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PHYSIOLOGY

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Physiological responses of elite karate athletes during simulated competition

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Abstract
Background: Physiological measurements during simulated competitions are useful to make training programs more specific to sport-specific demands.
Problem and Aim: The objective of the present study was to analyze the physiological response of kumite karate athletes during a simulated competition.
Methods: Ten athletes from Chile's national karate team (5 males, age: 24.2 ± 1.8 years, height: 1.67 ± 0.07 m, body mass: 77.8 ± 16.7 kg, and 5 females, age: 23.2 ± 4.1 years, height 1.61 ± 0.04 m, body mass: 62.2 ± 3.7 kg) participated in a simulated competition composed of 4 matches for each athlete. We measured the following variables: blood lactate concentration, heart rate, rating of perceived exertion, respiratory rate, and body temperature.
Results: An effect of time on body temperature was for found in males and females, heart rate mean in males ($P = 0.009$), and 1-minute heart rate recovery in females ($P = 0.044$).
Conclusions: The simulated karate competition under the new Olympic weight categories presented elevated cardiovascular and metabolic responses, which increased in intensity as the fighting progressed.

Introduction

Combat sports have achieved great popularity around the world, with karate being one of the most practiced [Chaabene *et al*. 2012]. Karate has recently been added to the Olympic program and its official debut will be at the Tokyo 2020 Olympic Games.

One of the karate modalities, kumite, corresponds to a specialty with intermittent characteristics [Beneke *et al*. 2004; Chaabene *et al*. 2014a], which makes it difficult to quantify the levels of intensity during competition or training [Foster *et al*. 2001]. Some authors have measured the type and number of actions performed during matches [Beneke *et al*. 2004; Chaabene *et al*. 2014a; Chaabene *et al*. 2015], as well as blood lactate concentration ([La]) [Chaabene *et al*. 2014b], heart rate (HR) [Iide *et al*. 2008], hormonal variables [Chaabene *et al*. 2016], rating of perceived exertion (RPE) [Slimani *et al*. 2017; Tabben *et al*. 2013] and oxygen consumption (VO_2) [Beneke *et al*. 2004; Doria *et al*. 2009]. The contribution of the energy systems for kumite karate has been established, presenting a predominance of the oxidative metabolism, but with important participation of the phosphagens system during the execution powerful actions (e.g., kick and punching techniques) [Beneke *et al*. 2004; Doria *et al*. 2009], and the glycolytic system when successive actions are repeatedly executed [Beneke *et al*. 2004].

In other high-intensity intermittent sports such as soccer, new measures have been incorporated to control training sessions, for example, the monitoring of core body temperature and respiratory rate [Di Paco *et al*. 2014; Duffield, Coutts, Quinn 2009]. The measurement of such variables could be useful for the control of *kumite karate* training in athletes, because they can provide information regarding the intensity of the effort, making possible to adjust the training exercises to simulate those experienced by athletes during combat, as well as to monitor the athletes responses to a specific task during different training phases, establishing the best strategies to improve performance. Thus, the objective of the present study was to analyze the physiological response of elite kumite karate athletes during a simulated competition.

Material and Methods

Participants

Volunteers included 10 adult kumite karate athletes from Chile's national team (5 males, age: 24.2 ± 1.8 years, standing height: 1.67 ± 0.07 m, body mass: 77. 8 ± 16.7 kg, and 5 females, age: 23.2 ± 4. 1years, standing height 1.61 ± 0.04 m, body weight mass: 62.2 ± 3.7 kg). Athletes who were injured or who were taking medications were not included in this sample. All participants signed an informed consent. This study was approved by the local ethics committee. The study complied with the Declaration of Helsinki for human experimentation.

Procedures and measures

A week before the simulated matches all athletes were assessed in a laboratory setting. To measure resting heart rate, each athlete sat on a bench and rested for 12 min. The lowest heart rate recorded during this period was considered the resting heart rate. Next, to determine $VO_{2max\ a}$nd maximum HR (HR_{max}), athletes performed a graded exercise test with cardiopulmonary measurement, starting at 6.4 km/h and increasing by 1.6 km/h every minute. Seven days after these measurements, at 9 am., athletes completed the simulated matches at the High Performance Center where they usually train.

Simulated Competition. Simulations consisted of four 3-min and 2-min matches for males and females, respectively, in accordance to the official regulations of the World Karate Federation [World Karate Federation, 2018] and reproducing real characteristics of a competition. For females, the intervals between the first and second matches, second and third, third and fourth, were 14 ± 5 min, 11 ± 4 min, and 9 ± 4 min, respectively. For males, the intervals between matches were 13 ± 6 min; 17 ± 10 min, and 11 ± 2 min, respectively. These intervals were based in real competitive tournament observations. The athletes were divided into Olympic weight categories: females: 55-61 kg (n = 2), > 61 kg (n = 3); males: 67-75 kg (n = 2) and > 75 kg (n = 3).

Measurements. HR, respiratory rate and body temperature were measured using the Zephyr's Bioharness 3 system (model BH3), placing it at the level of the sternum. Variables were monitored in real time using the Zephyr's PSM training ECHO software, integrated heart rate monitor (Polar, Finland). Heart rate variables — peak (HR_{peak}), average (HR_{mean}) and 1-minute recovery ($HR1_{min}$) — along with respiratory rate (RR) and body temperature (BT) were also measured. Values for each variable were obtained for each match.

[La] were measured in the sitting position, one minute pre and post each match and the delta (post – pre) was calculated. [La] was measured using a portable analyzer (HP Cosmos, Germany). Participants were asked about their perceived exertion 1 minute after each match. All athletes were familiar with the Borg 6-20 scale [Borg 1982].

This study adopted a repeated measures design. A group of high-level kumite karate athletes participated in four successive simulated matches in which physiological responses and perceived exertion were measured. All athletes were evaluated over a period of two weeks.

Statistical Analysis

The statistical package GraphPad Prism 7.0 was used to analyze the data. The data were described using mean

and standard deviation (SD) or median and interquartile intervals for non-parametrical variables. To determine differences between the four matches, the nonparametric Friedman Test for repeated measures was used followed by Dunn's multiple comparison test. In addition, the effect size (ES) was calculated using the following formula: $r = Z/\sqrt{N}$ and classified using the following scale: <0.2 (trivial); 0.2 – <0.6 (small); 0.6 – 1.2 (moderate); 1.2 – 2.0 (large) and >2.0 (very large). A significance level of alpha = 0.05 was established.

Results

During the maximal cardiopulmonary ergospirometry test we observed VO_{2max} and HR_{max} values of 46.0 [40.5, 48.0] ml/kg/min and 181 [179,191] bpm for females and 51.0 [45.5,55.0] ml/kg/min and 198 [195,199] bpm for males.

The results of all the variables measured during the matches are shown in Table 1 and Table 2 for men and women, respectively.

We found an effect of time for BT in males (Z =2.032, $p < 0.001$, r = 0.643), with lower value in match 1 compared with match 4, and females (Z = 2.032, $p < 0.001$, r = 0.643), with lower temperature during match 1 compared with match 4.

Likewise, we found an effect of time for HR_{mean} in males (Z = 0.023, p = 0.009, r= 0.640), with lower values in match 1 compared with match 4, but no difference was found for females (Z = 1.095, p = 0.188, r = 0.346). On the other hand, we did not find differences in HR_{1min} for males (Z = 0.135, p= 0.741, r = 0.135), but did observe a difference for females (Z = 0.023, p = 0.044, r = 0.640), with lower values after match 1 compared to match 4. For males, there was no difference in $[La]_{pre}$ (Z = 1.214, p = 0.578, r = 0.384), but an increase (Z = 0.023, p = 0.02, r = 0.640) was observed from match 1 to match 3 for females.

Finally, we did not observe an effect of time ($p > 0.005$), in any sex, for $HR_{peak,}$ RPE, RR, LA_{post}, and LA_{delta}.

Discussion

The objective of the present study was to investigate physiological responses after four simulated karate matches.

Table 1. Physiological variables of men karate athletes during simulated conditions (data are presented as median [interquartile intervals].

Measurement	Match 1	Match 2	Match 3	Match 4
HR_{mean} (bpm)	152 [150, 166]	170 [164, 173]	169 [162, 176]	176 [171, 180][a]
HR_{peak} (bpm)	189 [186, 207]	197 [194, 200]	198 [195, 200]	197 [192, 211]
HR_{1min} (bpm)	179 [162, 185]	186 [177, 190]	184 [169, 192]	187 [160, 195]
RPE (a.u.)	14 [13, 15]	15 [15, 16]	14 [13, 16]	14 [12, 17]
RR (bpm)	43 [39, 46]	44 [36, 45]	41 [36, 42]	35 [33, 42]
$[LA]_{pre}$ $mmol.L^{-1}$	3.3 [2.4, 5.6]	6.8 [2.5, 9.3]	7.9 [3.0, 12.9]	6.5 [3.6, 15.0]
$[LA]_{post}$ $mmol.L^{-1}$	9.4 [6.6, 12.7]	14.6 [10, 18.5]	8.5 [7.2, 14.9]	13 [9.5, 15.7]
$[La]_{delta}$ (lactate post-match – lactate pre-match) $mmol.L^{-1}$	3.4 [2.6, 10.1]	10.0 [1.6, 13.6]	3.2 [0.7, 4.2]	3.9 [0.7, 7.2]
BT (ºC)	37.8 [37.7, 38.0]	38.1 [38.0, 38.5]	38.1 [38.0, 38.7]	38.5 [38.2, 38.8][a]

[a] = different from 1st match ($P < 0.05$). HR_{mean} = average heart rate; HR_{peak}= higher heart rate; HR_{1min} = heart rate 1-minute recovery; RPE = rating of perceived exertion; RR = respiratory rate; LA_{delta} = lactate delta (post minus pre-match); BT = body temperature

Table 2. Physiological variables of women karate athletes during simulated conditions [interquartile intervals]

Measurement	Match 1	Match 2	Match 3	Match 4
HR_{mean} (bpm)	159 [153, 168]	169 [153, 183]	166 [161, 176]	162 [154, 181]
HR_{peak} (bpm)	184 [176, 192]	193 [179, 198]	186 [182, 199]	188 [183, 200]
HR_{1min} (bpm)	141 [132, 143]	144 [131, 168]	139 [125, 157]	152 [142, 172][a]
RPE (a.u.)	13 [11, 15]	13 [13, 14]	13 [12, 15]	13 [13, 15]
RR (bpm)	43 [41, 46]	45 [43, 45]	46 [41, 46]	41 [39, 43]
$[LA]_{pre}$ $mmol.L^{-1}$	2.3 [2.1, 4.5]	5.5 [4.8, 8.4]	6.0 [4.9, 10.5][a]	8.1 [4.4, 9.2]
$[LA]_{post}$ $mmol.L^{-1}$	9.9 [7.1, 11.9]	7.9 [5.2, 12.2]	8.9 [6.4, 16.1]	10 [8.7, 15.3]
$[La]_{delta}$ (lactate post-match – lactate pre-match)	5.9 [4.9, 8.4]	2.6 [-0.3, 4.4]	3.2 [1.3, 5.7]	5.8 [2.3, 6.2]
BT (ºC)	37.8 [37.8, 38]	38 [37.9, 38.2]	38 [38, 38.3]	38.1 [38, 38.5][a]

[a] = different from 1st match ($P < 0.05$). HR_{mean}=Heart Rate mean; HR_{peak}= Heart Rate peak; HR_{1min}=Heart Rate 1-minute recovery; RPE=Rating of Perceived Exertion; RR=Respiratory Rate; LA_{delta}=Lactate delta; BT=Body Temperature

The main results indicated a high cardiovascular demand and a maintenance of the glycolytic system activation throughout the successive matches.

The HR_{mean} obtained during matches suggests that the demand on cardiovascular system is high during simulated competition. These responses were found to be lower than during official karate competitions: 183 ± 8 bpm, corresponding to 91 ± 3% of HR_{max} [Tabben *et al.* 2013], versus 169 ± 9.1 bpm, corresponding to 93 ± 4% of maximum during simulated matches [Iide *et al.* 2008]. In our study, the HR_{mean} for male in the fourth match was higher than in the first, suggesting that cardiovascular demands increased through successive matches. During official matches, no significant increases in HR_{mean} have been observed [Tabben *et al.* 2013], but in simulated matches lasting 2 and 3 min, increases in HR_{mean} have been reported [Iide *et al.*, 2008]. HR_{peak} for all the matches was lower in comparison to that measured in karate athletes submitted to a specific maximum effort aerobic test for karate [Tabben *et al.* 2014a]. Previous research obtained a HR_{peak} similar to this study when comparing winning versus losing athletes in a kumite karate championship (193 ± 8 bpm for winners and 191 ± 1 bpm for losers) [Chaabene *et al.* 2014a].

The post-match [La] was similar to other studies conducted in official competitions, 10.92 ± 4.0 $mmol.L^{-1}$ [Tabben *et al.* 2013] 11.14 ± 1.8 $mmol.L^{-1}$ [Chaabene *et al.* 2014b], 11.29 ± 1.56 $mmol.L^{-1}$ [Chaabene *et al.*, 2014a] and during simulated matches, 7.7 ± 1.9 $mmol.L^{-1}$ [Beneke *et al.* 2004], 5.2 ± 2.2 $mmol.L^{-1}$ [Roschel *et al.* 2009], and 10.6 ± 4.8 $mmol.L^{-1}$ [Doria *et al.* 2009]. Additionally, a study with three different types of karate training modalities found [La] results similar to the present study (13.5 ± 1.6 $mmol.L^{-1}$) [Tabben *et al.* 2014b]. Taken together these results suggest that our simulation resulted in a similar glycolytic activation as that typically observed during competition, match simulation and training. A previous investigation observed a difference in the LA_{delta} 5.9 ± 1.6 $mmol.L^{-1}$ in the first match, followed by a significant decrease in the contribution glycolytic metabolism in the following matches [Beneke *et al.* 2004], whereas another study [Tabben *et al.* 2013] found a difference in [La] of 5.97 ± 2.1 $mmol.L^{-1}$ for the first match (measurements were not recorded for subsequent matches). In the present study, the difference in [La] from pre to post first match (3.4 [2.6,10.0] $mmol.L^{-1}$) and fourth (5.9 [4.9,8.4] $mmol.L^{-1}$) for males and females are to these previous investigations. The present study had a shorter resting time between the 1st and 2nd matches compared to the study by Tabben *et al* [2013] which had a 33.6 min rest after the first match and 14.5 min between matches 2 and 3. This would suggest that the physiological demands of the athletes are maintained during all matches, when adequate time for recovery is provided. The glycolytic demand during matches and the fact that the [La] was not altered between matches, may suggest the need to study [La] before each match in order to better understand its variations, and implications for glycolytic activation. This is especially relevant considering a significant and positive correlation (r = 0.49) was found between [La] accumulation and net action rate during simulated karate matches [Beneke *et al.* 2004].

Concerning RPE, values reported in the current study were higher than those reported in another investigation [Milanez, Pedro 2012] where an average of 12.2 ± 2.2 arbitrary units (a.u.) was obtained during karate training, whereas a higher average (19.7 ± 8.7 a.u.) was registered in an international competition [Tabben *et al.* 2013]. Recently, a review presented evidence of the RPE method as a tool to quantify the internal load similar to [La] and HR during karate training, simulated and official competitions [Slimani *et al.* 2017].

The correct functioning of the human body depends on the maintenance of BT between 36.5 to 38.5°C, and the systems lose efficiency when they are outside this range [Moran, Mendal 2002]. The values of the present study showed a higher BT in the fourth compared to the first simulated match, for both sexes. This finding demonstrates the importance of developing BT maintenance strategies, such as hydration, ice, and adequate clothing, among others. The increase in BT is attributed to the increase in muscle activity and to the extent that the production of heat is balanced with the loss, BT remains constant [Gleeson 1998], and may be accentuated by the use of the karate uniform, gloves, shin and other body protectors commonly used by these athletes [Carballeira *et al.* 2018]. In our study, the increase in temperature could indicate greater muscular activity during matches, which could be confirmed by the consequent increase in HR observed in males.

In our study, the average RR was 42 ± 4 bpm, which represents an increase of three times the average resting value for humans. According to Nicolo, Massaroni, & Passfield [2017], this respiratory rate corresponds to a perceived effort of 12-13 (on a scale of 6 to 20), but RPE was slightly higher after the matches. It is important to monitor this parameter, since it is known that respiratory muscle fatigue, which may be associated with higher RR, increases the risk of fatigue induced by the muscular metabolic reflex [Romer, Polkey 2008].

One of the main strengths of the present work was that we used a sample of elite athletes, representatives of a national team for international tournaments. In addition, physiological variables were evaluated during simulated matches, which represents novel information. Although a limitation of this study was the number of athletes, the number corresponds to the population of the Chilean national karate team, and high-level athletes are by definition limited in number.

Conclusions

The simulated karate competition under the new Olympic weight categories presented high cardiovascular and metabolic responses. A probable hypothesis is that the results reflect a high temporal demand of matches, however, in this study, the ratio between effort and rest was not measured. Therefore, future research should analyze the temporal structure of simulated karate competitions with the new Olympic categories to confirm the conclusions of this study.

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Fizjologiczne reakcje elity zawodników karate podczas symulowanej walki

Streszczenie

Tło. Sporty walki zdobyły ogromną popularność na całym świecie, a karate jest jednym z najczęściej uprawianych sportów. Karate zostało ostatnio dodane do programu olimpijskiego, a jego oficjalny debiut odbędzie się na Igrzyskach Olimpijskich w Tokio 2020. Jedna z metod walki w karate, *kumite*, ma nieciągłą charakterystykę, co utrudnia ilościowe określenie poziomów intensywności podczas zawodów lub treningu. Celem pracy była więc analiza fizjologicznej reakcji elity zawodników karate kumite podczas symulowanej walki.

Materiał i metody. Dziesięciu zawodników z chilijskiej narodowej drużyny karate (5 mężczyzn, wiek: 24,2 ± 1,8 lat, wzrost: 1,67 ± 0,07 m, masa ciała: 77,8 ± 16,7 kg i 5 kobiet, wiek: 23,2 ± 4,1 lat , wzrost 1,61 ± 0,04 m, masa ciała: 62,2 ± 3,7 kg) wzięło udział w symulowanych zawodach składających się z 4 walk dla każdego zawodnika. Zmierzono następujące zmienne: stężenie mleczanu krwi, częstość akcji serca, ocenę odczuwanego wysiłku, częstość oddechu i temperaturę ciała.

Wyniki. U mężczyzn i kobiet stwierdzono wpływ czasu na temperaturę ciała, średnie tętno u mężczyzn (P = 0,009) oraz 1-minutową regenerację tętna u kobiet (P = 0,044).

Wnioski. Symulowane zawody karate w nowych olimpijskich kategoriach wagowych charakteryzowały się wysokimi reakcjami sercowo-naczyniowymi i metabolicznymi. Prawdopodobną hipotezą jest to, że wyniki odzwierciedlają chwilowy wysoki poziom walki, jednak w tym badaniu nie zmierzono stosunku wysiłku do odpoczynku. Dlatego też przyszłe badania powinny przeanalizować strukturę czasową symulowanych zawodów karate z nowymi

kategoriami olimpijskimi, aby potwierdzić wnioski pochodzące z tego badania.