The relationship between body composition and aerobic energy expenditure during technical performance of kendo

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Abstract

Background and Study Aim: There is no reasonable enough scientific knowledge about the aerobic energy expenditure from practicing kendo techniques. Therefore, this study aim is an aerobic energy expenditure ($\dot{E}$) during the practice of kendo techniques. We verify the hypothesis that $\dot{E}$, metabolic rate (as metabolic equivalent unit, MET) and the rate of carbohydrate oxidation are proportional in magnitude to the amount of regional and whole-body fat-free mass (FFM) of the kendo practitioners.

Material & Methods: Ten male participants (29.0 ±7.6 years, 82.0 ±14.2 kg, 174.4 ±7.5 cm) underwent body composition evaluation by dual-energy X-ray absorptiometry (DXA), progressive tests to determine $\dot{V}O_{2max}$, and performance of kendo protocol, with 11 warm-up and 31 kendo techniques (*waza*). During the protocol, gas exchange were measured using K4b² (COSMED®). Based on $\dot{V}O_2$ and $\dot{V}CO_2$ data, the $\dot{E}$ was calculated using ($\dot{E} = 3.941 \cdot \dot{V}O_2 + 1.106 \cdot \dot{V}CO_2$) and converted to MET, assuming the constant (= 4.184 $kJ \cdot kg^{-1} \cdot h^{-1}$). Pearson coefficient (r) tested the correlations between regional and whole-body composition data with the values obtained for $\dot{E}$ during warm-up and *waza*. A significance level of $p \leq 0.05$ was considered.

Results: The peak aerobic rate during warm-up and *waza* reached 7.5 ±1.4 (METs) and 8.0 ±1.9 (METs), respectively. The FFM of the trunk, lower and upper limbs correlated with total $\dot{E}$ (76.3 ±13.2 kcal) during warm-up, with (r) ranging from 0.72 to 0.92, as well as with total $\dot{E}$ (218.5 ±34.8 kcal) for the execution of entire protocol (r = 0.67 to 0.75).

Conclusion: The practice of kendō is classified as vigorous exercise requiring high cost of aerobic energy, which is higher in practitioner with larger regional FFM

Key words: fat-free mass• kakari-geiko • martial art • metabolic equivalent • oxygen consumption

Tutorial video: www.youtube.com/watch?v=XOmIKoQN4po

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Metabolic equivalent – a measurement of resting oxygen consumption, varying with age, sex, race, and other factors. One MET is approximately 3.5 $mlO_2 \cdot kg^{-1} \cdot min^{-1}$. During activities or work, the measurements of METs can be used to determine health status and exercise prescription.

Energy expenditure – the chemical reactions involved in the production and utilization of various forms of energy in muscle cells, hereby in oxidative pathway.

Regional and whole-body composition – the relative amounts of various components in the whole-body, or its parts, such as percentage of body fat or percentage of trunk fat.

Kakari-geiko – attack practice in which the attacker unleashes a barrage of techniques to develop technical skill, stamina, and fighting spirit [34].

Kake-goe – vocalization used to dishearten the opponent, lift your own spirits, and indicate a successful attack [34].

Kumite – is a semi-contact karate competitive concurrence, where two athletes perform various kicking, punching and blocking techniques towards each other with maximum control in order to gain points and win the match. Destruction is fictive (Ozawa H. in the *Kendo. The Definitive Guide* [35] not include the term "kumite").

Dan (dan'i) – a term used to denote one's technical level or grade [34].

Waza – a technique or movement which is based on a standard form and is used to challenge and defeat the opponent [34].

INTRODUCTION

Knowledge of metabolic demands for a given sport modality is important for the choice of physical training procedures that would better match the specificity of the modality's performance, as well as for the systematization of the modality's skills in a training program for the athlete or recreational practitioner. Campos et al. [1] observed that oxidative metabolism in taekwondo is predominantly active during fighting when compared to anaerobic metabolisms. However, when considering the acyclic and powerful nature of the techniques, the authors conclude that the determining metabolism for competitive performance is anaerobic alactic, and consequently training session should be planned to improve both systems, aerobic and anaerobic alactic.

While studying muay thai, Crisafulli et al. [2] observed a high contribution of all metabolic pathways. As a result, they recommend that performance in this modality be associated with training planned to demand the aerobic and anaerobic energy during the practice. Additionally, in karate, it was observed that the anaerobic metabolism plays an important role in performance [3]; however, the predominance during combat (*kumite*) is for aerobic metabolism [4]. Different from combat, the practice of specific techniques (*katas*) demands both aerobic and anaerobic energy supply [5]. Due to karate's powerful and acyclic nature, Iide et al. [3] recommend that practitioners perform exercises of this nature to match the conditioning specificities of this modality. However, all studies have emphasized that aerobic fitness is important for performance, especially in the kumite (e.g., the specific training to improve fighting skills) practice.

For kendo, in turn, there is a lack of information about the physiological response during its practice. Kendo is a Japanese combat sport practiced by more than two million people in the world [6], based on offensive and defensive movements with a bamboo sword [7-9]. Schmidt et al. [10] demonstrated that during kendo combat, lasting five minutes, energy expenditure was 14.6 ±0.7 metabolic equivalents (MET). Some studies of this modality have demonstrated that the execution of technical skills of kendo requires high cardiorespiratory response and high oxygen uptake [11, 12]. When considering a direct relation between oxygen uptake and energy expenditure, one can suppose that the execution of sequential kendo movements would result in great energy demands. However, for kendo, as observed for other non-Olympic combat sports, the lack of physiological knowledge results in training routines based on practitioner expertise. Consequently, energy expenditure $\dot{E}$, in kilocalories (kcal) or metabolic equivalents (MET) and carbohydrate oxidation ($grams \cdot min^{-1}$) resulting from important phases of training, such as specific warm-up and the execution of technical skills (*waza*), should be known to support the professional intervention (i.e., training schedule and recovery needs).

When considering that whole-body mass and more specifically fat-free mass has been traditionally correlated to the aerobic energy expenditure of many physical activities (13-15), but that no study found, to the best of our knowledge, made such comparisons with specific martial art activities, this study has a two objective: 1) the knowledge about energy expenditure during the practice of the main kendo techniques; 2) the relationship of regional and whole-body composition with aerobic expenditure resulting from the practice of kendo.

Application purpose is useful information for the planning of specific training routines in this modality.

We verify the hypothesis that $\dot{E}$, metabolic rate (as metabolic equivalent unit, MET) and the rate of carbohydrate oxidation are proportional in magnitude to the amount of regional and whole-body fat-free mass (FFM) of the kendo practitioners.

MATERIAL AND METHODS

Subjects

The sample was comprised of 10 male participants (29.0 ±7.6 years, 82.0 ±14.2 kg, 174.4 ±7.5 cm, and 27.1 ±5.5% whole-body fat), healthy, practitioners of kendo for at least three years, having graduate level between 1st and 2nd dan. All participants received verbal and written information about the study design and gave their signed consent, in accordance with the declaration of Helsinki for studies on humans [16]. The study was approved by the Local Ethics Committee from School of Sciences (FC) of São Paulo State University (UNESP) (process 016375 FC/UNESP).

The participants visited the laboratory for three consecutive days, on the first to analyse regional and whole-body composition followed by a maximum incremental treadmill ramp-test; on the second and third to perform a protocol developed to reproduce a kendo training (warm-up and *waza*). During the incremental test and the performance of kendo techniques, pulmonary gases were breath-by-breath sampled through a portable CPET unit (K4b^2, Cosmed, USA), which were respectively applied to the assessment of maximal aerobic power and thresholds, and to the estimation of energy expenditure during the practice. All volunteers were instructed to avoid substances with caffeine, alcohol and nicotine in the 48 hours prior to testing, and to be well hydrated.

Body composition

Whole-body and regional (legs and arms on the left and right sides and the trunk) mass (BM), the percentage of fat mass (%Fat) and whole-body and regional fat-free mass (FFM) were measured by body scanning, using dual-energy X-ray absorptiometry (DXA; model QDR Discovery Wi, Hologic, Waltham, USA), and APEX® (Hologic, Waltham, USA) body composition software. The equipment was calibrated in accordance with manufacturer recommendations and all procedures were conducted by an experienced lab technician.

Incremental protocol

The treadmill test was conducted on a motorized treadmill (ATL 1500 Embramed, Porto Alegre, Brazil) with a 1% slope. After three minutes of warm-up at 6.0 km·h^{-1}, the test begins at a speed of 7.0 km·h^{-1} and 0.9 km·h^{-1} was added every 60s, until voluntary exhaustion.

Experimental protocol

All participants conducted the protocol applied in the Sancassani; Pessôa Filho [12] study. This protocol, synthetically included 11 techniques in the warm-up phase (*joge-buri*, *sayu-joge-buri*, *zen-shin-ko-tai*, *sho-men-uchi*, *L-sho-men-uchi*, *san-po-zen-shin-san-po-ko-tai-sho-men-uchi*, *kote-men-do*, *ki-ba-dashi*, *choyaku-suburi*, *ia-men*, *choyaku-kirikaishi*) and 31 in the *waza* phase (*kiri-kaeshi*, *do-no-kirikaeshi*, *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*, *kakari-geiko*). During the entire protocol, the participants wore the traditional clothing (*keiko-gi* and *hakama)* and *bogu* (kendō's protective armour, consisting of *men* (helmet), *kote* (gloves), *do* (chest/abdomen) and *tare* (waist/thighs).

Metabolic measurements

Participants breathe through a face mask into a low resistance flow meter (bi-directional turbine, 28mm) and pulmonary gases were continuously sampled through a capillary line for gas response analysers (K4b^2, Cosmed, Rome, Italy). Pulmonary ventilation ($\dot{V}_E$), oxygen uptake ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), end-tidal O_2 pressure ($P_{ET}O_2$) and end-tidal CO_2 pressure ($P_{ET}CO_2$) were obtained breath-by-breath. System sensors and volume were calibrated before each test, following the procedures of Cosmed^{Ò} Software (10.1 version). Heart rate (HR) was recorded every 5s using short range telemetry (Polar RS 400sd, Kempele, Finland).

Maximum $\dot{V}O_2$ ($\dot{V}O_{2max}$) was determined as the highest value, on average of 9s, reached during the test's final stages. To ensure reaching maximum aerobic power during the test, at least two of the following criteria were observed: (1) identification of a plateau in the curve between $\dot{V}O_2$ – velocity (that is, an increase under 100 ml·min^{-1}); (2) respiratory exchange ratio (RER) over 1.10; and (3) final HR of the test between ±10 beats·min^{-1} (or at 95%) of the maximum predicted for age (220 – age) [17]. The highest HR value during the final stage of the progressive test was considered maximum (FC_{max}). The Gas Exchange Threshold (GET) and the Respiratory Compensation Point (RCP) were determined by visual inspection of respiratory indicator responses during incremental exercise, as per recommendations by Whipp et al. [18] and Beaver et al. [19]. The GET was defined as running speed at which an increase was observed in the $V_E·VO_2^{-1}$ and $P_{ET}O_2$ ratio without a concomitant increase in the $\dot{V}_E·\dot{V}CO_2^{-1}$ and $P_{ET}CO_2$ ratio. The RCP was defined as running speed at which a continuous increase was observed in $\dot{V}_E·\dot{V}O_2^{-1}$ and $\dot{V}_E·\dot{V}CO_2^{-1}$.

During the warm-up and *waza* protocol, $\dot{V}O_2$ breath-by-breath response was aligned with time for each performance of kendo protocol, and each response curve was analysed for exclusion of noise (non-characteristic events of the $\dot{V}O_2$ response) [20, 21]. All participants were instructed to avoid the "*kiai*" (shout) during practice to prevent disturbances to the exhaled gas sampling, since that is an additional source of noise. After that, $\dot{V}O_2$ data were interpolated to provide values at every second tand, then, they were weighed to obtain a single response (6). However, the analysis of $\dot{V}_E$, RER, $\dot{V}CO_2$, $P_{ET}O_2$ and $P_{ET}CO_2$ responses during protocols followed the same procedures adopted for $\dot{V}O_2$ after the elimination of the data line corresponding to $\dot{V}O_2$ excluded as noise.

Calculation of energy demand

The aerobic energy expenditure ($\dot{E}$) was estimated in kilocalories (kcal) using equation 1 [22] for every minute of the $\dot{V}O_2$ and $\dot{V}CO_2$ data set, interpolated second-by-second during the warm-up and *waza* protocols. The Weir equation for estimating $\dot{E}$ (kcal·min^{-1}) was:

$$\dot{E} = 3.941 \cdot \dot{V}O_2 + 1.106 \cdot \dot{V}CO_2 \qquad (1)$$

The highest $\dot{E}$ value obtained during each of the protocols (warm-up and *waza*) was considered the peak energy expenditure ($\dot{E}_{PeakWarm}$ and $\dot{E}_{PeakWaza}$, respectively). The mean energy expenditure during each protocol was considered ($\dot{E}_{MeanWarm}$ and $\dot{E}_{Mean\textit{Waza}}$, respectively). The sum of energy expenditure during the execution of each phase was considered ($\dot{E}_{TotalWarm}$: $\dot{E}_{Total}$ of warm-up; $\dot{E}_{TotalWaza:}$ $\dot{E}_{Total}$ of *Waza*; and $\dot{E}_{TotalProt:}$ $\dot{E}_{Total}$ of the protocols $_=$ $\dot{E}_{TotalWarm}$ + $\dot{E}_{TotalWaza}$).

The amount (grams) and the rate (grams·min^{-1}) of carbohydrate (glycose/glycogen, CHO) and fat (FAT) oxidations were determined according [23], from equations 2 and 3:

$$CHO = 4.585 \cdot \dot{V}CO_2 - 3.226 \cdot \dot{V}O_2 \qquad (2)$$

$$FAT = 1.695 \cdot \dot{V}O_2 - 1.701 \cdot \dot{V}CO_2 \qquad (3)$$

in which $\dot{V}O_2$ and $\dot{V}CO_2$ are expressed in L·min^{-1}.

Energy expenditure values were also transformed into metabolic equivalents (MET), standardized per hour. The MET value was determined individually by calculating the rest energy expenditure ($\dot{E}_{REP}$), from the $\dot{V}O_2$ and $\dot{V}CO_2$ values measured in the sitting position for 10 minutes [15]. The MET unit was calculated using equation 4:

$$1MET\ (kJ \cdot kg^{-1} \cdot h^{-1}) = [(\dot{E} \cdot 60)/BM] \cdot 4.184 \qquad (4)$$

where $\dot{E}$ is expressed in kcal·min^{-1}, body mass (BM) in kg and 4.184 (kJ·kg^{-1}·h^{-1}) is the work relative to the metabolic unit, according to Ainsworth et al. [14].

Statistical Analysis

The data set for the regional and whole-body composition and the energy expenditure were tested for normality by the Shapiro-Wilk test. The Pearson correlation tested the magnitude and type of proportionality between regional and whole-body composition parameters to the energy expenditure indexes ($\dot{E}_{MeanWarm}$, $\dot{E}_{MeanWaza}$, $\dot{E}_{PeakWarm}$, $\dot{E}_{PeakWaza}$, $\dot{E}_{TotalWarm}$, $\dot{E}_{TotalWaza}$, $\dot{E}_{TotalProt}$, METs, and CHO and FAT amounts and rates for warm-up and *waza*), as well as, between these indexes for energy expenditure to maximum and sub-maximum indicators for aerobic fitness level. One-way ANOVA (with Bonferroni p*ost hoc* analysis) tested differences among means for CHO and FAT rates at the moments (25-, 50-, 75 – and 100%) of each phase (warm-up and *waza*). Reliability was analysed for each procedure using the standard error of measurement (SEM), minimum and maximum values (range), and 95% confidence interval (95% CI). The significance level considered was $p<0.05$. Data were analysed using SPSS 18.0 (SPSS Inc., Chicago, USA). The sample power for relationships from two-tailed Pearson's coefficient was determined considering equation 5. Data input included sample size (n = 10), the value of "r" from Pearson's lineal coefficient, Z_a = 1.96 for a security index of a = 0.05, and (c) Z_{1-b} as the power expected to satisfy 80% (Z_b scores ranking for standard normal distribution), following Díaz and Fernandéz [24]:

$$Z_{1-\beta} = \sqrt{n-3}\ \frac{1}{2} Ln\left(\frac{1+r}{1-r}\right) - Z_{1-\alpha/2} \qquad (5)$$

RESULTS

The maximum aerobic power ($\dot{V}O_{2max}$), GET and RCP are represented in METs (Figure 1). The average value of $\dot{V}O_{2max}$ was 3.2 ±0.5 l·min^1 and GET and RCP threshold values were located at 74.5 ±6.2% $\dot{V}O_{2max}$ and 91.4 ±1.9% $\dot{V}O_{2max}$, respectively. The mean, peak and total aerobic energy expenditure values obtained during the warm-up and *waza* phases are shown in Table 1.

Table 1. Aerobic energy cost during kendo protocols: warm-up and waza (n = 10).

Variables	Warm-up	Waza
$\dot{E}_{Mean}$ (kcal·min^{-1})	9.7 ±1.6	13.1 ±2.7
*SEM	0.49	0.87
Range (min÷max)	7.9÷12.1	8.9÷17.5
95% CI	8.9÷10.7	11.6÷14.9
$\dot{E}_{Peak}$ (kcal·min^{-1})	13.5 ±2.7	14.3 ±2.9
*SEM	0.84	0.91
Range (min÷max)	10.6÷17.7	10.1÷18.7
95% CI	12.0÷15.1	12.7÷16.1
$\dot{E}_{Total}$ (kcal)	76.3 ±13.2	142.3 ±26.5
*SEM	4.2	8.4
Range (min÷max)	55.0÷96.4	99.2÷192.8
95% CI	69.0÷84.2	127.2÷158.0

*SEM: standard error of measurement

In Figure 1, observe that the warm-up phase represented an energy demand equivalent to typically progressive activity that continued to increase until the first moments of the *waza* phase. After that, there is a relative stability throughout the protocol. The mean values for the metabolic equivalents, respectively, during warm-up and *waza* were 5.5 ±1.0 METs (range: 4.2 to 7.2; 95% IC: 4.8 to 6.0) and 7,3 ±1.7 METs (range: 4.7÷10.0; 95% IC: 6.3 to 8.3), while peak values were 7.5 ±1.4 METs (range: 5.9÷9.7; 95% IC: 6.7 to 8.2) and 8.0 ±1.9 METs (range: 5.3÷11.5; 95% IC: 6.9 to 9.1).

The amount of CHO (73.5 ±10.8 grams; range: 57.6 to 94.5; 95% IC: 67.5 to 80.4) and FAT (2.07 ±1.18 grams; range: 0.4÷4.1; 95% IC: 1.4÷2.9) required during the practice of the entire protocol ensure high reliance on glycose/glycogen expenses for kendo practice, which is further detailed in Figure 2 considering the rate of CHO and FAT expenditure over the time to perform warm-up and *waza*. The rate of CHO utilization during warm-up phase differed from first (25%) to third (75%) quarters (p = 0.008), second (50%) to fourth (100%) quarters (p<0.001), and third (75%) to fourth (100%) quarters (p<0.001); but only first (25%) to third (75%) quarters differed (p = 0.015) during *waza* phase (panel A, Figure 2). For FAT utilization, first-quarter differed from second (50%, p = 0.039), third (75%, p = 0.010) and fourth (100%, p<0.001) quarters; second (50%) to third (75%) quarters (p<0.007); and third (75%) to fourth (100%) quarters (p<0.001) all during warm-up phase (Panel B, Figure 2).

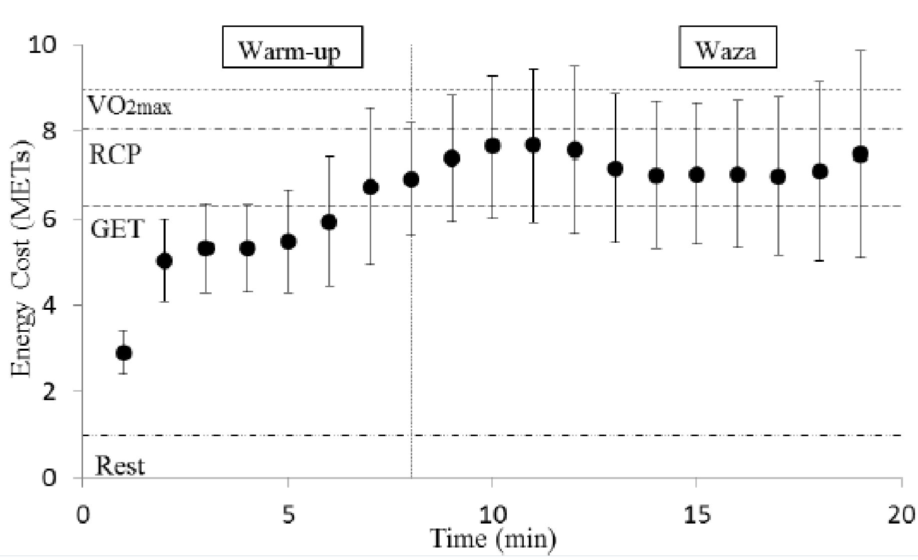

Figure 1. Solid dots (●) indicate the aerobic energy cost profile during warm-up and *waza* exercise protocols, expressed in metabolic equivalent units (METs). The horizontal dashed lines indicate the METS values at rest, GET, RCP and VO_{2max}, respectively, from the bottom part of the graph. The dashed vertical line indicates the transition between warm-up and *waza*. The MET values for GET, RCP and VO_{2max} correspond to 6.31, 8.07 and 8.97, respectively.

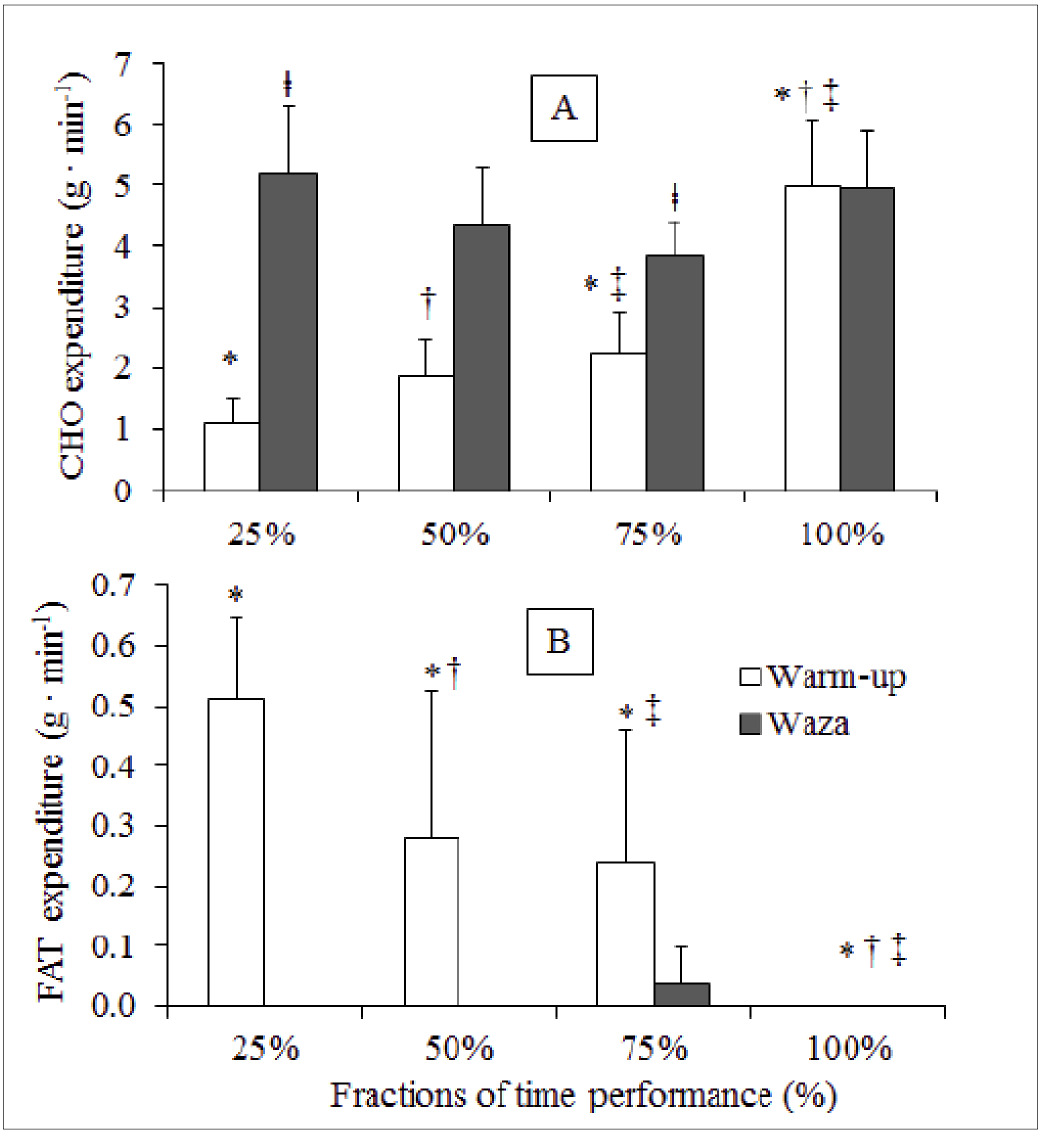

Figure 2. Rates of carbohydrate (CHO) (A) and fat (FAT) (B) expenditure over the time to perform warm-up and *waza* phases of the protocol. Symbols indicate differences were significance ($p \leq 0.05$) among rates of CHO (Panel A) and FAT (Panel B) utilization while practicing both warm-up and *waza* phases. See text for detailed information. No differences were observed for FAT utilization during *waza* perform.

Table 2 shows the correlations between energy expenditure values for warm-up, *waza* and the glycose/glycogen expenses with regional and whole-body total mass, fat-free mass and area values. The regional FFM values were 27.3 ±4.7 kg (trunk; SEM: 1.5 kg; range: 22.0÷36.5 kg), 10.0 ±2.0 kg (left leg; SEM: 0.6 kg; range: 7.6÷13.4 kg), 10.0 ± 2.1 kg (right leg; SEM: 0.6 kg; range: 7.3÷10.0 kg), 3.3 ± 0.6 kg (left arm; SEM: 0.2 kg; range: 2.6÷4.7 kg) and 3.6 ±0.6 kg (right arm; SEM: 0.2 kg; range: 2.8÷4.7). The value for the whole-body FFM was 63.3 ±14.2 kg (SEM: 4.5 KG; range: 50.4÷95.9). The regional mass values were 38.4 ±7.7 kg (trunk; SEM: 24,4 kg; range: 27.4÷49.9 kg), 13.9 ±2.8 kg (left leg; SEM: 8.9 kg; range: 12.3÷15.6 kg), 13.9 ±2.9 kg (right leg; SEM: 9.1 kg; range: 12.3÷15.6 kg), 4.4 ±0.7 kg (left arm; SEM: 225.5 kg; range: 3.2÷5.7 kg) and 4.7 ±0.7 kg (right arm; SEM: 220.5 kg; range: 3.5÷5.8 kg). The values of regional area were: 407.6 ±46.6 cm^2 (left leg; SEM: 14.7 cm^2; range: 354.0÷492.7 cm^2), 385.5 ±46.6 cm^2 (right leg; SEM: 14.7 cm^2; range: 327.8÷460.4 cm^2), 219.3 ±21.5 cm^2 (left arm; SEM: 6.8 cm^2; range: 187.1÷264.3 cm^2) and

Table 2. Correlations between regional and whole-body masses (total and fat-free mass) with the aerobic energy cost during kendo protocols.

Variables	$\dot{E}_{PeakWarm}$ (kcal·min^{-1})	$\dot{E}_{PeakWaza}$ (kcal·min^{-1})	$\dot{E}_{MeanWarm}$ (kcal·min^{-1})	$\dot{E}_{MeanWaza}$ (kcal·min^{-1})	CHO_{Waza} (g·min^{-1})
FFM (kg)					
Trunk (95% CI)	0.842** 0.65÷0.97	0.835** 0.38÷0.98	0.868** 0.64÷0.99	0.833** 0.34÷0.99	0.843** 0.43÷0.96
Left leg (95% CI)	0.788** 0.32÷0.93	0.628* 0.07÷0.93	0.970** 0.89 – 0.99	----	0.732* 0.10÷0.95
Right leg (95% CI)	0.815** 0.55÷0.93	0.630* –0.15÷0.94	0.977** 0.92÷0.99	----	0.738* 0.07÷0.95
Left arm (95% CI)	----	0.712* 0.03÷0.93	0.784** 0.50÷0.97	0.702* 0.20÷0.92	0.683* –0.23÷0.92
Right arm (95% CI)	----	----	0.785** 0.42÷0.96	----	----
Total body	-----	-----	-----	-----	-----
Mass (kg)					
Trunk (95% CI)	0.874** 0.68÷0.99	0.736* 0.33÷0.95	0.771* 0.49÷0.94	0.744* 0.36÷0.97	0.786** 0.61÷0.94
Left leg (95% CI)	0.887** 0.69÷0.98	0.671* 0.29÷0.95	0.940** 0.83÷0.99	0.654* 0.25÷0.94	0.736* 0.35÷0.92
Right leg (95% CI)	0.884** 0.73÷0.97	0.666* 0.36÷0.94	0.937** 0.82÷0.99	0.655* 0.33÷0.94	0.743* 0.36÷0.93
Left arm (95% CI)	0.812** 0.62÷0.95	0.804** 0.53÷0.95	0.823** 0.54÷0.99	0.811** 0.38÷0.97	0.809* 0.49÷0.95
Right arm (95% CI)	0.733* 0.34÷0.91	0.699* 0.20÷0.93	0.848** 0.62÷0.96	0.662* 0.13÷0.92	0.643* 0.10÷0.89
Total body (95% CI)	0.919** 0.77÷0.99	0.748* 0.34÷0.96	0.888** 0.73÷0.97	0.744* 0.36÷0.97	0.798* 0.59÷0.94
Area (cm^2)					
Left leg (95% CI)	0.846** 0.51÷0.96	0.760* 0.03÷0.95	0.890** 0.63÷0.98	0.766** 0.07÷0.95	0.835** 0.35÷0.96
Right leg (95% CI)	0.899** 0.59÷0.98	0.728* 0.05÷0.95	0.926** 0.76÷0.98	0.727* 0.09÷0.95	0.795** 0.38÷0.95
Left arm (95% CI)	----	----	----	----	0.743** 0.11÷0.94
Right arm (95% CI)	0.719* 0.33÷0.91	0.638* –0.20÷0.89	0.730* 0.15÷0.93	0.674* –0.09÷0.91	0.847** 0.38÷0.96
Total body (95% CI)	0.890** 0.71÷0.99	0.776** 0.21÷0.97	0.896** 0.72÷0.98	0.793** 0.24÷0.98	0.857** 0.52÷0.97

*p≤0.05 and **p≤0.01. Sample power for 0.630 ≤ r^{3} 0.699 range from 48% to 61%; for 0.700 ≤ r^{3} 0.799 range from 61% to 80%; for 0.800 ≤ r^{3} 0.899 range from 80% to 96%; and for 0.900 ≤ r^{3} 0.980 range from 96% to 99%.

224.1 ±19.2 cm² (right arm; SEM: 6.1 cm²; range: 200.0÷264.7 cm²). The value for the whole-body area was 2233.0 ±230.0 cm² (SEM: 72.7 cm²; range: 1911.7÷2618.1 cm²). All indicators of the regional and whole-body total mass correlated to $\dot{E}_{PeakWarm}$, $\dot{E}_{PeakWaza}$, $\dot{E}_{MeanWarm}$ and $\dot{E}_{MeanWaza}$, as well as to the rate of CHO oxidation during *waza* (Table 2). Also, regional and whole-body area (excepting left arm) were higher related to all these variables. Even, was evidenced in Table 2 the relationship between parameters of regional FFM with variables of energy ($\dot{E}_{PeakWarm}$, $\dot{E}_{PeakWaza}$, $\dot{E}_{MeanWarm}$ and

Table 3. Correlations between maximum and sub-maximum parameters for aerobic level with the aerobic energy cost during kendo protocols.

Variables	$\dot{V}O_{2max}$	GET	RCP
$\dot{E}_{PeakWarm}$ (kcal)	0.821**	0.831**	0.797*
Sample power	86.4%***	88.1%***	82.1%***
95% CI	0.610÷0.985	0.537÷0.988	0.547÷0.997
$\dot{E}_{MeanWarm}$ (kcal)	0.936**	0.882**	0.934**
Sample power	99.4%***	95.4%***	99.4%***
95% CI	0.786÷0.998	0.673÷0.984	0.778÷0.996
$\dot{E}_{TotalWarm}$ (kcal)	0.911**	0.775*	0.901**
Sample power	98.2%***	77.6%	97.4%***
95% CI	0.647÷0.992	0.445÷0.962	0.598 – 0.993
$\dot{E}_{TotalProt}$ (kcal)	0.685*	----	0.667*
Sample power	60.3%	----	56.4%
95% CI	0.160÷0.960	----	0.073÷0.942
$\dot{E}_{MeanWaza}$ (kcal)	----	0.733*	----
Sample power	----	69.1%	----
95% CI	----	−0.015÷0.981	----
$\dot{E}_{PeakWaza}$ (kcal)	----	0.748*	----
Sample power	----	72.6%	----
95% CI	----	−0.005÷0.968	----

*p≤0.05 and **p≤0.01. $\dot{V}O_{2max}$: maximal oxygen uptake; GET: gas exchange threshold; RCP: respiratory compensation point. ***Sample power with Z_{1-b} scores ³ 0.840, which is the lower boundary to attain 80% of statistical power. Calculated values were: $\dot{V}O_{2max}$ (1.11; 2.55; 2.10 and 0.26), GET (1.19; 1.68; 0.77; 0.51 and 0.60), and RCP (0.92; 2.51; 1.95 and 0.17) for the relationships respectively showed from the upper to the lower part of the Table 3.

$\dot{E}_{MeanWaza}$) and carbohydrate expenses (CHO oxidation) during kendo practice, but not all parameters of FFM satisfied the level of significance to correlate with these variables.

In Table 3, the correlations between $\dot{V}O_{2max}$, GET and RCP with the aerobic energy expenditure during protocols showed higher relationship to warm-up variables ($\dot{E}_{peakWarm}$ and $\dot{E}_{totalWarm}$) compared to *waza*, which performance exhibited relationship only with GET. However, statistical power for relationships showed on Table 3 achieved desirable power (80%) only for $\dot{V}O_{2max}$, GET and RCP to the mean, peak and total aerobic energy cost during warm-up phase of the protocol. These results demonstrate that the progressive profile of energy demand during warm-up is related to all aerobic indicators, whereas the tendency for stability during *waza* depends on GET magnitude.

DISCUSSION

This study analysed the aerobic energy demand during kendo and postulated that this demand is related to regional and whole-body composition. The results demonstrated that the organization of kendo practice include techniques with progressive oxidative demand, and techniques with oxidative demand with small variations throughout the performance. Thus, the warm-up protocol was that which exhibited a set of techniques with progressive increase in oxidative metabolism up to the level recognized as high intensity exercise. Subsequently, the *waza* techniques keep oxidative metabolism under high demand, but relatively stable. These observations corroborated investigations in other martial arts, such as taekwondo, karate and muay thai, that suggested similar energy requirements and indicating the predominance of oxidative demand during their practices [1, 2, 4].

Other relevant information is that the $\dot{V}O_{2max}$, RCP and GET were related to the energy expenditure of both protocols (warm-up and *waza*) for kendo. This relationship means that the increase in exercise intensity and tolerance during kendo has its metabolic contribution directly associated with the magnitude of aerobic indicators. On the other hand, this association also permits the interpretation that the indicators of aerobic level may be determined in a specific context, applying this same set of techniques employed in the warm-up and *waza* protocols. This ecological perspective of assessment is reinforced by ascertaining that energy demand in kendo correlates to the quantity of fat-free mass and to the total mass of active body segments.

Reviewing literature, we observed just one study on energy expenditure during the practice of kendo. In this study, Schmidt et al. [10] reported mean values of ~15.6 ± 3.1 kcal·min^{-1} for the aerobic energy expenditure of fights lasting five minutes, in male athletes. In the present study, the mean aerobic energy expenditure during warm-up and *waza* (see Table 1) was less than reported by Schmidt et al. [10], however the peak energy expenditure for these practices presented very similar values. These small differences can be attributed to the organization characteristics of warm-up and *waza* when compared to the fight analysed by Schmidt et al. [10], and to the profile of volunteers in their study, whose aerobic power ($\dot{V}O_{2max}$: ~51.0 ±2.7 ml·min^{-1}·kg^{-1}) and whole-body composition (~14.4 ±4.7% fat) define better physical conditioning.

However, the energy expense reported in other martial arts [1, 2, 4, 5] is similar to that observed in this study. For example, in fight simulations in muay thai, the energy expenditure was equivalent to 14 kcal·min^{-1} [2]. In fight simulations in taekwondo, Campos et al. [1] reported an energy expenditure of ~28.8 kcal (120 ±22 kJ on average for three rounds of 2 minutes each) for aerobic participation, equal to 66.6% of total energy expenditure. In karate, Beneke et al. [4] and Doria et al. [5] described aerobic participation in ~62.7 kcal (258.8 ±49.8 kJ) and ~53.9 kcal (225.5 ±20.4 kJ), respectively for four minute fights, involving male athletes in each study. These authors reported that this oxidative energy supply equalled 70% to 80% of total energy expenditure. Although karate, kendo and taekwondo present different attack and defence movements, there are similarities as to the type of action and intensity of execution (ballistic and high power), which include moving the lower limb (*suri-ashi*), jumps (*choyaku-suburi* and *choyaku-kirikaishi*) and various defensive and offensive movements of the upper limb (*waza*). In kendo, these actions are accompanied by control of a bamboo sword (*shinai*) [12], demanding, on average ~13 kcal·min^{-1} of oxidative energy expenditure in the practice of *waza*. These values are similar to those found by Doria et al. [5] and Campos et al. [1], but ~16.0% lower than the energy expenditure observed by Beneke et al. [4]. The differences seem related to control of intensity and execution of technique, which in turn depends on the mode of performance (*kata* or *kumite*, i.e.: simulation of technique or fight) (i.e.: experience) and athlete's technical level [1, 4, 5]. However, relevant information from this study is the association of whole-body mass and fat-free mass with the aerobic energy expenditure of the practice of kendo, which has already been described for different types of physical activities [13, 25].

Although there are no studies relating the energy expenditure in fights with the regional and whole-body composition of fighters, the fact the fat-free mass is an important determining factor of aerobic energy expenditure in kendo corroborates the supposed association of a greater quantity of metabolically active mass to the total energy production of the activity [26]. According to Campos et al. [1] and Beneke et al. [4], the metabolic demand (aerobic and anaerobic), specifically in the martial arts using intermittent execution, relates to the increase in intensity of actions per minute, underscoring the alactic metabolism's activation as the main source of anaerobic supplementation and the associated compensatory oxidative mechanisms, activating aerobic metabolism during the rest between periods of exercise (i.e. fast phase of excess post-exercise oxygen consumption).

Although it was not the scope of the present study, the anaerobic contribution was estimated to obtain an approximation of its relevance to the performance of the proposed protocol. Thus, assuming that $\dot{V}CO_2$ in excess can be determined ($\dot{V}CO_2$ – RQrest×$\dot{V}O_2$) to estimate anaerobic energy contribution relying under the assumption that $\dot{V}CO_2$ in excess is the by-product of buffering mechanisms of acid disturbance from lactate output as anaerobic glycolysis increases it rate of energy supply [27, 28]. The values of blood lactate concentration (mmol×L^{-1}) for warm-up and *waza* performance were obtained from standard constants of conversion, considering: (a) 9 ml CO_2 equivalent to 36 mg of lactate; (b) 1 mg×dL^{-1} equivalent to 0.111 mmol×L^{-1} of lactate for a mean dilution space of 6 liters of blood; (c) energy conversion at the rate of 0.0689 kJ×kg^{-1}·mmol·L^{-1} and it is calorie equivalent (= 4.187 kJ) [27, 29]. The estimate for anaerobic contribution (warm-up: 9,2 + 6,8 kcal; *waza*: 44.8 + 15.7 kcal) for total energy contribution (warm-up: 10.8 + 7.3%; *waza*: 24.1 + 8.6%) is both lower and close to those reported in literature considering warm-up and *waza* phase, respectively. Beneke et al. [4] found for karate simulation competition for anaerobic lactic contribution of 20.3 ±9.0 kJ (6.2 ±2.4% of total energy expenditure) for the simulation of karate kumite. The finds reported to Bussweiler et al. [15] for anaerobic energy cost during kata (*Heian-Nidan*) practice in karate was 16.3 ±4.7 kJ and when performed consecutively it attained 24.7 ±5.1 kJ. However, these data are lower them those reported to Doria et al. [5] for kata (32.4 ±4.1 kJ) and kumite (36.1 ±10.4 kJ) practice.

With regard to exercise intensity, using metabolic equivalents, the Compendium of Physical Activities [24] classifies the practice of martial arts, including judo, karate and kick boxing, with a demand of ~10 METs. Thus, martial arts are considered vigorous exercises that demand significant anaerobic energy supply. Indeed, the anaerobic contribution in martial arts is estimated at ~20% [1, 4, 30] of total demanded energy. The present metabolic equivalent values during warm-up and *waza* were ~20% to 25% lower than the value described in the Compendium. Thus, the fact that it did not estimate the anaerobic contribution could explain this difference, although the relative contributions of the different metabolisms for practicing kendō have yet to be described. Therefore, this is a limitation of this study, since the anaerobic contribution for energy expenditure in kendō is evident from the rate of metabolic activation relative to $\dot{V}O_{2max}$ during the practice (see Figure 1). Thus, the non-intermittent practice of warm-up (11 exercises, 110 repetitions in 8 minutes) and *waza* (31 exercises, 140 repetitions in 10 minutes) raised the oxidative metabolism to 80.9% and 85.7% of METs corresponding to $\dot{V}O_{2max}$, respectively. By associating this metabolic rate with that presented at GET and RCP (70.5% and 90.3% of the METs in $\dot{V}O_{2max}$, respectively), it is possible to characterize the exercise domain in kendō as heavy, which in turn demands elevated anaerobic activation, without leading to metabolic acidosis [31].

The estimate of the rate of carbohydrate oxidation also corroborates the kendō practice as vigorous exercise. Other studies, as Hawley et al., [32] and Kuo et al. [33], reported the rate of carbohydrate oxidation reaching

354 ± 10 µmol·kg⁻¹·min⁻¹ (which approaches ~4.6 g·min⁻¹) and 81.9 ±4.5% of the energy required to cycling at 80% and 65%$\dot{V}O_{2max}$, respectively to earlier and later abovementioned studies. These data are similar to those reported in Figure 2, mainly for *waza* phase of the protocol. Despite no information being found regarding substrate oxidation during kendo, or other martial art modality, it emphasized the carbohydrate metabolism was highly activated during kendo practice.

However, another limitation to be overcome is the contextualization of aerobic rate compared to a specific maximum indicator for kendo, since the $\dot{V}O_{2max}$ reference was obtained by a maximum incremental treadmill test and that, therefore, does not consider the possible influence of skill levels among subjects. Furthermore, an additional limitation is the vocalization of *kake-goe* ("*kiai*") that was avoided during the performance of the techniques. Despite *kake-goe* takes part of kendo practice and perceived exertion could be increased while striking with *kake-goe*, it would increase sign noise during gas exchange sampling and leads to a misinterpretation of $\dot{V}O_2$ values. Therefore, future studies should also explore the progressive profile of the oxidative metabolism exhibited during warm-up, where the mean and peak energy expenditure related to all the aerobic indicators ($\dot{V}O_{2max}$, RCP and GET), as well as address the physiological process underlying the perception of higher exertion during the practice of kendo including *kake-goe*.

CONCLUSIONS

The results suggested that kendo is an exercise classified as heavy with regard to activation and control of the oxidative metabolism; and, thus, its energy expenditure associates with the markers for maximum and sub-maximum aerobic rates ($\dot{V}O_{2max}$, RCP and GET). This association also permits speculating that the oxidative profiles during warm-up and *waza* protocols characterize, respectively, incremental and rectangular exercises, and therefore with an application to the improvement of those same indexes. Other important information is that the regional fat-free mass was influential on the magnitude of aerobic energy production, thus associating the intensity (the power) of kendo practice with the quantity of metabolically active tissue.

HIGHLIGHTS

- During technical performance (*waza*), the aerobic energy expenditure attained ~8METs classifying the practice of kendo as vigorous exercise.
- Total aerobic energy expenditure during the performance of warm-up protocol is related to the physiological thresholds for acid buffering zone and maximal aerobic power, suggesting this set of techniques as specific to assess aerobic fitness of the practitioners.
- Regional fat-free mass enhancements should be an appropriate strategy to improve aerobic energy expenditure and, thus, powerful movements.

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