Repeated high-intensity technique training and repeated sprint training elicit similar adjustment in physiological responses, but divergent perceptual responses and combat-related performances in adolescent taekwondo matches

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Abstract

Purpose: This study investigated the effects of 4-weeks of repeated sprint training (RST) vs. repeated high-intensity-technique training (RTT) on the physiological responses [i.e., blood lactate ([La]), and mean and peak heart rate (HR)], rating of perceived exertion (RPE), technical-tactical performance, and time-motion variables during simulated taekwondo combats. **Methods**: Twenty-four taekwondo athletes (18 males and 6 females; age: 16 ± 1 years) were randomly and equally assigned to RST (10 × 35 m running sprints interspersed by 10 s rest) or RTT (10 × 6 s bandal-tchagui kicking executions interspersed by 10 s rest) groups in addition to their regular training. Both groups performed simulated combats before and after training. **Results**: The delta lactate [La] and HRpeak were attenuated following training (P<.001 and P=.03, respectively), with no differences identified between RTT and RST conditions. RPE values decreased after training only in the RTT (P=.002). Time fighting and preparatory activities increased following training (P<.001), with higher values observed following RTT than RST (P<.001). Non-preparatory time decreased after training (P<.001), with more pronounced reductions observed following RTT when compared to RST (P<.001). The number of single attacks decreased only following RST (P<.001), whereas combined attacks increased only after RTT training (P<.001). **Conclusions**: Similar adjustments in the physiological responses to combat were observed following four-weeks of either RST or RTT, but RTT elicited more favorable perceptual responses and combat-related performance. This highlights the importance of specificity of training and its effective transfer to combat.

Keywords: Combat sports; Specificity; Performance; HIIT

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Introduction

Taekwondo is a high-intensity intermittent striking combat sport that has regularly featured in the Olympic Games. During combat, athletes execute offensive and defensive techniques at high intensity (i.e., brief periods of fighting ~ 1-2 seconds), and these are interspersed with longer periods of low intensity actions, [1] producing effort-to-pause ratios ranging between 1:2 and 1:7. [2] To achieve success in competition, athletes need to produce both high force and velocity during successive movements and effectively recover within a short time. [3] To cope with the competitions demands, training must be oriented towards sufficiently develop athletes' physical, physiological, technical, tactical and psychological characteristics. [4]

Taking into consideration the specific characteristics of combat sports, the use of high-intensity interval training (HIIT) has been widely recommended to enhance athletes' performance. [5-8] Due to its efficient cost-benefit approach, researchers and trainers have been attracted by the positive results obtained via this training method, as well as the short time required to execute the sessions. [9] In fact, HIIT has been linked to significant improvement in both aerobic and anaerobic performance of combat sports athletes. [3,10] The effects of HIIT protocols in striking combat sports have been explored using generic or specific training protocols. [6,7,10]

Whilst several studies investigating striking combat sports [6,7] have reported positive responses to training using non-specific exercises (i.e. repeated running sprints), replacing non-specific physical training with sports-specific modalities has been proposed to enhance the specificity of the adaptations. [5,12] In fact, specificity is a training principle that is necessary to achieve both optimal adaptation and performance. [8,11] Specifically, regarding taekwondo, recent studies [7,8] demonstrate that 4 weeks of HIIT using specific technique training was suitable to improve the number of techniques during five sets of the frequency speed kick test (FSKT), agility, and the aerobic fitness of taekwondo athletes. Despite these encouraging findings, there have been few concerted attempts to directly compare the efficacy of generic (sprint) and specific (technical) HIIT training modes on the physiological and performance responses during combat. Using such physiological markers of internal training load is important since the results reported by Lupo et al. [12] showed that varied training loads were recorded in different training methods in young taekwondo athletes.

Therefore, the objective of the present study was to compare the physiological responses, time-motion parameters and technical-tactical aspects before and after four weeks of both repeated high-intensity technique training (RTT) and repeated sprint training (RST) programs. It was hypothesized that the specific training protocol (i.e., RTT) would elicit more favorable physiological responses, time-motion and technical-tactical performances during simulated taekwondo combats.

Methods

Subjects

Twenty-four taekwondo athletes (18 males and 6 females) competing at regional and national level were randomly and equally assigned (i.e., 9 males and 3 females) to either RST (n = 12; age: 16 ± 1 years; height: 1.66 ± 0.07 m; body mass: 56.9 ± 7.2 kg) or RTT (n = 12; age: 16 ± 1 years; height: 1.67±0.08 m; body mass: 55.6 ± 8.0 kg) groups. Athletes were training regularly 3 sessions/week, with each session lasting 2h. They had been practicing taekwondo for 7±1 years. Participants did not present any medical conditions or acute or chronic injuries during the experimental study. The study was conducted according to the Declaration of Helsinki for human experimentation and the protocol was fully approved by the local research ethics committee before the start of the study (N◦ 040/2018). All athletes and their parents gave written

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informed consent after a detailed explanation about the aims, benefits, and potential risks involved in the investigation.

Design

This study followed some procedures and included most of the participants from a previous investigation aimed at assessing the effects of 4 weeks of RST or repeated high-intensity technique training on taekwondo-specific aerobic and anaerobic tests, training load, monotony, strain and perceived recovery. [7] Adolescent taekwondo athletes were randomly assigned to an RST or an RTT group. The random assignments were prepared using a Microsoft Office Excel 2007 spreadsheet. The intervention commenced following two weeks of detraining to eliminate the effects of previous training programs. [13] In addition to their usual taekwondo training, the RST and RTT groups performed a total of eight instructed and supervised training sessions (two sessions per week) over a period of 4 weeks (Table 1). Athletes performed simulated taekwondo combat (consisting of 3 rounds of 2 min with 1min of rest in-between) before and 72 h after the final scheduled training session to ensuresufficient recovery for participants. Each athlete from theRST group was paired with the same opponent from the RTT group, with respect to weight categories, at both pre and post-training to minimize the inherent variability observed between opponents and as previously adopted. [13] All combats were recorded for subsequent analysis using 2 cameras (Canon 650D 18 Megapixels, ISO: 400, shutter speed: 1/125 seconds, f/4; Canon, Inc., Tokyo, Japan) placed at 1.5 m from the combat area. A control group (CG) was not used in this evaluation based on the fact that both RTT and RST had previously shown beneficial effects on non-specific and specific anaerobic and aerobic tests compared to habitual training (i.e., CG). [7] All combats were conducted at the same time of day (17h-19h) to overcome the diurnal variation of performance, and all athletes were familiarized with the experimental pre- and post-measures procedures in a habituation session. Participants were advised to avoid any strenuous exercises in the day preceding all test sessions.

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*** Table 1 near here***

Methodology

Physiological responses and perceived exertion

Blood samples were collected from the fingertip 10 min before and immediately after each combat, and blood lactate concentration [La] was measured using the Lactate Pro2 Analyzer (Arkray, Tokyo, Japan). [14] [La] at pre- and post-combats were determined, and delta lactate (Δ) was calculated and used for the analysis. Heart rate (HR) was measured every 5 seconds throughout the taekwondo combats (Polar Team2 Pro System, Polar Electro OY, Kempele, Finland), and themean (HRmean) and peak (HRpeak) values were used for the analysis. Furthermore, athletes reported their session rating of perceived exertion (s-RPE) scores in terms of CR-10 scores [15] 30 min after each combat simulation, after being well familiarized with the scale.

Combat session analysis

The recorded video footages were analyzed frame by frame (interval=0.016 s) using the Dartfish software (Dartfish Edition MPT34M Pro 5.5, Lausanne, Switzerland). [16] The technical-tactical analysis included determining single attacks, combined attacks, counterattacks and defense as well as fighting, preparatory and non-preparatory activities activity. [17] The definitions of technical-tactical, as well as time-motion variables are reported in table 2.To test the reliability of the analysis system, the same investigator analyzed thecombats twice with a

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one-week interval between the two analyses, and the intra-observer agreement was checked using the intra-class correlation coefficient (ICC), which was higher than 0.90, indicating excellent reliability of the analysis.

*** Table 2 near here***

Statistical analysis

Data were presented as mean and standard deviation. The statistical analysis was performed using SPSS 20.0 statistical software (SPSS Inc, Chicago, IL, USA). The normality of data sets was checked and confirmed using the Kolmogorov-Smirnov test. Sphericity was tested and confirmed using the Mauchly test. Performances at pre-training were compared between groups by means of Student's *t*-test. Regarding variables that differed between groups at pre-training (counterattacks), delta values between rounds at pre and post training period were calculated and these values were compared by means of a two-way (factor 1: 2 groups and factor 2: 3 rounds) analysis of variance with repeated measurements in the second factor followed by the Bonferroni test. Regarding variables (Delta lactate, HRpeak, HR mean and RPE), data were analyzed using a two-way analysis of variance (group [RTT and RST] ×training [before and after]) with repeated measurements to compare performances. The Bonferroni test was used as post-hoc test. Moreover, for single attacks, combined attacks, defense, fighting activity, preparatory activity, and non-preparatory activity variables data were analyzed using a three-way analysis of variance (group [RTT and RST] ×training [before and after] ×Rounds [round 1, round 2 and round 3]). The Bonferroni test was used as post-hoc test. When an interaction effect was found, this was the only result reported for a given variable to reflect differences in the response between conditions. The magnitude of differences between variables was interpreted using standardized effect size (Cohen's d) classified according to Hopkins [18] as follows: $d \leq 0.20$ (trivial), $0.20 < d \leq 0.60$ (small), $0.60 < d \leq 1.20$ (moderate), $1.20 < d \leq 2.0$ (large), $2.0 < d \leq 4.0$ (very large) and $d > 4.0$ (extremely large). Furthermore, upper and lower 95% confidence intervals of difference ($95\%CI_d$s) were calculated for corresponding variations. Statistical significance level was set at $P \leq .05$.

Results

The physiological and perceived exertion responses during simulated combats before and after training are presented in Table 3. Regarding delta blood lactate, there was a time effect ($F_{1,44}$ =99.488, P<.001), with lower values after compared to before training (95%CIdi =-10.2; -6.8; d= 3 (very large); P<.001). For HRpeak, there was also a time effect ($F_{1,44}$=5.017, P=.030), with lower values after compared to before training (95%CIdi =-14; -1; d= -0.65 (moderate); P=.030). Regarding RPE, there was a time and training group interaction effect ($F_{1,44}$ =12,144, P=.001), with RTT eliciting lower values compared to RST after training (95%CIdi =-2;-1; d=-1.29 (large); P=.002).

*** Table 3 near here***

Table 4 presents the time-structure performances during and after training programs.

For fighting activity, a training group and time interaction effect was found ($F_{1,132}$=134.916, P<.001), with RTT and RST showing longer fighting periods after compared to before training (95%CIdi =7.5;9.2 and 0.3;2; d=3.66 and 1.00 (very large and moderate); all P<.001, respectively). Moreover, RST elicited shorter periods compared to RTT after training (95%CIdi =-8.7;-6.9; d= -4.00 (large); P<.001).

For preparatory activity, a training group and time interaction effect was found ($F_{1,132}$ =5.277, P=.023), with RTT and RST spending longer periods after training compared to before training (95%CIdi =16.6;21.6 and 12.5;17.5; d= 3.01 and 2.81 (large); all P<.001, respectively), and

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longer periods were elicited by RTT compared to RST after training (95%CIdi =3.2;8.2; d=1.77 (large); *P*<.001).

For non-preparatory activity, a training group and time interaction effect was found ($F_{1,132}$ =17.662, *P*<.001), with RTT and RST spending longer periods before compared to after training (95%CIdi =-17.3; -13.5 and -11.6; -7.7; d= 3.62 and 2.25 (very large); all *P*<.001, respectively) and longer periods spent by RST compared to RTT after training (95%CIdi =5.3;9.1; d=3.33 (very large); *P*<.001).

*** Table 4 near here***

Table 5 presents the technical-tactical aspects before and after training programs.

For single attacks, a training group and time interaction effect was found ($F_{1,132}$=5.452, *P*=.021), with RST executing lower values after compared to before training (95%CIdi =-5;-1; d=-0.89 (moderate); *P*=.002). Moreover, RTT executed higher values than RST after training (95%CIdi =2;6; d=1.31 (large); *P*<.001). For combined attacks, a training group and time interaction effect was found ($F_{1,132}$=30.189, *P*<.001), with RTT executing higher values after compared to before training (95%CIdi =3;4; d=1.99 (large); *P*<.001). Moreover, RTT performed higher values than RST after training (95%CIdi =3;4; d= 2.21 (very large); *P*<.001).

*** Table 5 near here***

Discussion

The present study showed that delta blood lactate and HR peak in taekwondo combat were lower following training, and did not differ between the training mode. In contrast, the RTT program resulted in athletes performing longer periods of fighting and preparatory activity, lower proportions of non-preparatory activity, with a higher frequency of single and combined attacks during combat, when compared with RST. These findings emphasize the importance of the specificity of training in better preparing athletes to manage the activity, and technical/tactical requirements during combat.

It is worth to highlight that combat sports' performance model [19] and its consequent optimal training show their own specificity compared with field-based team sports in terms of metabolic demand. [20-22] These sports do encompass high-intensity repeated efforts, which, however, last less than combat sports' counterparts. Repeated sprint ability (RSA) and its training result relevant proxies for field-based team sports' match and training activities. The RST explicitly investigated here is inspired by RSA training in those sports. Unlike the selective use of different metabolic systems (e.g., anaerobic glycolysis and aerobic), which did not differ much between RST and RTT in current research, the investigated trainings achieved different levels of performance during after-training simulated combats, making RTT the preferable choice for taekwondo athletes. The HR and [La] responses to combat were attenuated by similar magnitude following 4-weeks training irrespective of the mode. These results are partially in line with those reported by Haddad et al. [5] who showed that the taekwondo-specific technical interval training induced similar HR responses as those recorded in short-duration running interval training in adolescent taekwondo athletes. Similar reductions in [La] were reported in judo athletes, [23] following 4-weeks of judo-specific technique repetitions (uchi-komi). Likewise, following 4-weeks of low-volume high-intensity training based on repeated sprint running or repeated techniques, Ouergui et al. [7] found that delta lactate was lower for the RTT group for both legs compared to RST group and control group during specific taekwondo exercises for both dominant and non-dominant legs. Such changes are often ascribed to increased oxidative ATP provision, increase O_2 kinetics, increase lactate clearance, and reduced reliance of anaerobic glycolysis. [24] Taekwondo combat is indeed characterized by high-intensity intermittent movements, during which the aerobic system plays a central role in the

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recovery process, and is paramount to successfully perform high-intensity techniques in the later stages. [6] Whilst it is not possible to deduce such/specific adaptations from HR and [La] measurements alone, the reduced HR and [La]responses to combat following training in our study suggest effective training adaptations; particularly in relation to the increased physical work rate observed.

In taekwondo as in all combat sports, HIIT and specifically the taekwondo-specific technical interval training has been recommended to develop and maintain cardiovascular fitness at the required level for competition. [3,5] In the present study, the HRpeak decreased following both training programs, which could reflect enhanced cardio-respiratory fitness. This response has been reported in a previous study, [6] where taekwondo athletes showed a decrease in their maximum HR (i.e., from 186 ± 1.95 to 178.9 ± 2.65 b·min^{-1}) following 4 weeks of running protocols. This decrease was attributed to improved ventricular filling, which resulted in an increase in both stroke volume and peak cardiac output following both training programs. [25]

In addition, a previous study highlighted the effectiveness of session-RPE as a simple and practical tool for monitoring training load in young taekwondo athletes during training. [12] In the present study, session-RPE scores decreased following training in the RTT, but not RST. This finding might reflect more specific training adaptations in RTT, resulting in reduced perception of effort at a given intensity.[26] The Borg CR10 scale was used in this study 30 minutes following the bout and therefore reflects the athlete's lower perceived exertion during the entire combat or session.

Understanding time-motion patterns appears to be critical, especially for sport-specific taekwondo tasks. [27] In terms of temporal structure, there was an increase in both fighting and preparatory activities, with a decrease in the non-preparatory activity commonly recorded within RTT group. This indicates that athletes were able to perform more techniques at high-intensity after the RTT program. In fact, it is likely that taekwondo athletes increased their preparatory activities as a strategy to create an opening to initiate an effective attack. [17] The increase in thecadence of thecombats following the RTT program might be attributed to its temporal structure and the use of specific technique that mimicthose of taekwondo competition, as well as the improvement in both aerobic and anaerobic fitness. [7] Findings from the present study indicate that adding taekwondo-specific techniques to a regular HIIT regime can induce specific improvements in taekwondo competition activity.

Since young taekwondo athletes were more engaged in offensive rather than defensive techniques, Tornello et al. [28] proposed that training should focus on offensive fighting to win a match and arrange different fight sequences during which children have to apply specific technical skills to various tactical situations. In the present study, single attacks and combined attacks were more frequent after the RTT than the RST program. Similar results were reported by Kamandulis et al. [29], where punching force and frequency were enhanced during a simulated boxing fight following 4 weeks of all-out punching training (i.e., 3 sessions per week with 2 minutes of all-out punching per session). These findings collectively emphasize the importance of the specificity of training and its effective transfer to combat.

Furthermore, technical-tactical and physical fitness are interlinked and influence each other, so underdeveloped physical attributes can limit the technical and tactical abilities of the athlete. [29] Therefore, due to the limited information about the effects of taekwondo-specific interval training on the technical-tactical performances in taekwondo combats, the results from the present study further support previous investigations using specific physical fitness tests. In fact, recent investigations[7,8] have shown that anadditional short-duration program (i.e., 4 weeks) using taekwondo-specific techniques executed intermittently increased the number of kicks in

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each of the five sets of the FSKT and in the FSKT-10s. Taekwondo athletes may have chosen to use more attacks during combat because offensive skills are more intuitive than defensive ones for effectively preventing opponent attacks,[28,30] and likely because of the improvement in repeated sprint ability performance. [7] Besides, based on the fact that technical skill development is conditioned by the physical preparation for the task requirements, [5] the increase in the number of offensive techniques during combat may well be linked to specific changes in physical fitness. However, the fact that both training programs enhanced offensive rather than defensive techniques is likely due to the sporadic nature of the later, [30] signaling a more dynamic fighting style. [31]

The degree of connection between training exercises and the performance accomplished during competition determines the transfer and effectiveness of the training process. [32] Therefore, the improvement of combined attacks following the RTT program could be explained by the fact that the repetition of techniques through the training program induced technique adaptations. [33] These adaptations might be mostly due to increased strength in specific muscles recruited during taekwondo technique execution, mainly biceps femoris and knee extensor muscles. [33] Such adaptations could be attributed to the development of coordination skills, which serve as the basis for the execution of complex and difficult techniques in later stages. [34] Therefore, the greater technical benefits from RTT could be explained by the fact that sprinting is a generic exercise mode, suggesting that adaptations to HIIT are stimuli-specific. [10,29] Supporting these findings, it has been reported that the degree of similarity between training activity and the task performed is crucial for the transfer and the productivity of the training process. [4,12]

Differences between rounds were observed only in the offensive activities, which is likely due to the sporadic nature of defensive techniques. [30] Besides, the level of technical skill development is determined by the physical preparation for task requirements. [5] Therefore, the gain in physical fitness following the two training programs might account for the decline in defensive techniques, signaling a more dynamic fighting style. [31] However, the increase in defensive skills after the RST program when compared to RTT could reflect attempts to conserve energy and reduce fatigue, because RPE scores following the RST program were higher than after the RTT program. Whereas athletes in the RTT group engaged more in offensive behavior, which may be explained by the enhanced physical fitness recorded for these athletes after the training program, as previously reported by Ouergui et al. [7].

The present study showed that counterattacks were higher in the RTT group than in the RST group. This improvement could indicate that the RTT program developed the ability of taekwondo athlete to interpret the movements of their opponents and react rapidly to them before receiving strikes. Moreover, since speed and agility are essential for many of the technical and tactical actions performed in taekwondo, [1] the increase in counterattacks following the RTT program can be related to the improvement of these physical aspects. In fact, Ouergui et al. [7] reported that taekwondo agility performance during both specific (i.e., taekwondo-specific agility test) and non-specific (i.e., T-test) tests improved after 4 weeks of the RTT program. Therefore, as counterattacks (i.e., anticipatory, simultaneous, or posterior) are associated with other offensive techniques (e.g., spinning techniques and indirect attacks) to achieve the highest possible score, [35] it seems that the RTT program was effective in increasing the level of tactical behavior.

This is the first study to compare the physiological responses, technical and tactical performance, and time-motion variables in simulated taekwondo combats among youth athletes before and after 4 weeks of RTT or RST programs. We acknowledge that the main limitation in the present study is the lack of a control group. A control group was not used in this evaluation because both RTT and RST have previously shown beneficial effects on anaerobic

and aerobic non-specific and specific tests compared to habitual training (i.e., CG). [7,10] Moreover, while the system applied for technical-tactical and time-motion analyses can be applied by different researchers to effectively study taekwondo competition,[17] the use of a single analyst in this study can be considered a limitation. [36] Finally, the effects of these two training modalities should be further studied using longer duration observation periods to establish more solid findings.

Practical Applications

These findings demonstrate the effectiveness of a low-volume, high-intensity technique training added to regular training regime in inducing specific improvements in technical-tactical skills, as well as time-motion variables during taekwondo combats. Thus, coaches and strength and conditioning professionals are highly encouraged to use RTT to better prepare athletes to cope with the specific competition demands. In fact, the decision to employ RST or RTT might reflect the phase of training within an annual periodized plan. For instance, RST could be employed more in the general preparatory phase, whereas RTT might feature more within the 'specific-preparatory' and 'pre-competition' phases of the annual training program.

Conclusions

The present study showed that the HR responses and [La] were attenuated in combat following 4weeks of either RST or RTT training. Compared to RST, the RTT program resulted in athletes performing longer periods of fighting and preparatory activities, lower proportions of non-preparatory activity, and a higher frequency of single and combined attacks during combat. The RTT also resulted in lower RPE responses than RST, despite increased levels of activity during the combats.

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Table 1. The 4-week repeated high-intensity technique training (RTT) and repeated sprint training (RST) programs.

	RST		RTT	
	Volume	Exercice	Volume	Exercice
Week 1	3 sets	- 10 × 35 m sprint running with 10 s of passive rest between repetitions. - 3 min of rest between sets	3 sets	- 10 × 6 s of repeating taekwondo technique (i.e., Bandal-tchagui) as much as possible with 10 s of passive rest between repetitions. - 3 min of rest between sets
Week 2	4 sets		4 sets	
Week 3	5 sets		5 sets	
Week 4	6 sets		6 sets	

Table 2. Definition of technical-tactical and time-motion indicators.

Criterion	Categories	Definition
Technical-tactical aspects	Single attacks	Offensive techniques performed in isolation.
	Combined attacks	Offensive techniques that are executed in a combination of two or more techniques.
	Counterattacks	Offensive actions that starts during, at the same time, or after the opponent's attack
	Defense	Movements used to avoid the impact of offensive actions by the opponent.
Time-motion variables	Preparatory activity time	Begins once the competitor adopts a fighting stance and moves to prepare the attack. The time ceases when the athlete moves out of the fighting stance or when a stoppage occurred.
	Fighting activity time	Initiates when athlete moves from the fighting stance to the exchange and ceases once the final execution is complete.
	Non-preparatory activity time	Commences if an athlete moves out of a fighting stance and ceases when a fighting stance is adopted or if a stoppage occurs.
	Stoppage time	Represents the combat period's interruptions caused by general, injury, and penalty stoppages (i.e., time required for the referee to separate the opponents after an exchange).

Table 3. Physiological responses during simulated combats before and after training programs for the repeated techniques training group (RTT) and the repeated sprint training group (RST) (Values are mean ± SD).

	RST (n=12)		**RTT (n=12)**		**Overall (n=24)**	
	Pre-Training	Post-Training	Pre-Training	Post-Training	Pre-Training	Post-Training
Delta [La] (mmol/L)	15.6 ± 3.3	6.8 ± 1.5	15.6± 4.4	7.2±1.5	15.6±3.8	7.1± 1.5 [a]
HR peak (beats.min^{-1})	204±13	193±9	196±13	193±8	200±13	193±8 [b]
HR mean (beats.min^{-1})	161±12	156±13	152±18	152±17	157±15	154±15
Session-RPE (a.u)	8±1	8±1	8±1	7±1 [c,d]	8±1	7±1 [a]

[a] main effect of time: lower values after compared to before training at $p<0.001$; [b] main effect of time: lower values after compared to before training at $p=0.03$; [c] interaction effect between time and training group: RTT elicited lower values after than before training at $p<0.001$; [d] interaction effect between time and training group: RTT elicited lower values compared to RST after training at $p=0.002$; [La]: blood lactate concentration; HR: heart rate; RPE: rating of perceived exertion; a.u: arbitrary unit.

Table 4. Match time-structure before and after repeated techniques training (RTT) and repeated sprint training (RST) programs (Values are mean ± SD).

		RST (n=12)			RTT (n=12)			Overall (n=24)		
		Pre-Training	Post-Training	Overall	Pre-Training	Post-Training	Overall	Pre-Training	Post-Training	Overall
Fighting activity (s)	Round 1	9.2± 1.1	10.1± 0.8	9.6± 1.1	9.5±2.0	18.4±2.2	14.0±5.0	9.3±1.6	14.3±4.6	11.8±4.2
	Round 2	9.1±1.9	10.5±0.7	9.8±1.6	9.4±1.8	18.2±3.0	13.8±5.1	9.3±1.9	14.3±4.5	11.8±4.3
	Round 3	8.7±1.2	9.9±0.9	9.3±1.2	9.8±2.0	17.3±2.8	13.6±4.5	9.3±1.7	13.6±4.3	11.4±3.9
	Overall	9.0±1.4	10.2±0.8[c]	9.6±1.3	9.6±1.9	18.0± 2.7[c,d]	13.8±4.8[b]	9.3±1.7	14.1±4.4 [a]	11.7±4.1
Preparatory activity (s)	Round 1	77.9±9.2	90.9±3.2	84.4±9.5	78.4±8.7	95.5±2.8	86.9±1.8	78.1±8.7	93.2±3.8[§]	85.7± 10.1[*]
	Round 2	69.9±3.5	89.1±1.1	79.5±10.1	71.0±6.3	95.2±5.4	83.1±13.6	70.4±5.0	92.2±4.9[§]	81.3± 12.0
	Round 3	77.2±5.7	89.9±0.6	83.6±7.6	80.5±6.2	96.5±4.1	88.5±9.7	78.9±6.1	93.2±4.4[§]	86.0±9.0[*]

	Overall	75.0±7.4	90.0±2.1[c]	82.5±9.3	76.6±8.1	95.7± 4.2[c, d]	86.2±11.5 [b]	75.8±7.7	92.9±4.4 [a]	84.3±10.6
Non-preparatory activity (s)	Round 1	25.1±7.1	19.9±2.3	22.5±5.8	24.0±6.2	10.0±1.5	17.0±8.4	24.6±6.5	15.0±5.4[§]	19.8±7.7
	Round 2	28.8±5.0	15.1±1.1	21.9±7.8	28.8±5.8	10.7±1.8	19.7±10.1	28.8±5.3	12.9±2.7[§]	20.8±9.0
	Round 3	27.1±4.0	17.0±1.4	22.0±6.0	23.9±4.5	9.8±1.5	16.8±7.9	25.5±4.5	13.4±4.0[§]	19.4±7.4
	Overall	27.0±5.6[¥]	17.3±2.6[†]	22.2±6.5[€]	25.6±5.9[¥]	10.2±1.6	17.9±8.9	17.9±8.9	13.7±4.2[µ]	20.0±8.0
Rest time (s)	Round 1	32.9±9.2	18.9±3.4	25.9±9.8	32.1±8.3	6.0±1.5	19.1±14.6	32.5±8.6	12.5±7.1	22.5±12.8
	Round 2	41.0±4.5	20.4±1.1	30.7±11.0	39.6±6.2	6.6±4.7	23.1±17.7	40.3±5.4	13.5±7.8	26.9±15.1
	Round 3	34.1±5.4	20.2±1.1	27.1±8.1	29.6±6.1	6.2±2.5	17.9±12.8	31.9±6.1	13.2±7.4	22.5±11.6
	Overall	36.0±7.4	19.8±2.2	27.9±9.8	33.8±8.0	6.3±3.1	20.0±15.1	34.9±7.7	13.1±7.3	24.0±13.3

[a] main effect of time: higher values after compared to before training at p< 0.001; [b] main training group effect: RTT elicited higher values than RST at p<0.001; [c] interaction effect between training group and time: RTT and RST elicited higher values after than before training at p<0.001; [d] interaction effect between training group and time: higher values in RTT than RST after training at p<0.001; [*] effect of round: higher values in rounds 1 and 3 compared to round 2 at p<0.001; [§] interaction effect between time and round: higher values in round 1, 2 and 3 after compared to before training at p<0.001; [€] main training group effect: RST elicited higher values than RTT at p<0.001; [µ] Main effect of time: lower values after compared to before training at p< 0.001; [¥] interaction effect between training group and time: RTT and RST elicited higher values before than after training at p<0.001; [†] interaction effect between training group and time: higher values in RST than RTT after training at p<0.001.

Table 5. Technical actions during match simulation before and after repeated techniques training (RTT) and repeated sprint training (RST) programs (Values are mean ± SD)

		RST (n=12)			RTT (n=12)			Overall (n=24)		
		Pre-Training	Post-Training	Overall	Pre-Training	Post-Training	Overall	Pre-Training	Post-Training	Overall
Single attacks (n)	Round 1	14±6	11±2	12±4	15±7	16±3	16±5	14±6	14±4	14±5[a]
	Round 2	11±3	8±2	10±3	12±5	12±4	12±4	12±4	10±4	11±4
	Round 3	12±4	9±2	11±3	12±5	12±3	12±4	12±4	10±3	11±4
	Overall	12±4	9±2[*]	11±4	13±6	13±4[d]	13±5 [b]	13±5	11±4 [c]	12±4
Combined attacks (n)	Round 1	2±1	2±1	2±1	2±2	5±1	4±2	2±2	4±2	3±2
	Round 2	2±2	3±1	2±2	2±2	6±2	4±2	2±2	4±2	3±2
	Round 3	1±1	2±1	2±1	2±1	5±2	4±2	2±1	4±2	3±2
	Overall	1±1	2±1	2±1	2±2	5±2[d, €]	4±2 [b]	2±2	4± 2 [§]	3±2
Counter-attacks (n)	Round 1	2±2	2±2	2±2	1±1	3±1	2±2	1±1	3±2	2±2
	Round 2	1±1	2±1	2±1	1±1	3±8	2±2	1±1	3±1	2±1
	Round 3	1±1	2±1	2±1	1±1	3±1	2±2	1±1	3±1	2±2

	Overall	1±1	2±1	2±1	1±1	3±1	2±2 [μ]	1±1	3±1	2±1
Defensive actions (n)	Round 1	11±4	9±2	10±3	10±3	6±2	8±3	10±4	7±2	9±3
	Round 2	8±4	8±1	8±3	7±3	7±1	7±2	7±3	7±2	7±3
	Round 3	9±4	8±2	9±3	7±3	7±1	7±3	8±4	8±2	8±3
	Overall	9±4	8±2	9±3[¥]	8±3	7±1	7±3	9±4	7±2[c]	8±3

[a] main effect of round: higher in round 1 compared to round 2 and 3 at $p< 0.05$; [b] main training group effect: RTT elicited higher values than RST at $p<0.001$; [c] effect of time: lower values after compared to before training at $p<0.05$; [d] interaction effect between training group and time: higher values in RTT than RST after training at $p<0.001$; [*] interaction effect between training group and time: RST elicited lower values after compared to before training at $p=0.002$; [§] Main effect of time: higher values after compared to before training at $p< 0.001$; [€] interaction effect between training group and time: RTT elicited higher values after than before training at $p<0.001$; [μ] Training group effect: RTT elicited higher values than RST at $p= 0.002$; [¥] Training group effect: RST elicited higher values than RTT at $p= 0.002$.