A New Individual and Specific Test to Determine the Aerobic–Anaerobic Transition Zone (Santos Test) in Competitive Judokas

Luis Santos,[1] Vicente González,[1] Marta Iscar,[2] Juan Ignacio Brime,[3] Javier Fernandez-Rio,[4] Jorge Egocheaga,[1] Blanca Rodríguez,[2] and M. Ángeles Montoliu[2]

[1]Medical Service of the Community of Cabo Peñas, Asturias, Spain; [2]Exercise Physiology Unit of the Hospital Universitario Central de Asturias, Spain; [3]Department of Functional Biology of the University of Oviedo, Asturias, Spain; and [4]University of Oviedo, Asturias, Spain

Abstract

Santos, L, González, V, Iscar, M, Brime, JI, Fernandez-Rio, J, Egocheaga, J, Rodríguez, B, and Montoliu, MÁ. A new individual and specific test to determine the aerobic–anaerobic transition zone (Santos Test) in competitive judokas. *J Strength Cond Res* 24(9): 2419–2428, 2010—The main goal of this research project was to design a specific, simple, and noninvasive field test to determine the individual aerobic–anaerobic transition zone in judokas. Our aim was to develop a field test as close as possible to real judo combat. Eight state- and national-level judokas participated in the study. To find the reliability of our test, all subjects repeated the same test under the same conditions within a 7-day period. Because the results were positive, we tested the validity of our proposal using a laboratory test that possessed the same characteristics. On both tests, the same parameters were studied. The mean data obtained in the laboratory test were as follows: maximum heart rate (HRmax): 198.2 ± 3.9 $b \cdot min^{-1}$, HR at the anaerobic threshold: 170.3 ± 5.7 $b \cdot min^{-1}$, percentage of HRmax at which the anaerobic threshold appears: 85.9 ± 2.9%, lactate max: 14.6 ± 1.4 $mmol \cdot L^{-1}$, lactate threshold: 4 ± 0.3 $mmol \cdot L^{-1}$, and $\dot{V}O_2max$: 58.3 ± 4.4 $ml \cdot kg^{-1} \cdot min^{-1}$. The mean data obtained in the field test were as follows: HRmax: 199.7 ± 1.8 $b \cdot min^{-1}$, HR at the anaerobic threshold: 169.7 ± 2.7 $b \cdot min^{-1}$, percentage of HRmax at which the anaerobic threshold appears: 85.0 ± 1.8%, lactate max: 17.0 ± 2 $mmol \cdot L^{-1}$, lactate threshold: 4.0 ± 0.3 $mmol \cdot L^{-1}$, and $\dot{V}O_2max$: 59.8 ± 3.6 $ml \cdot kg^{-1} \cdot min^{-1}$. There were no significant differences between the data obtained on both tests in any of the parameters evaluated, except for the lactate maximum. Therefore, we can conclude that our field test is a useful tool for judo training.

Key Words Judo, evaluation, bioenergetic, tatami, noninvasive, simple.

Introduction

Judo holds a tradition of hundreds of years in Japan, and it has become a very popular sport over the last couple of decades in the rest of the world. Nevertheless, a valid description of its physiological characteristics has been very complicated to achieve because of several reasons: the difficult task of quantifying the effort needed in a combat; the existence of several competitive categories depending on the weight of the athlete; the certainty of a series of effort cycles within a judo combat with a wide range of duration times (from a few seconds to several minutes); the possibility of taking part in several combats during the same day; or the differences between 2 opponents regarding anthropometric characteristics, technical–tactical level, or the specific technical actions performed (10,31,41).

Nevertheless, Verkhoshansky (52) believes that judo combat is a sport that requires a specific resistance capacity because of the variable conditions of its competition. It demands explosive efforts, and the competence to confront exhaustion without reducing effectiveness. Moreover, the competition takes place at a variable or intermittent work rate, and it also has a wide range of complex technical and tactical motor skills.

On the other hand, Pulkkinen (34) considers that the anaerobic energy production system is the primary source of energy production in judo combat. The high levels of lactate found on judokas (2,47) mean that athletes need to have a good glucolytic energy production system.

Nevertheless, other researchers (48) believe that judokas also need an adequate aerobic system to keep their performance at a high level during a single combat and throughout a complete tournament. The average length of a combat is 7–8 minutes, but the interruptions for penalties force judokas

Address correspondence to Luis Santos Rodríguez, l-net@mixmail.com.

24(9)/2419–2428

Journal of Strength and Conditioning Research

to withstand a longer period of time (28). Therefore, resistance training has great relevance in judo. The main benefit of an aerobic capacity workout is the improvement of the anaerobic threshold. Wasserman and McIlroy (53) introduced the idea of a threshold of the anaerobic metabolism: where there is a gradual shift from a fundamental oxidative metabolism to a physiological state with the slight presence of oxygen, that is, anaerobic metabolism.

The aerobic–anaerobic transition zone is a key element for the improvement of the aerobic capacity and the aerobic power. As described before, judo combat demands high levels of both energy systems. The problem is the great complexity of the sport and the absence of specific tests. Physiological analyses of judo combat have 3 big obstacles: imprecise telemetry (the competition is body to body and it creates interferences), nonspecific ergometers to be used in field tests, and an intermittent competition. Different tests have been developed to measure the physical fitness of the judo athlete. The problem is that some of them do not comply with the principles of specificity, individuality, and reproducibility, whereas others raise serious doubts of their reliability (36).

The goals of this research project were threefold: to evaluate the physical condition of a group of expert judokas, to design a field test to determine the specific and individual aerobic–anaerobic transition zone of judokas, and to create a simple, low-cost, noninvasive, and applicable test.

Methods

Experimental Approach to the Problem

After considering all the factors mentioned in the Introduction, we designed a working plan with several steps:

First, we tried to find a group of judokas that could fulfill these requirements: (a) There must be one athlete for each official male weight category: −60, −66, −73, −81, −90, −100, and +100 kg. (b) All subjects must possess black belt Dan 1 (expert judokas). (c) They had to be state champions and runners-up in the under-18, university, and national championships. (d) They must have more than 10 years of experience in state and university championships, and they must have participated in several national championships.

Most competitive judokas that participate in state and national championships practice 6 $d \cdot wk^{-1}$ during 11 months carrying out technical, tactical, and conditioning workouts. Therefore, research conducted in these subjects could be extrapolated to any competitive judoka. Nevertheless, more tests need to be done to gather more information on the specific metabolic demands of judo combat and be able to help coaches.

Second, we designed the field test based on a deep analysis of judo competition and using the literature mentioned in the Introduction. One goal was to develop a field test as close as possible to real competition. Another goal was to make a field test easy to use, low cost, and noninvasive. Therefore, our test had to be carried out on a tatami (where the competition takes place), with the help of a second judoka that behaved as a partner, and both subjects dressed in a judogui (judo clothes). To make the test more realistic, the subject had to use his own specific technical actions (the ones that he uses in competition). Finally, the intermittency of judo competition was also considered in the test. Working and resting periods were controlled to match the times that the existing literature indicates (10,20,28,40,45). Through all these requirements, the field test was kept as close as possible to real competition, and the special metabolic characteristics of judo combat were attended.

Third, To find the reliability of the test (30), we repeated all field tests under the same conditions (see Table 2). Because the results were positive, we activated the final stage of our research project: test the validity of our proposal. We design a laboratory test with the same characteristics as the field test to find out if the results obtained in the field test were valid.

Therefore, the working hypotheses of our research project were 3: (a) If a group of judokas go through a progressive and intermittent effort test in which each judoka uses his or her own individual technique, the physiological response could be representative of the bioenergetic demands of the sport. (b) If the results obtained from the field tests agree with the ones obtained in a similar laboratory test, the reliability of the field test would be proven. (c) If the field test is proven to be reliable, it could be used as a tool to design and assess training protocols.

Subjects

The study was carried out on a population of 8 male competitors. Subjects were informed of the experimental risks and signed a written consent, before the investigation, approved by the Bioethics Committee of the Central University Hospital of Asturias (HUCA, Oviedo, Spain) according to the Declaration of Helsinki.

All subjects were over 18 years of age. Their anthropometrical data are set out in the Results section. The test group consisted of state champions and runners-up in the under-18, senior, and university national championships. They all have had more than 10 years of experience in state and university championships, and all of them had participated in national championships.

In judo, the morphological characteristics of the athlete are very important (21). Each judoka is included in a specific category according to his or her weight. Our subjects belonged to different categories to avoid the influence of weight on the results of the investigation.

All subjects trained for 11 months completing 2 macrocycles: The first one lasted from mid-August till the end of December, and it was aimed at the state championship. The second one started at the beginning of January and got over at the end of June, and it was centered on national and international competitions. The weekly training program of all the subjects was the same: 5–6 days (90 minutes each session), 3–4 days focused on technical–tactical training, and 2–3 on conditioning improvement.

Procedures

Laboratory Test. These consisted of a physical fitness test and an ergospirometric test. Both were carried out at the Exercise

Physiology Unit of the HUCA. Special environmental measures were implemented to ensure perfect ventilation. Meteorological conditions were constant throughout the trial period: temperature between 17 and 20°C, and atmospheric pressure between 730 and 740 mmHg. The time lapse between field and laboratory tests was always less than 7 days.

A treadmill (Laufergotest LEB, Würzburg, Germany) was used to carry out the physical fitness test with a precision of $\pm$0.2 km·h^{-1}, a velocity range of 0.1–29.9 km·h^{-1}. It is the ergometric apparatus universally recommended and specifically designed to analyze sport activity with an inclination of 0–19.55% (33). A Stages Progressive Interval and Maximal test (SPIM) was designed according to the following protocol: initial velocity of 5 km·h^{-1}, velocity increments of 2 km·h^{-1}, 3-minute effort stages, 5% treadmill inclination (constant), and a 30-second pause between the effort stages. This protocol reflects the generally accepted recommendations (1) for evaluating $\dot{V}O_2$ and HR in 3-minute work steps, because both these values were established within ibis time frame (12,13). This type of SPIM test is widely used in a variety of sport specialties (26). Regarding the 3-minute effort interval, Wasserman et al. (54) did not find any differences when determining the ventilatory threshold between intermittent effort tests with effort steps between 1 and 4 minutes. Besides, Stegman and Kindermann (42) and Stegman et al. (43) recommend a running protocol (using a treadmill) of 3 minutes per step with an intensity increment of 2 km·h^{-1} until exhaustion as the best approach to determine the individual anaerobic threshold (IAT). According to Chicharro et al. (12,13), the heart rate (HR) and the maximum oxygen uptake stabilize within this 3-minute time frame.

Respiratory data were recorded using a CardioO_2 & CPX/D gas analyzer (Medgraphics, St. Paul, MN, USA). The oxygen analyzer was zirconium, whereas the carbon dioxide analyzer was infrared. The ventilation was measured with a Hans–Rudolph mask, fitted with a Pittot pneumotachograph, calibrated before and after each test. The average of all the values was measured breath by breath, and calculated each 30 seconds. The peak value was the highest of all the averages obtained. Continuous electrocardiogram analyses were carried out to advise one of any variations in the cardiac rhythm and to measure the subjects' HR. Blood pressure was also measured with a precision mercury sphygmomanometer.

Blood lactate was analyzed using an Accusport (Boehringer, Biberach, Germany) machine (16). Gullstrand et al. (26) investigated whether lactate concentrations in blood obtained from an incremental test on a treadmill vary when the blood sample is extracted during a 30-second pause between effort steps or if the subject does not stop. His results showed that no step of the test yielded statistically significant differences between the average lactate values in capillary blood or in HR. In addition, Beneke et al. (4) investigated whether the interruptions needed to get blood samples during a constant effort test had any impact on the lactate concentrations in blood, on the maximum lactate steady state, on the effort in the maximum lactate steady state, or on the relative work intensity in the maximum lactate steady state. He found that such interruptions of the workload (30 and 90 seconds) lead to a decrease in the lactate value in blood only after a 30-minute work period. None of our laboratory tests lasted more than 30 minutes. Therefore, the pauses required to collect blood samples did not affect lactate concentration.

The following parameters were evaluated: maximum heart rate (HRmax), HR at the anaerobic threshold (HR threshold), percentage of threshold HR with respect to the maximum (HR threshold %), maximum oxygen uptake ($\dot{V}O_2$max) measured in ml·kg^{-1}·min^{-1}, concentrations of basal blood lactic acid at the end of each effort stage and 3 minutes after the conclusion of the test (mmol·L^{-1}), lactate maximum (mmol·L^{-1}), and maximum speed attained by the subjects on the treadmill (km·h^{-1}).

The criterion employed to determine the realization of the maximum effort was as follows: respiratory quotient (RQ) $\geq$ 1 and HR $\geq$ 85% of the theoretical value. Franklin's (23) and Gibbons' (24) criteria were applied to finish the test.

As explained earlier, the laboratory test follows an SPMI protocol, just as the field test does, too. The idea behind carrying out a laboratory test using standard technology, under standard conditions, and following internationally accepted scientific protocols as reference to determine whether the information gathered from the field test was valid is based on the comparison of physiological parameters, not on the comparison of protocols. Thus, the subjects performed a field test, and to find out whether these physiological data are valid, the results were compared to those obtained from an equivalent laboratory test. This way, the results of the laboratory test serve as a reference for the field test, because they are representative of the subject's physical response.

Field Test. Our field test was based on an in-depth study of the scientific literature published so far on judo combats, and we tried to keep it is as close as possible to real competition. Therefore, all field tests were performed in the tatami (competition judo floor) set in the gymnasium of the Sports Science Department of the University of Oviedo. The temperature was kept at 17° C, and atmospheric pressure varied between 730 and 740 mmHg. To carry out the test, 2 judokas were required: the subject and a supporting partner. To replicate the environment of a real competition, both judokas belonged to the same weight category and were dressed in judo suits (judogui), too.

During the test, each subject had to perform several sequences of 3 specific technical skills. These were the ones that the judoka uses more during competition, the ones that he performs best (in judo this is called tokui-waza or special techniques). Each sequence had 2 phases: The first one was active and progressively sequential, whereas the second one was passive:

(a) *Active phase:* the judoka had to perform a specific technical skill without bringing the opponent to the floor. This lasted 40 seconds. The dependent variable was the number of repetitions carried out by the subject, which produced a progressive increase in the intensity of the process. During the test, 3 different technical skills were performed in successive sequences. In the first one, the subject raised his partner from the floor. In the second one, he unbalanced his opponent completely. Finally, in the third one, the subject chose to lift the opponent or unbalance him completely. Thus, we created a format that was repeated throughout the whole test: technique 1 performed in the first 40-second phase, technique 2 in the second 40-second phase, and technique 3 in the third 40-second phase. The next cycle started again with the first technique and continued with the same sequence until exhaustion.

(b) *Passive phase:* the judoka and his supporting partner, grabbing each other with their hands, had to move from one side of the tatami to the other. This activity tried to represent the movements that occur in real combats. It lasted 15 seconds. This second phase took place right after every active phase (40 seconds) and gave the test its intermittent character, a key element in judo training and combat.

The progressiveness of the test was based on the increase of 1 repetition on each new 40-second series. The first active phase started with 7 repetitions. Thus, the first series consists of 7 repetitions, the second of 8, the third of 9, and so on, until exhaustion prevented the judoka from executing the specific technical skill with the required quality. This meant that he was not able to raise his partner from the floor, throw him off balance and/or complete the correct number of repetitions in 40 seconds.

The regular (not irregular) character of the test (as in competition) is because most studies refer to intervals of a regular character to detail work time and pause time during combats (20,21,28,32,34,40).

The reason for dividing the field test into 2 phases (effort and pause) was based on the irregularly intermittency of judo competition as described by Franchini (21). Favre-Juvin (20) reported effort times of 20 to 40 seconds with interruptions from 10 to 20 seconds. Gorostiaga (25) affirmed that the pause phases ranged from 3 seconds to 1 minute 58 seconds, with the most frequent values being located between 7 and 15 seconds. In the light of all these data, we estimated that the best rate of activity and pause was 40 and 15 seconds, respectively. Our goal was to match, as closely as possible, the effort in competition.

Regarding the 3 special techniques that the judoka must perform during the test, always in the same sequence, we must clarify that each judoka has his own "judo," expressed through the 3 or 4 techniques that he has mastered and always uses in competition. For the test to yield specific and individual bioenergetic data, the judoka must perform his own judo through his special techniques. This way, the test is adapted to each judoka's characteristics, and it can thus show a truly individual and specific anaerobic threshold. Previous studies (6,7,27,40) have revealed that Olympic and world champions use an average of 6 standing judo techniques. According to Sterkowicz and Maslej (45) and Franchini (21), this shows that, despite the existence of 100 internationally recognized techniques, the best judokas use just a few. Nevertheless, although performing the special techniques, all subjects had to raise his opponent from the floor or completely unbalance him. Through this procedure, we tried to give the test a common protocol and make the test applicable to any judoka.

To produce a real effort, the judoka had to perform the technique as if he or she was in a competition. To assure that this requirement was met, he had to raise the other judoka from the floor on each repetition. In those techniques in which the opponent cannot be lifted, the criterion is manifested through the complete unbalancing of the opponent. Therefore, the judoka who suffered the actions had to grab

TABLE 1. Values obtained in the laboratory test and the field test.*

	HRmax ($b \cdot min^{-1}$)	HR threshold ($b \cdot min^{-1}$)	HR threshold (%)	Lactate max. ($mmol \cdot L^{-1}$)	Lactate threshold ($mmol \cdot L^{-1}$)	$\dot{V}O_2max$ ($ml \cdot kg^{-1} \cdot min^{-1}$)
Laboratory test (mean ± *SD*)	198.2 ± 3.9	170.3 ± 5.7	85.9 ± 2.9	14.6 ± 1.4	4.0 ± 0.3	58.3 ± 4.4
Field test (mean ± *SD*)	199.7 ± 1.8	169.7 ± 2.7	85.0 ± 1.8	17.3 ± 2.0	4.0 ± 0.3	59.8 ± 3.6
Significance	NS ($p < 0.477$)	NS ± ($p < 0.727$)	NS ($p < 0.3$)	S ($p < 0.019$)	NS ($p < 0.65$)	NS ($p < 0.46$)

*HRmax = maximum heart rate; HR threshold = heart rate in the anaerobic threshold; HR threshold % = anaerobic threshold with respect to the maximum heart rate; Lactate max = maximum lactic acid concentration; Lactate threshold = lactate in the anaerobic threshold; $\dot{V}O_2max$ = maximum consumption of oxygen in relative terms.

Table 2. Reliability of the field test*

	HRmax (b·min^{-1})	HR threshold (b·min^{-1})	HR threshold %	Lactate max. (mmol·L^{-1})	Lactate threshold (mmol·L^{-1})	$\dot{V}O_2$max (ml·kg^{-1}·min^{-1})
Test 1	199.7 ± 1.8	169.7 ± 2.7	85.0 ± 1.8	17.3 ± 2	4.0 ± 0.3	59.8 ± 3.6
Test 2	200 ± 1.1	170.3 ± 1.2	85.4 ± 2.1	16.8 ± 1.8	3.9 ± 0.5	58.9 2.2
Significance	P: NS ± 0.477	P: NS 0.727	P: NS 0.600	P: NS 0.598	P: NS 0.732	P: NS 0.372
T	0.751	−0.363	−0.548	−0.552	−0.357	0.954

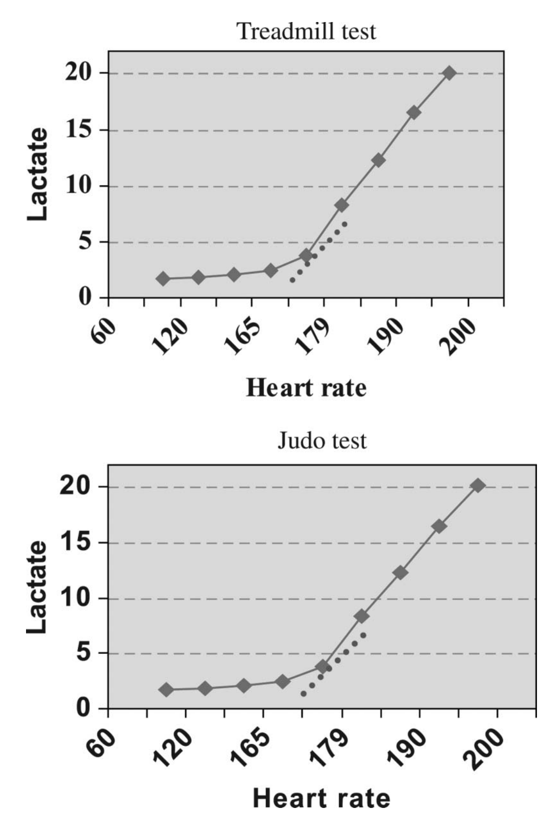
*HRmax = maximum heart rate; HR threshold = heart rate in the anaerobic threshold; HR threshold % = anaerobic threshold with respect to the maximum heart rate; Lactate max = maximum lactic acid concentration; Lactate threshold = lactate in the anaerobic threshold; $\dot{V}O_2$max = maximum consumption of oxygen in relative terms.

the one who is doing the test to prevent himself from falling to the floor. This way, the specificity of the test was ensured.

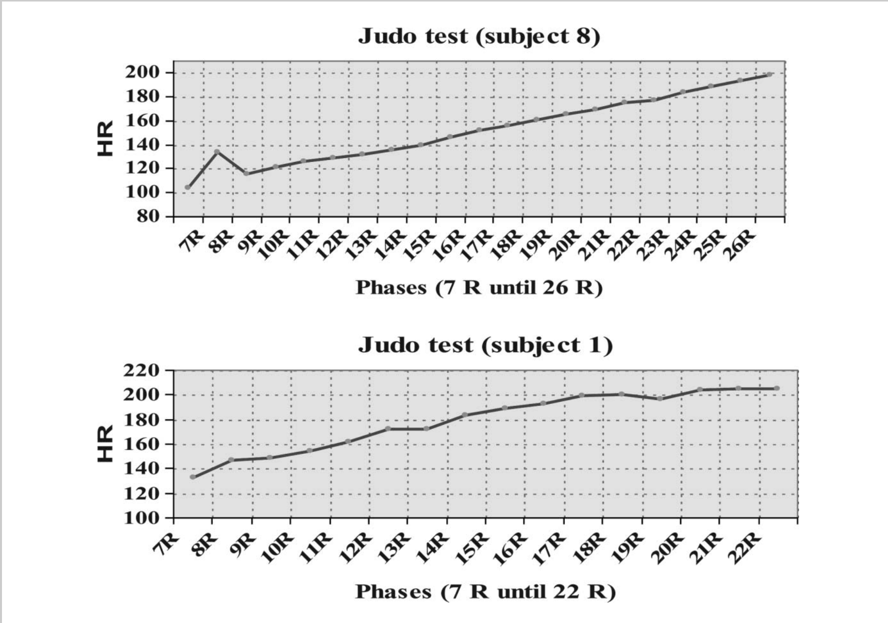
The inclusion in the field test of periods of movement of the judokas (passive phase) is because of the fact that during a judo combat they move constantly from one side to the other of the tatami. This constitutes a frequent maneuver in competition. Its inclusion gives the field test its intermittent character, characteristic of the judo effort (20,21,32,39,46).

During the field test, the judokas wore a $\dot{V}O_2$ 2000 portable gas analyzer (Med Graphics, St. Paul, MN, USA). The dimensions of this system were as follows: length 11 cm, width 14 cm, and thickness 6.5 cm. Its weight was 1,200 g. It was calibrated before and after each test with Aerograph software (Windows 95 and 98 compatible). The ergospirometric parameters studied were oxygen uptake, carbon dioxide production, ventilation, and respiratory coefficient. The HR was continuously recorded by means of a heart rhythm monitor (Polar S810, OY, Oulu, Finland), and it was digitalized using a Digital Wireless Industrial Transceiver (model Wit 2410 E, 2.4 GHz). Throughout the test, microsamples of arterialized blood were obtained from perforation of the earlobe to determine the blood concentrations of lactic acid. The samples were taken before the test (basal sample), when the ventilation threshold was being reached (as determined from the data obtained in real time from the portable gas analyzer), and 5 minutes after the end of the test. The test was considered finished when the athletes could no longer meet the previously indicated quality requirements. The blood lactate was analyzed with the same equipment and procedure used in the laboratory tests. To verify the validity of our proposal, the same parameters were studied in the field and laboratory tests.

Reliability of the Field Test. Because our field test was completely new, there was a need to find out if this test could be applied several times, generating valid results on each one of its applications. According to López Chicharro et al. (30), the concept of reliability of a test refers to the capacity of a test to be repeated (under the very same conditions), yielding the same data in each interaction. All 8 judokas repeated the field test after 7 consecutive days and under the same conditions: place, time, rest periods, etc. to verify its reliability (Table 2).



Figures 1 and 2. Individual anaerobic threshold of case number 8 in laboratory (1) and in the field test (2) obtained from Keul's methodology (11,29,30,42,43,50,51). The heart rate corresponding to the dot cut heart rate by a tangent on the lactate curve with an angle of 51°, represents the individual anaerobic threshold (IAT).



Figures 3 and 4. Judo test of case numbers 8 and 1. On the graphics, the heart rate (in pulsations per minute) is related to the phase of the test (with the number of times that has to be repeated in each of them).

Determination of the Anaerobic Threshold. On both tests (laboratory and field), we determined each subject's IAT using Keul's methodology (11,29,30,42,43,50,51). This author considers that the workload, the $\dot{V}O_2$ or the treadmill velocity corresponding to the point cut by a tangent on the lactate curve with an angle of 51° represents the IAT of the subject.

Statistical Analyses

The statistical analyses were carried out using the SPSS 12.0 program for Windows, applying the Student *T*-test, and considering the minimum level of significance as $p \leq 0.05$. This procedure was used because it is considered valid to compare different performances of the same subjects (33). To verify whether the differences between the mean data of laboratory and field tests were statistically significant, and the data obtained to show the reproducibility of the field test, we carried out the statistical *t*-test, also known as Student's *t*-test.

Results

The anthropometrics values (age, weight, and height) of the subjects were 23.8 ± 3.1 years, 73.8 ± 14 kg, and 174.6 ± 6.2 cm. Table 1 shows the application of the statistical *t*-test to the means of the values obtained in the 2 tests: Laboratory and Field.

Results showed that the differences between the main data in both tests were not statistically patent in any of the parameters studied, except in the maximum concentration of lactic acid. Table 2 shows the results obtained in the reproducibility (reliability) study of the Field test:

There were almost no differences between the data obtained in the first and the second field tests (7 days later), both were performed under the same conditions.

Figures 1 and 2 show the IAT results of the subject number 8 in the laboratory test (Figure 1) and in the field test (Figure 2) obtained with Keul's methodology (11,29,30,42,43,50,51). The HR frequency correspondent to the point cut by the tangent on the lactate curve with a 51° angulation represents the IAT.

Figures 3 and 4 compile judo tests of subjects 8 and 1. The graphic line represents the relationship between HR and number of repetitions of the specific technical skill.

Discussion

This research project has developed a specific judo field test (Santos test) that shows the physiological demands of judo combat. It is performed in the tatami (competition floor) with the help of a second judoka, both dressed in the judogui (competition clothes). The subject under evaluation had to perform a series of specific technical skills. The intermittency of effort in judo combat was perfectly considered through the protocol of the test, which had a work pause of 40–15 seconds. Finally, the aerobic–anaerobic transition zone, a key parameter to improve aerobic power and capacity, can also be determined through this test.

Several judo physiological parameters have been obtained through laboratory and field tests. In the laboratory test, our judoka population achieved $\dot{V}O_2$max values of 58.3 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ (see Table 1). The existing literature (8,9,19,20,44,48) shows values of 59.2, 53.2, 59, and 58.5 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ in high-level judokas. These results confirm that our subjects have $\dot{V}O_2$max levels similar to those of the elite. Furthermore, there were no significant differences between laboratory and field tests in $\dot{V}O_2$max (see Table 1).

On the other hand, our group of judokas showed a mean maximum HR of 198.2 $b{\cdot}min^{-1}$ in the laboratory test (see Table 1). Thomas et al. (48) recorded a maximum value of 191 $b{\cdot}min^{-1}$ at the end of a treadmill running test in judokas of the Canadian men's senior national team. In the field test, a maximum value of 199.7 $b{\cdot}min^{-1}$ was recorded (see Table 1), similar to the values obtained by previous researchers. Sanchis et al. (35) recorded a mean HR of 198 b·min^{-1} in a competition among regional-level judokas.

We obtained analogue values in our research project, because there were no significant differences between the mean HRmax data obtained in the laboratory and in the field test, which allows us to affirm that, in both, cases the judokas effort was maximal.

Regarding the highest values of lactic acid, the mean obtained was 14.6 mmol·L^{-1} in the laboratory test (see Table 1). Thomas et al. (48) recorded a mean lactate value of 15.2 mmol·L^{-1} in Canadian judokas in a laboratory treadmill test. When the tests were carried out on the tatami, the values that appeared ranged from 9.18 to 17.9 mmol·L^{-1} (18,27,35,40). In our field tests, we obtained a mean value of 17.3 mmol·L^{-1}. At maximal efforts, we found higher levels of lactic acid in the field test than in the laboratory test. This is possible because of the greater muscular involvement required in the field test. Judo combat requires the implication of a greater number of muscles than running does. In a race, the main muscular groups involved are the leg muscles, whereas judo requires the collaboration of almost every muscle of the body. Hence, more muscular groups involved could mean higher production of lactic acid. Therefore, there were statistical differences between the results obtained in the laboratory test and the ones obtained in the field test (see Table 1).

The absence of significant differences in these 2 parameters ($\dot{V}O_2$max and HRmax), key elements in any effort test, allows us to affirm that the judokas have carried out a maximum effort performance on the laboratory and the field tests. Therefore, the HR obtained from the athletes at the end of both tests may be considered their HRmax.

Usually, judokas undergoing laboratory tests (44) manifest their IAT: a 4 mmol·L^{-1} lactate concentration running between 9 and 13 km·h^{-1} (depending on the physical condition of the athlete). Our mean data were 170.3 b·min^{-1}, which is equivalent to 85.9% of HRmax (Table 1). We do not know of any published study in international journals that has attempted to determine, outside the laboratory, the individual anaerobic level in the sport of judo. In our field test, all judokas manifested their IAT between 11 and 15 repetitions (depending on the physical condition of the subject), with an HR of 169.7 b·min^{-1}, which is equivalent to 85.0% of HRmax (Table 1). Therefore, no significant differences were observed between the values obtained in the laboratory and in the field test (see Table 1).

Regarding the cardiac response to a progressive effort, our field test also fulfills the requirement of Conconi (a break-off in the ascendant regularity of effort means the beginning of the aerobic–anaerobic transition zone of the subject under assessment) (15). Therefore, a coach will be able to determine the specific and individual aerobic–anaerobic transition zone of his judokas applying our field test and using a heart-rate meter (a simple and noninvasive method). Moreover, our test can be considered specific and individual because (a) It is based on the use of the specific technical skills of the judoka. (b) Effort and pause times match those indicated by previous researchers (20,25). (c) Data obtained in our study are similar to data obtained by previous researchers (9,18,19,27,35,37,45,46,48). (d) Laboratory data and field test data are similar (Table 1). (e) The specific test follows the reliability principle (Table 2).

Regarding the protocol used in the investigation, we want to emphasize that the test cannot begin until the judoka's HR is lower than 80–85 b·min^{-1}. Sometimes, evaluation context raises the HR to more than a 100 b·min^{-1}, which causes error data to be registered. At the end of each 40-second phase of effort, the HR of the judoka must be registered. Therefore, at the end of the test, the coach will have a number of records that will reflect an upward curve. According to Conconi et al. (15), a break-off in the ascendant regularity of effort means the beginning of the aerobic–anaerobic transition zone of the subject under assessment. This way, a coach has objective information (HR) to develop aerobic and/or anaerobic specific training protocols, to add to the technical/tactical work in judo.

In addition, after each 40-second phase of effort, during the short phase of pause (15 seconds), the lactic acid concentration can be assessed taking of a small arterialized blood sample from the earlobe. There is plenty of time to proceed successfully, and the test will go on without any disturbance. The lactic acid data will be registered next to the correspondent HR data. This way, the coach will have more objective data to prescribe specific and individual training tasks to improve the judoka's performance.

Another important element is to let the judoka under assessment continue performing the test until he reaches his individual limits. The aerobic–anaerobic transition zone will show the point before the subject reaches his maximum capacity, but if we let the judoka keep on performing the specific technical skill, we could see how the tiredness affects the quality of his technical actions and his capacity to confront suffering. This is very important in judo competition, because all combats have an emotional and affective load. Repeating the test along the training process will allow the coach to compare all this information and improve the judoka's performance.

We would like to emphasize the fact that the judo athlete under assessment must perform all the technical actions with the highest technical quality. He should try to throw his opponent on the floor, as in competition. This is a specific test for judo, and the subject must do judo. This way, the data obtained will be specific, individual, and reliable. Furthermore, our test has been designed to set several physiological parameters of the judoka's performance, so it must be used with active judo athlete competitors. It has been developed to be tested on men judo athletes belonging to any of the weight categories that the judo international federation certifies as official. It can be applied to all kinds of judokas, not just high-level ones. At the same time, the test can be used at any stage of the training program of the judo athlete. Moreover, it will help coaches evaluate the judoka's physical condition development to maintain or modify training protocols. The aerobic–anaerobic transition zone is one of the most important parameters of judo competition, and its assessment can benefit any sportsman. The overall information will help the coach find out if the workout done by the athletes is yielding the desired results.

In light of all the ideas that have emerged in the text, we can draw the following conclusions: (a) The $\dot{V}O_2$max of our judokas is very close to 60 $ml \cdot kg^{-1} \cdot min^{-1}$ (58.3 in the laboratory test and 59.8 in the field test). These data indicate that this sporting discipline, at the level of performance of these athletes, requires a significant aerobic capacity. (b) The HR values reached very high values (laboratory and field results), which indicates that the subjects performed a maximum effort during both tests. (c) The HR and the concentration of lactic acid in IAT, $\dot{V}O_2$max, and HRmax show no significant differences between the field test and the one carried out in standard conditions in the laboratory. These data, the specificity of the technical actions, and the length of the effort-pause stages suggest that the protocol developed can be used in the evaluation of the physical condition of judokas and in the selection of training tasks for the sport of judo. (d) The data obtained allow coaches to work with just one physiological variable, the HR, to control the intensity of an exercise. It does not require costly and sophisticated technology or invasive methodologies. Therefore, it could be used by coaches and/or clubs with limited resources.

In addition, we want to highlight the following points: (a) This study is the first step to validate a specific test to evaluate and control specific bioenergetic training in judo. We are aware that it is necessary to evaluate a population greater than the one used in the present study. Nevertheless, a comparison of the data obtained in the laboratory test (validated and recognized internationally) and obtained in our field test allows us to affirm that we are going in the right direction. (b) Our specific test collects the most important variables involved in competition and, at the same time, shows the different relationships that exist among them during combat. Therefore, it represents the reality of judo competition.

Practical Applications

Our field test allows coaches to design training protocols toward the improvement of the aerobic and anaerobic systems of their judokas. It also allows the mixture of technical–tactical and physical aspects of the training process. Our test is carried out on the tatami (where the judo combat takes place), and it does not require expensive equipment or expert physiological knowledge. Therefore, this tool can help judokas improve their performance in competition.

Our research project is important for daily training. Based on the results of the test, coaches can select the correct tasks to achieve their goals. Parameters such as intensity, HR, lactic acid concentration, number of repetition…. can be used for training control and assessment. For example, if the coach knows when a judoka reaches his aerobic–anaerobic transition zone (using the HR, the lactic acid concentration of the test, and the number of repetitions that the athletes must perform in a certain phase), he will be able to control de intensity of the workout just by tracking the number of repetitions performed by the judoka in an exercise. Moreover, the coach will be able to control the effects of different training periods through this simple procedure, and decide what to do next, but scientifically based.

If a coach wants to use this specific test, he or she must follow its phases and use these resources: 2 judo athletes dressed on their judogui (one to be evaluated and the other one to collaborate on the test), a judo tatami, a data record table with the sequence of special techniques of the judoka to asses (technical action in the first phase, second phase, third phase, etc.), a chronometer, an HR monitor, and a section to record the HR.

Acknowledgments

The authors want to express their sincere acknowledgments to the masters and judokas of Takeda Gimnasium in Oviedo (Asturias, Spain) and the excellent professional team of Exercise Physiology of Hospital Universitario Central of Asturias (Spain) that made this study possible. This investigation was awarded with a national prize by the University of Oviedo (Asturias, Spain) in 2005.

References

1. American College of Sports Medicine. *Guidelines for Exercise Testing and Prescription.* (6th ed.). Baltimore, MD: Lippincott, Williams, & Wilkins, 2000.
2. Amorim, AR. Judo na adolescencia: Capacidade aeróbia e anaeróbia composiçao corporal e treinamento. Monografia Bacharelado em Educaçao Física, Deparmento de Educaçao Física do Instituto de Biocencias da UNSEP-Campus Rio Claro, 1995.
3. Amorim, AR, Drigo, AJ, and Kokubun, E. Treinamento intermitente no judo e lactato sangüíneo. XIX Simposio Internacional de Ciencias do Esporte-Saúde e Desempehno. CELASFISCS, Sao Paulo. Anais. Sao Caetano do Sul, 1994.
4. Beneke, DJ, Hutler, M, Von Duvillard, SP, Sellens, M, and Leithauser, RM. Effect of test interruptions on blood lactate during constant workload testing. *Med Sci Sports Exerc* 35: 1626–1630, 2002.
5. Bracht, V, Moreira, N, and Umeda, O. Efeito de lutas sucessivas sobre o nivel de ácido láctico sanguíneo de judocas. *Rev Educ̨ Física* 6: 25–28, 1986.
6. Branco, JC. A observaçao no judo: Recolha efectuada nos campeonatos nacionais de 1979 (por categoría de peso). *Ludens* 4: 30–52, 1979.
7. Brown, C and Mcmurray, G. 1996 Olympic Judo statistics–Technique utilization and effectiveness. Available at: http://www.engr.orst.edu/-odoms/statistics.htm. 1997. Accessed July 26, 2004.
8. Callister, R, Callister, RJ, Fleck, J, and Dudley, GA. Physiological and performance responses to overtraining in elite judo athletes. *Med Sci Sports Exerc* 6: 816–824, 1990.
9. Callister, R, Callister, RJ, Staron, RS, Fleck, SJ, Tesch, P, and Dudley, GA. Physiological characteristics of elite judo athletes. *Int J Sport Med* 2: 196–203, 1991.

10. Castarlenas, JL and Planas, A. Estudio de la estructura temporal del combate de judo. *Apunts–Educación Física y Deportes* 47: 81–86, 1997.
11. Cavazani, RN. Lactato antes e após sucessivos combates de Judo. Monografia (Bacharelado em Educaçao Física), Departamento de Educaçao Física do Instituto de Biociencias da UNSEP–Campus Rio Claro, 1991.
12. Chicharro, JL, Legido, JC, Huertas, M, et al. Determinación del umbral ventilatorio mediante la frecuencia respiratoria en niños entrenados. Comunicación. I Congreso de la Sociedad Española de Medicina de la Educación Física y el Deporte. Barcelona, 1990.
13. Chicharro, JL, Pérez, M, Vaquero, AF, Lucía, A, and Legido, JC. Lactic threshold vs. ventilatory threshold during a ramp test on a cycle ergometer. *J Sport Med Phys Fitness* 37: 117–121, 1997.
14. Coen, B, Urhausen, A, and Kindermann, W. Individual anaerobic threshold: Methodological aspects of its assessment in running. *Int J Sports Med* 22: 8–16, 2001.
15. Conconi, F, Grazzi, G, Casona, I, Guglielmini, C, Borsetto, C, Ballarin, E, and Mazzoni, G. The Conconi Test: Methodology after 12 years of application. *Int J Sports Med* 17: 509–519, 1996.
16. Dascombe, BJ, Reaburn, PRJ, Sirotic, AC, and Coutts, AJ. The reliability of the i-STAT clinical portable analyser. *J Sci Med Sport* 10: 135–140, 2007.
17. Degoutte, F, Jouanel, P, and Filaire, E. Energy demands during a judo match and recovery. *Br J Sports Med* 3: 245–249, 2003.
18. Drigo, AJ, Martins, CJ, Marineli, EJ, Mathias, R, Amorim, AR, and Kokubun, E. Lutas de projeçao e de solo no judo: Estudo pelo lactáto sanguíneo. V Simpósio Paulista de Educaçao Física–Edcuaçao Física: que porfissao é essa? Sao Paulo, Dpto. Educaçao Física, IB, UNSEP/Río Claro 128, 1995.
19. Ebine, K, Yoneda, I, Hase, H, Aihara, K, Aihara, M, Akaike, M, Ishida, H, Nishimoto, K, Nombra, M, Tsuda, H, and Tsuyuki, K. Physiological characteristics of exercise and findings of laboratory tests in Japanese elite judo athletes. *Méd Sport* 65: 2, 1991.
20. Favre-Juvin, A, Majean, H, Gallita, L, Callec, C, and Eterradossi, J. Approche physiologique du Judo. *Sport Méd Actual* 40: 5–10, 1989.
21. Franchini, E. Judo. *Desempenho Competitivo.* Tamboré (Brasil): Manole Ltda., 2001.
22. Franchini, E, Takito, MY, Lima, JRP, Haddad, S, Kiss, MAPDM, Regazzini, M, and Böhme, MTS. Características fisiológicas em testes laboratoriais e desposta da concetraçao de lactato sangüíneo em 3 luttas em judocas das classes Juvenil A, Junior y Senior. *Rev Paul Educ Física* 1: 5–16, 1998.
23. Franklin, BA, Whaley, MH, and Howley, ET. *ACSM'S Guidelines for Exercise Testing and Prescription.* (6th ed.). Baltimore, MD: Lippincott, Williams, & Wilkins, 2000.
24. Gibbons, RA, Balady, GJ, and Beasely, JW. ACC/AHA guidelines for exercise testing. *J Am Coll Cardiol* 30: 260–315, 1997.
25. Gorostiaga, EM. Costo energético del combate de Judo. *Apunts* 25: 135–139, 1998.
26. Gullstrand, L, Sjödin, B, and Svedenhag, YJ. Blood sampling during continues running and 30-second intervals on a treadmill. Effects on the lactate threshold results. *Scand J Med Sci Sports* 4: 239–242, 1994.
27. Heinisch, HD. L'Analisi dell'allenamento e della gara nel Judo. *Riv Cult Sport* 37: 53–62, 1997.
28. Idarreta, J. El entrenamiento de la resistencia específica a través del randori. En: VVAA. El Judo y las ciencias de la educación física y el deporte. Vitoria Gasteiz, Spain: SHEE-IVEF, 1997. pp. 149–156.
29. Keul, J, Simon, G, Berg, A, Dickhuth, HH, and Goertler, I. Bestimmung der individuellen anaeroben schwelle zur leistungsbewertung und trainingsgestaltung. *Dtsch Z Sportmed* 30: 212–218, 1979.
30. López Chicharro, J, Aznar, S, Fernández, A, López, LM, Lucía, A, and Pérez, M. Transición aeróbica-anaeróbica. Concepto, metodología de determinación y aplicaciones. Madrid, Spain: Master Line & Prodigio S.L, 2004.
31. Majean, H and Galliat, ML. Étude de l'acide lactique sanguine chez le judoka en function des méthodes d'entrainement. *Médec Spor* 60: 194–197, 1986.
32. Monteiro, LF. Estructura e custo energético do combate de Judo. IV Congreso de Educaçao Física e Ciencias do Desporto dos Países de Língua Portuguesa. Universidade de Coimbra, 1995.
33. Montoliu, MA, González, V, Rodríguez, B, and Palenciano, L. A comparison between laddermill and treadmill maximal oxygen consumption. *Eur J Appl Physiol* 76: 561–565, 1997.
34. Pulkkinen, WJ. *The Sport Science of Elite Judo Athletes. A Review and Application for Training.* Toronto, Canada: Hatasitha Enterprises, 2001.
35. Sanchis, C, Suay, F, Salvador, A, Llorca J, and Moro, M. Una experiencia en la valoración fisiológica de la competición en Judo. *Apunts* XVIII: 51–58, 1991.
36. Santos, L, Prieto, JA, and González, V. Descripción de diversos test para la valoración de la condición física en judo. *Rev Artes Marc Asiât* 3: 46–59, 2008.
37. Sbriccoli, P, Bazzucchi, I, Di Mario, A, Marzattinocci, G, and Felici, F. Assessment of maximal cardiorespiratory performance and muscle power in the italian olympic judoka. *J Strength Cond Res* 21: 738–744, 2007.
38. Schmidt, RJ, Housh, TI, and Hughes, RA. Metabolic responses to kendo. *J Sports Med* 25: 202–206, 1985.
39. Serrano, MA, Salvador, A, González-Bono, E, Sanchis, C, and Suay, F. Relationships between recall of perceived exertion and blood lactate concentration in a Judo competition. *Percept Motor Skills* 92: 1139–1148, 2001.
40. Sikorski, W, Mickiewicz, G, Majle, B, and Laksa, C. Structure of the contest and work capacity of the judoist. Proceedings of the International Congress on Judo Contemporary Problems of Training and Judo Contest. Spala, Poland 58–65, 1987.
41. Silva, M. Caracterizaçao do esforço em modalidades desportivas mensuráveis e nao mensuráveis: o judo como caso ejemplar. *Treino Desportivo* 10: 36–46, 1988.
42. Stegmann, H and Kindermann, W. Comparison of prolonged exercise tests at the individual anaerobic threshold and the fixed anaerobic threshold of 4 mmol/l lactate. *Int J Sports Med* 3: 105–110, 1982.
43. Stegmann, H, Kindermann, W, and Schnabel, A. Lactate kinetics and individual anaerobic threshold. *Int J Sports Med* 2: 160–165, 1981.
44. Sterkowicz, S. The special judo fitness test. *Antropomotoryka* 12–13: 29–44, 1995.
45. Sterkowicz, S and Maslej, P. An evaluation of the technical and tactical aspects of judo matches at the senior level, International Judo Coaches Alliance Site. Available at: http://www.judoamerica.com/ijca/sterkowizc/index.html, 1999. Accessed June 14, 2004.
46. Sterkowicz, S, Uchowicz, A, and Kubica, R. Levels of anaerobic and aerobic capacity indices and results for the special fitness test in judo competitors. Available at: www.judoinfo.com. 1998. Accessed October 26, 2004.
47. Taylor, A and Brassard, L. A physiological profile of the Canadian Judo Team. *J Sports Med* 21: 160–164, 1981.
48. Thomas, S, Cox, MH, Legal, YM, Verde, TJ, and Smith, HK. Physiological profiles of the Canadian national Judo team. *Can J Sport Sci* 3: 142–147, 1989.
49. Tumilty, DMcA, Hahn, AG, and Telford, RD. A physiological profile of well-trained male judo players. In: *Procedings of the VIII Commonwealth and International Conference on Sport, Physical Education, Dance, Recreation and Health.* Watkins, J, Reilly, T, and Burwitz, L, eds. London, United Kingdom: E & F.N. Spon 1986, pp. 3–10.

50. Urhausen, A, Caen, B, Weiler, B, and Kindermann, W. Individual anaerobic threshold and maximum lactate steady state. *Int J Sports Med* 14: 134–139, 1993.

51. Urhausen, A, Weiler, B, Caen, B, and Kindermann, W. Plasma catecholamines during endurance exercise of different intensities as related to the individual anaerobic threshold. *Eur J Appl Physiol* 69: 16–20, 1994.

52. Verkhoshansky, Y. Teoría y Metodología del entrenamiento deportivo. Barcelona, Spain: Paidotribo, 2002.

53. Wasserman, K and Mcllroy, MB. Detecting the threshold of anaerobic metabolism in cardiac patients during exercise. *Am M Cardiol* 14: 844–852, 1964.

54. Wasserman, K, Whipp, BJ, Koyal, SN, and Beaver, WL. Anaerobic threshold and respiratory gas exchanged during exercise. *J Appl Physiol* 35: 236–243, 1973.