BRIEF REVIEW

Effects of High-Intensity Interval Training on Olympic Combat Sports Athletes' Performance and Physiological Adaptation: A Systematic Review

Emerson Franchini,[1,2] Stuart Cormack,[2,3] and Monica Y. Takito[4,5]

[1]*Sport Department, Martial Arts and Combat Sports Research Group, School of Physical Education and Sport, University of Sao Paulo, Sao Paulo, Brazil;* [2]*Combat Center, Australian Institute of Sport, Canberra, Australia;* [3]*School of Exercise Science, Australian Catholic University, Melbourne, Australia;* [4]*Human Movement Pedagogy Department, School of Physical Education and Sport, University of Sao Paulo, Sao Paulo, Brazil; and* [5]*University of Canberra, Canberra, Australia*

Abstract

Franchini, E, Cormack, S, and Takito, MY. Effects of high-intensity interval training on Olympic combat sports athletes' performance and physiological adaptation: A systematic review. *J Strength Cond Res* 33(1): 242–252, 2019—Combat sports represent around 25% of all Olympic medals disputed, and the success in these sports are determined by technical-tactical excellence and supported by physiological and psychological development. Although the training in combat sports is intermittent training by nature, some researchers have started to focus their attention on the effects of complementary high-intensity interval training (HIIT)-coupled standard combat sports-specific training on morphological, physiological, and performance adaptations. Thus, in this systematic review, we aimed to verify the effects of this type of training on these variables. A total of 117 articles in the electronic databases Pubmed, Scopus, and Web of Science were retrieved, and 9 studies remained in the present systematic review. A total of 228 athletes (138 judo athletes, 40 taekwondo athletes, 18 boxers, 17 karate athletes, and 15 wrestlers) were investigated in these 9 studies (5 with judo athletes, 1 with boxers, 1 with karate athletes, 1 with wrestlers, and 1 with taekwondo athletes). The HIIT protocols investigated did not generate any change in body fat percentage or body mass but generally resulted in increases in $\dot{V}O_2max$ or $\dot{V}O_2peak$, varying from 4.4 to 23.0%. However, the most observed benefit of HIIT protocols was an increase in anaerobic fitness, represented by improvements in anaerobic power and capacity.

Key Words intermittent training, body composition, aerobic and anaerobic performance, martial arts

Address correspondence to Monica Y. Takito, efranchini@usp.br.

33(1)/242–252

Journal of Strength and Conditioning Research

Introduction

Combat sports represent around 25% of all Olympic medals disputed (15). At the Tokyo 2020 Olympics, individual male and female will be contested in boxing, fencing, judo, karate and freestyle wrestling, and taekwondo, whereas only males will compete in Greco-Roman wrestling. In addition, there will be medals for team events in fencing and judo (36). The success in these sports are determined by technical-tactical excellence and supported by physiological and psychological development, although the key elements for grappling and striking combat sports seem to vary (2,6–8,17,41). Time-motion studies reported striking combat sports, such as boxing (39), karate (40), and taekwondo (38), as well as weapon-based combat sport–fencing (43), have shorter high-intensity efforts interspersed by longer pause periods compared with grappling combat sports such as judo (30) and wrestling (34). Therefore, grappling combat sports rely more on strength endurance and higher levels of maximal strength (16,25,34), whereas striking combat sports depend more on muscle power and speed (5,9,11,39,41). Consequently, grappling combat sports contests have a higher glycolytic contribution (25,34) compared with striking combat sports (5,9,11,24). To cope with the high-intensity intermittent effort pattern and the physiological demand in these sports, athletes perform high-intensity interval training sessions varying in terms of exercise mode (general–e.g., running, rowing, and cycling–and sport-specific), effort and pause intensities, durations, and ratios (7,16,21,23,33,41). High-intensity interval training has been used extensively in many different sports for a long time (1) but has gained increased interest of researchers especially in the last 2 decades, resulting in specific classification of the different types of variable combinations to promote particular adaptations (3,4).

Combat sports-specific training, especially combat simulation, is intermittent by nature (16,39), but only recently researchers have started to focus their attention on the effects of complementary high-intensity interval training combined with standard combat sports-specific training on morphological, physiological, and performance adaptations. Hence, the understanding of the physiological adaptations and performance benefits of high-intensity interval training for Olympic combat sports athletes by coaches and sport scientists can add valuable information to improve the training programs and performance of these athletes. Thus, in this systematic review, we aimed to verify the effects of high-intensity interval training on physiological, morphological, and performance variables.

Methods

Experimental Approach to the Problem

The results of this systematic review are reported according to the Preferred Reporting Item for Systematic Reviews and Meta-analysis statement (31). A literature search was conducted using PubMed, Scopus, and Web of Science databases, from inception up to June 2018, for peer-reviewed articles, with no language restriction. The following groups of keywords were used in combination: (a) Olympic combat sports–related terms–"boxing," "boxer," "fencing," "judo," "judoka," "karate," "karateka," "taekwondo," "wrestler," and "wrestling"; (b) high-intensity interval training–related terms –"high-intensity interval training," "high-intensity intermittent training," "repeated sprint training," "sprint interval training," and "intervals." Moreover, reference lists of all original studies retrieved were manually searched for potentially eligible original articles, which were included if considered relevant.

Subjects

Participants were not restricted by age or sex, but only athletes were considered. Investigations reporting practitioners as subjects were not included in the current review. Only studies that directly compared high-intensity interval training, repeated sprint training or sprint interval training added to the usual combat sports-specific training or a control condition were included. In investigations that used 2 or more interval training protocols, all protocols were described (i.e., the exercise mode, intensity of effort and rest, duration of effort and rest, and number of sets and repetitions for each protocol were presented). Studies with a minimum training duration of 4 weeks were considered. The focus of the present systematic review was on original articles that investigated the effects of high-intensity interval training on body composition, aerobic and anaerobic power and capacity-related variables, and combat sports-specific performance. Data originally presented in figures were digitized using Digitizelt 2.2 (Germany). The brief review was approved by the Research Ethics Committee of the School of Physical Education and Sport, University of Sao Paulo (the number of the protocol is 62743516.7.0000.5391).

Procedures

Types of Interval Training. The classification proposed by Buchheit and Laursen (3) was used to differentiate the protocols applied in the studies reviewed. Briefly, these authors proposed 4 main types of high-intensity interval training protocols:

- High-intensity interval training using long intervals, with intensities equivalent or just below maximal aerobic power, applying effort duration lasting more than 1 minute and work:rest ratios of 1:1, 1:2, or 1:3, mainly focusing on aerobic power and the anaerobic systems development;

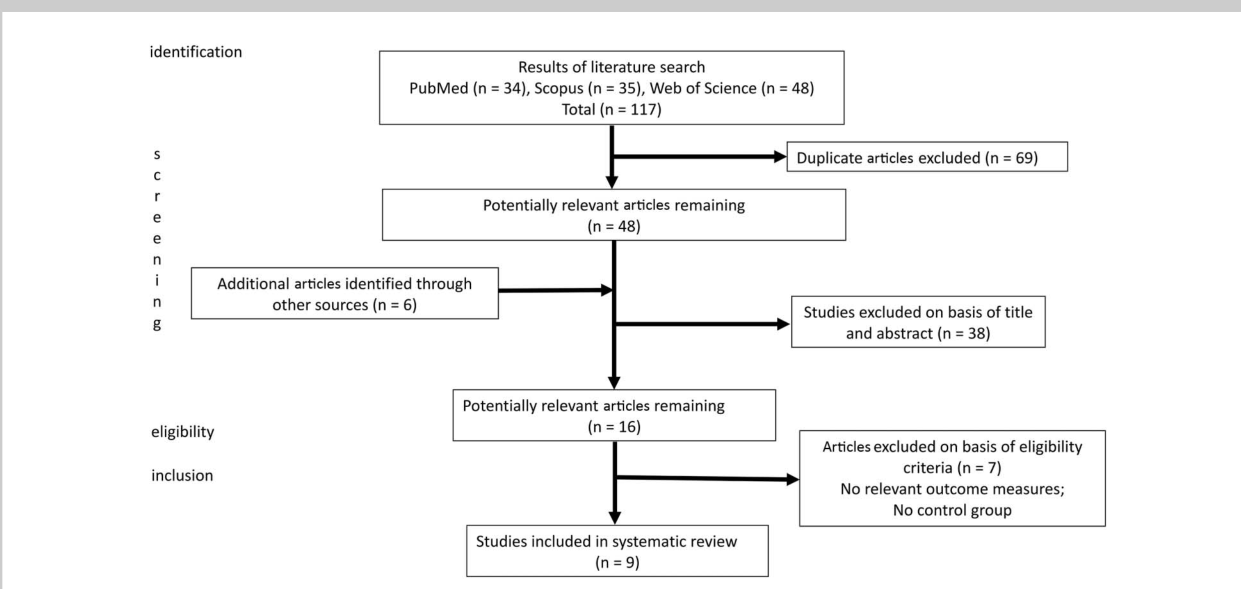

Figure 1. Flow chart presenting the different phases of the search and study selection process.

TABLE 1. Investigations about high-intensity interval training in adult Olympic combat sports athletes.*

Combat sport and study	Groups	Training protocol	Duration (wk)
Boxing			
Kamandulis et al. (26)	Control ($n = 9$), M	Three 3-min rounds (with 1-min intervals), 3 times per week at low-intensity to simulate a match against an imaginary opponent, and light training (20-min jogging, rope skipping, or simulated boxing with an imaginary opponent for 30-min and 10-min stretching exercise), 3 times per week.	4
	Repeated sprint training group ($n = 9$), M	Simulated 3-round match (with 1-min intervals), each comprising 14 sets of 3-second all-out punches interspersed by 10-second intervals, 3 times per week, plus the light training executed by the control group, 3 times per week.	
Judo			
Kim et al. (28)	Resistance training + judo training ($n = 18$), M	7 h per week of resistance training (4 times per week; no details provided about loads, sets, and exercises) + judo training (10 h per week of typical judo training; 5 times per week)	8
	HIIT + judo training ($n = 11$), M	6 h per week (4 times per week; 30-second running efforts with 4-min intervals; weeks 1–2: 6 sprints; weeks 3–8: 8 sprints; weeks 9–12: 10 sprints; weeks 1–2: intensity at 80% maximal aerobic velocity; weeks 3–12: intensity at 90% maximal aerobic velocity) + judo training as in the resistance training group	
Norkowski et al. (35)	Control ($n = 5$), M	25 standard judo training sessions	5
	HIIT ($n = 5$), M	6 × 10-second all-out efforts with 45 rest intervals (some hours before the judo training) + judo training as in the control group	
Lee et al. (29)	Control (judo training only) ($n = 9$), M	10 h per week of typical judo training (5 times per week)	12
	Resistance training + judo training ($n = 10$), M	6 h per week of resistance training (weeks 1–2: 2 × 12 rep at 70% 1RM; weeks 3–8: 3 x 12 rep at 80% 1RM; weeks 9–12: 4 × 12 rep at 80% 1RM; Monday and Tuesday exercises: leg curl, leg dead lift, cable one-leg curl; Thursday and Friday: squat, leg extension, leg press, lunge) + judo training as in the control group	
	HIIT + judo training ($n = 10$), M	6 h per week (4 times per week; 30-second running efforts with 4-min intervals; weeks 1–2: 6 sprints; weeks 3–8: 8 sprints; weeks 9–12: 10 sprints; weeks 1–2: intensity at 80% maximal aerobic velocity; weeks 3–12: intensity at 90% maximal aerobic velocity) + judo training as in the control group	
Franchini et al. (18)	Control ($n = 8$), M	Regular judo training (no specifications reported)	4
	Lower-body HIIT ($n = 9$), M	2 blocks of 10 × 20-second all-out efforts on a lower-body cycle ergometer by 10-second rest intervals between sets and 5 min between blocks (twice per week) + regular judo training	
	Upper-body HIIT ($n = 9$), M	2 blocks of 10 × 20-second all-out efforts on an upper-body cycle ergometer by 10-second rest intervals between sets and 5 min between blocks (twice per week) + regular judo training	
	Uchi-komi HIIT ($n = 9$), M	2 blocks of 10 × 20-second all-out uchi-komi using arm or hip techniques (throwing the partner at the end of each set) by 10-second rest intervals between sets and 5 min between blocks (twice per week) + regular judo training	

Franchini et al. (19)	Control ($n = 8$), M	Regular judo training (no specifications reported)	4
	Lower-body HIIT ($n = 9$), M	2 blocks of 10 × 20-second all-out efforts on a lower-body cycle ergometer by 10-second rest intervals between sets and 5 min between blocks (twice per week) + regular judo training	
	Upper-body HIIT ($n = 9$), M	2 blocks of 10 × 20-second all-out efforts on an upper-body cycle ergometer by 10-second rest intervals between sets and 5 min between blocks (twice per week) + regular judo training	
	Uchi-komi HIIT ($n = 9$), M	2 blocks of 10 × 20-second all-out uchi-komi using arm or hip techniques (throwing the partner at the end of each set) by 10-second rest intervals between sets and 5 min between blocks (twice per week) + regular judo training	
Karate			
Ravier et al. (37)	Control ($n = 8$), M	4–5 times of karate training per week (details not specified)	6–7
	HIIT ($n = 9$), M	7–9 sets of 20-second running at 140% $\dot{V}O_2$max with 15-second rest intervals (twice per week) + karate training as in the control group	
Taekwondo			
Monks et al. (32)	High-intensity continuous training ($n = 20$), 10 M and 10 F	5 km at 85% HRmax (3 times per week on the first 3 wk and twice per week on the last week) + calisthenics (3 sets of 40 rep for the following sit-ups: V-ups, scissors kicks, back extensions, and V-ups combinations; 3 times per week) + typical taekwondo program (5 times per week, no details provided)	4
	HIIT ($n = 20$), 10 M and 10 F	Three times per week, running at 85–100 HRmax (sets varying from 10 to 60 s with 40- to 120-second intervals, distributed along the 4 weeks) + calisthenics and taekwondo training as in the high-intensity continuous training group	
Wrestling			
Farzad et al. (13)	Control ($n = 7$), M	Three wrestling sessions (technique drills, wrestling practice, and calisthenics), 2 weight training (back squat, bench press, military press, bicep curl, power clean exercises; no load, sets, or repetitions described), and 1 plyometric training (press-ups and hand clap, jump down and off the box, squat jumps, explosive start throws, overhead throws, tuck jumps; no sets, repetitions, and intervals provided) per week	4
	HIIT ($n = 8$), M	6 × 35-m sprints with 10-second rest intervals between sprints, twice per week (week 1: 3 sets, with 3-min intervals between sets; 1 set added per week) + same training as control group	

*M = males; HIIT = high-intensity interval training1RM = 1 repetition maximum; $\dot{V}O_2$max = maximal oxygen uptake; HRmax = maximal heart rate; F = females; Uchi-komi = judo technique repetition.

TABLE 2. Effects of high-intensity interval training on body mass and body fat percentage in adult Olympic combat sports athletes.*

Authors	Combat sport and method of body fat percentage determination	Groups	Body mass (kg)	Body fat (%)	Main outcome
	Judo				
Kim et al. (28)	DSM-BIA method, using In-Body 3.0	Resistance training + judo training ($n = 18$), M	Pre: 75.61 ± 10.09 Post: NR	Pre: 13.11 ± 1.79 Post: 12.66 ± 1.47	No difference between groups and no change in any group
		HIIT + judo training ($n = 11$), M	Pre: 74.91 ± 7.73 Post: NR	Pre: 13.36 ± 2.68 Post: 12.28 ± 2.16	
Lee et al. (29)	DSM-BIA method, using In-Body 3.0	Control (judo training only) ($n = 9$), M	Pre: 77.56 ± 11.05 Post: 77.63 ± 12.18	Pre: 13.36 ± 1.36 Post: 13.28 ± 1.01	↓ BM and BF% in the HIIT vs. C
		Resistance training + judo training ($n = 10$), M	Pre: 74.58 ± 9.32 Post: 72.59 ± 9.05	Pre: 12.97 ± 2.09 Post: 12.27 ± 1.71	
		HIIT + judo training ($n = 10$), M	Pre: 73.94 ± 7.41 Post: 71.15 ± 7.92	Pre: 13.31 ± 2.82 Post: 12.27 ± 2.57	
Franchini et al. (19)	Skinfold thickness, Drinkwater and Ross (12) equation	Control ($n = 8$), M	Pre: 80.2 ± 10.3 Post: 80.6 ± 11.2	Pre: 14.6 ± 3.5 Post: 14.2 ± 4.2	No difference between groups and no change in any group
		Lower-body HIIT ($n = 9$), M	Pre: 76.9 ± 10.9 Post: 77.1 ± 10.7	Pre: 12.8 ± 3.7 Post: 12.0 ± 3.0	
		Upper-body HIIT ($n = 9$), M	Pre: 84.2 ± 13.5 Post: 84.2 ± 12.6	Pre: 15.5 ± 4.3 Post: 15.6 ± 4.1	
		Uchi-komi HIIT ($n = 9$), M	Pre: 78.1 ± 13.4 Post: 78.2 ± 12.5	Pre: 15.4 ± 5.0 Post: 15.3 ± 3.6	
	Taekwondo				
Monks et al. (32)	Dual X-ray absorptiometry, using QDR-4500 W	High-intensity continuous training ($n = 20$), 10 M and 10 F	Pre: 70.5 ± 2.28 Post: 70.1 ± 2.25	Pre: 17.7 ± 0.63 Post: 18.2 ± 0.61	Higher ↓ in BM for HIIT vs. the high-intensity continuous training group. BF% ↑ in the HIIT group
		HIIT ($n = 20$), 10 M and 10 F	Pre: 68.4 ± 2.35 Post: 67.0 ± 2.32	Pre: 16.3 ± 0.65 Post: 16.8 ± 0.63	

*M = males; NR = not reported; F = females; ↓ = denotes decrease; Uchi-komi = judo technique repetition; ↑ = denotes increase.

Table 3. Effects of high-intensity interval training on maximal oxygen uptake or peak oxygen uptake in adult Olympic combat sports athletes.*

Combat sport, and study	Groups	$\dot{V}O_2$max or $\dot{V}O_2$peak	Pre	Post	Main outcome
Boxing					
Kamandulis et al. (26)	Control ($n = 9$), M	$\dot{V}O_2$peak ($ml \cdot kg^{-1} \cdot min^{-1}$) determined on a upper-body cycle ergometer (direct gas analysis measurement)	35.0 ± 1.2	35.2 ± 1.5	Higher ↑ in the HIIT group vs. C
	Repeated sprint training group ($n = 9$), M		33.1 ± 1.2	40.7 ± 2.3	
Judo					
Kim et al. (28)	Resistance training + judo training ($n = 18$), M	$\dot{V}O_2$max ($ml \cdot kg^{-1} \cdot min^{-1}$) determined on a treadmill test (direct gas analysis measurement)	46.63 ± 4.99	50.09 ± 4.28	No change and no difference between groups
	HIIT + judo training ($n = 11$), M		49.84 ± 4.08	53.12 ± 4.44	
Lee et al. (29)	Control (judo training only) ($n = 9$), M	$\dot{V}O_2$max ($ml \cdot kg^{-1} \cdot min^{-1}$) determined on a treadmill test (direct gas analysis measurement)	46.56 ± 2.62	48.74 ± 2.61	Higher ↑ in the HIIT group vs. C
	Resistance training + judo training ($n = 10$), M		46.95 ± 6.45	49.88 ± 5.49	
	HIIT + judo training ($n = 10$), M		49.88 ± 4.30	54.39 ± 4.32	
Franchini et al. (19)	Control ($n = 8$), M	$\dot{V}O_2$peak ($L \cdot min^{-1}$) determined on upper- and lower-body cycle ergometers (direct gas analysis measurement)	UB: 2.86 ± 0.37 LB: 3.56 ± 0.49	UB: 2.72 ± 0.83 LB: 3.54 ± 0.74	No change and no difference between groups
	Lower-body HIIT ($n = 9$), M		UB: 2.78 ± 0.41 LB: 3.62 ± 0.50	UB: 3.03 ± 0.37 LB: 3.68 ± 0.80	
	Upper-body HIIT ($n = 9$), M		UB: 3.10 ± 0.70 LB: 3.82 ± 0.59	UB: 3.22 ± 0.58 LB: 3.86 ± 0.44	
	Uchi-komi HIIT ($n = 9$), M		UB: 3.16 ± 0.30 LB: 3.87 ± 0.44	UB: 3.27 ± 0.33 LB: 3.74 ± 0.36	
Karate					
Ravier et al. (37)	Control ($n = 8$), M	$\dot{V}O_2$max ($ml \cdot kg^{-1} \cdot min^{-1}$) determined on a treadmill test (direct gas analysis measurement)	58.2 ± 3.1	58.1 ± 4.4	↑ in the HIIT group
	HIIT ($n = 9$), M		58.7 ± 3.1	61.4 ± 2.6	
Taekwondo					
Monks et al. (32)	High-intensity continuous training ($n = 20$), 10 M and 10 F	$\dot{V}O_2$max ($ml \cdot kg^{-1} \cdot min^{-1}$) determined on a treadmill test (direct gas analysis measurement)	51.5 ± 1.34	52.4 ± 1.53	↑ in both groups
	HIIT ($n = 20$), 10 M and 10 F		56.1 ± 1.38	60.8 ± 1.58	
Wrestling					
Farzad et al. (13)	Control ($n = 7$), M	$\dot{V}O_2$max ($ml \cdot kg^{-1} \cdot min^{-1}$) determined on a treadmill test (direct gas analysis measurement)	51.2 ± 6.1	50.1 ± 4.7	↑ in HIIT group
	HIIT ($n = 8$), M		49.3 ± 4.4	52.0 ± 3.4	

*M = males; $\dot{V}O_2$peak = peak oxygen uptake; ↑ = denotes increase; C = control group; $\dot{V}O_2$max = maximal oxygen uptake; F = females; LB = lower-body; UB: upper-body; Uchi-komi = judo technique repetition.

TABLE 4. Effects of high-intensity interval training on anaerobic power and capacity variables in adult Olympic combat sports athletes.*

Combat sport, and study	Groups	Variable	Pre	Post	Main outcome
Judo					
Kim et al. (27)	Resistance training + judo training ($n = 18$), M	LB PP ($W\cdot kg^{-1}$)	12.86 ± 1.93	13.88 ± 2.27	↑ PP and MP in the HIIT group
		LB MP ($W\cdot kg^{-1}$)	9.19 ± 1.67	9.65 ± 3.15	
	HIIT + judo training ($n = 11$), M	LB PP ($W\cdot kg^{-1}$)	12.84 ± 1.33	15.46 ± 1.68	
		LB MP ($W\cdot kg^{-1}$)	9.43 ± 1.10	12.14 ± 2.12	
Norkowski et al. (34)	Control ($n = 5$), M	LB PP ($W\cdot kg^{-1}$)	11.02 ± 1.07	11.21 ± 0.64	↑ PP and TW in the HIIT group
		LB TW ($J\cdot kg^{-1}$)	90.20 ± 3.43	93.44 ± 4.56	
	HIIT ($n = 5$), M	LB PP ($W\cdot kg^{-1}$)	11.26 ± 0.41	12.54 ± 0.72	
		LB TW ($J\cdot kg^{-1}$)	96.83 ± 4.70	106.32 ± 5.05	
Lee et al. (28)	Control (judo training only) ($n = 9$), M	LB PP ($W\cdot kg^{-1}$)	12.40 ± 2.14	13.19 ± 2.13	↑ PP in RT group, while ↑ MP in RT and HIIT groups vs. C
		LB MP ($W\cdot kg^{-1}$)	9.41 ± 1.86	9.44 ± 1.86	
	Resistance training + judo training ($n = 10$), M	LB PP ($W\cdot kg^{-1}$)	13.23 ± 1.48	15.07 ± 1.32	
		LB MP ($W\cdot kg^{-1}$)	9.13 ± 1.43	11.17 ± 2.92	
	HIIT + judo training ($n = 10$), M	LB PP ($W\cdot kg^{-1}$)	12.9 ± 1.35	14.42 ± 1.15	
		LB MP ($W\cdot kg^{-1}$)	9.52 ± 1.11	13.02 ± 1.77	
Franchini et al. (19)	Control ($n = 8$), M	UB PP ($W\cdot kg^{-1}$)	9.36 ± 1.09	8.53 ± 1.81	↑ UB and LB PP in the uchi-komi HIIT group; ↑ LB PP in the HIIT groups pooled.
		LB PP ($W\cdot kg^{-1}$)	11.72 ± 2.74	10.78 ± 1.96	
		UB MP ($W\cdot kg^{-1}$)	5.67 ± 0.77	5.48 ± 0.75	
		LB MP ($W\cdot kg^{-1}$)	8.18 ± 1.13	8.02 ± 1.31	
	Lower-body HIIT ($n = 9$), M	UB PP ($W\cdot kg^{-1}$)	9.27 ± 1.11	9.84 ± 1.35	
		LB PP ($W\cdot kg^{-1}$)	10.29 ± 1.60	12.04 ± 1.31	
		UB MP ($W\cdot kg^{-1}$)	6.63 ± 0.62	6.47 ± 0.72	
		LB MP ($W\cdot kg^{-1}$)	8.03 ± 1.39	8.85 ± 0.84	
	Upper-body HIIT ($n = 9$), M	UB PP ($W\cdot kg^{-1}$)	7.88 ± 1.23	8.63 ± 1.22	
		LB PP ($W\cdot kg^{-1}$)	10.73 ± 1.41	10.31 ± 2.00	
		UB MP ($W\cdot kg^{-1}$)	5.82 ± 0.77	5.72 ± 0.91	
		LB MP ($W\cdot kg^{-1}$)	8.02 ± 1.14	7.34 ± 1.31	
	Uchi-komi HIIT ($n = 9$), M	UB PP ($W\cdot kg^{-1}$)	8.18 ± 1.33	9.40 ± 1.06	
		LB PP ($W\cdot kg^{-1}$)	10.48 ± 1.31	10.91 ± 1.26	
		UB MP ($W\cdot kg^{-1}$)	5.61 ± 0.73	6.15 ± 0.66	
		LB MP ($W\cdot kg^{-1}$)	7.88 ± 1.11	8.04 ± 1.08	
Karate					
Ravier et al. (36)	Control ($n = 8$), M	MAOD ($mL\cdot kg^{-1}$)	65.5 ± 7.3	62.0 ± 10.0	↑ MAOD in the HIIT group
	HIIT ($n = 9$), M		63.9 ± 6.2	70.5 ± 6.4	
Taekwondo					
Monks et al. (31)	High-intensity continuous training ($n = 20$), 10 M and 10 F	LB PP (W)	695.61 ± 28.96	693.33 ± 26.67	↑ PP and MP in the HIIT group
		LB MP (W)	461.65 ± 20.62	478.95 ± 17.18	
	HIIT ($n = 20$), 10 M and 10 F	LB PP (W)	709.33 ± 29.71	761.00 ± 29.09	
		LB MP (W)	479.08 ± 20.61	563.13 ± 17.67	
Wrestling					
Farzad et al. (13)	Control ($n = 7$), M	LB PP ($W\cdot kg^{-1}$)	948.9 ± 316.3	862.7 ± 238.3	↑ PP and MP in the HIIT group
		LB MP ($W\cdot kg^{-1}$)	399.9 ± 71.17	400.7 ± 71.1	
	HIIT ($n = 8$), M	LB PP ($W\cdot kg^{-1}$)	953.1 ± 312.2	1,137.9 ± 433.7	
		LB MP ($W\cdot kg^{-1}$)	462.7 ± 119.0	491.6 ± 133.9	

*M = males; LB = lower-body; PP = peak power; MP = mean power; ↑ = denotes increase; TW = total work; RT = resistance training; UB: upper-body; Uchi-komi = judo technique repetition; MAOD = maximal accumulated oxygen deficit; F = females.

- High-intensity interval training using short intervals, with intensities equivalent or just above maximal aerobic power (up to approximately 120%), applying effort duration lasting less than 1 minute and work:rest ratios of 1:1, 2:1, or 3:1, mainly directed to develop aerobic power and the anaerobic systems;
- Repeated sprint training, using very short actions (5–8 seconds) at intensities around 120–160% $\dot{V}O_2$max, with

very long recovery periods, and directed to neuromuscular and metabolic development frequently needed in team sports;
- Sprint interval training, using four to six 30-second all-out efforts separated by 3- to 4-minute intervals, allowing for full recovery, but resulting in very high aerobic and anaerobic demands.

Assessment of Risk of Bias. Titles and abstracts of the articles retrieved from the literature search were assessed by the first and last authors. Briefly, to select an article, both authors searched for the following aspects (31): (a) clear inclusion criteria, especially concerning the inclusion of athletes from one of the Olympic combat sports; (b) clear description of the athletes training experience; (c) clearly defined intervention, specifically reporting exercise mode, intensity of effort and pause, frequency (training sessions per week), number of weeks of training, duration of effort and pause, number of series, and repetitions for the high-intensity interval training protocol used; (d) the same tests would be applied before and after intervention to all groups; (e) use of a control or continuous training group; (f) clearly defined outcome variables among those of interest for the present review; and (g) appropriate statistical analysis. There was no disagreement between the authors concerning the articles' selection process.

Results

Search Results

Figure 1 presents a flow chart of the results of the systematic search conducted, which retrieved a total of 117 articles in the electronic databases Pubmed, Scopus, and Web of Science. After adding relevant studies from other sources (i.e., articles listed in original and review articles) and after removing duplicates, screening the articles by title and abstract, and removing ineligible articles, 9 studies remained in the present systematic review. A total of 228 athletes (138 judo athletes, 40 taekwondo athletes, 18 boxers, 17 karate athletes, and 15 wrestlers) were investigated in these 9 studies (5 with judo athletes, 1 with boxers, 1 with karate athletes, 1 with wrestlers, and 1 with taekwondo athletes).

Discussion

Based on the information in Table 1, training programs varied from 4 (13,18,19,26,32) to 12 weeks (29), with high-intensity interval training being executed from 2 (18,19,36) to 5 (36) times per week. Few studies used combat sport–specific tasks (18,19,26), whereas all the other studies used running or cycling exercises, with intensities varying from submaximal efforts (80% of maximal aerobic velocity) (28,29) to all-out efforts (13,18,19,26,35). Most of the studies did not include a full description of the combat sport–typical training sessions (18,19,26,28,29,32,35), normally conducted by the control groups, and some studies also included resistance (13,28,29) and plyometric training (13) for the control groups. Moreover, only one study included female athletes (31), which were analyzed together with male athletes; thus, studies analyzing exclusively female combat sports athletes are needed to verify whether they adapt in a similar way as males.

As combat sports athletes are classified in weight categories and frequently engage in weight loss procedures, the maintenance or decrease of body mass, decrease in body fat, and increase in muscle mass are desired training outcomes (15). Despite the relevance of these variables, only 3 studies measured body mass and 4 estimated body fat percentage in Olympic combat sports athletes submitted to high-intensity interval training, using different methods (Direct Segmental Multi-frequency Bioelectrical Impedance Analysis [DSM-BIA]; dual X-ray absorptiometry; and skinfold thickness) (Table 2). Two studies reported decreased body mass (2.1–2.7%) in the high-intensity interval training groups (29,32), whereas 1 observed no change (19). For body fat percentage, 2 studies observed no change (19,28) and 1 found a decrease (7.8%) only for the high-intensity interval training group compared with the control group (29), whereas Monks et al. (32) indicated an increase (3%) for the high-intensity interval training group only. Considering that the groups investigated were composed of highly trained athletes with moderate to low body fat percentages and that the training programs were conducted for short periods (4–12 weeks) without any associated nutritional intervention, the finding of no change in body mass and body fat percentage as reported in the literature regarding high-intensity interval training is to be expected (27). The only negative effect of high-intensity interval training on body fat percentage (i.e., an increase) was not discussed by the authors (32), which makes it difficult to explain their findings in our review.

Aerobic power and capacity have been considered relevant to combat sports performance because of the predominance of the oxidative contribution reported in boxing (10), fencing (24), judo (25), karate (11), and taekwondo (5). Furthermore, aerobic fitness has been considered important to maintain volume and intensity of attacks during the match, to allow for faster creatine phosphate resynthesis in the short pause between high-intensity actions performed during the match, and to allow for a faster recovery between judo matches (14,22). Indeed, moderate to high values of $\dot{V}O_2max$ have been observed in boxing (8), fencing (41), judo (17), karate (6), taekwondo (2), and wrestling (7).

Table 3 presents the studies that investigated the effects of high-intensity interval training on $\dot{V}O_2max$ and $\dot{V}O_2peak$ in combat sports athletes. From 7 studies that investigated the effects of high-intensity interval training on $\dot{V}O_2max$ or $\dot{V}O_2peak$ in combat sports athletes, 4 found higher increases in the high-intensity interval training group (13,26,29,37), 1 observed a similar increase in the high-intensity interval training and high-intensity continuous group (32), whereas 2 did not report any change for any group (19,28). Thus, it seems that high-intensity interval training has a strong potential to increase aerobic power in combat sports athletes because the improvement revealed in the different studies indicated an increase from 4.4 to 23.0%, in periods varying from 4 to 7 weeks, which is similar to the improvements in active non-athletic individuals reported in a meta-analysis (42).

The high-intensity interval training programs investigated also resulted in other physiological changes. Lee et al. (29) reported that HRmax decreased in the high-intensity interval training group compared with the control group. Decreases in HRmax were also observed by Monks et al. (32) in both training groups (i.e., high-intensity interval training and high-intensity continuous training). Such a decrease in HRmax was probably related to an optimization of ventricular filling, resulting in a higher stroke volume and higher maximal cardiac output after the high-intensity interval training program compared with pre-values. Indeed, Farzad et al. (13) observed an increase in $\dot{V}O_2$/HRpeak in the high-intensity interval training group during the maximal graded exercise test, indicating an elevation in stroke volume and, hence, better oxygen delivery. The increase in stroke volume accompanied by oxygen use of active muscles (due to increases in capillarization and mitochondrial density) likely explains the higher $\dot{V}O_2$max observed in the studies conducted by Farzad et al. (13) and Monks et al. (32).

Farzad et al. (13) observed a 24% increase in time to exhaustion in the high-intensity interval training group, although $\dot{V}O_2$max did not change. Conversely, Franchini et al. (19) did not observe any change in $\dot{V}O_2$peak, but athletes in the upper-body high-intensity interval training group increased their maximal aerobic power in the maximal upper-body graded exercise test. Moreover, Kamandulis et al. (26) reported increases in both upper-body $\dot{V}O_2$peak and maximal aerobic power in boxers who performed sport-specific repeated sprint training and in the control group, with larger increments in the former. Based on these results, it seems that physiological and performance changes do not always occur in the same time window, and hence, further investigation is needed to better understand the sequence of adaptations in response to high-intensity interval training. Furthermore, the fact that, in 2 studies (13,19), combat sports athletes were trained and tested in non–sport-specific modes may have contributed to some of the improvements observed and to the dissociation between physiological and performance changes. However, boxers who trained using sport-specific actions (all-out effort punching bag) improved both physiological and performance markers.

Only one study (19) investigated submaximal variables in response to high-intensity interval training in combat sports athletes. This study reported an improvement in the intensity associated with onset of blood lactate accumulation during the upper-body graded exercise test in judo athletes who performed lower-body high-intensity interval training (Table 1), from 68 ± 22 W to 83 ± 14 W.

Anaerobic power has been considered important to support high-intensity actions during combat sports. These actions frequently result in scores and are represented by punching, kicking, and throwing techniques. Conversely, repeated high-intensity kicking, punching, throwing actions, and especially grip dispute (in wrestling and judo) are dependent on anaerobic capacity (5,10,11,25). Thus, anaerobic power and capacity are considered key elements for successful performance in combat sports. Table 4 presents studies that investigated the effects of high-intensity interval training on anaerobic power and capacity in combat sports athletes.

As presented in Table 4, all 6 studies that assessed peak power indicated that high-intensity interval training was effective in improving this variable. Four (13,28,29,32) of 5 studies demonstrated an increased Wingate test mean power in the high-intensity interval training groups, whereas 1 study also demonstrated an increased total work in the first repetition of a six 10-second cycle ergometer sprints, separated by 45-second intervals (35). In addition, Ravier et al. (37) demonstrated an improvement in the maximal accumulated oxygen deficit in their high-intensity interval training group. Thus, it can be concluded that high-intensity interval training protocols used in the studies selected in our systematic review were able to increase variables related to both anaerobic power and capacity. As Olympic combat sports are characterized by high-intensity actions interspersed by low-intensity phases (9,19,30,38,41,43), some investigations also analyzed the effects of high-intensity interval training on high-intensity intermittent performance (13,18,19,35). Farzad et al. (13) and Franchini et al. (19) used 4 Wingate bouts separated by 4 and 3 minutes, respectively. Farzad et al. (13) did not report the total work during the Wingate bouts but indicated increased mean power in bouts 1 and 2, whereas Franchini et al. (19) did not reveal any significant changes in total work for upper- or lower-body protocols, although increased mean power was detected in the fourth bout of the lower-body Wingate test when all high-intensity interval training groups were pooled. The lack of increase in total work in this study seems to be related to the fact that mean power (pooled across the 4 lower-body Wingate bouts) increased only for the lower-body high-intensity interval training group, whereas the decrease in the same variable was observed for the upper-body and uchi-komi (technique repetition) high-intensity interval training groups. Norkowski et al. (35) used a six 10-second all-out effort separated by 45-second rest intervals between sets and revealed increased mean and peak power in each set for the high-intensity interval training group, but no measure of total work was reported. Taken together, these studies point to a positive effect of high-intensity interval training when the stimuli and testing procedures are specific in terms of muscle group assessed; however, training differently than the testing mode can result in decreased performance.

Two studies used sport-specific tasks (i.e., tasks that were composed by sport-specific actions, such as judo throws and number of punches during a 3-second task) (18,26). Franchini et al. (18) used the Special Judo Fitness Test (SJFT), which is a high-intensity intermittent task (15, 30, and 30 s of effort and 10-second rest intervals between sets) using 1 judo throwing technique (ippon-seoi-nage). They observed an increased number of throws for the upper-body high-intensity interval training group, whereas the SJFT index–considered a representation of combined anaerobic and aerobic qualities (20)–improved in the uchi-komi high-intensity interval training group, suggesting that the high-intensity interval training adaptations are stimuli-specific. However, Kamandulis et al. (26) assessed the number of punches during a 3-second task and did not find any change after 4 weeks of all-out sport-specific training. Only 2 studies investigated the performance and physiological responses in an Olympic combat sport–specific condition (i.e., judo match simulation) (18,28). Kim et al. (28) reported no change in heart rate after a 5-minute judo match in any of the groups analyzed. Similar results were observed by Franchini et al. (18) (i.e., no change in heart rate, rating of perceived exertion, or blood lactate during the 5-minute judo match simulation), for any of the groups investigated. In addition, these authors (18) revealed no change in technical actions performed during the simulated judo match. However, they observed decreased creatine kinase response to the judo match simulation at post-training compared with pre-training. When groups were analyzed in isolation, the difference was confirmed for the upper-body high-intensity interval training group, probably due to the lower total muscle mass involved in this protocol compared with the other high-intensity interval training protocols used. Moreover, the testosterone-cortisol ratio response to the judo match simulation was higher post-training compared with pre-training, indicating that this condition induced a more anabolic state in these judo athletes. In terms of temporal structure, the only change observed was a decrease in the number of standing sequences for the lower-body high-intensity interval training group, which was attributed to the improvements in aerobic and anaerobic fitness commonly generated by high-intensity interval training, allowing the athletes to perform techniques at higher intensity despite spending less time in this combat phase where more scores are achieved.

Practical Applications

The studies selected in this systematic review used training programs that varied from 4 to 12 weeks, with high-intensity interval training being executed from 2 to 5 times per week. Investigations typically involved running and cycle ergometer bouts, with only 2 studies reporting a combat sport–specific task. Intensity varied from submaximal efforts (80% of maximal aerobic velocity) to all-out efforts. The high-intensity interval training protocols were added to the typical combat sport training, conducted by the control groups, and some studies also included resistance and plyometric training for the control groups. These high-intensity interval training protocols typically did not generate any change in body fat percentage or body mass, indicating it can be useful to maintain the athletes in their current weight categories. High-intensity interval training generally resulted in increases in $\dot{V}O_2$max or $\dot{V}O_2$peak in combat sports athletes, varying from 4.4 to 23.0%. As aerobic fitness has been reported to contribute to faster recovery, these results suggest that high-intensity interval training can help to improve athletes' recovery between successive high-intensity actions or between matches. Moreover, the most observed benefit of high-intensity interval training protocols was an increase in anaerobic fitness, represented by improvements in anaerobic power and capacity, which can potentially benefit combat sports athletes because these 2 variables are relevant to scoring actions and repeated high-intensity actions, respectively.

As only 3 studies included combat sport–specific tasks in their evaluation process and only 2 studies used a combat sport–specific high-intensity interval training protocol, future investigations should focus on the transfer benefits of high-intensity interval training to the match or specific tests in each of the combat sports. Furthermore, only one study included female athletes in their sample, but they were grouped with male athletes; thus, investigations analyzing female athletes only are needed to verify how they adapt to high-intensity interval training.

Acknowledgments

The authors would thank for São Paulo Research Foundation support E. Franchini (FAFESP 2017/08167-2) and M.Y. Takito (FAPESP 2017/19280-4).

References

1. Billat, LV. Interval training for performance: A scientific and empirical practice–Special recommendations for middle- and long-distance running. Part I: Aerobic interval training. *Sports Med* 31: 13–31, 2001.
2. Bridge, CA, Ferreira da Silva Santos, J, Chaabène, H, Pieter, W, and Franchini, E. Physical and physiological profiles of taekwondo athletes. *Sports Med* 44: 713–733, 2014.
3. Buchheit, M and Laursen, PB. High-intensity interval training, solutions to the programming puzzle. Part I: Cardiopulmonary emphasis. *Sports Med* 43: 313–338, 2013.
4. Buchheit, M and Laursen, PB. High-intensity interval training, solutions to the programming puzzle. Part II: Anaerobic energy, neuromuscular load and practical applications. *Sports Med* 43: 927–954, 2013.
5. Campos, FA, Bertuzzi, R, Dourado, AC, Santos, VG, and Franchini, E. Energy demands in taekwondo athletes during combat simulation. *Eur J Appl Physiol* 112: 1221–1228, 2012.
6. Chaabene, H, Hachana, Y, Franchini, E, Mkaouer, B, and Chamari, K. Physical and physiological profile of elite karate athletes. *Sports Med* 42: 829–843, 2012.
7. Chaabene, H, Negra, Y, Bouguezzi, R, Mkaouer, B, Franchini, E, Julio, U, et al. Physical and physiological attributes of wrestlers: An update. *J Strength Cond Res* 31: 1411–1442, 2017.
8. Chaabène, H, Tabben, M, Mkaouer, B, Franchini, E, Negra, Y, Hammami, M, et al. Amateur boxing: Physical and physiological attributes. *Sports Med* 45: 337–352, 2015.

9. Davis, P, Leithäuser, RM, and Beneke, R. The energetics of semicontact 3 × 2-min amateur boxing. *Int J Sports Physiol Perform* 9: 233–239, 2014.
10. Davis, P, Wittekind, A, and Beneke, R. Amateur boxing: Activity profile of winners and losers. *Int J Sports Physiol Perform* 8: 84–92, 2013.
11. Doria, C, Veicsteinas, A, Limonta, E, Maggioni, MA, Aschieri, P, Eusebi, F, et al. Energetics of karate (kata and kumite techniques) in top-level athletes. *Eur J Appl Physiol* 107: 603, 2009.
12. Drinkwater, DT and Ross, WD. Anthropometric fractionation of body mass. In: M Ostyn, G Beunen, and J Simons, eds. *Kinanthropometry II.* Baltimore, MD: University Park Press, 1980. pp. 177–189.
13. Farzad, B, Gharakhanlou, R, Agha-Alinejad, H, Curby, DG, Bayati, M, Bahraminejad, M, et al. Physiological and performance changes from the addition of a sprint interval program to wrestling training. *J Strength Cond Res* 25: 2392–2399, 2011.
14. Franchini, E, Artioli, GG, and Brito, CJ. Judo combat: Time-motion analysis and physiology. *Int J Perform Anal Sport* 13: 624–641, 2013.
15. Franchini, E, Brito, CJ, and Artioli, GG. Weight loss in combat sports: Physiological, psychological and performance effects. *J Int Soc Sports Nutr* 9: 52, 2012.
16. Franchini, E, Brito, CJ, Fukuda, DH, and Artioli, GG. The physiology of judo-specific training modalities. *J Strength Cond Res* 28: 1474–1481, 2014.
17. Franchini, E, Del Vecchio, FB, Matsushigue, KA, and Artioli, GG. Physiological profiles of elite judo athletes. *Sports Med* 41: 147–166, 2011.
18. Franchini, E, Julio, UF, Goncalves Panissa, VL, Lira, FS, Agostinho, MF, and Magnani Branco, BH. Short-term low-volume high-intensity intermittent training improves judo-specific performance. *Arch Budo* 12: 219–229, 2016.
19. Franchini, E, Julio, UF, Panissa, VL, Lira, FS, Gerosa-Neto, J, and Branco, BH. High-intensity intermittent training positively affects aerobic and anaerobic performance in judo athletes independently of exercise mode. *Front Physiol* 7: 268, 2016.
20. Franchini, E, Sterkowicz, S, Szmatlan-Gabrys, U, Gabrys, T, and Garnys, M. Energy system contributions to the special judo fitness test. *Int J Sports Physiol Perform* 6: 334–343, 2011.
21. Franchini, E and Takito, MY. Olympic preparation in Brazilian judo athletes: Description and perceived relevance of training practices. *J Strength Cond Res* 28: 1606–1612, 2014.
22. Gariod, L, Favre-Juvin, A, Novel, V, Reutenauer, H, Majean, H, and Rossi, A. Évaluation du profil énergétique des judokas par spectroscopie RMN du P31. *Sci Sports* 10: 201–207, 1995.
23. Herrera-Valenzuela, T, Zapata-Bastias, J, Guajardo-Medrano, M, Pons-Vargas, P, Santos, JFS, Garcia-Hertmoso, A, et al. Can simulation tasks reproduce the taekwondo match physiological responses? *Arch Budo* 14: 25–31, 2018.
24. Iglesias, X and Rodríguez, FA. Caracterización de la frecuencia cardiaca y la lactatemia en esgrimistas durante la competición. *Apunts Med Esport* 32: 21–32, 1995.
25. Julio, UF, Panissa, VLG, Esteves, JV, Cury, RL, Agostinho, MF, and Franchini, E. Energy-system contributions to simulated judo matches. *Int J Sports Physiol Perform* 12: 676–683, 2017.
26. Kamandulis, S, Bruzas, V, Mockus, P, Stasiulis, A, Snieckus, A, and Venckunas, T. Sport-specific repeated sprint training improves punching ability and upper-body aerobic power in experienced amateur boxers. *J Strength Cond Res* 32: 1214–1221, 2018.
27. Keating, SE, Johnson, NA, Mielke, GI, and Coombes, JS. A systematic review and meta-analysis of interval training versus moderate-intensity continuous training on body adiposity. *Obes Rev* 18: 943–964, 2017.
28. Kim, J, Lee, N, Trilk, J, Kim, EJ, Kim, SY, Lee, M, et al. Effects of sprint interval training on elite Judoists. *Int J Sports Med* 32: 929–934, 2011.
29. Lee, N, Kim, J, Am Hyung, G, Park, JH, Kim, SJ, Kim, HB, et al. Training effects on immune function in judoists. *Asian J Sports Med* 6: e24050, 2015.
30. Miarka, B, Panissa, VL, Julio, UF, Del Vecchio, FB, Calmet, M, and Franchini, E. A comparison of time-motion performance between age groups in judo matches. *J Sports Sci* 30: 899–905, 2012.
31. Moher, D, Liberati, A, Tetzlaff, J, Altman, DG; PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Med* 6: e1000097, 2009.
32. Monks, L, Seo, MW, Kim, HB, Jung, HC, and Song, JK. High-intensity interval training and athletic performance in taekwondo athletes. *J Sports Med Phys Fitness* 57: 1252–1260, 2017.
33. Nakamura, FY, Pereira, LA, Abad, CC, Franchini, E, and Loturco, I. Cardiac autonomic and neuromuscular responses during a karate training camp before the 2015 Pan American games: A case study with the Brazilian national team. *Int J Sports Physiol Perform* 11: 833–837, 2016.
34. Nilsson, J, Csergö, S, Gullstrand, L, Tveit, P, and Refsnes, PE. Work-time profile, blood lactate concentration and rating of perceived exertion in the 1998 Greco-Roman wrestling World Championship. *J Sports Sci* 20: 939–945, 2002.
35. Norkowski, H, Borowiak, W, Sikorski, W, and Śledziewski, D. Effect of interval training in the competitive period on anaerobic capacity in judo athletes. *J Combat Sports Mart Arts* 5: 49–52, 2014.
36. *Olympic Games Tokyo 2020, Tokyo Organising Committee of the Olympic and Paralympic Games [internet].* Available at: https://tokyo2020.org/en/games/sport/olympic/. Accessed March 19, 2018.
37. Ravier, G, Dugué, B, Grappe, F, and Rouillon, JD. Impressive anaerobic adaptations in elite karate athletes due to few intensive intermittent sessions added to regular karate training. *Scand J Med Sci Sports* 19: 687–694, 2009.
38. Santos, VG, Franchini, E, and Lima-Silva, AE. Relationship between attack and skipping in taekwondo contests. *J Strength Cond Res* 25: 1743–1751, 2011.
39. Slimani, M, Chaabène, H, Davis, P, Franchini, E, Cheour, F, and Chamari, K. Performance aspects and physiological responses in male amateur boxing competitions: A brief review. *J Strength Cond Res* 31: 1132–1141, 2017.
40. Tabben, M, Coquart, J, Chaabène, H, Franchini, E, Ghoul, N, and Tourny, C. Time-motion, tactical and technical analysis in top-level karatekas according to gender, match outcome and weight categories. *J Sports Sci* 33: 841–849, 2015.
41. Turner, A, James, N, Dimitriou, L, Greenhalgh, A, Moody, J, Fulcher, D, et al. Determinants of Olympic fencing performance and implications for strength and conditioning training. *J Strength Cond Res* 28: 3001–3011, 2014.
42. Weston, M, Taylor, KL, Batterham, AM, and Hopkins, WG. Effects of low-volume high-intensity interval training (HIT) on fitness in adults: A meta-analysis of controlled and non-controlled trials. *Sports Med* 44: 1005–1017, 2014.
43. Wylde, JM, Tan, FH, and O'Donoghue, GP. A time-motion analysis of elite women's foil fencing. *Int J Perform Anal Sport* 13: 365–376, 2013.