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Human Kinetics
ORIGINAL INVESTIGATION

Concurrent Training in Rugby Sevens: Effects of High-Intensity Interval Exercises

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Purpose: To assess the impact of 2 high-intensity interval-training (HIT) programs (short interval vs sprint interval training) on muscle strength and aerobic performances in a concurrent training program in amateur rugby sevens players. ***Methods:*** Thirty-six amateur rugby sevens players were randomly assigned to strength and short interval training (INT), strength and sprint interval training (SIT), or a strength-only training group (CON) during an 8-wk period. Maximal strength and power tests, aerobic measurements (peak oxygen uptake [VO_2peak] and maximal aerobic velocity), and a specific repeated-sprint ability (RSA) test were conducted before and immediately after the overall training period. ***Results:*** From magnitude-based inference and effect size (ES ± 90% confidence limit) analyses, the current study revealed substantial gains in maximal strength and jump-height performance in all groups. The difference in change of slow concentric torque production was greater in CON than in SIT (0.65 ± 0.72, moderate). VO_2peak and, consequently, mean performance in the RSA test were improved in the SIT group only (0.64 ± 0.29, moderate; –0.54 ± 0.35, moderate). ***Conclusions:*** The study did not emphasize interference on strength development after INT but showed a slight impairment of slow concentric torque production gains after SIT. Compared with INT, SIT would appear to be more effective to develop VO_2peak and RSA but could induce lower muscle-strength gains, especially at low velocity.

Keywords: strength training, aerobic training, interference

Many team sports require high-intensity efforts repeated over time. Thus, athletes must train both strength and endurance qualities simultaneously.[1] This has a particularly important impact in rugby sevens. Indeed, with only 14 players on a rugby union field and given the ~45% greater relative running volume and 135% greater high-velocity meters covered than in 15-player rugby games, it is likely that international-level rugby sevens players should have high levels of endurance and explosive strength.[2] However, previous studies have shown that compared with strength training alone, combining strength with endurance exercises, in a so-called concurrent training program, impairs strength gains.[3,4]

The first evidence that concurrent training attenuates the development of strength was provided by Hickson.[4] Subsequent observations[3,5] corroborated the idea of an interferential effect. Moreover, these studies revealed that concurrent training produces improvements in peak oxygen consumption (VO_2peak) and markers of aerobic capacity similar to those of aerobic training alone. So, interferences have only negative effects on strength development. The influence of several factors, such as order of training sessions,[6] recovery periods between sessions[7,8] and intensity and volume of exercises,[3] have been previously addressed to minimize interference. A recent meta-analysis identified duration, frequency, and modality of endurance exercises as the main factors supporting the interferential effect.[3]

To date, most studies have implemented continuous or long-interval endurance training protocols or both[4,9] alongside strength training. However, in team sports, it seems more relevant to use high-intensity interval training (HIT) such as short-interval training (<60-s efforts interspersed with recovery <60 s) or sprint-interval training (30 s all-out efforts interspersed with 2–4 min passive recovery). These 2 types of training strongly elicit the anaerobic glycolytic pathway and a large neuromuscular load[10]; they are also effective for maximum VO_2 improvements.[11,12] This is of particular interest when considering HIT is a time-efficient strategy for promoting mitochondrial biogenesis and associated improvements in oxidative capacity.[10] It is also favored in conditioning programs tailored for enhancing repeated-sprint ability (RSA).[6]

Nevertheless, with similar cardiorespiratory responses, short- and sprint-interval training would induce different adaptations. Indeed, sprint-interval training seems to provide greater physiological strain for the neuromuscular system and produce greater blood lactate accumulation than short-interval training.[10] So, different strength adaptations could be expected when concurrent training is differentiated by type of HIT. To our knowledge, no study has examined physiological adaptations to concurrent training with running sprint-interval training.

Therefore, the purpose of the current study was to investigate the impact of 2 HITs (short interval vs sprint interval), within concurrent training, on maximal muscular strength and power, aerobic capacity, and RSA and to compare with a strength-only training group. For that, physical performances were measured before and after an 8-week training period. Through greater neuromuscular strain, we hypothesized that gains in muscular strength and power would be greater after a concurrent training program with sprint interval training.

Methods

Subjects

Thirty-six amateur rugby sevens players volunteered to participate in the study but 6 of them were excluded because of injuries and

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lack of participation in all training sessions (Table 1). All were free from severe injuries for the last year. Players practiced resistance training for a minimum of 2 years. Their practice volume was ~5 to 6 hours per week shared in 3 rugby and 1 resistance training sessions. Volunteers were randomized into 3 experimental groups: 2 concurrent strength and aerobic training groups and 1 strength-only training group considered as a control group (CON). The difference between the 2 concurrent training groups was the type of HIT. One concurrent training program combined strength with short-interval training (INT), whereas the other combined strength with sprint-interval training (SIT). The experiment was performed during the summer off-season. Subjects had to avoid any supplementary workload. They were asked to restrict fatiguing efforts at least 2 days before each test session and were also advised to maintain their normal dietary intake throughout the study. No food supplement was administered during all the protocol duration. All participants were informed about the study protocol and gave written informed consent for participation. The study was in agreement with the Code of Ethics of the World Medical Association (Declaration of Helsinki) and was approved by the ethics committee (ComEth) of Grenoble.

Experimental Approach

The experiment lasted 11 weeks, with the first week dedicated to familiarization with all equipment and testing procedures. The second week involved initial tests, the next 8 weeks the training programs, and the last week the final tests (Figure 1). This randomized controlled study aimed to assess the effects of 2 HIT programs (short- vs sprint-interval training) on muscular strength and aerobic performances within a concurrent training program compared with CON. The workload for INT and SIT consisted of 2 strength and endurance sequences a week. Strength training was always performed first and was followed, after a 24 hour period, by HIT. Forty-eight hours elapsed between the first HIT and the second strength training of the week. CON completed only strength sequences with a 72-hour delay between them.

Dependent variables were designed to assess muscular strength and power, aerobic capacity, and RSA. The test sessions were conducted on the same days, in the same order, and at the same time on each occasion. The players were asked to have the same dietary intake before each test session.

Table 1 Subject Characteristics, Mean ± SD

	n	Age (y)	Height (cm)	Mass (kg)
SIT	10	26.4 ± 3.0	179.7 ± 8.0	89.3 ± 10.3
INT	9	25.0 ± 3.7	180.1 ± 7.7	86.2 ± 10.5
CON	11	27.5 ± 2.5	177.3 ± 5.6	89.4 ± 14.2

Abbreviations: CON, strength training; INT, concurrent strength and short-interval training; SIT, concurrent strength and sprint-interval training.

Muscle Measurements

Field Tests. Maximal strength was measured with the 1-repetition-maximum (1RM) test: half-squat (HS) exercise with 90° knee flexion for the lower body and bench-press (BP) and bench-row (BR) exercises for the upper body. 1RM tests were performed to measure gains related to training but also to determine appropriate work intensities for strength training. To warm up, subjects performed 3 submaximal sets with increasing loads. Then, they began the test by performing sets of only 1 repetition with progressively heavier weights until the 1RM was achieved. The precision was 2.5 kg for BP and BR movements and 5 kg for HS.[13] 1RM BP and BR were done with free weights, whereas 1RM HS was done on a guided machine.

The countermovement jump (CMJ) height was determined to estimate maximal power of the lower limbs with an Optojump system (Microgate, Bolzano, Italy).[14] Arms were kept on the hips during the duration of the movement to minimize the upper body contribution. The position of the upper body was standardized to avoid flexion and extension of the trunk.[14] Participants performed 3 trials, and the highest jump was retained for analyses.

Laboratory Tests. Maximal voluntary torque of the right knee extensors was measured on a previously validated Contrex isokinetic dynamometer (Medimex, Switzerland).[15] Participants were seated upright on the dynamometer with an 85° hip angle. Velcro straps were applied tightly across the thorax and pelvis, the leg being fixed to the dynamometer lever arm. The axis of rotation of the dynamometer was aligned to the lateral femoral condyle. Leg extensions were conducted within a 90° range of motion (from 100° to 10° knee flexion; 0° corresponding to complete leg extension). For all torque measurements, appropriate corrections were made for the gravitational effect of the leg.

Each session began with a standardized warm-up composed of submaximal contractions: 8 concentric at 180°/s, 6 concentric at 60°/s, and 2 isometric at 75°. After warm-up, quadriceps maximal

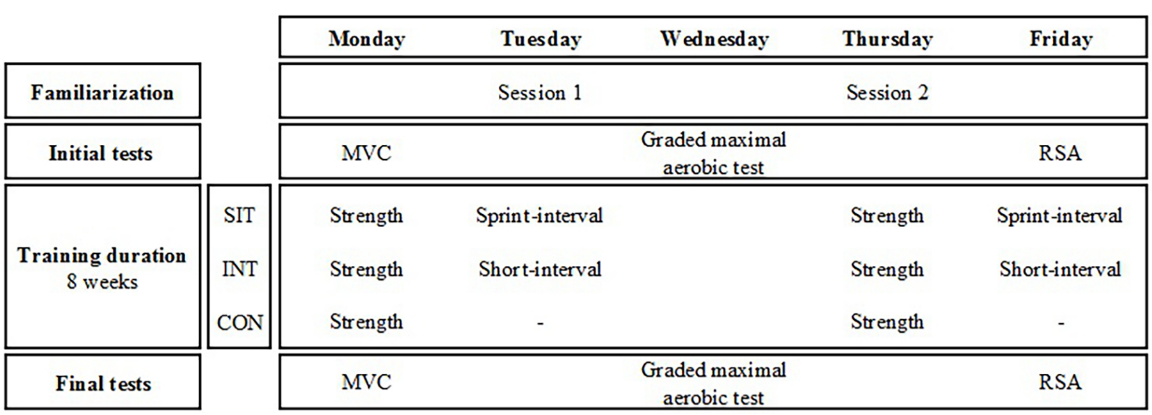

Figure 1 — Experimental design of the study. Abbreviations: CON, strength training; INT, concurrent strength and short-interval training; MVC, maximal voluntary contraction; RSA, repeated sprint ability; SIT, concurrent strength and sprint-interval training.

voluntary torque was measured in isometric and concentric conditions. Two isometric contractions (maximal voluntary contraction [MVC]) were maintained 5 seconds at a 75° knee-flexion angle. Sets of 3 concentric contractions were performed at 60°/s (MVC_{60}) and at 180/s (MVC_{180}). Two attempts were made for each condition with 2-minute recoveries between trials. Maximal torque was measured at a 75° angle during isometric and concentric conditions. The best attempt was retained in the analysis.

Aerobic-Capacity Measurements

A graded maximal aerobic running test to volitional exhaustion was performed on a mechanical treadmill (Medical Development, Andrezieux, France) with simultaneous electrocardiogram. The initial velocity (8 km/h) was maintained for 2 minutes and then increased by 0.5 km/h every minute. VO_2 was measured continuously using a breath-by-breath analyzer (Jaeger, Oxycon pro, Wuerzburg, Germany). VO_2peak was determined as the highest 30-second rolling average of VO_2 during the test and was retained for analyses. Heart rate was continuously measured using a portable heart rate monitor. Maximal heart rate was determined as the highest 15-second rolling average. The last velocity sustained for 1 minute was the maximal aerobic velocity (MAV).

RSA Test

The RSA test, incorporating both anaerobic and aerobic metabolism, consisted of twelve 20-m sprints every 15 seconds, interspaced with 10-m individual active recovery. Each sprint time was measured by means of photoelectric cells (Smartspeed, Fusion Sport, Sumner Park, QLD, Australia) positioned at a 1-m height. Before tests, subjects specifically warmed up to repeated sprint efforts. The tests were performed on a synthetic field covered and protected from wind, and subjects wore specific shoes for better reproducibility. The best sprint (RSA_{max}), the average of all sprints (RSA_{mean}), and the fatigue index (RSA_{FI}) were retained for analyses. Fatigue index was calculated using the following formula:

$$RSA_{FI}\ (\%) = [(RSA_{mean}/RSA_{max}) - 1] \times 100$$

All of the measurements were moderately to highly reliable, with the intraclass correlation coefficient ranging from .80 to .99 in neuromuscular field tests, from .83 to .93 in neuromuscular properties measurements, from .84 to .86 in the aerobic performance test, and from .71 to .88 in RSA test.

Strength Training

Every session began with a warm-up focused on core training. Strength training included exercises of the lower (HS, deadlift, and leg extension) and upper (BP and BR) body (Table 2). Training was divided into 3 periods during which the intensity progressively increased. The first period (wk 1–3) aimed to prepare participants for maximal strength training. The second (wk 4–6) and the third (wk 7–8) periods were designed to increase maximal strength (Table 2). Each set of HS (guided machine) was immediately followed by plyometric jumps. In addition, sets of leg extensions were combined with eccentric exercises on hamstring muscles. Leg extension and HS exercises were performed with specific Cybex guided machines (Medway, MA, USA). All contractions for upper body and deadlift exercises were performed in isoinertial conditions with free weights. Exercises were alternated during each training session, alternating lower- and upper-body exercises. Participants were free to change weight during the training period to work at the targeted intensities.

High-Intensity Interval Training

Two different HITs were used. They were performed outside on a track. The first consisted of short intervals and included 2 sets of interval running. Subjects alternated 30-second runs at 100% of their individual MAV with 30 seconds of active recovery at 50% MAV. MAV was obtained with a graded maximal aerobic running test performed on a mechanical treadmill during the test session. Subjects wore an individual heart rate monitor (Polar Electro Oy, Kempele, Finland) during each session to assess the cardiac workload during the 2 sets and to regulate the distance to cover during the 30-second efforts. Distance to cover for the next sessions was increased by 2.5 m if the 2-set mean heart rate was lower than 90% of the maximal heart rate. The second HIT, sprint interval, included repetition of 30 seconds of running all-out efforts with 4 minutes of passive recovery. A specific 15-minute warm-up, consisting of moderate to cruising and sprinting runs, preceded each aerobic training session.

Statistical Analyses

Data were assessed for practical significance using magnitude-based inference.[16] We chose to use inferential statistics because traditional statistical methods often fail to indicate the magnitude of an effect. All data were log-transformed before analyses to reduce bias arising from nonuniformity of error. For clarity, however, the values presented in the text and figures are not transformed. Changes were analyzed as percentages. Within- and between-trial changes were calculated for each group.[17] The between group differences were also conducted with baseline test values of each variable used as a covariate. The standardized differences or effect sizes (ESs; ES ± 90% confidence limit) were calculated using the pooled SD. The magnitude of the change was interpreted by using values 0.2, 0.6, 1.2, 2.0, and 4.0 as thresholds for trivial, small, moderate, large, very large, and, extremely large differences, respectively.[16] In addition, we calculated probabilities to establish whether the true (unknown) values were lower, similar, or higher than the smallest worthwhile change (SWC).[16] The SWC was calculated by multiplying 0.2 by the between-subjects SD based on Cohen ES principle.[18] Changes were considered substantial when they exceeded ± SWC. Quantitative chances of higher (beneficial) or lower (detrimental) differences were evaluated qualitatively as follows: <1%, almost certainly not; 1% to 5%, very unlikely; 5% to 25%, unlikely; 25% to 75%, possible; 75% to 95%, likely; 95% to 99%, very likely; >99%, almost certain.[16] Where the 90% confidence limits overlapped small positive and negative effects (±0.2), the result was deemed unclear.[13]

Results

1RM and CMJ

1RM and CMJ performance changes are depicted in Table 3 and Figure 2. At the end of the protocol, 1RM BP, BR, HS, and jump height increased in all groups. However, the between-group differences in training-induced changes were unclear.

Torque Production Capacity and Muscle Properties

MVC changes are depicted in Table 3 and Figure 3. MVC_{60} increased in all groups, although the increase was trivial for SIT. The difference in change of MVC_{60} was greater in CON than in SIT (0.65 ± 0.72, moderate). There was no other meaningful

Table 2 Description of the Training Programs

	Training period		
	Wk 1–3	Wk 4–6	Wk 7–8
Strength Workload			
Core training exercises			
sets	2	3	3
duration	3 min	3 min	4 min
recovery	30 s	30 s	30 s
Main exercises			
sets upper body	3	3	3
sets lower body	3	3	3
repetitions	10	6	3
intensity (% 1RM)	70	80	90
recovery	2 min	3 min	3 min
Complementary Exercises			
Repetition plyometric	6	6	6
Repetition hamstring	6	6	6
Aerobic Workload			
Short interval	2 × 8 min of 30/30 s	2 × 10 min of 30/30 s	2 × 12 min of 30/30 s
Sprint interval	4 × 30 s all-out	6 × 30 s all-out	8 × 30 s all-out

Note: Upper limb: bench press and bench row; lower limb: half squat, leg extension and deadlift. The strength workload was reduced by 33% every 4 sessions. Subjects did 2 sets instead of 3 for upper and lower body movements during these lightweight sessions. In addition, core training workload was reduced to 4 minutes (2 × 2 min) during weeks 1–3, 6 minutes (2 × 3 min) during weeks 4–6, and 9 minutes (3 × 3 min) during weeks 7–8. The aerobic workload was reduced by 25% every 4 sessions. During weeks 1–3, subjects ran 2 × 6 minutes of 30/30 s for INT or 3 × 30 seconds all-out for SIT; during weeks 4–6, they ran 1 × 8 minutes and 1 × 7 minutes of 30/30 s for INT or 4 × 30 seconds and 1 × 15 seconds all-out for SIT; during weeks 7–8, they ran 2 × 9 minutes of 30/30 s for INT or 6 × 30 seconds all-out for SIT. The reduction of strength and aerobic workload was applied to avoid overreaching.

Abbreviations: 1RM, 1 repetition maximum; 30/30 s, 30-s run at 100% of the individual maximal aerobic velocity alternated with 30 s of active recovery at 50% maximal aerobic velocity; CON, strength training; INT, concurrent strength and short-interval training; SIT, concurrent strength and sprint-interval training.

between-groups difference in training-induced changes. MVC_{180} and maximal isometric volumetric contraction (MVC_{iso}) increased in all groups but there was no meaningful between-groups difference in training-induced change.

Graded Maximal Aerobic Running Test

Changes in MAV and VO_2peak are reported in Table 4. MAV increased in SIT and INT, whereas change was unclear in CON at the end of the program. The difference in change of MAV between SIT and INT was unclear. VO_2peak increased in SIT, whereas changes in response to INT and CON training were trivial. The differences in change of VO_2peak were greater in SIT than in INT (0.75 ± 0.77, moderate) and CON (1.16 ± 0.76, moderate).

Repeated-Sprint Ability

RSA performance changes are depicted in Table 4. At the end of the protocol, changes of RSA_{max} were unclear in all experimental groups. The RSA_{mean} and RSA_{FI} performance improved in SIT, whereas changes were trivial or unclear in INT and CON at the end of the program. The differences in change of RSA_{mean} were greater in SIT than in INT (0.50 ± 0.69, moderate) and CON (0.60 ± 0.75, moderate). The difference in change of RSA_{FI} was greater in SIT than in CON (0.60 ± 0.76, moderate).

Discussion

The aim of the current study was to investigate the impact of different forms of HIT within concurrent training on muscular strength, aerobic capacity, and specific repeated-sprint performance. The main findings emphasized, to a small extent, an impairment of slow concentric torque production gains in the lower body following SIT only. In addition, the development of oxidative qualities would depend on the type of HIT, SIT inducing higher gains of VO_2peak and, consequently, RSA_{mean}.

The current study provided no clear demonstration of impairment of maximal strength and power development after INT. This result contrasts with a recent meta-analysis that reported significantly lower strength and power gains with concurrent training as compared with strength training.[3] Short-interval training, such as the one used here, generally induces muscular and cardiorespiratory adaptations (eg, pulmonary diffusion and mitochondrial volume

Table 3 Before and After Maximal Strength, Vertical Jump, and Maximal Voluntary Contraction Performances, Mean ± SD

	Before	After	Change ± 90% CL	Qualitative inference	Effect size ± 90% CL	Qualitative inference
1RM BP (kg)						
SIT	95.0 ± 19.3	102.5 ± 21.6	7.7 ± 3.2	almost certainly +	0.35 ± 0.15	small
INT	83.9 ± 13.4	91.4 ± 13.9	9.0 ± 2.8	almost certainly +	0.49 ± 0.16	small
CON	89.3 ± 12.3	99.5 ± 14.2	11.4 ± 2.9	almost certainly +	0.70 ± 0.19	moderate
1RM BR (kg)						
SIT	90.8 ± 12.1	98.3 ± 10.1	8.6 ± 2.9	almost certainly +	0.65 ± 0.23	moderate
INT	81.4 ± 8.4	90.8 ± 8.0	11.7 ± 3.7	almost certainly +	1.04 ± 0.34	moderate
CON	93.0 ± 11.1	102.0 ± 11.1	9.9 ± 2.9	almost certainly +	0.74 ± 0.22	moderate
1RM HS (kg)						
SIT	161.0 ± 18.7	184.0 ± 38.6	12.8 ± 8.5	very likely +	0.65 ± 0.44	moderate
INT	145.6 ± 17.4	163.3 ± 16.8	12.4 ± 8.9	very likely +	0.96 ± 0.70	moderate
CON	161.4 ± 18.2	187.3 ± 34.1	15.0 ± 4.7	almost certainly +	0.88 ± 0.29	moderate
CMJ (cm)						
SIT	32.7 ± 3.1	34.2 ± 4.7	4.1 ± 3.1	likely +	0.33 ± 0.24	small
INT	32.6 ± 4.8	33.6 ± 4.2	3.1 ± 4.6	possibly +	0.21 ± 0.31	small
CON	31.3 ± 4.7	34.2 ± 4.9	7.1 ± 4.3	very likely +	0.44 ± 0.27	small
MVC_{60} (N·m)						
SIT	254.9 ± 28.3	261.9 ± 35.2	2.5 ± 3.2	possibly +	0.19 ± 0.24	trivial
INT	233.0 ± 27.0	243.0 ± 39.4	3.7 ± 5.2	likely +	0.24 ± 0.33	small
CON	235.0 ± 47.2	253.3 ± 45.9	8.1 ± 4.2	very likely +	0.39 ± 0.21	small
MVC_{180} (N·m)						
SIT	196.8 ± 23.8	207.2 ± 25.5	5.3 ± 4.4	likely +	0.39 ± 0.33	small
INT	179.3 ± 22.4	191.7 ± 23.3	6.9 ± 3.1	very likely +	0.50 ± 0.23	small
CON	185.0 ± 37.6	196.8 ± 38.5	6.5 ± 2.7	almost certainly +	0.30 ± 0.13	small
MVC_{iso} (N·m)						
SIT	323.4 ± 49.0	344.6 ± 42.7	6.9 ± 3.3	very likely +	0.43 ± 0.21	small
INT	307.9 ± 52.5	323.7 ± 55.6	5.2 ± 2.4	very likely +	0.27 ± 0.13	small
CON	315.9 ± 73.2	342.4 ± 73.2	8.8 ± 4.5	very likely +	0.34 ± 0.18	small

Abbreviations: 1RM, 1-repetition maximum, BP, bench press; BR, bench row; CON, strength training; CMJ, countermovement jump; HS, half-squat; INT, concurrent strength and short-interval training; MVC_{60}, maximal voluntary contraction at 60°/s; MVC_{180}, maximal voluntary contraction at 180°/s; MVC_{iso}, maximal isometric voluntary contraction; SIT, concurrent strength and sprint-interval training.

density)[19] but also other adaptations, such as the reduction of the maximal shortening speed of fast-twitch fibers, the change of skeletal muscle-fiber population in favor of slow-twitch fibers,[20] and the limitation of rapid voluntary neural activation.[21] These neural adaptations are in contradiction with those induced by strength training and could limit strength and power development during concurrent training. The absence of interference after INT in the current study could be explained by high recovery duration between strength and aerobic sequences.[7] A recent study[7] showed no interference phenomenon following a concurrent training program using short-interval training with 24-hour recovery between training sessions. This would avoid interference of strength and aerobic-specific signaling pathways and, consequently, would reduce inhibition of anabolic responses (mTOR and p70S6K phosphorylation) due to AMPK activation.[6] Indeed, anabolic and metabolic (AMPK activation) signaling responses to strength and endurance exercises lasted ~24 hours and 3 hours, respectively.[6] In addition, 24-hour recovery delay between sequences may allow these anabolic responses to proceed unimpeded during early recovery.[6]

The current study showed only slight impairment of slow concentric torque production gains after SIT. In this case, however, antagonistic physiological adaptations might not be the main mechanism to explain this impairment. Indeed, sprint-interval training involves a significant contribution of anaerobic glycolytic energy production and significant neuromuscular strain.[9] Consequently, we hypothesized that sprint-interval training would optimize neuromuscular adaptations induced by resistance training rather than induce contradictory adaptations. In fact, the interferential effect could be explained by

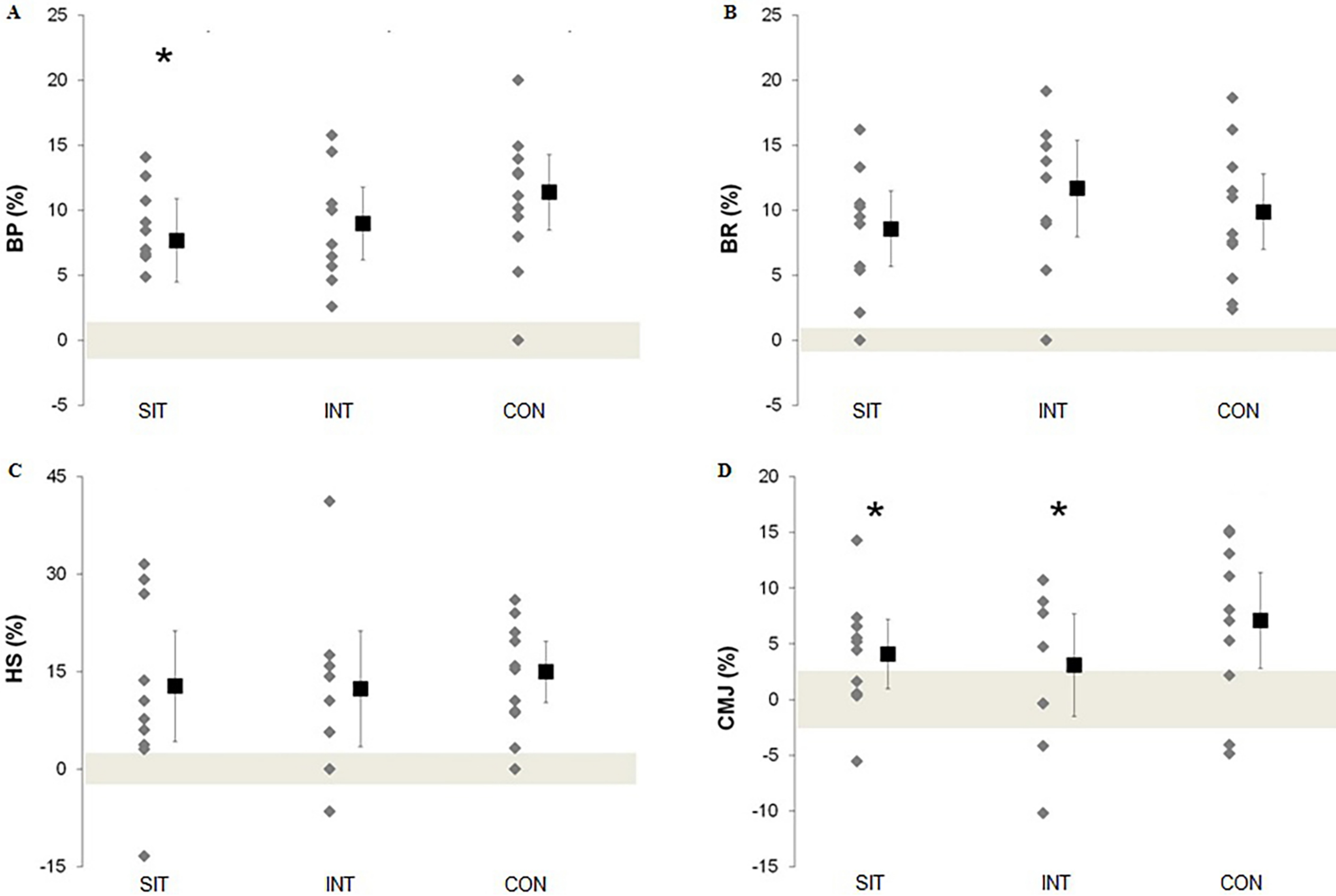

Figure 2 — Mean and individual within-group changes for 1RM and height jump. (A) BP, (B) BR, (C)HS, (D) CMJ. The black squares represent the mean variations, whereas the gray diamonds represent individual variations, Bars, on each side of the averages, indicate uncertainty in the true mean changes with 90% confident interval. Trivial area was calculated from the smallest worthwhile change (see Methods). *Improvement was possibly (>75% probability) lower compared with CON group. Abbreviations: BP, bench press; BR, bench row; CMJ, countermovement jump; CON, strength training; HS, half squat; INT, concurrent strength and short-interval training; SIT, concurrent strength and sprint-interval training.

another mechanism related to exacerbated residual fatigue. The present configuration of training proposed 48 hours of recovery between the first HIT sequence and the second strength sequence. However, Howatson and Milak[22] have shown repeated sprint exercises induce a significant decrement of quadriceps MVC and a significant increase in muscle soreness lasting for up to 48 hours. Their results confirmed sprint-interval-training-induced muscle fatigue can impair the quality of the second resistance training of the week and consequently limit training-induced muscle adaptations. In addition, we could explain lower torque production gains after SIT because of higher group mean preintervention value, inducing a ceiling effect for adaptation in this sample, compared with those in INT and CON. The current study did not reveal clear difference in the changes in slow concentric torque production values between SIT and INT. So, it would not be obvious to highlight an interference effect induced by SIT.

Our conclusion agreed partially with results observed in a recent study.[23] Using a similar concurrent training program, but with cycle sprints, Cantrell et al[23] did not find impairments of muscle strength and power gains. We can speculate that the concentric contractions of cycle sprint might produce less muscle soreness and muscular fatigue than running activity with an important eccentric component.[24] In addition, strength training quality could be more easily sustained without impairing lower-limb power and strength gains.[3,25]

Consistent with the principle of training specificity, no increase in MAV occurred in CON, whereas we observed significant gains for the 2 concurrent training groups. However, only SIT improved VO_2peak after the training period. Several studies[11] corroborate our results, emphasizing significant gains of VO_2peak after varying durations of sprint-interval training (2–7 wk). Although the effect of short-interval training has been proved to increase oxidative potential,[12] we did not observe any clear VO_2peak improvements following INT. A larger sample of subjects would probably be needed to confirm a possibly increased VO_2peak. The higher VO_2peak levels induced by SIT compared with those induced by INT could be explained by specific physiological adaptations. It is well established that rapid adaptation to sprint-interval training is related to significant fiber recruitment occurring during all-out bouts.[26] Specifically, the potential stress of type II muscle fibers is considered an important factor for sprint-interval training to elicit changes in oxidative capacity.[26] The better gains in VO_2peak after SIT could be related to a greater increase in oxidative potential in fast muscle fibers.[12] The aerobic system helps to quickly restore the reserves of energy substrates such

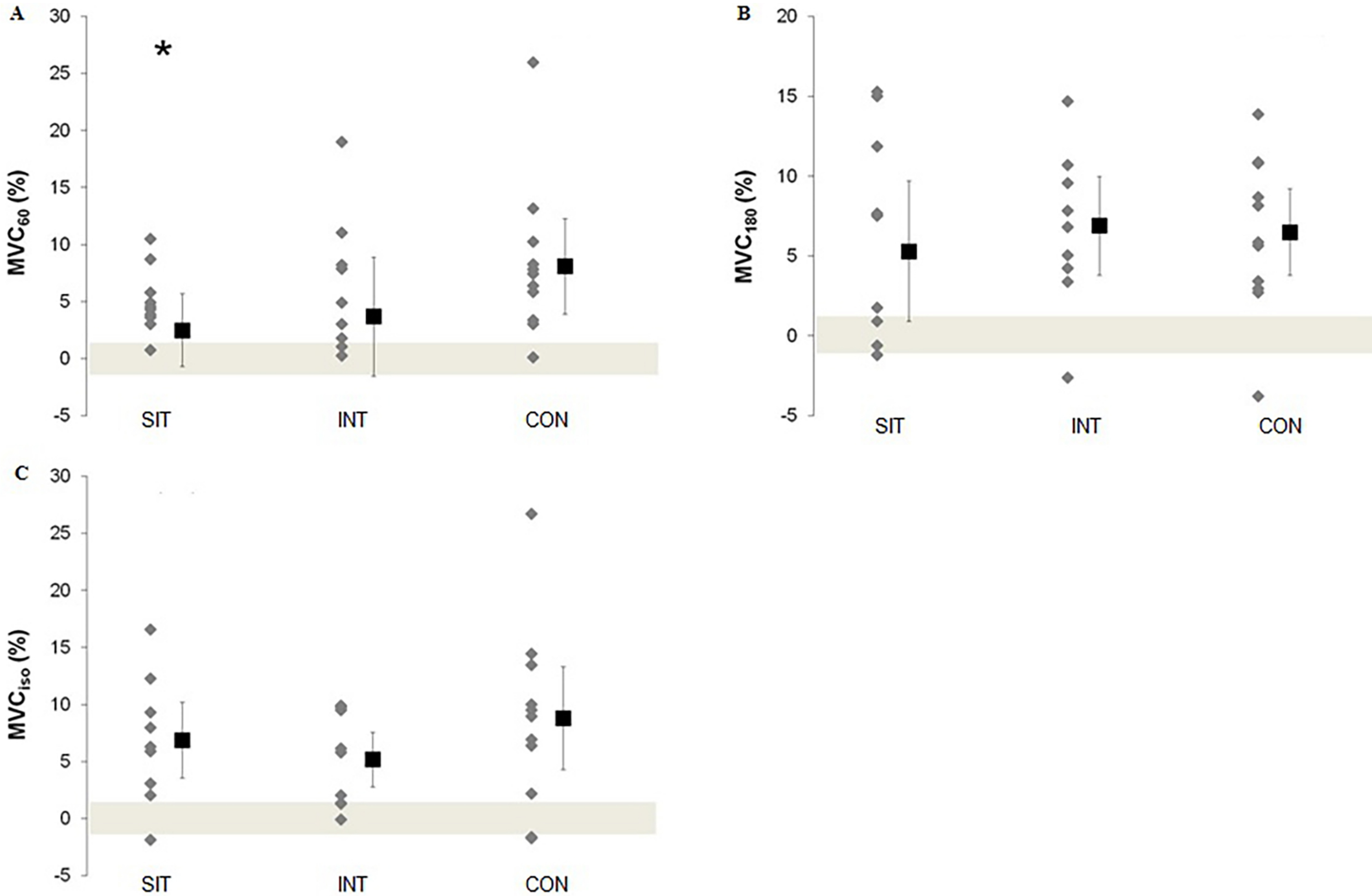

Figure 3 — Mean and individual within-group changes for MVC. (A) MVC_{60}, (B) MVC_{180}, (C) MVC_{iso}. The black squares represent the mean variations whereas the gray diamonds represent individual variations. Bars, on each side of the averages, indicate uncertainty in the true mean changes with 90% confident interval. Trivial area was calculated from the smallest worthwhile change (see Methods). *Improvement was possibly (>75% probability) lower compared with CON group. Abbreviations: CON, strength training; INT, concurrent strength and short-interval training; MVC_{60}, maximal voluntary contraction at 60°/s; MVC_{180}, maximal voluntary contraction at 180°/s; MVC_{iso}, maximal isometric voluntary contraction; SIT, concurrent strength and sprint-interval training.

as phosphocreatine between intense efforts.[27] Therefore, the gains in VO_2peak after SIT could explain the improvement in RSA_{mean}. This improvement might be the expression of lesser fatigability at the end of the training period without any improvement in the best performance. These results confirm that aerobic pathways play an important role in improving RSA. The results measured after INT, which emphasizes maintenance of VO_2peak and RSA performance, further strengthen this conclusion.

Conclusions

The main results of the current study did not emphasize interference on strength development following INT but showed only a slight impairment of slow concentric torque production gains following SIT. The absence of interferential effect could be explained by high recovery delay between strength and aerobic sessions. Oxidative adaptations were apparently dependent on the type of aerobic training, with higher VO_2peak gains measured after SIT. The results of the current study show SIT can be an appropriate method to develop VO_2peak and, consequently, RSA performance but also may slightly interfere with maximal torque production gains. A limitation of the study was the relatively small sample size, acknowledged as insufficient to detect clear effects.

Practical Applications

Although a slight interferential effect on slow concentric torque production gains, coaches should propose preferentially concurrent programs with sprint-interval training. Indeed, conducting this type of training twice a week for 8 weeks seems to be more efficient than short-interval training to improve VO_2peak and RSA performance. Nevertheless, the fatigue induced by this type of exercise must be finely monitored to limit the interferential effect. Many variables, eg, increased recovery delay between sequences or different recovery strategies, could be manipulated to optimize recovery at baseline performance. Another solution would be to practice SIT on a bicycle to reduce delayed-onset muscle soreness.

Acknowledgments

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Table 4 Before and After Graded Maximal Aerobic and RSA Test Performances, Mean ± SD

	Before	After	Change ± 90% CL	Qualitative inference	Effect size ± 90% CL	Qualitative inference
VO_2 (mL/min)						
SIT	4079 ± 289	4301 ± 326	5.4 ± 2.4	very likely +	0.64 ± 0.29	moderate
INT	4150 ± 406	4213 ± 408	1.5 ± 2.3	possibly +	0.14 ± 0.29	trivial
CON	3919 ± 374	3939 ± 423	0.4 ± 2.2	likely +	0.04 ± 0.19	trivial
MAV (km/h)						
SIT	13.4 ± 0.8	14.2 ± 0.8	5.6 ± 1.9	almost certainly +	0.84 ± 0.29	moderate
INT	14.0 ± 1.1	14.5 ± 1.1	4.1 ± 1.7	very likely +	0.47 ± 0.19	small
CON	13.2 ± 1.0	13.1 ± 1.1	–0.6 ± 2.5	unclear	–0.06 ± 0.28	unclear
RSA_{max} (s)						
SIT	3.24 ± 0.13	3.24 ± 0.16	–0.1 ± 1.8	unclear	–0.03 ± 0.37	unclear
INT	3.29 ± 0.16	3.29 ± 0.11	0.1 ± 1.6	unclear	0.01 ± 0.34	unclear
CON	3.33 ± 0.16	3.33 ± 0.18	0.0 ± 1.6	unclear	0.00 ± 0.29	unclear
RSA_{mean} (s)						
SIT	3.67 ± 0.25	3.24 ± 0.13	–3.2 ± 2.1	very likely –	–0.54 ± 0.35	small
INT	3.67 ± 0.28	3.62 ± 0.16	–1.2 ± 2.2	possibly –	–0.18 ± 0.32	trivial
CON	3.80 ± 0.23	3.76 ± 0.22	–1.1 ± 1.7	possibly –	–0.17 ± 0.25	trivial
RSA_{FI} (%)						
SIT	13.3 ± 3.6	9.9 ± 2.7	–26.3 ± 21.3	very likely –	–1.06 ± 0.67	moderate
INT	11.3 ± 5.5	9.8 ± 2.8	–6.4 ± 28.2	unclear	–0.15 ± 0.57	unclear
CON	14.2 ± 5.2	12.9 ± 3.1	–5.8 ± 12.4	possibly –	–0.17 ± 0.25	trivial

Abbreviations: CON, strength training; INT, concurrent strength and short-interval training; MAV, maximal aerobic velocity; RSA, repeated-sprint ability; RSA_{max}, best performance among the 12 sprints; RSA_{mean}, average of the performance of the 12 sprints; RSA_{FI}, fatigue index during the test; SIT, concurrent strength and sprint-interval training; VO_2peak, peak oxygen consumption.

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