science in Sports and Exercise, 12*,175-182.

Lee, K. M. (1996). Tae Kwon Do, techniques and training, *Sterling Publishing Comp.*, New York, NY.

Matsushigue, K. A., Harmann, K., & Franchini, E. (2009). Taekwondo: physiological responses and match analysis. *Journal of Strength and Conditioning Research,* 23, 1112-1117.

Melhim, A. F. (2001). Aerobic and anaerobic power responses to the practice of taekwon-do. *British Journal of Sports Medicine, 35*, 231-234.

Nicklin, R., O´Bryant, H., Zehnbauer, T., & Collins, M. (1990). A computerized method for assessing anaerobic power and work capacity using maximal cycle ergometry. Journal *of Applied Sport Sciences Research, 4,* 135-140.

Olsen, P.D. & Hopkins, W.G. (2003). The effect of attempted ballistic training on the force and speed movements. *The Journal of Strength and Conditioning Research*, 17(2), 291-298.

O´Sullivan, D. O., Chung, C., Lee, K., Kim, E., Kang, S., Kim, T., & Shin, I. (2009). Measurement and comparison of taekwondo and yongmudo turning kick impact force for two target heights. *Journal of Sports Science and Medicine, 8(CSSI III),* 13-16.

Radman, I., Wessner, B., Bachl, N., Ruzic, L., Hackl, M., Prpic, T., & Markovic, G. (Epub 2015, Nov). The acute effects of graded physiological strain on soccer kicking performance: a randomized, controlled cross-over study. *European Journal of Applied Physiology, 116(2),* 373-382. doi: 10.1007/s00421-015-3293-7.

Ravier, G., Grappe, F. & Rouillon, J.D. (2004). Application of force-velocity cycle ergometer test and vertical jump tests in the functional assessment of karate competitor. *Journal of Sports Medicine and Physical Fitness*, 44(4), 349.

Roosen, A., & Pain, M. T. G. (2006). Impact timing and stretch in relation to foot velocity in a taekwondo kicking combination. *Journal of Biomechanics, 39, s562.,* doi: http://dx.doi.org/10.1016/S0021-9290(06)85319-4.

Ross, W. D., & Marfell-Jones, M.J.(1991). Kinanthropometry. In Physiological testing of the high-performance athlete. (pp 22-29). *Champaign, Illinois: Human Kinetics Books*.

Sant´Ana, J., Diefenthaeler, F., Dal Pupo, J., Detanico, D., Guglielmo, L.A.,& Santos, S. G. (2014). Anaerobic evaluation of taekwondo athletes. *International SportMed Journal, 15(4),* 492-499.

Zupan, M. F., Arata, A. W., Dawson, L.H., Wile, A. L., Payn, T. L., & Hannon, M. E. (2009). Wingate anaerobic test peak power and anaerobic capacity classifications for men and women intercollegiate athletes. *The Journal of Strength and Conditioning Research, 2,* 2598-2604

Chapter 5:

Overall conclusions and recommendations

Overall conclusions

The major propose of this thesis was to investigate the possibility of using two ground tests, specifically for taekwondo/martial arts. This claim arises from the need to prevent and diagnose overtraining in these athletes. Overtraining is a state of maladaptation in which the unexpected decrease in performance may be a valid indicator. The lack of specific tests for physical fitness evaluation in taekwondo athletes creates a gap that exacerbates the difficulty of dealing with this phenomenon.

This research was based on a literature review on the concept of overtraining and then expanded in two empirical manuscripts that objectively address the concurrent validity of using two assessment protocols of aerobic and anaerobic fitness in taekwondo athletes. The following specific issues were addressed in this research: (i) a narrative overview of the literature about the overtraining syndrome; (ii) a predictive equation model for aerobic power determination, and; (iii) a new perspective for anaerobic fitness assessment in taekwondo athletes.

As regard to the first issue, the results are quite clear: this overtraining syndrome is wrapped in a set of situations (multifactorial etiology) - the true result of identification is a challenge for coaches and sport scientists, and so far the best possible diagnosis is by the exclusion of diseases that can mask the phenomena. Several biological and behavioral markers are suggested (including by specific literature in taekwondo) such as heart rate variability and training load (Monoem et al., 2014) and even hormonal and mood parameters (Toskovic, 2001; Pieter and Heijmans, 2000). Nevertheless, monitoring performance seems to be the best consensus sign (Bridge et al., 2014) - decreased performance as well as the reduced ability to perform high-intensity exercise (Mackinnon, 2000) would be a valid indicator for the detection of overtraining. Such task involves having a set of standardized and validated instruments, for the changes over time can be explained. Performance in conjunction with other indicators may establish a precocious identification chart of athlete's fatigue level and assist the coach to prevent overtraining syndrome

The second issue addressed (in chapter 3) was related to the aerobic power evaluation in taekwondo athletes; the following research question was asked: considering the 20-meter multistage shuttle run test (SRT) as a standard method for aerobic evaluation, is there a concurrent validity in a maximal taekwondo-specific test (TST) to predict VO_{2max}? We found comparable observed VO_{2max} values in both protocols. However, the Léger predictive equation underestimated the VO_{2max} by 10%. The TST results fell within the range shown by several studies. The adjusted model doesn´t include muscular power because we have not found a significant correlation between the bandal chagui power techniques and $VO_{2max.}$ The mathematical equation that best describes the relationship between $VO_{2max,}$ mean HR, height, TST time and test time multiplied by the weight in TST is as follows: VO_{2max} = – 1.4 + 0.58 *(height)* – 0.32 *(meanHR*) + 3.84 (time) – 0.03*(time*weight*) (1).

Concerning the third issue (in chapter 4) - assessing anaerobic fitness - the established initial hypothesis advocated that general test (such as the Wingate tes) underestimates the anaerobic performance of taekwondo athletes. Our results showed that both the Wingate test (WAnT) and the taekwondo-specific anaerobic test (TSAT) are in a range that allows the use of two measurement methods interchangeably. In fact, the Wingate test does not underestimate the anaerobic performance of these athletes but further research is required to provide evidence of the effectiveness and feasibility of the TSAT, especially regarding the instrument used to evaluate the impact force. Though, we were able to measure the performance effort quantitatively, and it has produced a set of equations with a level of agreement with WAnT, giving the TSAT great specificity in the evaluation of anaerobic fitness.

Practical applications and future research

We consider this work to be a novel approach to assessing aerobic and anaerobic fitness in taekwondo athletes. Both protocols have characteristics that reproduce the motor patterns of this sport, giving evidence for convergent validity with some accuracy among models (tested and standard). This suggests that the two models examined in this study can be used interchangeably for the prediction of VO_{2max} and anaerobic fitness in taekwondo athletes. Thus, coaches and researchers incorporating these assessments into their programs can with simple, inexpensive, and time-efficient tools assess and monitor the training status of these athletes.

Despite these encouraging findings, future research needs to examine the convergent validity of these models using different statuses (e.g., recreational practitioners), ages, genders (e.g., a female sample), and weight categories to determine whether the relationships found in this study hold and can be generalized to larger, more diverse groups of taekwondo athletes.

Limitations

Despite the relevance of the present results, various limitations should be acknowledged.

We already presented one limitation of the sampling design, particularly the range of weight categories. We could have chosen subjects within one Olympic category for better results.

Regarding metabolic evaluation, we also could have measured the blood lactate concentration in both protocols and noted the correlation between some variables such as HR, test time, VO_{2max}, and impact force.

Another key point in this work was the impact force assessment. As we stated earlier, further research in the methods, techniques, and instrumentation regarding how to measure the impact force of *Bandal Chagui* without the negative reflex of fatigue is important, i.e., a more accurate and sensitive device could produce different results.

References

Bridge, C. A, Santos, J. F. S., Chaabène, H., Pieter, W. & Franchini, E. (2014). Physical and physiological profiles of taekwondo athletes, Review article. *Sports Medicine, 44,* 713-733.

Mackinnon, L. (2000). Overtraining effects on immunity and performance in athletes. Immunology *and Cell Biology, 78*, 502-509.

Monoem, H., Behm, D., Tebben, M. & Chamari, K. (2014). Monitoring training load, recovery, overtraining and upper respiratory infection in taekwondo. In: *Performance optimization in Taekwondo: from laboratory to field*, ed. *OMICS Group eBooks. Foster City, CA,* 1-23.

Toskovic, N. N. (2001). Alterations in selected measures of mood with a single bout of dynamic Taekwondo exercise in college-age students. *Percept Motor Skills, 92,* 1031-103.

Pieter, W. & Heijmans, J. (2000). *Scientific coaching for Olympic Taekwondo* (2nd edition). Oxford, UK: Meyer & Meyer Sport, 151–180.