ARTIGO ORIGINAL

Relationship between vagal withdrawal and reactivation indices and aerobic capacity in taekwondo athletes

Relação entre a retirada e reativação vagal com a capacidade aeróbia em atletas de taekwondo

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Abstract – The aim of this study was to evaluate the relationship between vagal withdrawal and reactivation indices and maximal running velocity (Vmax) in taekwondo athletes. Eleven elite taekwondo athletes (seven men: 23.7±2.2 years, 72.4±7.0 kg, 178.8±7.5 cm, 51.9±2.9 $ml.kg^{-1}.min^{-1}$, and four women: 18.8±1.5 years, 61.8±1.8 kg, 168.0±4.4 cm, 41.6±2.4 $ml.kg^{-1}.min^{-1}$) performed a graded exercise test until exhaustion, with the last complete stage performed corresponding to Vmax. Heart rate variability (HRV) parameters were calculated at 1-minute intervals until 85% of maximum HR and plotted against time for the estimation of vagal withdrawal indices (τ, amplitude (A) and area under the curve (AUC)). Vagal reactivation indices were determined based on HR recovery during the first 60 s (HRR60s) and negative reciprocal of the slope of the regression line obtained during the first 30 s of HRR (T30). The vagal withdrawal parameters A and AUC were moderately and significantly correlated with Vmax (r = 0.61-0.71, $P < 0.05$), whereas τ presented a low correlation (r = 0.22-0.40, $P > 0.05$). T30 and HRR60s were also significantly correlated with Vmax (r = -0.77 and 0.64, $P < 0.05$, respectively). The present results showed that vagal withdrawal (A and AUC) and vagal reactivation (T30 and HRR60s) indices were significantly correlated with Vmax, suggesting that these indices can be used for the evaluation and monitoring of aerobic fitness in taekwondo athletes.

Key words: Exercise; Heart rate; Combat sports.

Resumo – *O objetivo deste estudo foi verificar em atletas de taekwondo a relação entre a retirada e reativação vagal com a velocidade aeróbia máxima (Vmax). Onze atletas de elite de taekwondo (sete homens: 23,7±2,2 anos, 72,4±7,0 kg, 178,8±7,5 cm, 51,9±2,9* $ml.kg^{-1}.min^{-1}$*; e quatro mulheres: 18,8±1,5 anos, 61,8±1,8 kg, 168,0±4,4 cm, 41,6±2,4* $ml.kg^{-1}.min^{-1}$*) realizaram um teste progressivo até exaustão, sendo a Vmax considerada o último estágio completo realizado. Os parâmetros da variabilidade da freqüência cardíaca (VFC) foram calculados a cada minuto do teste até o atingimento de 85% da FC máxima, e plotados contra o tempo para a estimativa dos indicadores de retirada vagal (τ, amplitude (A) e área sob a curva (ASC)). Os indicadores de reativação vagal foram determinados pela recuperação da FC nos primeiros 60 s (RFC60s) e recíproca negativa da reta de regressão linear obtida pela RFC dos primeiros 30 s (T30). Os parâmetros de retirada vagal A e ASC foram moderado e significativamente correlacionados à Vmax (r = 0,61-0,71,* $P < 0{,}05$*), enquanto o τ apresentou baixa correlação (r = 0,22-0,40,* $P > 0{,}05$*). O T30 e RFC60s apresentaram correlação significante com a Vmax (r = -0,77 e 0,64,* $P < 0{,}05$*, respectivamente). Os resultados do presente estudo mostraram que os indicadores da retirada (A e ASC) e reativação vagal (T30 e RFC60s) foram significativamente correlacionados com a Vmax, sugerindo que esses indicadores poderiam ser utilizados na avaliação aeróbia e monitoramento do treinamento de atletas de taekwondo.*

Palavras-chave: *Exercício; Freqüência cardíaca; Esportes de combate.*

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INTRODUCTION

The high blood lactate concentration (~10 mM) observed at the end of taekwondo fights indicates that anaerobic metabolism is important for energy supply[1,2]. In addition, aerobic metabolism also plays an important role in taekwondo performance. Markovic et al.[3] reported significantly higher aerobic capacity indices (i.e., ventilatory threshold) in athletes who won medals at World and European championships when compared to those who did not. In addition, Bouhlel et al.[1] reported that high level taekwondo athletes possess both high aerobic (VO_{2max} = 56.2 ml.kg^{-1}.min^{-1}) and anaerobic power (855 W in 7-s test). Therefore, anaerobic and aerobic fitness assessment should be included in the evaluation of taekwondo athletes.

Recently, vagal withdrawal during graded exercise tests[4,5] and its reactivation after maximal efforts[6-8] have been used as noninvasive indicators for the assessment of autonomic function[4,9]. Lewis et al.[4] found a strong relationship between the rate of reduction in vagal withdrawal (e.g., work rate associated with a 50% reduction in the high frequency spectral component of heart rate variability (HRV) during progressive exercise) and maximal aerobic power estimated during progressive exercise. Furthermore, Sugawara et al.[9] showed a significant correlation between the negative reciprocal of the regression slope obtained during the first 30 s of HR recovery (T30) after reaching VO_{2max}. To our knowledge, these relationships have not been tested in taekwondo athletes during field tests. Since these indices are considered to be sensitive to changes in training loads and fitness status of athletes and non-athletes[10-13], they might be used to monitor training-induced adaptations. However, for practical application to taekwondo and other sports, the adequacy of alternative and straightforward HRV indices should be tested (i.e., geometric and time domain indices).

Therefore, the aim of the present study was to evaluate the relationship between vagal withdrawal and reactivation indices estimated during and after a progressive Léger test, respectively, and maximal running velocity (Vmax) in taekwondo athletes. We hypothesized that both exercise and autonomic indices of recovery are correlated with Vmax obtained in a field running test. The confirmation of this hypothesis would support the use of autonomic and performance indices as correlation measures to monitor positive adaptations to training[14-15] and/or detrimental effects induced by overreaching[15] and overtraining[16].

METHODS

Participants

Eleven elite taekwondo athletes (seven men: 23.7 ± 2.2 years, 72.4 ± 7.0 kg, 178.8 ± 7.5 cm, 51.9 ± 2.9 ml.kg^{-1}.min^{-1}, and four women: 18.8 ± 1.5 years, 61.8 ± 1.8 kg, 168.0 ± 4.4 cm, 41.6 ± 2.4 ml.kg^{-1}.min^{-1}) participated in this investigation. The athletes had experience in international competitions (including Olympic Games, World Championships and South American Championships), had no orthopedic injury at the time of the investigation, and were not taking any medications that might influence the autonomic nervous system. All athletes provided voluntary written informed consent to participate in the study. The sample size was calculated assuming a minimum value for strong correlation (r = 0.80) between variables of interest, with β of 0.80 and α of 0.05. The estimated sample size required to accomplish this study was 9 athletes (Medcalc® v 9.2.1.0). The protocol and procedures employed were reviewed and approved by the institutional Ethics Committee on research involving humans of Universidade Estadual de Londrina (process No. 192/07).

Progressive Léger test

Prior to the test, the baseline HR of the subjects was recorded while they were resting in the standing position (2 min) (Polar® S810i, Polar Electro Oy, Kempele, Finland). Next, the subjects stretched and warmed-up at the first stage velocity of the progressive Léger test (1 min). The test started after the subject's HR had returned to baseline. The subjects ran back and forth over a 20-m course delimited by cones at an initial speed of 8.5 km.h^{-1}, with speed increments of 0.5 km.h^{-1} per minute, according to the pace dictated by a sound signal on an audio tape[17]. The subjects were strongly encouraged to keep pace with the signal as long as possible. The test was terminated when the subjects could no longer follow the pace (i.e., failure to reach the cones in synchrony with the audio signal on two consecutive laps). The last complete stage velocity (Vmax) was used to predict VO_{2max} using the equation proposed by Léger et al.[17]: VO_{2max} (ml.kg^{-1}.min^{-1}) = - 24.4 + 6.0 · Vmax (km.h^{-1}). After achieving peak velocity, all athletes cooled down for 1 min at a speed of 4.5 km.h^{-1}.

Analysis of heart rate variability

RR intervals were recorded during the 2-min resting period and throughout the progressive Léger test using a portable HR monitor (Polar® S810i, Polar Electro Oy). This device has been validated against a standard ECG by Gamelin et al.[18]. Signals were extracted (Polar Protrainer 4.0, Polar Electro) and RR intervals were manually edited so that artifacts and non-sinus beats could be replaced by interpolation from adjacent normal RR intervals.

Time domain analysis: RR intervals were analyzed to obtain the root mean square of differences between successive RR intervals (RMSSD).

Poincaré plot analysis: Each RR interval was plotted as a function of the previous RR interval in a scatterplot, and the standard deviation of instantaneous beat-to-beat variability of the data (SD1) was used for analysis (Figure 1).

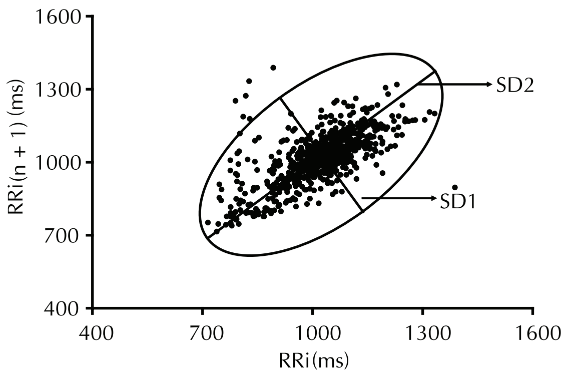

Figure 1. Example of a Poincaré plot showing the calculation of SD1 and SD2 from an ellipse fitted to the plot.

Vagal withdrawal indices

The RMSSD and SD1 data calculated for the 2-min resting period and each 1-min stage of the progressive Léger test were fitted to a first-order exponential decay equation (adapted from Lewis et al.[4]) (Figure 2A):

$$y = y_0 + Ae^{-x/\tau}$$

where y = RMSSD or SD1 (ms), A = amplitude (ms), x = time (s), and τ = time constant (s).

After fitting the SD1 and RMSSD data to a first-order exponential decay equation, the area under the curve (AUC) was estimated by integration (Microcal Origin 6.0 Northampton, USA) (Figure 2B).

To estimate the parasympathetic withdrawal indices (A, τ, AUC), the SD1 and RMSSD data were calculated until the stage corresponding to 85% of the maximum HR (HRmax) was achieved[4].

One female subject was excluded because of excessive movement artifacts on the RR intervals recorded. Therefore, the correlations between vagal withdrawal parameters and Vmax were calculated for 10 subjects.

Vagal reactivation indices

The vagal reactivation indices were assessed based on T30 and HR recovery (HRR) during the first 60 s (HRR60s). For the estimation of T30, the negative inverse of the slope of the linear regression fitted to the natural logarithm of HR during the 10^{th} to 40^{th} s of HRR (T30 = -1/slope)[19] was obtained. HRR60s was calculated as the absolute difference between the final HR observed at the end of exercise and the HR recorded 60 s later[7].

Statistical analysis

A Gaussian distribution of the data was confirmed by the Kolmogorov-Smirnov test (with Lilliefor correction). The Pearson product moment correlation coefficient was used to quantify the relationship between vagal withdrawal and reactivation indices and Vmax. The level of statistical significance was set at $P < 0.05$. All data analyses were performed using the Statistical Package for Social Sciences for Windows (SPSS), version 13.0. The results are expressed as means ± standard deviation (SD).

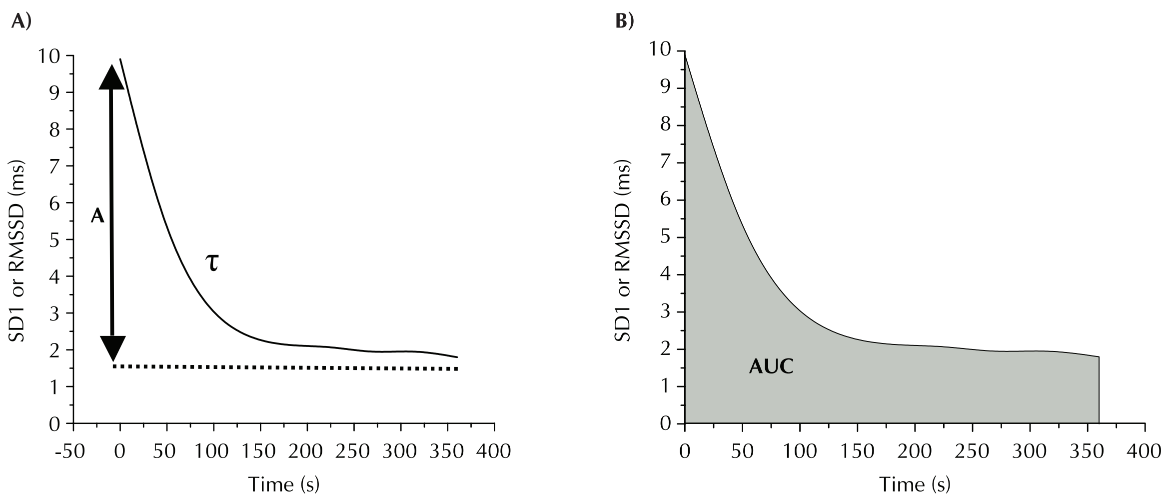

Figure 2. Estimation of amplitude (A), tau (τ) and area under the curve (AUC) during the progressive Léger test.

RESULTS

The athletes reached a Vmax of 12.1 ± 1.0 km.h^{-1} and VO_{2max} of 48.1 ± 5.8 ml.kg^{-1}.min^{-1}. The coefficients of determination (R^2) of the curve fit for SD1 and RMSSD and the A, τ, AUC estimates for the respective vagal index are shown in Tables 1 and 2, respectively.

Table 1. Coefficients of determination (R^2) of the curve fit for SD1 and A, τ, AUC estimates (n = 10).

SD1	R^2	A (ms)	τ (s)	AUC (ms.s)
Mean	0.99	39.55	37.04	2325
SD	0.00	33.38	5.70	1432

SD1: Standard deviation of instantaneous beat-to-beat variability of the data; R^2: coefficient of determination; A: amplitude; τ: tau; AUC: area under the curve.

Table 2. Coefficients of determination (R^2) of the curve fit for RMSSD and A, τ, AUC estimates (n = 10).

RMSSD	R^2	A (ms)	τ (s)	AUC (ms.s)
Mean	0.99	54.79	37.66	2941
SD	0.00	46.42	6.17	2016

RMSSD: Root mean square of differences between successive RR intervals; R^2: coefficient of determination; A: amplitude; τ: tau; AUC: area under the curve.

The correlations between A and AUC, obtained by fitting the SD1 data to a monoexponential decay equation, and Vmax were moderate (A vs. Vmax: r = 0.61, *P* = 0.08; AUC vs. Vmax: r = 0.70, *P* = 0.04). The τ showed a low correlation with Vmax (r = 0.40, *P* = 0.30), whereas A and AUC were strongly correlated with one another (r = 0.98, *P* < 0.001). Similar correlations were obtained for RMSSD (A vs. Vmax: r = 0.65, *P* = 0.06; AUC vs. Vmax: r = 0.71, *P* = 0.03; τ vs. Vmax: r = 0.22, *P* = 0.56; A vs. AUC: r = 0.99, *P* < 0.001).

The mean ± SD of the vagal reactivation indices assessed after the progressive Léger test were 429.2 ± 150.6 s for T30 and 29 ± 8 bpm for HRR60s. T30 and HRR60s showed a moderate and significant correlation with Vmax (T30 vs. Vmax: r = - 0.77, *P* < 0.01; HRR60s vs. Vmax: r = 0.64, *P* = 0.03) and a strong correlation with one another (T30 vs. HRR60s: r = - 0.81, *P* < 0.01).

DISCUSSION

The main findings of the present study were the significant moderate correlations between vagal withdrawal (A and AUC) and reactivation (T30 and HRR60s) indices, estimated during and after the progressive Léger test, respectively, and Vmax in taekwondo athletes.

In the present study, SD1 and RMSSD were determined during the progressive Léger test to evaluate the vagal withdrawal decay pattern. These two straightforward HRV indices were used since they are only minimally influenced by breathing frequency[20] and do not depend on data non-stationarity[21] during progressive exercise[22]. The R^2 values determined based on SD1 and RMSSD curve fitting (monoexponential decay equation) were similar, in agreement with the findings of Brennan et al.[23] who showed that SD1 and RMSSD indeed represent mathematically equivalent indices of short-term variability and vagal modulation ($RMSSD = \sqrt{2} \cdot SD1$).

The coefficients of determination found by fitting SD1 and RMSSD data to a monoexponential decay equation in taekwondo athletes were high (R^2 = 0.99) and higher than those reported by Lewis et al.[4] for healthy subjects when analyzing the high frequency spectral component (R^2 = 0.85 – 0.90). The high R^2 value observed in the present study might be attributed to the use of time-domain measures of vagal modulation that are less influenced by data non-stationarity[21,22]. Furthermore, the inclusion of elite athletes, who exhibit higher and more consistent levels of training-induced vagal modulation[10], may also explain the R^2 values. Nevertheless, the present results demonstrate the applicability and easy use of the monoexponential decay equation for describing vagal withdrawal during exercise, a parameter that can be used to monitor training and elite performance.

The vagal withdrawal indices calculated in the present study were τ, A and AUC, whereas Lewis et al.[4] estimated the rate of reduction (i.e., the work rate associated with a 50% reduction in vagal outflow during progressive exercise). In that study, the rate of reduction in vagal withdrawal showed a strong and significant correlation with maximal aerobic power estimated in the progressive test[4]. In the present study, τ showed a low correlation with Vmax (r = 0.40 and 0.22 for SD1 and RMSSD, respectively). These results suggest that τ of the vagal withdrawal decay is not a good predictor of running performance during the progressive Léger test in taekwondo athletes. On the other hand, A and AUC were moderately correlated with Vmax (r = 0.61 – 0.71). The correlation of A with Vmax is of interest since the A estimate takes into account resting HRV, which has been used as an aerobic adaptation index[24,25]. Moreover, a strong and significant correlation between A and AUC (r = 0.98 and 0.99 for SD1 and RMSSD, respectively, *P* < 0.001) was demonstrated and suggests that AUC can be used as an indicator of aerobic fitness in taekwondo athletes.

Since increased vagal outflow has been observed for the same absolute submaximal loads following intense and low-dose training[10,12], regular training may increase the AUC during a progressive exercise test. Indeed, we observed an increase in SD1 after short-term high-intensity training[11], suggesting that training can increase both AUC and Vmax. This possibility should be tested in future investigations for taekwondo athletes or athletes performing other sports. If the AUC is sensitive to training effects, this autonomic index can be used to monitor training adaptations[14] and, possibly, to assess overreaching and overtraining[16].

In the present study, the vagal reactivation indices (T30 and HRR60s) were significantly associated with one another (r = - 0.81, P < 0.01) and with aerobic capacity (Vmax) (r = - 0.77, P < 0.01; and r = 0.64, P = 0.03; respectively). These findings are in contrast to some reports[8,26], whereas others also reported significant associations of HRR60s and T30 with aerobic capacity[7,9,19,27]. In addition, vagal reactivation indices have been reported to be sensitive to exercise training[13,28] and to changes in training workload during the season[29]. Therefore, the present results suggest that vagal withdrawal and reactivation parameters can be used to evaluate and monitor overall aerobic fitness in elite taekwondo athletes.

This study was a cross-sectional investigation and determination of the effects of training on vagal withdrawal and reactivation indices is therefore essential to confirm the possible use of these variables for the evaluation of aerobic fitness in taekwondo athletes. Moreover, the reliability of the vagal withdrawal and reactivation indices estimated during and after a progressive exercise test in taekwondo athletes needs to be examined to increase the practical application of these measures. Finally, the exclusive use of female or male athletes in the study design may weaken the correlations found. However, similar conclusions regarding the relationship between parasympathetic withdrawal indices and Vmax in an intermittent field test were drawn in a previous study from our group involving only male handball players[5].

CONCLUSION

The present results showed that vagal withdrawal (A and AUC) and vagal reactivation (T30 and HRR60s) indices obtained during and after a progressive Léger test, respectively, were significantly correlated with maximal aerobic velocity (Vmax) in taekwondo athletes. Thus, these straightforward and simple vagal parameters might be potentially useful for the evaluation and monitoring of aerobic fitness in taekwondo athletes. Further longitudinal studies should be performed to determine the importance of these indices for athlete monitoring, particularly the identification of overtraining and/or overreaching.

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