Exercise domain profile through pulmonary gas exchange response during kendo practice by men

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A Study Design
B Data Collection
C Statistical Analysis
D Manuscript Preparation
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Abstract

Background & Study Aim: The metabolic rate demanded during the practice of kendo techniques has not been reported, despite of it importance to physical training program. This study aimed to characterize exercise intensity during kendo practice based on pulmonary gas exchange profiles.

Material & Methods: Nine skilled male athletes (29.7±7.8 years old, 174.9±9.1cm, 82.1±14.9kg body weight) underwent the following protocols: (1) body composition via DXA, (2) progressive treadmill test to assess $\dot{V}O_2$max, gas exchange threshold (GET) and respiratory compensation point (RCP), and (3) 11 types of warm-ups using kendo techniques and 31 types of kendo waza. The techniques were performed twice, with a 24h break in between. The $\dot{V}O_2$ value was obtained using K4b2 (COSMED®) technology, and heart rate (HR) was recorded by 420sd (Polar®) frequencimeter.

Results: The $\dot{V}O_2$ profile reached 84.7±13.5% $\dot{V}O_2$max and 85.3±17.2% $\dot{V}O_2$max at the end of warm-up and waza protocols, respectively. $\dot{V}CO_2$ showed the same profile: 83.5±9.40% and 81.1±13.7% $\dot{V}CO_2$max for warm-up and waza. However, HR (97.8±3.3% and 103.4±3.6% HRmax) and $\dot{V}_E$ (90.1±15.6 and 107.8±13.2% $\dot{V}_E$max) elicited values that were trunked to maximum rates at the end of warm-up and waza. The RER values at the end of warm-up (1.19±0.15) and waza (1.16±0.05) were greater than 1.1. All variables did not differ from their respective maximum rate values at the end of warm-up and waza (p≤0.05, ANOVA with Tukey as post-hoc).

Conclusions: Thus, $\dot{V}O_2$ and $\dot{V}CO_2$ profiles classified the kendo practice as a heavy domain exercise, while HR, E and RER classified it as a heavy-to-severe domain exercise.

Key words: martial arts • oxygen • during exercise • continuous heart rate monitoring • skill performance • exercise classification

Tutorial video: http://www.archbudo.com/text.php?ids=100502

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Introduction

Throughout the history of martial arts, changes in z *bujutsu* (the "martial art of war/combat" among other plausible translations) gave rise to the *budo* (the "martial art as a way" among other plausible translations) as a proclivity for the martial arts, which generated distinct modalities [1,2]. In this context, kendo, the specific combat techniques using the *shinai* (bamboo sword), was inserted. However, kendo is not just the art of skilled control of the *shinai* (or another type of sword, as *bokuto* (wooden sword) or *katana* (Japanese long sword), but also must approach the mind and spirit refinement, as well as, the *reigi* (politeness). The practice consists of striking blows against opponents while protected by the *bogu* (armour). There are four valid striking areas: *men* (head), *kote* (forearm), *do* (stomach) and *tsuki* (throat) [3]. After proper technique performance, exhibiting *ki-ken-tai* (energy, correct position of the sword and correct body position), the final movement is *zanshin* (physical and mental alertness against the opponent's counterattack) [4].

Exercise domain - a quality terminology (moderate, heavy and severe) for aerobic and anaerobic demand during exercise, generally based on the rate of $\dot{V}O_2$ response and acid-base regulation.

Pulmonary gas exchange - measurement of *oxygen uptake* ($\dot{V}O_2$) and *carbon dioxide* ($\dot{V}CO_2$) exchange, as well as *ventilation* ($\dot{V}_E$), in lung by a mouth apparatus connected with an automated breath-by-breath gas analyser system.

Physiological information - indices of aerobic demand ($\dot{V}O_2$), cardiocirculatory adjustments (HR) and acid-base regulation ($\dot{V}_E \cdot CO_2^{-1}$, $\dot{V}_E$, RER) during exercise.

Basically, the techniques are comprised of two types of movements: upper-limbs and whole-body. The horizontal whole-body movement (*suri-ashi*) is characterized by sliding the feet without crossing the legs (one foot in front of the other). The *suri-ashi* must be performed while the upper-limbs move the *shinai* in vertical or diagonal lines, the strikes, which has a powerful striking phase [4]. Thus, *suri-ashi* is not only applied to promote body displacement, but to maximize the power of *shinai* strike by using the energy extracted from the link between feet and floor.

Kendo is a martial art practiced by more than two million people in more than 100 countries [3,4]. There are many studies concerning kendo's motor learning and philosophical assumptions, but few that address physiological responses during its practice. Studies address physiological information in others combat modalities, such as boxing [5, 6], karate-do [7], pencak silat [8] and sumo [9]. In Smith's study [5] with British boxers (juniors and seniors) showing a $\dot{V}O_2$max of 63.8±4.8 (ml×kg^{-1}×min^{-1}), the physiological profile during the practice was characterized as a mixed metabolic demand (aerobic and anaerobic). Another study with boxers [6] was designed to compare the aerobic fitness of practitioners from different countries. The findings showed $\dot{V}O_2$max values of 54-61 (ml×kg^{-1}×min^{-1}) for Indian, 55.8 (ml×kg^{-1}×min^{-1}) for Greek, 56.6 (ml×kg^{-1}×min^{-1}) for Hungarian and 64.7 (ml×kg^{-1}×min^{-1}) for French boxers. Even in the aforementioned study, authors have concluded that boxing has short-time movement patterns, which require high intensity and intermittent metabolic (anaerobic) supply, and also requires high aerobic function to avoid fatigue and tolerate intermittent exercise bouts during the fight. Thus, boxing could be characterised as 70-80% anaerobic and 20-30% aerobic metabolic demand [10].

In other martial arts, such as karate-do, the aerobic fitness ($\dot{V}O_2$peak) of athletes range from 48.9 to 49.9 (ml×kg^{-1}×min^{-1}) [7], and $\dot{V}O_2$max presents a value of 52.1 (ml×kg^{-1}×min^{-1}) for pencak silat, which are very similar to the value ranges of other martial arts, such as 51.4 (ml×kg^{-1}×min^{-1}) for tae-kwon-do and 56.1 (ml×kg^{-1}×min^{-1}) for judo [8]. When the aerobic capacity was evaluated among athletes with high whole-body weight and fat content (24%), such as sumo wrestlers, $\dot{V}O_2$max attains lower values (31.1 ml×kg^{-1}×min^{-1}) in comparison to the values of the athletes in the aforementioned martial arts, including reference values for practitioners of modalities that have not yet been described, such as wrestling (55.7 ml×kg^{-1}×min^{-1}) and kendo (54.9 ml×kg^{-1}×min^{-1}) [9].

Characterization of exercise intensity and metabolic demand during martial arts practice could help coaches plan training routines better, in order to match the sport's specificity [5,6]. Measures from practitioner's $\dot{V}O_2$max, physiological thresholds and heart rate (HR) and blood lactate concentration records provide insights into the aerobic and anaerobic requirements for daily practice of one combat sport modality, and decision-making strategies for training and competition [5]. However, continuous metabolic information records during the real (environment and motor) sport situation would improve data validity to assess and plan training programs [7].

An important assumption for $\dot{V}O_2$ response during continuous exercise is the analysis of the oxidative function and associated constraints, such as intramuscular oxidative metabolism, level of training, distribution of fibre types and recruitment pattern [11,12]. Thus, the different $\dot{V}O_2$ responses distinguish different areas of continuous exercise and constant intensity, which also relate to the $\dot{V}CO_2$ responses and lactic acid concentration. Moderate exercise is performed below the lactate threshold (LT or gas exchange threshold (GET) when analysed by pulmonary gas exchange), which provides a mono-exponential slope of $\dot{V}O_2$ response to the steady-state phase, lasting 2-3 min on average. In turn, heavy exercise (intensity between LT and critical CP or RCP power - respiratory gas exchange threshold - when analysed by pulmonary gas exchange) has a slow $\dot{V}O_2$ response (CL) component, which will overlay the initial and rapid increase leading to a delayed stability, or gradually and slowly increase until the end of the exercise. In turn, severe exercise (performed above CP) is the one characterized by maximal aerobic power ($\dot{V}O_2$max) range, which is an exhaustive and poorly tolerated task [11,13,14].

In regard to martial arts, the sports environment gathers many risk situations (forceful contacts and falls) capable of damaging the equipment. Thus, the practice simulation is an alternative method to adjust the equipment and consider the physiological information. Kendo is a martial art in which the simulation is almost equivalent to the competitive context, given that the movements and goals do not disturb data collection. However, physiological responses during kendo practice provide sparse information. Therefore, the purpose of this study was to analyse the exercise intensity during kendo practice by $\dot{V}O_2$, heart rate (HR) and other gas exchange parameters responses, by simulating key techniques used during combat. It was hypothesized that kendo requires high-intensity movements able to elicit maximal values for functional (HR), metabolic ($\dot{V}O_2$, RER) and acid compensatory ($\dot{V}_E$, $\dot{V}CO_2$) mechanisms.

Methods

Participants

All nine male participants (age = 29.7 ± 7.8 years old, weight = 82.1 ± 14.9 kg, height = 174.9 ± 9.1 cm, and 27.3 ± 5.5 % body fat) were healthy and have been practicing kendo for at least three years. All of them received verbal and written information about the design of the study and gave their signed consent, as per Helsinki's declaration for human studies [15]. The study was approved by the local Ethics Committee (process 016375 FC/UNESP).

The study participants visited the laboratory three times for DXA (dual-energy X-ray absorptiometry) analysis, a maximal treadmill progressive test and a training session (*waza*) protocol performed twice, with 24h in between, and separate from the progressive test. Participants were instructed to avoid substances with high caffeine, alcohol and nicotine content 48 hours before the progressive test and other protocols, as well as drink plenty of fluids before the tests.

Measurements

Pulmonary gas exchange was measured breath-by-breath throughout the exercise tests. Participants breathed through a facial mask into a low-resistance flow meter (Bi-directional turbine, 28mm, Cosmed, Rome, Italy), which had a flow range of 0.08-20 l/s, ventilation range of 0-300 l/min, accuracy (Flow×Volume^{-1}) of ±2%, flow resistance <0.7 $cmH_2O \times L^{-1} \times s^{-1}$, and 8 ml resolution. Gas was continuously drawn down a capillary line into rapid-response gas analysers (K4b2, Cosmed, Rome, Italy) and the gas exchange variables were calculated with ±0.02% for $\dot{V}O_2$ and ±0.01% for $\dot{V}CO_2$ accuracy. Values were displayed breath-by-breath after accounting for the delay between volume and concentration signals. The volume was calibrated before each test using a 3L calibration syringe, and the analysers were calibrated with precision-analysed gases that spanned the expected range of expired $\dot{V}O_2$ and $\dot{V}CO_2$ concentrations. Heart rate (HR) was recorded every 5s using short-range telemetry (Polar RS 400sd, Kempele, Finland).

$\dot{V}O_2$max was calculated as the highest 9s value achieved during the test. To ensure a maximal aerobic rate would be reached during the test, two of the following criteria were observed [16]: (1) identification of a plateau in $\dot{V}O_2$ – speed ratio (i.e., an increase of less than 100 ml×min^{-1}); (2) respiratory exchange ratio (RER) above 1.10; and (3) HR was within ±10b×min^{-1} (or 5%) of the age-predicted maximum (220-age in years). The highest value of HR attained during the last step of the progressive test was considered the maximum (HRmax) and correspondent to $\dot{V}O_2$max.

To determine GET (gas exchange threshold) and RCP (respiratory compensation point) the slopes were visually examined based on the plots of time against 9s averaged values of $\dot{V}_E \times CO_2^{-1}$, $\dot{V}_E \times O_2^{-1}$, $PETCO_2$ and $PETO_2$ parameters [17]. The GET criteria were: increase in $\dot{V}_E \times O_2^{-1}$ and $PETO_2$, with no concurrent change in $\dot{V}_E \times CO_2^{-1}$ and $PETCO_2$, respectively. For RCP, the criterion used was the continuous increase in $\dot{V}_E \times VO_2^{-1}$ and $\dot{V}_E \times CO_2^{-1}$ with a concurrent reduction in $PETCO_2$ [18]. Two independent and expert observers analysed the plots of each index to determine GET and RCP, and if the results would not match, a third one was consulted.

During warm-up and *waza* protocols, the breath-by-breath $\dot{V}O_2$ response was aligned by time for each set of kendo practice, and each curve response was analysed for noise exclusion (uncharacteristic events of the $\dot{V}O_2$ response) [19]. Noise was defined as deviations greater than three standard deviations from the local average (4–-5 breaths) [13]. All participants were instructed to avoid shout (*ya, kiai, men* or *kote*) during the practice, preventing the disturbance of expired gas sampling by add an acknowledge font of noise. Later, the data were interpolated to provide values at each second for protocols performance, and then were averaged to obtain a single response for each set of kendo practice [20]. The overall time taken for each (warm-up and *waza*) protocol was fractioned in quarters (25, 50, 75 and 100%), and the $\dot{V}O_2$ response analysed in (±10 seconds) each quarter. The procedures used to analyse HR response during the protocols were time-aligned, interpolating each second and the mean values were obtained for the performances. Despite the analysis of RER, $_E$ and $\dot{V}CO_2$ responses during the protocols following the same procedures steps adopted to $\dot{V}O_2$, starting from the elimination of the data row corresponding to $\dot{V}O_2$ that was excluded as noise.

Incremental protocol

The treadmill test was performed on a motorized treadmill (ATL 15000 Embramed, Porto Alegre, Brazil) with the grade set at 1%. After a 3-min warm-up at 6.0 km.h^{-1}, initial test speed 7.0 km×h^{-1} was increased by 0.9 km×h^{-1} every 60s, until volitional exhaustion.

Experimental protocol

All participants performed the protocol shown on Table 1 twice. The protocol was assigned to two *sensei* (master/teacher) who both hold kendo third dan (grade). During the warm-up phase, all participants practiced the techniques alone, wearing *keiko-gi* and *hakama* (traditional kendo clothing), *bogu* (protective kendo amour, consisting of *men* (helmet), *kote* (gloves), *do* (chest/belly), *tare* (waist/thigh) and holding the *shinai* (bamboo sword). The *waza* (training techniques) phase was performed by two participants, but only the *kakarite* (attacker) had to use a respiratory facemask the entire time during protocol. For this reason, the *kakarite* performed the *waza* phase without wearing the *men* (helmet), whereas the *motodachi* (receiver) participated fully equipped. The protocols (warm-up and *waza*) were performed without interruption, between each other and over the techniques sequence. Verbal instructions ensured the orderly and continuous performance of the techniques sequences. The participants used their own set of equipment's, but with the same characteristics: *bogu* - *kote* (800 g of weight), *men* (1700 g of weight), and *do* (1550 g of weight), and *shinai* (120 cm in length and 510 g of weight). The equipment's used during the test were the same used during the routines of training, ensuring minimal contextual disturbance during the test.

Statistical treatment

The data are expressed as mean ÷ SD. The statistical difference between maximum $\dot{V}O_2$, HR, RER, $\dot{V}CO_2$ and $\dot{V}_E$ values with paired average values during 25, 50, 75 and 100% of kendo practice were analysed using the ANOVA (one-way, using Tukey HSD as post-hoc test). The t-test for independent samples was applied to compare $\dot{V}O_2$ and $\dot{V}CO_2$ final responses for the warm-up and *waza* performance. The parametric statistical method was applied to compare means after the Shapiro-Wilk Normality Test. The level of significance was set at $\rho \leq 0.05$. All statistical analyses were performed using the SPSS 18.0® statistical software package.

Results

the mean values for aerobic parameters (Table 2) showed that participants had cardio-respiratory fitness ($\dot{V}O_2$max = 38.0±3.2 ml×min^{-1}×kg^{-1}) rated as below average, when compared to age-group scores. However, respiratory thresholds for sustained (GET: 74.5±6.2% $\dot{V}O_2$max) and non-sustained (RCP: 91.4±1.9% $\dot{V}O_2$max) increase in $\dot{V}O_2$ response and blood lactate appearance were in the range of those reported for the group of persons with average cardiorespiratory fitness (GET: 65-75% $\dot{V}O_2$max; RCP: 80-90% $\dot{V}O_2$max).

The final $\dot{V}O_2$, HR, RER, $\dot{V}CO_2$ and $\dot{V}_E$ values for warm-up and *waza* were not statically different from the respective maximum values observed at the progressive tests, and neither differed from each other at the end of each protocol of warm-up and *waza* (Figure 1). Despite the mean final values for $\dot{V}O_2$ and $\dot{V}CO_2$ between GET and RCP for both warm-up and *waza* response, the $_E$, HR and RER profiles seemed to project exercise intensity above RCP and

Table 1. Experimental protocol design.

	Techniques	Repetitions
Warm-up		
	joge-buri / sayu-joge-buri / zen-shin-ko-tai / sho-men-uchi / san-po-zen-shin-san-po-ko-tai-sho-men-uchi	30
	sho-men-uchi / ki-ba-dashi / ia-men	20
	kote-men-do	10
	choyaku-suburi / choyaku-kirikaishi	50
Waza		
	Kirikaeshi / do-no-kirikaeshi	2x9
	men-uchi / kote-uchi / kote-men-uchi / kote-do-uchi / do-uchi / tsuki / hiki-men / hiki-kote / hiki-do / men-kaeshi-do / men-kaeshi-men / men-debana-men / men-debana-kote / men-suriage-men / kote-kaeshi-kote / men-nuki-do / kote-nuki-men / kote-uchi-otoshi-men / ai-kote-men / do-uchi-otoshi-men / seme-men / seme-kote / seme-do / uchi-otoshi-men / harai-men / shikake-men / shikake-kote / shikake-do	4
	kakarigeiko	10

Table 2. Kendo practitioners progressive test parameters.

	Mean	SD
$\dot{V}O_2$max (ml×min^{-1})	3163.6	521.7
$\dot{V}O_2$ at GET (ml×min^{-1})	2335.1	279.7
$\dot{V}O_2$ at RCP (ml×min^{-1})	2889.6	474.1
RERmax	1.24	0.13
$\dot{V}_E$max (l×min^{-1})	118.58	18.94
$\dot{V}CO_2$max (ml×min^{-1})	3742.43	380.96
HRmax (bpm)	185.8	14.5

closer to the maximum level at the final phase of both warm-up and *waza* protocols (Figure 2 and 3). When comparing the group's mean $\dot{V}O_2$ and $\dot{V}CO_2$ values at 25% intervals (25, 50, 75, 100%) of the warm-up and *waza* performances, they reflected a continuous progressive and constant exercise, respectively, since $\dot{V}O_2$ and $\dot{V}CO_2$ values at 100% differ from other intervals during warm-up, while no differences were observed among the *waza* intervals (Table 3).

The subject's individual $\dot{V}O_2$, HR, $\dot{V}CO_2$, $\dot{V}_E$ and RER profiles while continuously performing the protocols (Figures 2A to 2E) are aligned to the group's responses mean values (Figures 3A to 3E) for each protocol, as per the quarters analyses. During warm-up protocol, $\dot{V}O_2$ and $\dot{V}CO_2$ responses were below GET during intervals 25% to 75%, presenting a slow (Figures 2A and 2C) or absent (Figures 3A and 3C) gain profile. However, it increased to the respective RCP values when reached interval 100% of the profile. At warm-up intervals 25%, 50% and 75%, $\dot{V}O_2$ and $\dot{V}CO_2$ profiles substantially differed from $\dot{V}O_2$max ($p<0.01$). The overall $\dot{V}O_2$ and $\dot{V}CO_2$ response during *waza* were located below GET and above RCP for all intervals (Figures 2A, 2C, 3A and 3C). No statically significant differences were observed between $\dot{V}O_2$max and $\dot{V}O_2$ values at intervals 25%, 50%, 75% and 100%, and neither between $\dot{V}O_2$ values throughout all intervals of this protocol (Table 3). The $\dot{V}CO_2$ profile differed from the $\dot{V}O_2$ profile only by the differences between $\dot{V}CO_2$max and $\dot{V}CO_2$ at *waza* intervals 50% and 75%, meaning that the $\dot{V}CO_2$ values during intervals 25% and 100% did not differ from $\dot{V}CO_2$max.

Most of the $\dot{V}O_2$ statistical behaviour observed during warm-up and *waza* protocols was exhibited in the HR profile (Figures 2B and 3B). Mean values of HR remained within the HR values in GET and RCP during warm-up intervals 25%, 50% and 75%, but during warm-up intervals 75% and 100% throughout all *waza* intervals, the HR responses were closer to or did not differ from HRmax. Hyperventilation was a common profile at the last interval of warm-up and throughout all four intervals of *waza* protocols (Figures 2D and 3D). The $_E$ Values differed from $V_E$max only during warm-up intervals 25%, 50% and 75%, which were the only interval that presented V_E profiles below V_E values in RCP while performing warm-up and *waza*. The RER response at 25, 50 and 75% intervals differed from RER at $\dot{V}O_2$max for both warm-up and *waza* profiles (Figures 2E and 3E). However, at warm-up intervals 100% and all throughout *waza* intervals, RER responses were located very close to, or above, the values at RCP. Only values at 100% of warm-up and *waza's* intervals did not differ from RERmax. However, mean RER value was above 1.1 at RCP and almost reached values above 1.2 at the maximum rates (Table 2).

Discussion

The results indicated that kendo practice is an exercise performed in heavy-to-severe domains, with physiological responses induced to its maximum, if practices are organized to be performed continuously, and endured for over 20 minutes. This finding is concurrent with

Table 3. $\dot{V}O_2$ and $\dot{V}CO_2$ values during warm-up and *waza* protocols.

	Warm-up				Waza			
	25%	50%	75%	100%	25%	50%	75%	100%
$\dot{V}O_2$max (ml×min^{-1})	1898.6 (±213.1)	1949.8 (±355.2)	2086.0 (±306.1)	2528.0 (±547.4)	2639.4 (±610.3)	2484.6 (±587.8)	2479.3 (±553.7)	2545.8 (±639.9)
$\dot{V}CO_2$max (ml×min^{-1})	1688.12 (±254.09)	1816.93 (±318.56)	2205.27 (±284.89)	3113.27 (±574.30)	2975.84 (±603.97)	2682.81 (±519.84)	2607.13 (±508.76)	3030.24 (±650.49)

*$\dot{V}O_2$ and $\dot{V}CO_2$ differences observed during intervals corresponding to protocols (independent sample *t*-test, $\rho \leq 0.05$). †Differences observed when comparing the respective intervals between warm-up and *waza* in relation to the $\dot{V}O_2$max or $\dot{V}CO_2$max responses (Anova with Tukey post-hoc test, $\rho \leq 0.05$). There were no differences observed between the $\dot{V}O_2$ and $\dot{V}CO_2$ responses between *waza* intervals.

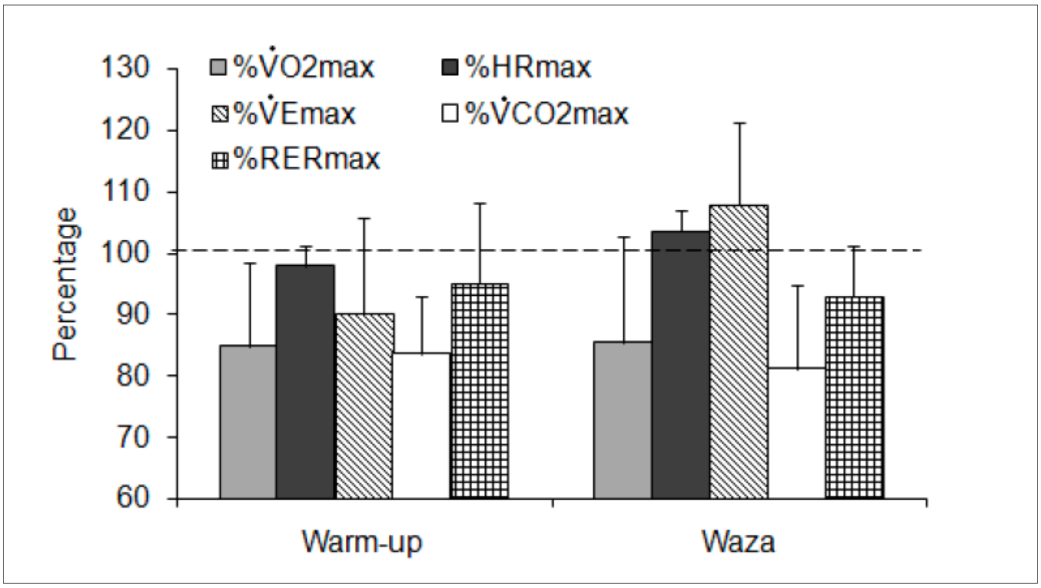

Figure 1. Final $\dot{V}O_2$, HR, RER, and $_E$ mean values for warm-up and *waza* protocols in kendo techniques. No differences were observed at 0.05 level when compared to their respective maximum values, neither from each paired value at the end warm-up and *waza*.

this study's initial conjecture that high intensity upper-limb movements associated to whole-body vertical and horizontal movements are required to perform kendo techniques, and it requires a metabolic supply from both aerobic and anaerobic pathways. The information reported for the first time in this study was that the $\dot{V}O_2$ profile during *waza* characterizes the exercise intensity at upper-limit of heavy domain. Despite the lack of metabolic analyses references in kendo, $\dot{V}O_2$ and other gas exchange parameters profiles have been extensively related to steady or non-steady metabolic responses during exercises [17].

Gas exchange and HR responses during warm-up performance suggested a two-phase metabolic rate (MR): a steady-state MR in the first half, and non-steady-state MR for the second half of the protocol. The steady-state MR is a basic feature of constant exercise, encompassing physiological responses for moderate exercise (below GET): steady HR, steady and coupled $\dot{V}O_2$ and $\dot{V}CO_2$ responses, no hyperventilation and RER increment remains below the unit [11,13,17]. The non-steady-state phase could be a fashion of incremental exercise, with sudden WR stages or high intensity constant exercise (above RCP, i.e., severe domain), either leading to incremental physiological rate until the tolerance limit or end of the exercise [17,21]. Mostly, gas exchange and cardiac responses during the non-steady phase of exercise are: HR and $\dot{V}O_2$ eliciting maximum values, extra-aerobic volume of $\dot{V}CO_2$ output, hyperventilation and RER increment above de unit (1.0) [16,17,22]. While most of $\dot{V}O_2$ and $\dot{V}CO_2$ profile responses during *waza* protocol showed a steady MR, the protocol is characterised as an exercise that is not extensively tolerated (i.e.: exhaustion is related to the amount of anaerobic reserves and to the ability of buffering process to control acid-base homeostasis), since the mean values responses are kept close to the higher limit of heavy domain (i.e.: RCP). Still, some $\dot{V}O_2$ and $\dot{V}CO_2$ mean values placed *waza* MR just above heavy domain, since at least four subjects reached the minimum MR capable to elicit $\dot{V}O_2$max (i.e., ^{3}95%VO_2max, as suggested to Caputo and Denadai, [23]). As the HR response throughout *waza* was trunked to its maximum, and $\dot{V}_E$ remained very close to $\dot{V}_E$max, with significant hyperventilation during the last protocol quarter. *Waza* would better indicate an exercise MR of heavy-to-severe domain. Thus, *waza* could be considered the exercise intensity capable to increase the respiratory and cardiac parameters, and despite the discussion on naming the intensity's exercise domain, the authors agree that increasing the respiratory and cardiac parameters to the maximum values in this intensity is a tendency of the strength production high phosphate cost; which is due to the serial use of type II fibbers and the progressive loss of muscle metabolic homeostasis due to the intramuscular acidosis, increased levels of circulating catecholamine and increased muscle temperature [12-14,24]. Thus, exercise is performed in the tolerance limit and $\dot{V}O_2$, $\dot{V}CO_2$ and $\dot{V}_E$ would reach maximal rates before exhaustion, if performing the exercise above a critical metabolic threshold, called critical power (CP) [12], or RCP (an equivalent gas exchange criteria) [25].

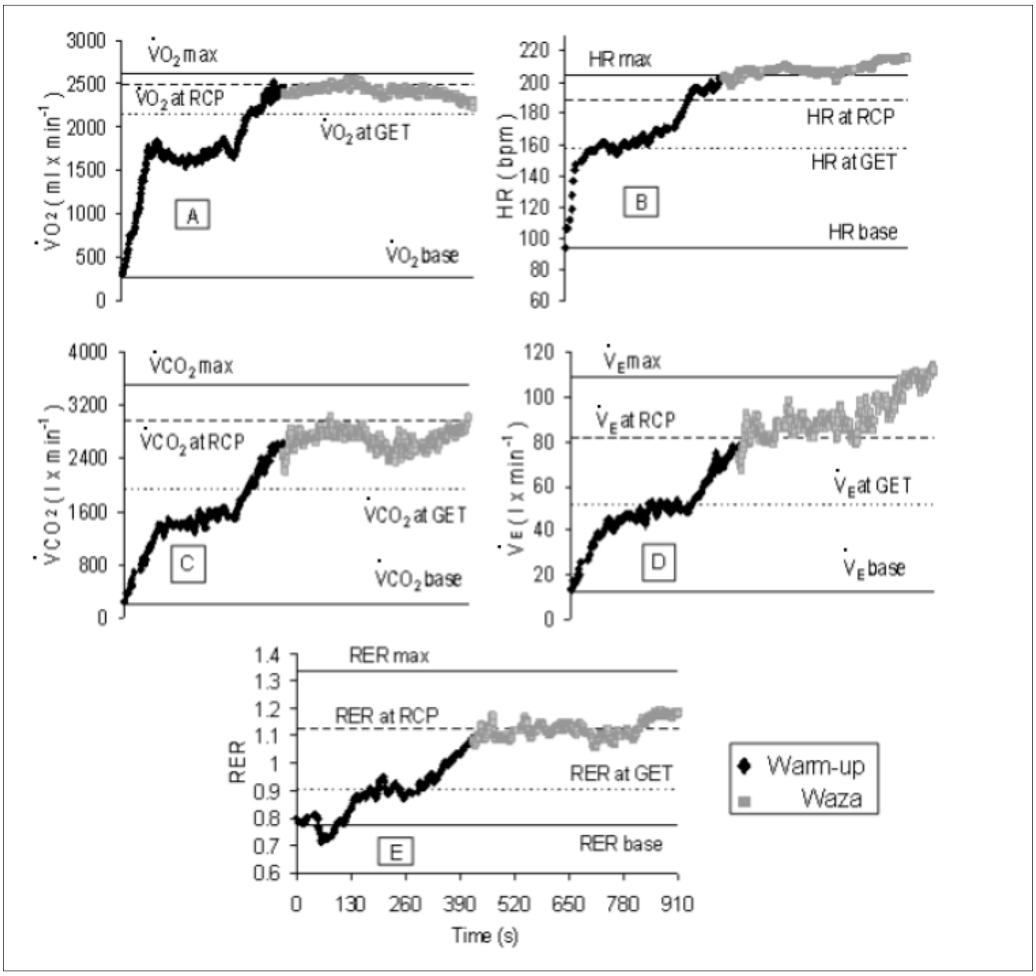

Figure 2. Individual mean $\dot{V}O_2$ (A), HR (B), $\dot{V}CO_2$ (C), $\dot{V}_E$ (D) and RER (E) profiles in both warm-up (black filled diamonds) and *waza* (grey filled square) protocols performances, lasting 910s (Subject 3). The baseline, threshold of moderate and heavy physiological domain and maximum values are represented by the horizontal lines from bottom to top, respectively.

The analysis of MR during the performance of martial art techniques have been performed from HR and lactate responses. The findings report values of 89% of age-predicted HRmax and lactate values around 5 mmolxL^{-1} at the end of the simulated *wushu* competition mode in *daoshu* form (performed with the sword) [26]. Heart rate response at the end of the third boxing round reached maximum rates, and lactate ranges from 7.1 to 9.9 mmolxL^{-1} for Indian junior boxers of different weight categories [6]. For senior England international amateur boxers, blood lactate ranges from 7.6 to 17.7 mmolxL^{-1} after three rounds of three minutes, and HR elicited maximum rates during four rounds of two minutes [5]. In the present study, heart rate (HR) at the end of warm-up (97.8±3.3% HRmax) and *waza* (103.4±3.6% HRmax) are aligned to the aforementioned studies, collectively supporting the information about high intensity, generally driven to the limit of tolerance, which is how combat sports modalities are practiced.

Finally, two major constraints related to the present analysis should be presented. One is the difference in the exercise needed to reach the physiological thresholds for moderate and heavy domains (running on a treadmill) and the one used in experimental protocols to analyse gas exchange profiles (kendo techniques). The authors of this study are aware that a progressive test based on the modality's specificities would potentially improve the exercise domain classification validity for this study. However, running is the exercise preferred by the subjects of the present study for training their aerobic capacity. Running is also how such capacity is tested in studies on fighters of most combat modalities [9]. Furthermore, there was no metabolic rate information on the kendo practice, which has been changed by this study, resulting

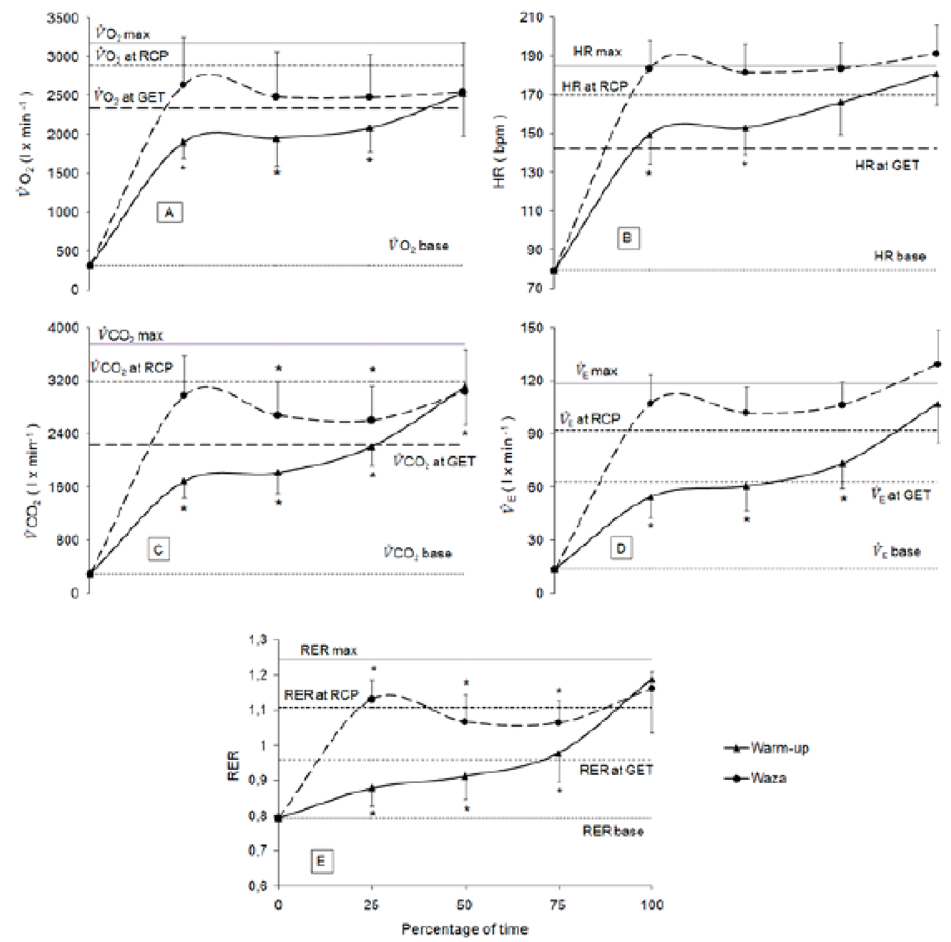

Figure 3. Participants $\dot{V}O_2$ (A), HR (B), $\dot{V}CO_2$ (C), $\dot{V}_E$ (D) and RER (E) mean profiles in warm-up (black filled triangles) and *waza* (black filled circle) 25% intervals (25%, 50%, 75%, 100%). Each protocol was isolated and analyses were considered from baseline values. Horizontal lines represent baseline, moderate and heavy physiological domain thresholds and maximum values, respectively from below to the top of each graph. *Differences observed with respective maximum values.

in the observation that the last quarters' techniques of warm-up and *waza* protocols provide great stress on cardio-respiratory systems, and thus it could be applied to develop an appropriate test to measure the aerobic capacity on kendo practitioners. Another study limitation concerns the kind of movements when performing kendo techniques. The analysis of O_2 profile has been formally designed to classify exercise domain during the transitions from resting to exercising, performed with constant intensity cyclic movements. Kendo techniques are a set of ballistic movements, designed in the present study to be performed continuously. Thus, changes in the order of techniques performance, as well as, substitution of the techniques chosen (Table 1) by new others would lead to different physiological responses. Finally, further concernments about limitations are technical expertise and physical conditioning status. While improvements in skill level could suggest a better movement economy (low oxygen cost) during the performance of the techniques, on another hand, changes of physical condition with training leads to alterations of the exercise domains, and both should alter the exercise classification for the same designed protocol. However, further studies, considering the same or another modified protocol, or even other combat modalities, will be required to provide enough information about the suitability of this approach.

Conclusions

Based on the results, it can be stated that kendo performance tolerance is related to the rate of $\dot{V}O_2$ supply and aerobic energy turnover, as well as, the ability of buffer mechanisms to keep acid-base homeostasis near resting values, as has been suggested for cyclic sport modalities performed within the heavy domain [12,16;21,27]. Thus, kendo athletes must focus on a training program to develop O_2max and increase the heavy domain upper-limit to higher fractions of O_2max, improving high intensity exercise tolerance [27]. Planning sessions that contain sprint interval workouts and continuous low-intensity endurance training (at the RCP or CP restricted intensity limit) appears to be an effective way to increase: O_2max, number of myoglobin and mitochondria in slow-contracting and fast-contracting muscle fibres, increased stroke volume and cardiac output, and rapid disappearance of lactate from muscle and blood [27-29]. Moreover, the present work states: (a) O_2 and CO_2 profiles during *waza* performance presents a steady-state phase at a higher aerobic rate and up to the critical threshold for tolerance; (b) HR and $_E$ increase up to or even above the maximum progressive test rate, during *waza*; (c) RER was kept close to or above the compensatory reference value for the metabolic acidosis during *waza* performance; and (d) metabolic rates (MR) during kendo performance characterized it as heavy to severe domain.

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Competing interests

Authors declare that do not have any financial or personal relationships with other people or organisations that could inappropriately influence paper.

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