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Effect of a Short HIIT Program with Specific Techniques on Physical Condition and Activity during Simulated Combat in National-Level Boxers

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Abstract: The present study investigated the effect of an additional short-duration HIIT program using boxing-specific techniques on activity during a simulated competition. Additionally, we investigated the impact on physical fitness, specifically aerobic performance and lower-body muscle power. Sixteen boxers were randomized into a control (n = 8) or experimental groups (n = 8). The experimental protocol consisted of 3 blocks of 5 repetitions of 30s all-out effort, with 6s recovery between repetitions and 1 min rest interval between blocks, conducted 3 days per week for 4 weeks. A two-way (group, two levels; moment, two levels) analysis of variance with repeated measurements in the second factor was used. For the experimental group, there was a change in body mass (ES = −0.13 (trivial)), body fat percentage (ES = −0.12 (trivial)), VO_{2max} (ES = +0.42 (small)), CMJ (ES = +0.12 (trivial)), CMJ-left (ES = −0.11 (trivial)), CMJ-right (ES = +0.22 (trivial)), actions (ES = +0.68 (moderate)), time (ES = −0.29 (small)) and punches (ES = +0.56 (moderate)). For the control group, there was a change in body mass (ES = +0.04 (trivial)), body fat percentage (ES = −0.12 (trivial)), VO_{2max} (ES = +0.11 (trivial)), CMJ (ES = −0.27 (small)), CMJ-left (ES = −0.39 (small)), CMJ-right (ES = +0.08 (trivial)), actions (ES = +0.08 (trivial)), time (ES = −0.65 (moderate)) and punches (ES = −0.57 (moderate)). The punches variable was significant concerning group-by-time interaction ($F_{1,14}$ = 11.630; p = 0.004; n^2 = 0.454). The present study indicated that the addition of a boxing-specific HIIT program is effective to increase the number of punches during a simulated match.

Keywords: combat sports; high-intensity intermittent training; athletic performance; physical conditioning

1. Introduction

Boxing is an ancestral combat sport and has been part of the modern Olympic Games since 1904. In simulated competition, the predominant energy system comes from the oxidative system (77%), responsible for the recovery processes between effort during combat, followed by the ATP–PC (phosphagen system, 19%), accountable for the high-intensity scoring actions, and finally, 4% is attributed to the glycolytic system [1]. This distribution is directly linked to the intermittent characteristics of boxing competition, as the work-to-rest ratio in high-level boxing official matches is 18:1 [2,3]. During an official match, boxers execute a total of approximately 130 punches (round 1: 46.7; round 2: 40.6; round 3: 42.3) in the case of novice athletes and approximately 196 punches in the case of elite athletes (round 1: 61.0; round 2: 70.8; round 3: 63.8) [3]. Therefore, boxers require an optimal level of neuromuscular fitness for the execution of explosive movements and punches and adequate aerobic fitness to recover between efforts [1,3,4]. Generally, aerobic power is measured through the maximum oxygen consumption (VO_{2max}), and male boxers present values between 49 and 65 mL/kg/min, whereas female boxers present values between 44 and 52 mL/kg/min [5]. Boxer's lower-body muscle power is frequently evaluated through jump tests such as the countermovement jump with arms (CMJ-arm), achieving values between 41.7 and 43.6 cm for males [5].

Although combat-sports athletes normally perform intermittent efforts, typical high-intensity interval training (HIIT) programs can be classified as "long intervals" (>60 s), "short intervals" (<60 s), "sprints interval training" and "repeated sprint training" [6], producing specific adaptations in the cardiovascular [6] and neuromuscular systems [7]. However, only some investigations have shown positive effects of high-intensity interval training in combat sports [8], such as boxing [9], judo [10,11], karate [12,13], taekwondo [14–18] and Olympic wrestling [19]. Although HIIT programs with specific techniques have been proposed [20,21], only five studies [9,10,14,16,18] investigated the effects of combat-sports-specific movement during HIIT in physical performance. Improvements in both aerobic and anaerobic performance have been reported for judo athletes [10], boxers [9] and taekwondo [14,16] after HIIT protocols compared to control conditions, showing that 4 weeks of additional HIIT may be enough to improve physical performance in combat-sports athletes [9,10,14,16]. Specifically in boxers, only Kamandulis et al. [9] applied a HIIT program with specific techniques, three times a week for 4 weeks. In this study, each session comprised three rounds of 14 × 3 s of all-out bag-punching bouts (10 s of rest between each bout) with 1 min of rest between rounds. Authors reported improvements in upper-body VO_{2peak} ($F_{1,16}$ = 5.89; p = 0.028), with greater improvement in the experimental group than control group (from 33.1 ± 1.2 to 40.7 ± 2.3 and from 35.0 ± 1.2 to 35.2 ± 1.5 mL/kg/min, respectively); additionally, they reported improvements in the number of punches during round 2 ($F_{1,16}$ = 7.75; p = 0.013) and round 3 ($F_{1,16}$ = 10.48; p = 0.005) as well as in the total number of punches during all three rounds of the simulated match ($F_{1,16}$ = 11.52; p = 0.01) with the experimental group increasing significantly over the control group [9]. Additionally, the principle of individuality of training has been recently studied through the inter-individual response of athletes to training programs by classifying athletes into responders (Rs) and non-responders (NRs) [18,22]. However, only one investigation used this approach in combat sports [18]. Ojeda-Aravena et al. [18] analyzed the inter-individual response of taekwondo athletes who executed a HIIT program with specific techniques for four weeks, reporting the percentage of NRs for countermovement jump (100%) and aerobic performance (12.5%).

Therefore, the aim of this study was to investigate the effect of an additional short-duration HIIT program using boxing-specific techniques on activity during the simulated competition. Additionally, we investigated the impact on physical fitness, specifically aerobic performance and lower-body muscle power. We hypothesized that the additional short-duration HIIT program using boxing-specific techniques would induce better physical conditioning and activity during simulated combat in national-level boxers.

2. Materials and Methods

2.1. Experimental Approach to the Problem

The boxers were randomly allocated into control or experimental groups where the random assignments were prepared using Excel spreadsheet (Microsoft Office Excel 2007) (Figure 1). The control group performed only boxing-specific training for 4 weeks. The experimental group performed the same regular boxing training program as the control group and, additionally, a short-duration HIIT program using boxing-specific techniques three times a week for four weeks. The athletes from control and experimental groups performed simulated competition and fitness tests before and after the training period. Simulated combat and physical fitness tests were executed in the training center where each athlete trained, during the competitive period. Before the testing session, general and specific warm-up routines were performed. It was composed of running, stretching and punches, totaling approximately 15 min. Figure 2 shows the experimental design.

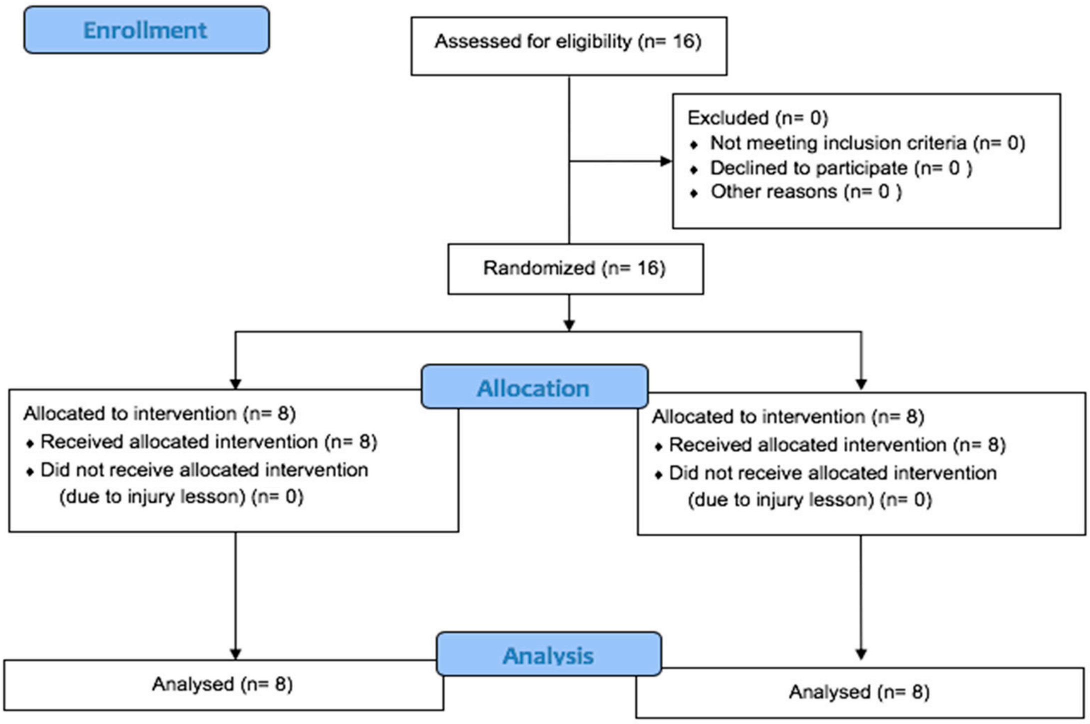

Figure 1. CONSORT diagram of the full recruitment and randomization process.

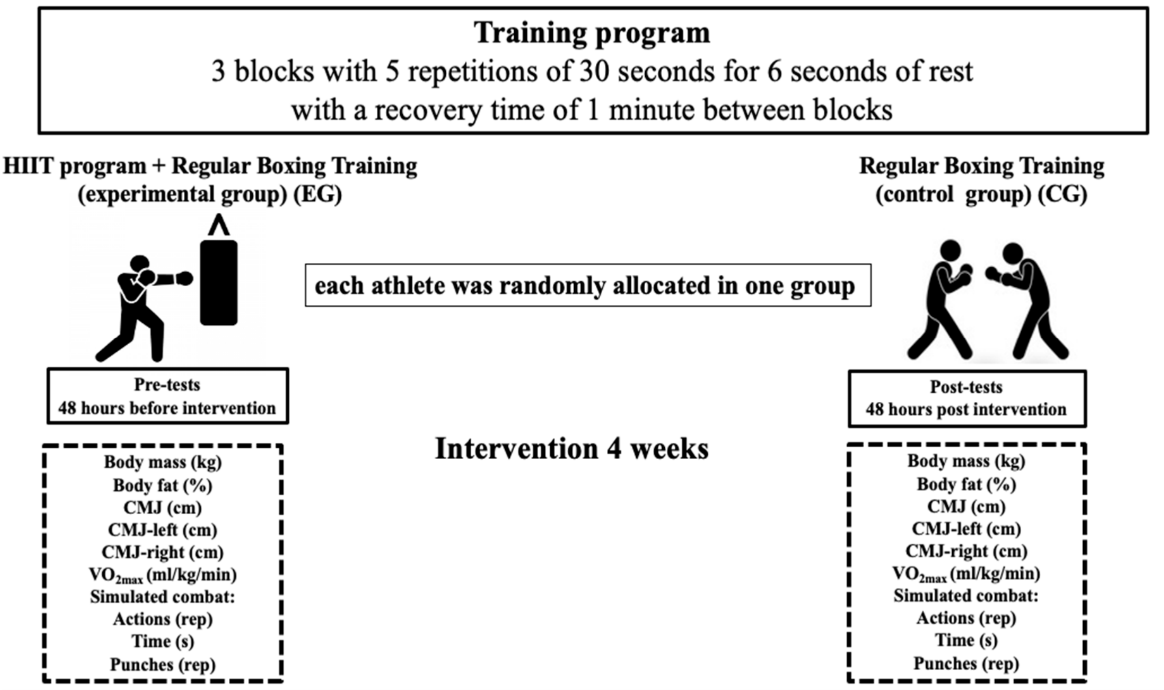

Figure 2. Design experimental.

2.2. Subjects

A convenience sample of sixteen national-level male boxers from a boxing club in Santiago de Chile participated in this study. The control group (CG) was composed of 8 athletes (mean ± standard deviation; age: 28.1 ± 8.4 years; body mass: 77.9 ± 5.2 kg; height: 1.74 ± 0.06 m; competition experience: 3.3 ± 1.5 years; competitive level: national) and the experimental group (EG) was composed of 8 athletes (mean ± standard deviation; age: 27.6 ± 4.2 years; body mass: 79.7 ± 10.5 kg; height: 1.72 ± 0.05 m; competition experience: 2.4 ± 1.1 years; competitive level: national). All were competitive boxers and met the following inclusion criteria: (a) greater than 1 year of competition experience; (b) training three or more times per week. None of them was reducing weight during the period this study was conducted, which was the in-season competition phase. The boxers were free from any injury and neuromuscular disorder.

Following previous criteria [22], the non-responders (NRs) for each of the dependent variables were defined as athletes who were unable to demonstrate an increase or decrease (in favor of beneficial changes) that was greater than twice the error typical measurement (TE) far from zero. All athletes provided written consent after being informed about the procedures and risks associated. This research was approved by the Institutional Ethics Committee (Universidad Santo Tomás, Code: 43.18).

2.3. Regular Boxing Training

The control and experimental groups participated in the same regular boxing training sessions. Boxing training was conducted three times per week for 4 weeks. Each training session lasted 90 min and consisted of technical and tactical exercises. The session began with a general warm-up, approximately 15 min long and consisting of calisthenics exercises, followed by punching the bag, followed by a low-intensity boxing combat simulation. The main part of the training lasted 60 min and was composed of high-intensity tactical exercises to prepare the athlete for specific combat situations and a high-intensity combat simulation. The last 15 min included flexibility exercises.

2.4. High-Intensity Interval Training (HIIT) Protocol

The HIIT protocol consisted of punching the bag with speed and force, with free combinations, the work was divided into 3 blocks with 5 repetitions of 30 s for 6 s of rest, with a recovery time of 1 min between blocks, and the protocol was applied 3 times a week for 4 weeks. The experimental HIIT protocol was conducted 10 min after the boxing training session.

Taking into account the temporal structure of the sport and its regulations, an experimental training program was designed to improve physical fitness and generate modifications in the temporary structure of combat. To organize the training protocol, the duration of the training was established following the provisions of the International Boxing Association AIBA (https://www.aiba.org; Access: 3 May 2021): 3 rounds of 3 min with 1 min rest between rounds. This effort–pause relationship was used to simulate the time movement of boxing matches. A punching bag (LUS, Chile) hanging at the height of the trunk and head of the athlete was used as training material. Finally, the recorded audio designed for this investigation was followed by the athletes.

2.5. Performance Assessments

2.5.1. Physical Fitness Assessments

The evaluations before and after the intervention were VO_{2max}, estimated through the 1000 m test, which consists of running 1000 m in the shortest time possible ($VO_{2max} = 71.662 - 5.850 \times (time)$) [23], countermovement jump (CMJ) and one foot, with right leg and left leg (CMJ-right and CMJ-left, respectively) using the My Jump 2 application [24], and the percentage of body fat through bioimpedance, with a Tanita Ironman BC-548 digital scale using the protocol recommended [25].

2.5.2. Simulated Combat

Before and after the intervention program, each of the athletes performed simulated combat with the same opponent. The simulated combat was composed of three 3 min rounds with 1 min rest between rounds. A 240 Hz high-speed video camera (HSC) (Casio EXILIM EX-ZR400) positioned 5 m from the boxing ring was used to record the simulated combat for each athlete, and the actions executed in each round were registered. These recordings were analyzed with the Kinovea 08.15 program, and the number of actions (number of times the athlete performs a punch or combination of punches), the number of punches and total working time (working time during punching) were registered. The evaluator in charge of hit accounting was a coach with vast experience as a judge and amateur boxing referee, in addition to being a coach of the same sport. All physical fitness assessments were performed by a qualified professional.

2.6. Statistical Analysis

The distribution of the variables was examined using the Shapiro–Wilk test. The data are presented in mean and standard deviation. For the differences, the 95% confidence interval and the percentage of change are presented. Sphericity was tested and confirmed using the Mauchly test. A two-way (group, two levels; moment, two levels) analysis of variance with repeated measurements in the second factor was used. In addition, the Bonferroni test was applied as post hoc. The Mann–Whitney test was used to compare the differences between groups in the percentage of change. As a measure of the effect size (ES) of ANOVA, partial eta squared ($n^2{}_p$) was used; additionally, Cohen's d was calculated following the classification proposed by Rhea for recreationally trained participants (individuals training consistently for 1–5 years) (trivial < 0.25; small 0.25–0.50; moderate 0.50–1.0; large > 1.0) [26]. A change beyond twice the TE was representative of a high probability (i.e., 12 to 1 probabilities) of the observed response outside of a true physiological adaptation beyond what might be expected as a result of technical or biological variability. Therefore, the TE was as follows: fat %, 0.51 (%) × 2; body mass, 1.54 (kg) × 2; VO_{2max}, 1.91 (mL/kg/min) × 2; CMJ, 2.57 (cm) × 2; CMJ-left, 1.42 (cm) × 2; CMJ-right, 2.47 (cm) × 2; actions, 18.62 (rep); time, 32.90 (s); and punches, 52.17 (punches). In addition, the Fisher's exact test was used for comparisons between groups of subjects who were at the 2 × TE calculated on each outcome (NR) or more than twice the TE (responders (Rs)) [22].

3. Results

Table 1 presents the significance level of the comparisons executed in the presented study for each of the variables, Table 2 presents the effects of 4 weeks of a specific HIIT program plus boxing (experimental) and only boxing training (control) on pre and post intervention, and Table 3 presents the group pre–post change (group % change) and number and percentage of responders (Rs) for performance variables, whereas Figure 3 presents individual pre–post change.

Table 1. Significance in the group-by-time interaction for the measured variables.

Variables	F	P	$n^2{}_p$	Group-by-Time Interaction
Body fat (%)	$F_{1,14}$ = 0.47	P = 0.506	$n^2{}_p$ = 0.032	Not
Body mass (kg)	$F_{1,14}$ = 2.50	P = 0.136	$n^2{}_p$ = 0.151	Not
VO_{2max} (mL/kg/min)	$F_{1,14}$ = 1.64	P = 0.221	$n^2{}_p$ = 0.105	Not
CMJ (cm)	$F_{1,14}$ = 1.102	P = 0.312	$n^2{}_p$ = 0.073	Not
CMJ-left (cm)	$F_{1,14}$ = 0.563	P = 0.465	$n^2{}_p$ = 0.039	Not
CMJ-right (cm)	$F_{1,14}$ = 0.258	P = 0.619	$n^2{}_p$ = 0.018	Not
Actions (rep)	$F_{1,14}$ = 2.66	P = 0.125	$n^2{}_p$ = 0.160	Not
Time (s)	$F_{1,14}$ = 1.165	P = 0.299	$n^2{}_p$ = 0.077	Not
Punches (rep)	$F_{1,14}$ = 11.630	P = 0.004	$n^2{}_p$ = 0.454	Yes

VO_{2max}: maximum oxygen uptake; CMJ: countermovement jump with both feet; CMJ-left: countermovement jump with left leg; CMJ-right: countermovement jump with right leg; Actions: number of actions; Time: total duration of the actions; F = F value of ANOVA two-way test; P = significance value; $n^2{}_p$ = partial eta squared.

Table 2. Effects of 4 weeks of specific HIIT program plus boxing (experimental) and only boxing training (control) on pre and post intervention and for performance variables (values are presented as mean and standard deviation).

	Experimental Group (EG) (*n* = 8)			Control Group (CG) (*n* = 8)			
Variables	**Pre**	**Post**	**Effect Size Pre vs. Post**	**Pre**	**Post**	**Effect Size Pre vs. Post**	**Effect Size CG vs. EG**
Body fat (%)	18.4 ± 4.3	17.9 ± 4.1	0.12	17.9 ± 2.6	17.6 ± 2.5	0.12	0.09
Body mass (kg)	79.7 ± 10.5	78.3 ± 9.9	0.13	77.9 ± 5.2	78.1 ± 6.4	0.04	0.10
VO_{2max} (mL/kg/min)	46.52 ± 5.05	48.62 ± 5.61	0.42	47.60 ± 3.83	48.01 ± 3.61	0.11	0.05
CMJ (cm)	30.0 ± 4.7	30.6 ± 5.1	0.12	31.7 ± 4.8	30.4 ± 4.0	0.27	0.16
CMJ-left (cm)	14.0 ± 2.7	13.7 ± 2.2	0.11	15.4 ± 2.8	14.4 ± 3.2	0.39	0.42
CMJ-right (cm)	12.7 ± 4.9	13.8 ± 3.7	0.22	14.3 ± 2.3	14.5 ± 3.4	0.08	0.27
Actions (rep)	122 ± 34	145 ± 42	0.68	111 ± 25	113 ± 30	0.08	0.55
Time (s)	212.1 ± 62.2	193.9 ± 46.2	0.29	203.3 ± 66.3	160.0 ± 45.1	0.65	0.40
Punches (rep)	238 ± 91	289 ± 80 ^{a,b}	0.56	230 ± 78	185 ± 56 ^{c}	0.57	0.64

VO_{2max}: maximum oxygen uptake; CMJ: countermovement jump with both feet; CMJ-left: countermovement jump with left leg; CMJ-right: countermovement jump with right leg; Actions: number of actions; Time: total duration of the actions; a = different from control group in post-intervention ($p = 0.009$; main effect); b = different from experimental group in pre-intervention ($p = 0.023$; main effect); c = different from control group in pre-intervention ($p = 0.04$; main effect).

Table 3. Effects of 4 weeks of specific HIIT program plus boxing (experimental) and only boxing training (control) on pre–post change and responders (Rs) for performance variables (values are presented as percentage and standard deviation or number and percentage).

	Experimental Group		Control Group	
Variables	**% Change (SD)**	**R, n (%)**	**% Change (SD)**	**R, n (%)**
Body fat (%)	−2.5 ± 4.0	6 (75)	−1.3 ± 4.5	3 (37.5)
Body mass (kg)	−1.7 ± 1.6	1 (12.5)	0.3 ± 3.3	0 (0)
VO_{2max} (mL/kg/min)	2.1 ± 3.0	2 (25)	0.4 ± 2.2	1 (12.5)
CMJ (cm)	0.6 ± 4.0	1 (12.5)	−1.3 ± 3.2	0 (0)
CMJ-left (cm)	−0.3 ± 2.2	1 (12.5)	−1.1 ± 1.8	0 (0)
CMJ-right (cm)	1.1 ± 3.6	1 (12.5)	0.2 ± 3.5	1 (12.5)
Actions (rep)	22.6 ± 26.5	2 (25)	2.3 ± 23.4	0 (0)
Time (s)	−18.3 ± 41.4	0 (0)	−43.2 ± 50.7	0 (0)
Punches (rep)	51.1 ± 39.4	1 (12.5)	−45.1 ± 69.4	0 (0)

VO_{2max}: maximum oxygen uptake; CMJ: countermovement jump with both feet; CM-left: countermovement jump with left leg; CMJ-right: countermovement jump with right leg; Actions: number of actions; Time: total duration of the actions; R: responders; n: number; SD: standard deviation.

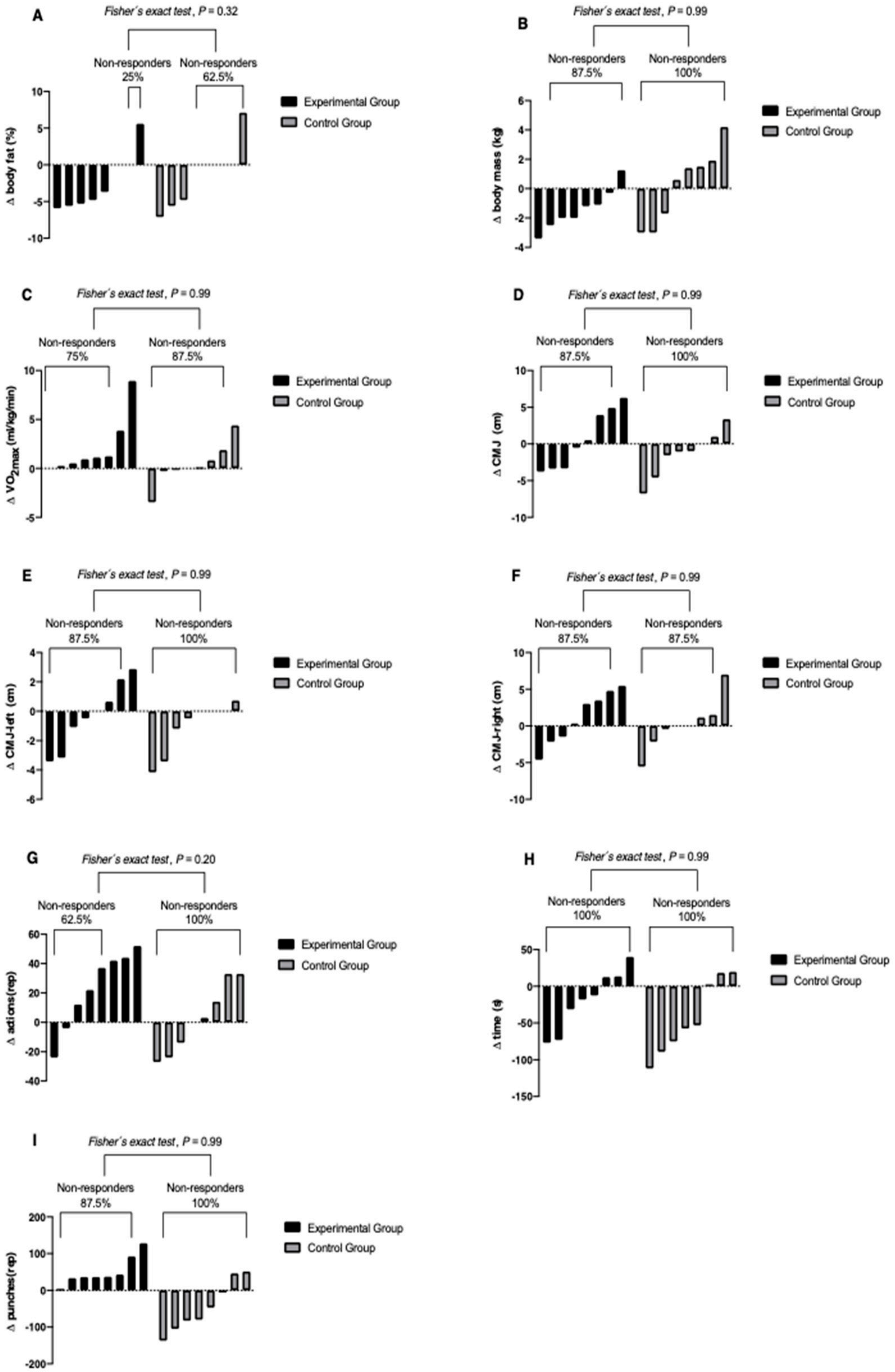

Figure 3. Effects of 4 weeks of specific HIIT program, plus boxing (experimental) and only boxing training (control) on individual pre−post change for (**A**) body fat %, (**B**) body mass, (**C**) VO_{2max}, (**D**) CMJ, (**E**) CMJ-left, (**F**) CMJ-right, (**G**) actions, (**H**) time and (**I**) punches.

4. Discussion

The aim of this study was to investigate the effect of an additional short-duration HIIT program using boxing-specific techniques on activity during a simulated competition. Additionally, we investigated the impact of this program on physical fitness, specifically aerobic performance and lower-body muscle power (bi- and monopedal countermovement jumps). The main finding of the present study is a significant group-by-time interaction for the number of punches, with an increase of 51.1 ± 39.4% (moderate) for the experimental group probably due to an increase in the performance of anaerobic metabolism or other adaptations that were not measured in our study [27]. We hypothesized that the additional short-duration HIIT program using boxing-specific techniques would induce better physical conditioning and actions and increased activity during simulated combat in national-level boxers. Our results suggest that adherence to a HIIT program using boxing-specific techniques with free combinations (3 blocks with 5 repetitions of 30 s by 6 s of rest, with a recovery time of 1 min between blocks, 3 times a week for 4 weeks) would be effective to increase the number of punches during simulated combat, but it was not sufficient to produce significant improvements in the physical performance of boxers. Therefore, our hypothesis was partially rejected.

The VO_{2max} was estimated through the 1000 m test, which has a correlation with the directly measured VO_{2max} (r = 0.86) and consists of running 1000 m in the shortest time possible ($VO_{2max} = 71.662 - 5.850 \times (\text{time})$) [23]. For the VO_{2max}, there was no significant improvement and only 25% of boxers were considered as "responders" in the EG. Considering that the protocol used in the present study can be characterized as repeated sprint training (RST) [6] and that the athletes were highly trained, it was unlikely that most of them would improve their VO_{2max} in such a short period of time. However, there was a significant increase in the number of punches, although only 12.5% of athletes in the EG improved it above the TE. This finding is similar to that reported by Kamandulis et al. [9] who found an increment in the total number of punches in rounds 2 and 3 after their intervention. These authors suggested that the increase in VO_{2max} could be related to the punch frequency maintenance and to delayed fatigue, as aerobic power has been associated with the ability to perform all-out or supramaximal efforts repeatedly [9,28]. On the other hand, although during a combat-sports match, the contribution of aerobic metabolism is predominant [1,29–31], it is important to consider that performance during intermittent effort is not only determined by the oxidative system since it depends on a complex integration between the oxidative system, glycolytic system and ATP–PC [32,33]. Specifically, during a simulated boxing match, the oxidative system contributes 77% whereas the anaerobic metabolism contributes 23% [1]. Therefore, a possible explanation for the increase in the number of punches could be an increase in the performance of anaerobic metabolism, which provides the energy for high-intensity actions such as punches. On the other hand, the ability to perform high-intensity intermittent efforts depends on various adaptations, such as higher VO_2 kinetics, a higher reoxygenation rate after sprinting and a higher lactate threshold [27]—variables that were not measured in our study.

The percentage of body fat was determined through bioimpedance, using a Tanita Ironman BC-548 digital scale following the recommended protocol [25]. There were no significant changes in body mass and body fat. These results are similar to those observed in a recent systematic review about HIIT and Olympic combat sports [8]. This response is likely related to the frequent low body-fat percentage of combat-sports athletes, the short duration of the investigations (4 to 8 weeks) and the lack of energy intake control to induce an energy deficit during the training period. Regarding body mass and fat percentage, they were not significantly modified. This is consistent with that documented by Franchini et al. in their recent review, where little or no changes were observed after the interventions that used HIIT in combat sports [8]. In the present study, 75% of the boxers were considered responders for the variable of fat percentage in the EG compared to 37.5% in the CG, whereas only 12.5% of the boxers changed their body mass in the EG. These data are consistent with 60% of the "responders" subjects in the rate of fat oxidation after two weeks of interval training [34]. However, for lower-body muscle power measured through the My Jump 2 application [24], there was no improvement in any test performed. Only 12.5% of boxers were considered as "responders" for the CMJ, CMJ-left and CMJ-right in the GE.

Our results agree with a recent study in taekwondo athletes [16], where athletes who executed a HIIT program that consisted of 10 × 6 s of as many repetitions as possible of a taekwondo technique (i.e., bandal tchagui), intercepted with 10 s of passive rest between series and 4 weeks of duration, increased CMJ performance compared to pre-intervention values, but no statistically significant differences were reported compared with the group that performed a repeated sprint training (RST) that consisted of 10 × 35 m sprint running with 10 s of passive rest between repetitions or with the control group. Similarly, the study by Ojeda-Aravena et al. [18] applied a HIIT program with specific techniques and 4 weeks of duration to taekwondo athletes, without finding improvements in CMJ performance. However, HIIT can stimulate the fast fibers, improving neuromuscular performance [7]. Therefore, the volume of HIIT applied in our study was not enough to produce improvements in neuromuscular performance. More volume of HIIT or specific stimuli are probably necessary to improve jumping performance.

The main limitations of the present study were related to the lack of physiological measurements during both the training sessions and the tests (especially during the boxing-specific simulated task), which would help to better characterize the type of HIIT session and to explain the physical adaptations. Other important limitations were (i) a convenience sample and (ii) small sample size.

5. Conclusions

In conclusion, the present study indicated that the addition of a boxing-specific HIIT program is effective to increase the number of punches during a simulated match. This is relevant to boxing performance as successful boxers are characterized by executing a high punch frequency during the match. Therefore, coaches and strength and conditioning professionals can use the boxing-specific techniques during a HIIT program to increase the number of punches. This type of protocol can be especially valuable when there is a short period of time or preparing for a boxing competition.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The datasets generated during and/or analyzed during the current research are available from the Corresponding author on reasonable request.

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Conflicts of Interest: The authors declare no conflict of interest.

References

1. Davis, P.; Leithäuser, R.M.; Beneke, R. The Energetics of Semicontact 3 × 2-min Amateur Boxing. *Int. J. Sports Physiol. Perform.* **2014**, *9*, 233–239. [CrossRef]
2. Davis, P.; Benson, P.R.; Pitty, J.D.; Connorton, A.J.; Waldock, R. The Activity Profile of Elite Male Amateur Boxing. *Int. J. Sports Physiol. Perform.* **2015**, *10*, 53–57. [CrossRef]

3. Slimani, M.; Chaabène, H.; Davis, P.; Franchini, E.; Cheour, F.; Chamari, K. Performance Aspects and Physiological Responses in Male Amateur Boxing Competitions: A Brief Review. *J. Strength Cond. Res.* **2017**, *31*, 1132–1141. [CrossRef]
4. de Lira, C.A.B.; Peixinho-Pena, L.F.; Vancini, R.L.; Fachina, R.J.D.F.G.; de Almeida, A.A.; dos Santos Andrade, M.; da Silva, A.C. Heart rate response during a simulated Olympic boxing match is predominantly above ventilatory threshold 2: A cross sectional study. *Open Access J. Sports Med.* **2013**, *4*, 175–182. [CrossRef]
5. Chaabène, H.; Tabben, M.; Mkaouer, B.; Franchini, E.; Negra, Y.; Hammami, M.; Amara, S.; Chaabène, R.B.; Hachana, Y. Amateur Boxing: Physical and Physiological Attributes. *Sports Med.* **2015**, *45*, 337–352. [CrossRef] [PubMed]
6. Buchheit, M.; Laursen, P.B. High-Intensity Interval Training, Solutions to the Programming Puzzle: Part I: Cardiopulmonary Emphasis. *Sports Med.* **2013**, *43*, 313–338. [CrossRef] [PubMed]
7. Buchheit, M.; Laursen, P.B. High-intensity interval training, solutions to the programming puzzle: Part II: Anaerobic energy, neuromuscular load and practical applications. *Sports Med.* **2013**, *43*, 927–954. [CrossRef]
8. Franchini, E.; Cormack, S.; Takito, M.Y. Effects of High-Intensity Interval Training on Olympic Combat Sports Athletes' Performance and Physiological Adaptation: A Systematic Review. *J. Strength Cond. Res.* **2019**, *33*, 242–252. [CrossRef]
9. Kamandulis, S.; Bruzas, V.; Mockus, P.; Stasiulis, A.; Snieckus, A.; Venckunas, T. Sport-Specific Repeated Sprint Training Improves Punching Ability and Upper-Body Aerobic Power in Experienced Amateur Boxers. *J. Strength Cond. Res.* **2018**, *32*, 1214–1221. [CrossRef] [PubMed]
10. Franchini, E.; Julio, U.F.; Panissa, V.L.G.; Lira, F.S.; Gerosa-Neto, J.; Branco, B.H.M. High-Intensity Intermittent Training Positively Affects Aerobic and Anaerobic Performance in Judo Athletes Independently of Exercise Mode. *Front. Physiol.* **2016**, *7*, 268. [CrossRef] [PubMed]
11. Kim, J.; Lee, N.; Trilk, J.; Kim, E.-J.; Kim, S.-Y.; Lee, M.; Cho, H.-C. Effects of Sprint Interval Training on Elite Judoists. *Int. J. Sports Med.* **2011**, *32*, 929–934. [CrossRef] [PubMed]
12. Ojeda-Aravena, A.; Herrera-Valenzuela, T.; Garcia, J.; Ramirez-Campillo, R. Six weeks of HIIT based on repeated 5-meter sprints vs. countermovement jumps: Effects on physical performance among karate athletes. A pilot-study. *Ido Mov. Cult. J. Martial Arts Anthropol.* **2020**, *20*, 24–32. [CrossRef]
13. Ravier, G.; Dugué, B.; Grappe, F.; Rouillon, J.D. Impressive anaerobic adaptations in elite karate athletes due to few intensive intermittent sessions added to regular karate training. *Scand. J. Med. Sci. Sports* **2009**, *19*, 687–694. [CrossRef]
14. Aravena, D.; Román, V.; Santos, J.; Franchini, E.; Valdés-Badilla, P.; Orihuela, P.; Herrera-Valenzuela, T. High-intensity interval training improves specific performance in taekwondo athletes. *Rev. Artes Marciales Asiáticas* **2020**, *15*, 1–3. [CrossRef]
15. Monks, L.; Seo, M.-W.; Kim, H.-B.; Jung, H.C.; Song, J.K. High-intensity interval training and athletic performance in Taekwondo athletes. *J. Sports Med. Phys. Fit.* **2017**, *57*, 1252–1260. [CrossRef]
16. Ouergui, I.; Messaoudi, H.; Chtourou, H.; Wagner, M.O.; Bouassida, A.; Bouhlel, E.; Franchini, E.; Engel, F.A. Repeated Sprint Training vs. Repeated High-Intensity Technique Training in Adolescent Taekwondo Athletes—A Randomized Controlled Trial. *Int. J. Environ. Res. Public Health* **2020**, *17*, 4506. [CrossRef]
17. Seo, M.-W.; Lee, J.-M.; Jung, H.C.; Jung, S.W.; Song, J.K. Effects of Various Work-to-rest Ratios during High-intensity Interval Training on Athletic Performance in Adolescents. *Int. J. Sports Med.* **2019**, *40*, 503–510. [CrossRef]
18. Ojeda-Aravena, A.; Herrera-Valenzuela, T.; Valdés-Badilla, P.; Cancino-López, J.; Zapata-Bastias, J.; García-García, J. Effects of 4 Weeks of a Technique-Specific Protocol with High-Intensity Intervals on General and Specific Physical Fitness in Taekwondo Athletes: An Inter-Individual Analysis. *Int. J. Environ. Res. Public Health* **2021**, *18*, 3643. [CrossRef]
19. Farzad, B.; Gharakhanlou, R.; Agha-Alinejad, H.; Curby, D.G.; Bayati, M.; Bahraminejad, M.; Mäestu, J. Physiological and Performance Changes from the Addition of a Sprint Interval Program to Wrestling Training. *J. Strength Cond. Res.* **2011**, *25*, 2392–2399. [CrossRef] [PubMed]
20. Herrera-Valenzuela, T.; Valdés-Badilla, P.; Franchini, E. Recomendaciones de entrenamiento intervalado para atletas de deportes de combate olímpicos durante la pandemia del COVID-19. *Rev. Artes Marciales Asiáticas* **2020**, *15*, 1–3. [CrossRef]
21. Franchini, E. High-Intensity Interval Training Prescription for Combat-Sport Athletes Energy-System Contributions. *Int. J. Sports Physiol. Perform.* **2020**, *15*, 767–776. [CrossRef] [PubMed]
22. Ramirez-Campillo, R.; Alvarez, C.; Gentil, P.; Moran, J.; García-Pinillos, F.; Alonso-Martínez, A.M.; Izquierdo, M. Inter-individual Variability in Responses to 7 Weeks of Plyometric Jump Training in Male Youth Soccer Players. *Front. Physiol.* **2018**, *9*, 1156. [CrossRef]
23. García, A.M.G.; Bermúdez, S.R.; Aguirre, O.D. Calidad científica de las pruebas de campo para el cálculo del VO2máx. Revisión sistemática. *Rev. Cienc. Salud* **2016**, *14*, 247–260. [CrossRef]
24. Balsalobre-Fernández, C.; Glaister, M.; Lockey, R.A. The validity and reliability of an iPhone app for measuring vertical jump performance. *J. Sports Sci.* **2015**, *33*, 1574–1579. [CrossRef]
25. Moon, J.R. Body composition in athletes and sports nutrition: An examination of the bioimpedance analysis technique. *Eur. J. Clin. Nutr.* **2013**, *67* (Suppl. 1), S54–S59. [CrossRef]
26. Rhea, M.R. Determining the Magnitude of Treatment Effects in Strength Training Research through the Use of the Effect Size. *J. Strength Cond. Res.* **2004**, *18*, 918–920. [CrossRef] [PubMed]
27. Bishop, D.; Girard, O.; Mendez-Villanueva, A. Repeated-Sprint Ability–Part II. *Sports Med.* **2011**, *41*, 741–756. [CrossRef]
28. Rampinini, E.; Sassi, A.; Morelli, A.; Mazzoni, S.; Fanchini, M.; Coutts, A.J. Repeated-sprint ability in professional and amateur soccer players. *Appl. Physiol. Nutr. Metab.* **2009**, *34*, 1048–1054. [CrossRef]

29. Campos, F.A.D.; Bertuzzi, R.; Dourado, A.C.; Santos, V.G.F.; Franchini, E. Energy demands in taekwondo athletes during combat simulation. *Eur. J. Appl. Physiol.* **2012**, *112*, 1221–1228. [CrossRef] [PubMed]
30. Doria, C.; Veicsteinas, A.; Limonta, E.; Maggioni, M.A.; Aschieri, P.; Eusebi, F.; Fanò, G.; Pietrangelo, T. Energetics of karate (kata and kumite techniques) in top-level athletes. *Eur. J. Appl. Physiol.* **2009**, *107*, 603–610. [CrossRef] [PubMed]
31. Julio, U.F.; Panissa, V.L.; Esteves, J.V.; Cury, R.L.; Agostinho, M.F.; Franchini, E. Energy-System Contributions to Simulated Judo Matches. *Int. J. Sports Physiol. Perform.* **2017**, *12*, 676–683. [CrossRef] [PubMed]
32. Franchini, E.; Takito, M.Y.; Kiss, M.A.P.D. Performance and energy systems contributions during upper-body sprint interval exercise. *J. Exerc. Rehabil.* **2016**, *12*, 535–541. [CrossRef] [PubMed]
33. Gaitanos, G.C.; Williams, C.; Boobis, L.H.; Brooks, S. Human muscle metabolism during intermittent maximal exercise. *J. Appl. Physiol.* **1993**, *75*, 712–719. [CrossRef] [PubMed]
34. Astorino, T.A.; Schubert, M.M. Individual Responses to Completion of Short-Term and Chronic Interval Training: A Retrospective Study. *PLoS ONE* **2014**, *9*, e97638. [CrossRef]