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

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Abstract

Background & Study Aim: The metabolic rate demanded during the practice of kendo techniques has not been reported, despite of its 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


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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 reiki (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-kun-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].
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 $\dot{V}O_2$, 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 $\dot{CO}_2$ 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].
movements able to elicit maximal values for functional (HR), metabolic (\(\dot{V}O_2\), RER) and acid compensatory (\(\dot{V}lHCO_3\), \(\dot{V}CO_2\)) 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\(_2\)O×L\(^{-1}\)×s\(^{-2}\), and 8 ml resolution. Gas was continuously drawn down a capillary line into rapid-response gas analysers (K4b2, Cosmed, Rome, Italy), which had a flow range of 0.08-20 l/s, ventilation range of 0-300 l/min, 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 \(\dot{V}lHCO_3\), \(\dot{V}CO_2\), PETCO\(_2\) and PETO\(_2\) parameters [17]. The GET criteria were: increase in \(\dot{V}lHCO_3\) and PETO\(_2\), with no concurrent change in \(\dot{V}CO_2\) and PETCO\(_2\), respectively. For RCP, the criterion used was the continuous increase in \(\dot{V}lHCO_3\) and \(\dot{V}CO_2\) 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 adding 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\(_{\dot{V}lHCO_3}\) 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 sen-sei (master/teacher) who both hold kendo third dan (grade). During the warm-up phase, all participants practiced the techniques alone, wearing keiko-gi and bakama (traditional kendo clothing), kote (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 sequences. 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 ($\dot{V}O_{max} = 38.0±3.2$ 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% $\dot{V}O_{max}$) and non-sustained (RCP: 91.4±1.9% $\dot{V}O_{max}$) 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% $\dot{V}O_{max}$; RCP: 80-90% $\dot{V}O_{max}$).

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 $\dot{V}E$, HR and RER profiles seemed to project exercise intensity above RCP and
Table 2. Kendo practitioners progressive test parameters.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO₂ max (ml×min⁻¹)</td>
<td>3163.6</td>
<td>521.7</td>
</tr>
<tr>
<td>VCO₂ at GET (ml×min⁻¹)</td>
<td>2335.1</td>
<td>279.7</td>
</tr>
<tr>
<td>VCO₂ at RCP (ml×min⁻¹)</td>
<td>2889.6</td>
<td>474.1</td>
</tr>
<tr>
<td>RERmax</td>
<td>1.24</td>
<td>0.13</td>
</tr>
<tr>
<td>Vₘax (l×min⁻¹)</td>
<td>118.58</td>
<td>18.94</td>
</tr>
<tr>
<td>VCO₂ max (ml×min⁻¹)</td>
<td>3742.43</td>
<td>380.96</td>
</tr>
<tr>
<td>HRmax (bpm)</td>
<td>185.8</td>
<td>14.5</td>
</tr>
</tbody>
</table>

The subject’s individual VO₂, HR, VCO₂, VE 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, VO₂ and VCO₂ 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%, VO₂ and VCO₂ profiles substantially differed from VO₂max (p<0.01). The overall VO₂ and VCO₂ 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 VO₂max and VCO₂ values at intervals 25%, 50%, 75% and 100%, and neither between VO₂ values throughout all intervals of this protocol (Table 3). The VCO₂ profile differed from the VO₂ profile only by the differences between VCO₂max and VCO₂ at waza intervals 50% and 75%, meaning that the VCO₂ values during intervals 25% and 100% did not differ from VCO₂ max.

Most of the VO₂ 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 values differed from Vₘax only during warm-up intervals 25%, 50% and 75%, which were the only interval that presented Vₘax in RCP while performing warm-up and waza. The RER response at 25, 50 and 75% intervals differed from RER at VO₂ 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 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. VO₂ and VCO₂ values during warm-up and waza protocols.

<table>
<thead>
<tr>
<th></th>
<th>Warm-up</th>
<th>Waza</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25%</td>
<td>50%</td>
</tr>
<tr>
<td>VO₂ max  (ml×min⁻¹)</td>
<td>1898.6 (±213.1)</td>
<td>1949.8 (±355.2)</td>
</tr>
<tr>
<td>VCO₂ max (ml×min⁻¹)</td>
<td>1668.12 (±254.09)</td>
<td>1816.93 (±318.56)</td>
</tr>
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</table>

*VO₂ and VCO₂ differences observed during intervals corresponding to protocols (independent sample t-test, p ≤ 0.05). †Differences observed when comparing the respective intervals between warm-up and waza in relation to the VO₂ max or VCO₂ max responses (Anova with Tukey post-hoc test, p ≤ 0.05). There were no differences observed between the VO₂ and VCO₂ responses between waza intervals.*
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 

\[ \dot{V}O_2 \]

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 \n\[
\dot{V}CO_2
\]

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 \n\[
\dot{V}CO_2
\]

output, hyperventilation and RER increment above de unit (1.0) [16,17,22]. While most of 

\[ \dot{V}O_2 \] and \n\[
\dot{V}CO_2
\]

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 \n\[
\dot{V}O_2
\]

and \n\[
\dot{V}CO_2
\]

mean values placed waza MR just above heavy domain, since at least four subjects reached the minimum MR capable to elicit \n\[
\dot{V}O_2\max
\]

(i.e., \n\[
95%\dot{V}O_2\max
\]

, 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 \n\[
\dot{V}E\max
\]

, 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 \n\[
\dot{V}E
\]

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].
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 mmolL\(^{-1}\) at the end of the simulated *wuishi* 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 mmolL\(^{-1}\) for Indian junior boxers of different weight categories [6]. For senior England international amateur boxers, blood lactate ranges from 7.6 to 17.7 mmolL\(^{-1}\) 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
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 O2 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 concerns 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 VO2 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\(_{\text{max}}\) and increase the heavy domain upper-limit to higher fractions of O\(_{\text{max}}\), 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\(_{\text{max}}\), 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\(_{\text{2}}\) 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 \(\dot{V}_{\text{E}}\) 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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