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Highlighted Article

Monitoring Workload and Performance Response to Taekwondo Training

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Abstract: This study compared the association between Foster's and Banister's TRIMP methods for quantifying internal training load and training stimuli responses. *Methods*: A group of twenty-two Taekwondo competitors were divided by gender and level of expertise. The athletes practiced three different types of exercises to develop the following skills: a) speed, b) power, and c) aerobic power. *Results:* A significant correlation was obtained between the Foster's and Banister's TRIMP methods for developing aerobic capacity (r = 0.60, p = 0.004) and power (r = 0.52, p = 0.014). No significant correlation was suggested between training methods and speed training (r = 0.20, p = 0.377). *Conclusion:* Lactate and heart rate responses to different types of exercises suggested the need for aerobic and anaerobic-based training sessions. The use of rating of perceived exertion scale-based measurements to monitor workload is recommended for Taekwondo competitors.

Key Words: Foster's method; Banister's TRIMP; lactate, heart rate; speed; aerobic power; Taekwondo

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Introduction

Taekwondo is an Olympic sport practiced by people of all ages from more than 206 countries worldwide. It is an individual combat sport in which one athlete fights against an opponent of the same weight, gender, and category, usually by a direct elimination system [1, 2].

In Taekwondo, the athlete's goal is to strike the opponent's torso and head with kicks and punches in the allowed target areas to accumulate points. Thus, technical execution, tactical moves, high power, and agility are required [3]. In a typical Taekwondo tournament, athletes fight in three-round bouts with each round lasting two minutes, and there are usually five bouts per day. Finally, physical conditioning objectives are focused on improving endurance, speed, and power [1, 2, 4, 5].

Various components are taken into account in order for training to achieve sporting success. For instance, training control and athlete's response to training stimulus are crucial elements to pursuing physiological adaptations [6]. Thus, analyzing gender and sports experience is essential to understanding the physiological responses to stimuli and evaluating the different load control methodologies during Taekwondo training.

A person's heart rate (HR) response to exercise has been considered a useful tool for monitoring the internal training load (TL) in athletes [7]. The physiological rationale for using this technique is supported by the linear association between maximal work capacity (determined by a percentage of the maximal aerobic power, %VO2max) and the maximal HR (HRmax) [8] and is considered advantageous, because it is non-invasive, inexpensive, and easy to measure.

Training load quantification in sports has drawn the attention of researchers in sports medicine and exercise sciences. This information is mandatory The observed responses supported the importance of having adequate physical conditioning to meet the requirements for Taekwondo competition through both aerobic and anaerobic exercises to optimize athletic performance and avoid impairing an athlete's health [6]. Lactate response has been used for monitoring training load and effort during exercise [9]. In Taekwondo, lactate concentrations are related to the intensity and physical effort required to meet the anabolic demands during competition. Blood lactate measurement is practical and simple and only requires a single fingertip or earlobe blood test, which is analyzed easily on a portable device. Lactate measurement for training load control has been described in academic literature [10].

Physiological stress is also determined by recording an individual's perceived exertion and multiplying this figure by exercise endurance [11]. This method suggested by Foster et al. (2001) has been extensively used in sports such as basketball, Karate, soccer, cycling, water polo, and diving [12-17].

Another measurement approach for quantifying training load is named Training Impulse or TRIMP (TRaining IMPulse), based on HR measurements. Under this technique, minutes are multiplied by a specific intensity factor for both men and women [18]. This method was used as criteria to validate Foster's method in several athletic populations [13, 16, 17]. Edwards (1993) [19] and Lucia, Hoyos, Carvajal, and Chicharro (1999) [20] developed other ways based on HR measurements.

The use of session rating of perceived exertion (RPE) and HR measurement-based methods such as Banister's TRIMP and Edwards' Training Load in Taekwondo have shown concurrent and construct validity and equivalency for determining adolescent workload [21-23]. Nonetheless, these training load control methods have been under continuous scientific scrutiny to determine their usefulness and appropriateness in different sports and populations.

On the other hand, there is a lack of studies regarding monitoring progress of goals in Taekwondo adult athletes. The main purpose of this study was to analyze the association between Foster's and Banister's TRIMP methods for quantifying internal TL and comparing training stimuli responses between beginners and advanced Taekwondo adult competitors. A secondary aim was to verify the method's convergence as reported before [21, 23] in an adult competitor sample by considering their sport backgrounds.

Methods

Experimental Approach

This validation study investigated the convergence of Foster's TL method to quantify internal TL in adult Taekwondo performers. The TL obtained by Foster's method was compared to Banister's TRIMP method for quantifying internal TL. In addition, participants lactate and HR responses were analyzed by gender and expertise levels.

Participants

Twenty-two Taekwondo participants, 17 men (mean age = 23.9 ± 6.9 years) and 5 women (mean age = 21.0 ± 2.1 years) participated in this study, all of whom were volunteers and members of two Taekwondo clubs in two different cities in the autonomous community of Toledo, Spain. The two clubs at different levels of training and competition experience (from white to black belts). For this reason, they were categorized as either beginners (mean experience = 0.28 ± 0.03 years of practice) or experienced performers (mean experience = 4.93 ± 5.20 years of practice).

Before beginning the study, all the participants were informed about the potential risks and benefits associated with their participation. Furthermore, they were fully trained on the research procedures and informed of their right to withdraw from the study at any time without penalty. Finally, those who agreed signed a written informed consent form meeting the principles of the Declaration of Helsinki [24].

Experimental Procedure

A familiarization period was provided to participants before they took part in the experimental phase. To achieve this, volunteers were required to rate various activities. Three different types of exercise trainings were designed to develop speed, power, and aerobic power based on the Foster method. Training data were collected over fourteen days.

During the first measurement session, participants were required to complete speed and power exercises. During the second measurement session, athletes were asked to complete aerobic power exercises. The practice sessions were intended to improve speed by resembling a Taekwondo match under coaching guidance. To do this, athletes were asked to kick a Taekwondo focus paddle pad every 10 seconds in four two-minute rounds with a one-minute break between rounds. Also, participants could attack or counterattack, participants executed between 1 and 4 kicks (from about 0.5 to 5 seconds). The person holding the focus pad moved freely and showed the mitt to the athlete depending on whether athletes were instructed to attack or counterattack. Participants were asked to give their maximum effort when performing each exercise.

For the activities intended to increase power, every subject performed a sequence of 45 jumps as well as a technical action involving kicking a mitt. Participants were encouraged to perform each sequence continuously at maximum effort, without any specific rhythm or preset time limit (every jump and technical execution lasted approximately 5 seconds). The first 15 attempts were squat jumps. Then, participants repeatedly performed two roundhouse kicks with the same foot. The next 15 jumps were counter-movement jumps and two roundhouse kicks alternating their feet. The last 15 jumps were Abalakov-type with a further execution of two roundhouse kicks simultaneously in the air [25].

The aerobic interval training consisted of four exercise sessions lasting 4-min each. Sessions were separated by a 4-min rest period. This regime allowed us to complete the sparring. Each bout consisted of a short duration high-intensity interval kicking exercise; for example 10:20 (a 10-s kicking exercise interspersed with a 20-s passive recovery.) Finally, during the warm-up, each athlete performed a kick, such as a roundhouse kick, repeatedly for 10-s at maximum effort. Verbal encouragements were provided to generate 90-95% of the athlete's maximal repeated kicks over the four bouts [21]. Fifteen minutes before starting the exercise, each participant performed a moderate jog and some stretching exercises. Every training session was performed in a Taekwondo gymnasium between 7:00 p.m. and 10:30 p.m. in a similar environment (19.97 ± 1.0 °C, 49.67 ± 4.04% relative humidity). To avoid dehydration, fluids were readily available to the athletes during all training sessions. In addition, instructions were given to the athletes to fast for a period of 3-4 hours before the training session and to fully hydrate before arriving at the exercise sessions rather that ingest stimulants.

Testing Procedures

Preliminary measurements for all participants included height, weight, body composition analysis (InBody230, Seoul, Korea), and jumping ability by three counter-movement jumps (CMJ) (OptoJump, Microgate, Italy). For the jumping exercises the best execution was recorded for further analysis. Training intensity during each exercise session was recorded every 5-second using an HR monitor (Suunto t3c, RECTA, Finland). Resting HR was measured following a 10-minute supine position. The HRmax was the highest HR value recorded for each athlete at the end of the exercise session. When training tasks included recovery periods, HR was recorded during both exercise and recovery. Finally, HR was measured 3-min following recovery.

Training Load Methods

For the Foster method, the 20-item scale obtained from the individual's rating of perceived exertion during the exercise session was used. This figure was then multiplied by the session duration. The Banister's TRIMP method (Haddad, Chaouachi, Castagna, et al., 2011), weighs the length of time using a weighting factor that applies the formula TD HRR $\cdot 0.64 \cdot e^{1,92 \cdot HRR}$ for men and TD HRR 0.64 $e^{1,67 \cdot HRR}$ for women, where TD is the effective training session duration expressed in minutes and HRR is heart rate reserve. HRR is determined by the following equation: ([HRTS-HRB] / [HRmax - HRB]), where HRTS is the average training session HR, and HRB is the HR measured at rest (baseline).

Lactate Measurement

Blood lactate concentration was analyzed with the Lactate Scout analyzer (SensLab GmbH, Leipzig, Germany). A baseline resting lactate sample was obtained 10 minutes before starting the workout. Sampling was then scheduled 3 minutes after the end of each of the three exercise tasks.

Statistical Analyses

Statistical analyses were performed using the IMB SPSS for Windows version 20 (IBM Corporation, New York, USA). The results are presented as means ± SD. The data normality was verified using the Shapiro-Wilk W test. The Pearson product-moment correlation coefficient was used to determine the convergent validity between Foster's TL and Banister's TRIMP. The meaningfulness of the correlation coefficients was evaluated using Hopkins' classification: ≤ 0.1, trivial; 0.1–0.3 small; 0.3–0.5, moderate; 0.5–0.7, large; 0.7–0.9, very large; 0.9, nearly perfect; and 1.0, perfect [26]. In addition, Lin's concordance correlation coefficient was used to assess reproducibility between Foster' TL and Banister's TRIMP [27]. Lin's strength of agreement (ρc) was considered poor (< 0.90), moderate (0.90 - 0.95), substantial (0.95 - 0.99), or almost perfect (> 0.99) [27, 28].

Analysis of variance (ANOVA) was computed to determine HR and lactate concentration differences according to gender and practical experience in response to the different tasks. Significance was set a priori at $p < 0.05$.

Results

Descriptive statistics according to training experience for age, weight, height, BMI, body fat percentage, waist/hip ratio and jump power are presented in Table 1.

Table 1. Characteristics of participants according to training experience (n = 22)

	Beginners (n = 7)	Advanced (n = 15)	p =
Age (years)	21.9 ± 2.3	24.1 ± 7.3	0.449
Height (cm)	173.43 ± 5.22	174.17 ± 7.35	0.815
Weight (kg)	70.43 ± 4.63	71.75 ± 8.32	0.702
BMI (kg/m^2)	23.44 ± 1.47	23.4 ± 2.2	0.918

Body fat (%)	18.98 ± 9.93	16.0 ± 7.2	0.438
Waist/hip ratio	0.82 ± 0.02	0.83 ± 0.03	0.894
Jump height (cm)	28.6 ± 6.6	33.2 ± 5.4	0.104
Basal HR (beats·min^{-1})	53.4 ± 10.3	55.0 ± 5.4	0.640

BMI: Body mass index. HR: Heart rate

The results of the ANOVA showed no significant interactions between gender and training experience. However, gender differences were found in body fat percentage ($p < 0.0001$) and jump performance ($p < 0.0001$), where men revealed a lower fat percentage (13.5 ± 4.8 %) and jumped higher (33.9 ± 4.6 cm) than women (28.9 ± 4.4 % and 24.3 ± 4.1 cm). No significant differences were observed for the main training experience effect. A significant Pearson correlation was found between Foster's and Banister's TRIMP methods for resistance training ($r = 0.60$, $p = 0.004$) and power training ($r = 0.52$, $p = 0.014$). No significant Pearson correlation was observed between the two methods with speed training ($r = 0.20$, $p = 0.377$). Lin's concordance coefficient between Foster's and Banister's TRIMP methods for resistance (Rc = 0.00, CI95 % = 0.00-0.01), speed (Rc = 0.00, CI95 % = -0.00-0.01), and power training (Rc = 0.01, CI95 % = 0.00-0.0) were low.

The HR responses during aerobic power training were different over time ($p < 0.0001$). There was a clear trend that showed increases during execution and decreases during periods of rest and recovery (Figure 1). Bonferroni post hoc analyses suggested differences between each of the four exercise and resting periods, as well as between the last measurements made three minutes following recovery. Women demonstrated different HR after recovery including the other measurements. During power training, a difference between each of the measurements was determined, and there was a significant increase and recovery in HR at the end of the practice.

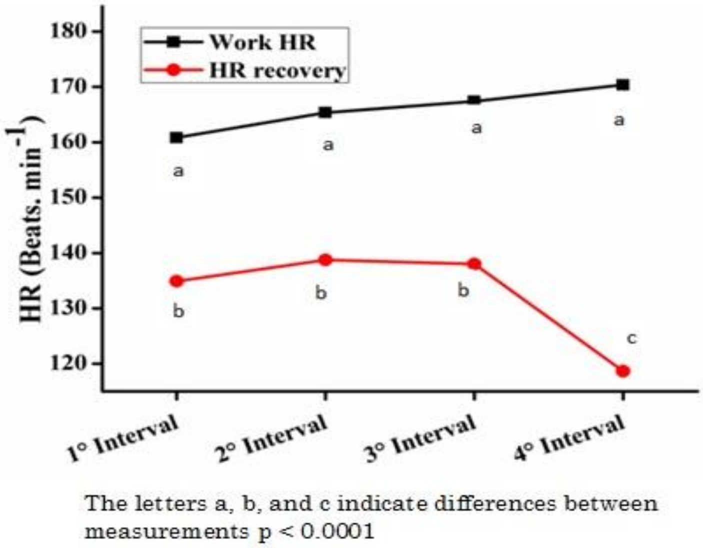

Figure 1. Heart rate response between measurements in endurance training

As shown in Figure 2, significant correlation between gender, experience, and measurements was obtained in speed training ($p < 0.011$). The two experience conditions increased their HR during exercise and achieved a significant recovery in the following 3-minute exercise. A significant difference was found between male and female advanced athletes in HR recovery ($p < 0.05$). Differences between the first round measurement and the other measurement periods and between the first resting period and the other measurement times ($p < 0.05$) were observed. A difference between the recovery measurement and all other measurements was determined in a male beginner group. In this group, an increased HR at the end of the fourth round was observed compared to the HR recorded during the second round, third round, and the resting period of the second round ($p < 0.05$). Women beginners also showed an elevated HR at the end of the fourth round compared to the measurements in the second and third round as well as the resting period of the second round ($p < 0.05$). Although no significant recovery was observed in the last measurement time, a significant interaction between genders was noted, both for advanced Taekwondo practitioners and beginners ($p < 0.05$). Beginner women showed lower HR responses from the second round measurement to the second round resting period ($p < 0.05$). A higher HR response was observed in beginner men compared to beginner women in the second round measurement ($p < 0.05$).

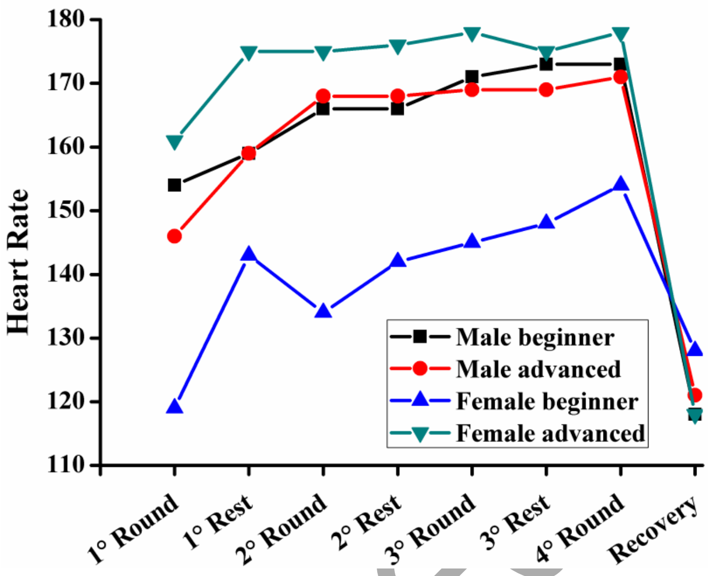

Figure 2. Heart rate changes between measurements in speed training

No significant interactions between gender and experience were found on the lactate response in training exercises ($p > 0.05$). Significant differences were noticed between the three different resistance measurements: time ($p < 0.001$), power ($p < 0.001$), and speed ($p < 0.001$). The initial lactate concentration in the aerobic power training was significantly lower (1.8 ± 0.5 mmol/l) than the immediate following exercise (11.4 ± 3.5 mmol/l) and after the 3-minute recovery period (10.4 ± 2.9 mmol/l) ($p < 0.05$). The initial lactate concentration in power training was significantly lower (1.7 ± 0.6 mmol/l) than the immediately following exercise (11.5 ± 3.3 mmol/l) and after the 3-minute recovery period (9.5 ± 2.9 mmol/l) ($p < 0.05$). The initial lactate concentration in the speed training was significantly lower (1.7 ± 0.6 mmol/l) than the immediate following exercise (10.0 ± 3.0 mmol/l) and after the 3-minute recovery period (8.0 ± 2.9 mmol/l) ($p < 0.05$).

Discussion

The aim of the study was to examine the association between Foster's and Banister's TRIMP methods for quantifying internal TL and to compare Taekwondo beginners and advanced athletes' physiological responses.

The main findings of this research suggested that Foster's and Banister's TRIMP methods have a low convergent validity. Consequently, the application of these methods in adult Taekwondo training should be carefully analyzed, and there should be a focus on selecting the most appropriate methodology for this population.

Previous research [21] has demonstrated moderate to high correlations (r = 0.55-0.90; $p < 0.001$) between Foster's and Banister's TRIMP methods for quantifying internal TL in junior Taekwondo athletes (13.1 ± 2.4 years). However, the findings of the present study suggested that TL quantification using the these methods might not be identical given the nature of Taekwondo training [1].

Furthermore, divergent validity between the two TL methods was found following replication of an aerobic training protocol previously used in Taekwondo athletes [23]. In the current study, Foster's and Banister's TRIMP methods for quantifying internal TL were moderately associated (r = 0.60, p = 0.004), which are in contrast to a previous study [23] in which the results showed r = 0.14 ($p > 0.05$).

The association between Foster's and Banister's TRIMP methods for quantifying internal TL reported in the present study has been found in aerobic exercise in the junior athletes participating in a training camp ($r = 0.60$, $p > 0.001$) [23]. Likewise, the relationship found in power training ($r = 0.52$, $p = 0.014$) was similar to that reported for training sessions using plyometric, speed, or intermittent exercises ($r = 0.32$, $p > 0.05$).

In the present study, Foster's and Banister's TRIMP methods for quantifying internal TL showed significant correlation coefficients. However, convergent validity between the two methods in terms of feasibility and accuracy require further research. Conclusions drawn from simple correlational analysis (e.g., Pearson) were insufficient to support the interchangeability of Foster's and Banister's methods for concordance between any two methods requires the application of other analytical techniques [29]. For instance, Lin's concordance coefficient correlation would be a necessary technique to estimate the association between the two measurement methods [27]. In addition to being reproducible, Lin's concordance combines the precision and accuracy to determine to what extent the observed data from both methods deviate from perfect agreement [29, 30]. Indeed, based on Lin's statistic (1989) [27], we observed poor concordance coefficients between Foster's and Banister's TRIMP as well as among TL methods for aerobic, speed, and power training.

Taekwondo training and competition is an intermittent sport in nature and requires high-intensity intervals interspersed with low-intensity intervals. The high-intensity intervals rely on anaerobic metabolism, and heart rate is dramatically increased during training and competition [9, 23, 31-33]. Since intermittent training may reduce the degree of correlation between perceived exertion (e.g., the Foster's method) and other methods (e.g., Banister's TRIMP) [13], this feature might also explain the weak convergence found between Foster's and Banister's TRIMP TL methods. In addition, Foster's method (i.e., RPE) has been suggested as a convenient and practical approach for monitoring TL when a combination of aerobic and anaerobic metabolism is present in other sports such as Taekwondo [31, 34, 35]. It is also important to consider other variables such as anxiety and stress that might negatively affect an individual's RPE during demanding scenarios such as training, especially during competition [36].

Further reliability studies on Foster's method during intermittent competition and training studies in Taekwondo are required. These studies are especially important when analyzing contact sports where the response to the same stimuli is likely to be different. For instance, kicking drills and combat strategy in Taekwondo are selected based on the opponents' characteristics; therefore, these drills are often modified during training and competition.

The participants of this study had similar physical characteristics to those previously reported. Participants in this study reported similar jump height values to those indicated in elite competitors, including men and women [36, 37]. Yet, this variable did not seem to differentiate between elite and a non-elite Taekwondo competitors. Adiposity, as determined by body fat percentage, ranges from 7-14% in men and 12-19% in women. These values were similar to those reported for Taekwondo male competitors (13.5 ± 4.8%), but were different from those of female competitors (28.9 ± 4.4%) [37-41].

A correlation between the participants' characteristics and those previously reported in other competitions was found in this study. In addition, similar training stimuli responses by sex and training experience were observed. This aspect supports the generalizability of the findings reported on TL methods. Physiological responses (i.e., HR and lactate) reported in this study were consistent with previous reports. For instance, adolescent Taekwondo men showed an increase in HR (63 ± 8 beats $\cdot$min^{-1} to 201 ± 6 beats$\cdot$min^{-1}) following an aerobic training regimen [23]. Acute changes in HR were also described following training drills similar to those used in this study (e.g., kicking a striking shield or combat simulations), where HR increased from the baseline to 148 ± 15 beats$\cdot$min^{-1} and 160 ± 17.4 beats$\cdot$min^{-1} [32]. Responses in HR during competition were also documented, changing from prior to the beginning of the bout (53 ± 3 beats$\cdot$min^{-1}), the beginning of the first round (175 ± 15 beats$\cdot$min^{-1}), and up to the end of a combat (199 ± 3 beats$\cdot$min^{-1}) [2, 9, 31, 33].

Post-exercise blood lactate increments following 220 s of physical exertion (baseline = 1.8 ± 0.6 mmol/l vs. post-exercise = 10.3 ± 2.5 mmol/l) [37] were similar in the present study (baseline = 1.7 ± 0.6 mmol/l versus. post-exercise = 11.4 ± 1.7 mmol/l). Lactate concentrations measured in Taekwondo competitors during official tournaments and simulation fights have shown high variability, ranging from 7.0 ± 1.5 mmol/l to 12.2 ± 4.6 mmol/l [2, 4, 9].

Evidence suggested that the blood lactate concentration is sensitive to changes in training intensity [42]. In this research, neither a mean increment in lactate values according to training modality was observed nor significant differences in participants' training experience. The observed responses supported the importance of having adequate physical conditioning to meet the requirements for Taekwondo competition through both aerobic and anaerobic exercises.

With regard to lactate levels, the use of HR and RPE to monitor TL looks appealing due to the fact that these techniques are non-invasive and reasonably inexpensive. The use of HR is widely accepted in endurance sports. However, its use is questionable in speed or power training and shows a lack of a significant cardio-respiratory component [6]. Therefore, the evidence supports the use of RPE-based measurements on TL control in Taekwondo.

Conclusions

Given the lack of convergent validity between Foster's and Banister's TRIMP TL methods, we consider that these two techniques should not be used interchangeably to quantify the TL in Taekwondo competitors.

It is inconvenient to use the TRIMP Banister to accurately quantify the training load in Taekwondo competitors. Taking into account the diversity of dynamic training and intermittent exercise characterized by the prevalence of anaerobic metabolism regardless of their experience, Banister TRIMP use is not recommended in this group of athletes. Monitoring the response to stimuli in athletes' training is a key factor to achieve the objectives pursued. Quantification of Taekwondo training is recommended by Foster's method, especially considering the necessity of having new studies to support its reliability in a variety of environments.

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