SCIENTIFIC JOURNAL OF SPORT AND PERFORMANCE

ORIGINAL ARTICLE

Effects of concurrent in-season training on physiological functions required for top handball performance athletes

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ABSTRACT

This study examined the physiological effects of combining contrast complex training (CCT) with either repeated short sprints (RSE) or high-intensity intervals (HIIT) on elite male handball players during the competitive season. The goal was to identify which training method more effectively enhances strength, endurance, and sprint performance. Fifteen elite handball players were divided into two groups during a 12-week training program, conducted alongside their regular handball practice. The RSE group (n = 8) performed 10 shuttle sprints (2x15m) with passive rest, while the HIIT group (n = 7) completed 5 repetitions of 30-second all-out sprints with directional changes. Both groups participated in CCT exercises, including squats at 90% of 1RM, jump squats at 50% of body weight, and drop jumps from 30 cm. Performance was assessed before and after the intervention using tests for jump squat rate of force development (RFD), 5-jump distance, 30m sprint, repeated shuttle sprint ability (RSSA), maximal squat strength, Yo-Yo intermittent recovery (YYIRT 1), and VO_{2max}. Both groups significantly increased maximal squat strength, with the RSE group improving by 8.8% and the HIIT group by 7.4% ($p < .01$). The HIIT group showed a greater improvement in RFD (63.3% vs. 56.3%, $p < .05$). VO_{2max} increased by about 2% in both groups. YYIRT 1 improved by 9.4% in the RSE group and 5.8% in the HIIT group. However, acceleration (5m sprint) declined in both groups, more notably in the RSE group (-5.7%). RSSA performance deteriorated in the RSE group, while the HIIT group significantly enhanced their fatigue resistance, with a 39.1% improvement in Sdec at RSA ($p < .09$). CCT increased strength and RFD but did not improve acceleration. HIIT was superior to RSE in maintaining or improving repeated sprint ability, making it the preferred method for elite handball players during the competitive season.
Keywords: Performance analysis, Intermittent sport, Repeated sprint ability, Rate of force development.

Cite this article as:
Belkadi, A., Beboucha, W., Benhammou, S., Moussa, M., Bouzoualegh, M., & Dairi, A. (2025). Effects of concurrent in-season training on physiological functions required for top handball performance athletes. *Scientific Journal of Sport and Performance*, *4*(1), 40-54. https://doi.org/10.55860/JIXW8099

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Submitted for publication September 02, 2024.
Accepted for publication November 07, 2024.
Published December 08, 2024.
Scientific Journal of Sport and Performance. ISSN 2794-0586.

doi: https://doi.org/10.55860/JIXW8099

INTRODUCTION

Handball is one of the fastest team sports and is characterized by maximum activities during shorter durations together with accelerations and decelerations which makes the game intermittent in nature (Barbero, Granda-Vera, Calleja-González, & Del Coso, 2014; Lars Bojsen Michalsik, Madsen, & Aagaard, 2015). This together with a large quantity repeated, high-intensity moments, such as sprints, jumps and shots, make modern handball a physically demanding intermittent team sport with high demands on different strength qualities, aerobic and anaerobic capacity. In other words, a high level of physical capacity is required to a elite handball players must be able to use their technical and tactical ability throughout an entire match (Lars Bojsen Michalsik et al., 2015).

The men's elite series includes 32 matches and runs from September to March (24weeks) with only a longer break of about three weeks(Hermassi, Chelly, Tabka, Shephard, & Chamari, 2011). This means an average of 1.3 series matches per week. In addition to this, additional matches may be added through cup games and possible national team games for the team and player respectively(L. B. Michalsik, Aagaard, & Madsen, 2013). Furthermore, the season is extended for most the teams including either playoffs or qualifying series. Overall, this means that the competition season is seven to eight months with a few longer periods of rest as well as relative many matches which allows an optimization of training to maintain (or increase) the physical the ability during the season is very important both for success and for long-term development(Hermassi, Wollny, Schwesig, Shephard, & Chelly, 2019).

To improve handball performance, elite players must in addition to specific handball training further train strength (A Belkadi & Mime, 2019), speed and endurance (Martin Buchheit, Mendez-Villanueva, Quod, Quesnel, & Ahmaidi, 2010). Few studies have investigated training effects in elite active or very fit athletes where high concurrent levels of strength as well as anaerobic and aerobic capacity are required to successfully perform (Androulakis-Korakakis et al., 2018; Breil, Weber, Koller, Hoppeler, & Vogt, 2010; Tanaka & Swensen, 1998; Wilson et al., 2012). Little is known about the best way to increase sport-specific performance in handball which makes it exist need for more and new experimental studies with interventional programs to increase knowledge and find new effective training methods for, among other things, agility, power and strength linked to the demands of handball (Manchado, Tortosa-Martínez, Vila, Ferragut, & Platen, 2013; Ziv & Lidor, 2009). A problem when developing programs is the risk of interference between different components of physical form arises when strength, sprinting, endurance, sport-specific factors and competitions are carried out simultaneously/combined (Geliebter et al., 1997; Granados, Izquierdo, Ibanez, Ruesta, & Gorostiaga, 2008; Holviala et al., 2012; Sperlich et al., 2017). Furthermore, handball has in the last decade developed and the amount of training increased significantly, as did the intensity of the game (A. Belkadi, Benchehida, Benbernou, & Sebbane, 2019). Based on these changes to the game, it is especially relevant to try to identify optimal training methods for today's elite players (Karcher & Buchheit, 2014; Pino-Ortega, Rojas-Valverde, Gómez-Carmona, & Rico-González, 2021).In order to further existing knowledge and train elite handball players to maintain (or improve) performance throughout the season (Adel Belkadi et al., 2015), this study will apply existing knowledge in practice. More specifically, the development of leg strength and power, physical fitness, and specialized endurance, as well as sprinting and the capacity to repeatedly sprint, are all important (RSA)(Saddek Benhammou et al., 2022; Manar, Adel, Lalia, & Saddak, 2023). Additionally, if conducting study on it involves some flaws and restrictions inherent in the natural sports arena, it is crucial to do so in order to apply and advance the body of already known information.

The aim of this study was to investigate the physiological effects of combination training, including strength training, contrast complex training (CCT) combined with interval training in the form of repeated short sprints

(RSE) or longer (30 s) high-intensity intervals (HIIT) in men's relay handball players, during competitive season.

MATERIAL AND METHODS

Participants

A men's team with experienced handball players (n = 18) was, after division into pools playing position (goalkeeper, winger, Pivot and centre-sixes), randomly divided into either the group that performed high-intensity intervals combined with CCT, the HIIT group (n = 9) or in the one who performed repeated sprints combined with CCT, the RSE group (n = 9) during the intervention. During the course of the study, three participants dropped out due to injury, respectively low participation in the exercise intervention. The reason for the wide spread in weight in HIIT group is that the two heaviest and the three lightest participants ended up in this group and that they different playing positions have different physical requirements. There was no significant difference between the groups' anthropometric measurements (Table 1) or performance measured at the pre-tests.

Table 1. Descriptive statistics for anthropometric variables of the participants.

	RSE (n = 8)	HIIT (n = 7)
Age (years)	20.8 ± 2.5	20.6 ± 2.15
Body weight (Kg)	91.7± 4.45	88.3 ± 9.31
Length (cm)	190 ± 5.16	188.1 ± 7.54

Procedure/test protocol/skill test trial/measure/instruments

Before the commencement of the study, participants received comprehensive verbal and written explanations regarding the study's objectives, potential risks, and benefits. They were assured that their participation was entirely voluntary and that they could withdraw from the study at any time without providing a reason. The confidentiality of personal data and results was strictly maintained, with access limited to the author and the head coach, ensuring that unauthorized individuals could not access the information. All participant data presented in the study were anonymized. The research was conducted in accordance with the principles of the Declaration of Helsinki (World Medical Association, 2013), and voluntary written consent was obtained from all participants, with parental consent provided for those under 18 years of age. Inclusion criteria for the study required participants to be members of elite handball teams with prior experience in traditional strength training(Adel et al., 2019). The team’s collective decision to participate determined selection. Participants were excluded from the study if they missed testing due to injury or illness or attended less than 85% of the training sessions.

Experimental overview

To investigate the effects and possible differences in RSA and other handball-specific performance as a result of the two intervention groups' training, a test battery of eight was taken various tests. The tests mainly included field tests but also laboratory tests which was carried out in LABOPAPS sports laboratory (Adel Belkadi, Remaoun, & Benbernou, 2017). The tests were divided into three different days (Table 2) where they the two initial days were followed by approx. 48 h of rest to minimize possible fatigue effects.

Trainers and participants were instructed not to perform any strenuous exercise 48 hours before the tests. Furthermore, any intake of food or supplements would be the same at the pre- and post-tests. Before the tests were carried out approx. 15 min, non-standardized warm-up, which included running, mobility exercises and explosive exercises. Participants received verbal encouragement during the tests.

Table 2. Experimental overview days of the tests.

Day	Tests
Day 1	- Test of isometric strength - Jump squat (JS) - 5-jump for distance test (5JT) - 30m sprint test - Repeated sprint test (RSSA)
Day 2	- 1 RM squat - Yo-Yo intermittent recovery test (YYIRD1)
Day 3	- Maximal oxygen uptake test (VO_{2max})

Familiarization To minimize the learning effects and reduce the risk of injury, three were carried out familiarization session with the participants the week before the pre-tests and the start of the intervention (Cherara, Belkadi, Mesaliti, & Beboucha, 2022). The familiarization sessions included training of the 5JT, RSSA, Yo-Yo and SJ tests as well as of the strength and plyometric exercises linked to the CCT program and RSE/HIIT. Participants received technical instruction and feedback during each exercise.

Isometric leg strength test

Isometric leg strength was measured by having the participant apply force for 6 seconds against a force plate (9281E; Kistler; Switzerland) placed on the footplate of a Hack-squat apparatus (Figure 1). Data were collected at 1 kHz. The angle in the knee joint during the test was set to 90°. The angle was kept fixed by an adjusted chain connected between the foot plate and the movable back plate (S. Benhammou, Mourot, Mokkedes, Bengoua, & Belkadi, 2021; Youcef, Mokhtar, & Adel, 2022). Two trials were carried out, of which the one with the highest value was used for analyses. The test was performed in LABOBAPS's physical test laboratory.

Figure 1. The footplate of a Hack-squat apparatus.

Yo-Yo Intermittent Recovery Test (YYIRT 1) - Specific Endurance Test

To measure sport-specific endurance and the ability of handball players to recover during high-intensity, repeated sprints, the Yo-Yo Intermittent Recovery Test Level 1 (YYIRT1) was used (Krustrup et al., 2003). The test consists of repeated 40-meter intervals (2 x 20 m with a 180° turn) with 10 seconds of active recovery between intervals, involving 2 x 5 m walking or slow running with a 180° turn. The test was conducted indoors on a plastic floor, on a handball court with cones marking the lanes. The speed of the intervals progressively increases and is controlled by an audio signal from a computer. The test continues until exhaustion. When a participant fails to reach the start/finish line on time for two consecutive intervals, the test is stopped, and the total distance (m) is recorded as the test result.

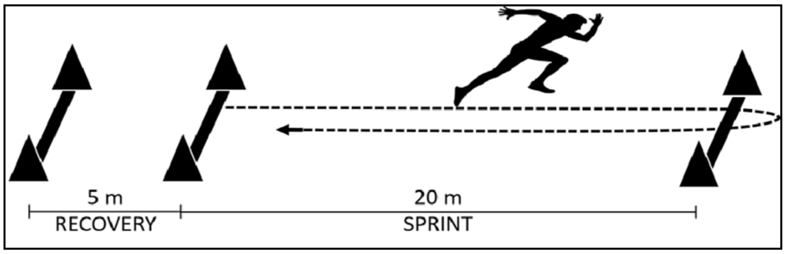


Figure 2. Yo-Yo Intermittent Recovery Test (YYIRT) consisting of repeated sprints of 2 x 20 m with 10 seconds of active recovery (2 x 5 m jog).

Maximal Oxygen Uptake (VO_{2max})

To determine maximal oxygen uptake (VO_{2max}), a progressive treadmill test was conducted where the running speed increased by 0.5 $km \cdot h^{-1}$ every 30 seconds until exhaustion(Sheridan et al., 2021). Blood lactate levels were measured at 1, 3, and 5 minutes post-test using an electro-enzymatic method, with the equipment calibrated against standard lactate solutions. Oxygen uptake was measured using the Oxycon Pro system, validated against the Douglas bag method and metabolic simulations(Macfarlane & Wong, 2012). The test recorded the time of exhaustion and corresponding running speed for analysis.

Complex Contrast Training (CCT)

The strength component of the study involved Complex Contrast Training (CCT), which consisted of performing three strength exercises in succession followed by a 4-minute rest before starting the next set. The exercises were:

Squats: 3 repetitions at 90% of 1 repetition maximum (1 RM),Jump Squats: 6 repetitions with 50% of body weight, Drop Jumps: 6 repetitions from a height of 30 centimetres (Maio Alves, Rebelo, Abrantes, & Sampaio, 2010)

Repeated Sprint Exercise (RSE)

The RSE group performed 10 shuttle sprints of 2 x 15 meters, similar to the RSA test, with a new sprint starting every minute, allowing about 54 seconds of rest (Girard, Mendez-Villanueva, & Bishop, 2011). At least two participants completed the sprints simultaneously, starting on a signal from the leader. The sprints were conducted on two different lanes to avoid interfering with HIIT runs.

High-Intensity Interval Training (HIIT)

HIIT consisted of 5 intervals of 30 seconds each, involving maximal running with directional changes, followed by 2.5 minutes of rest between intervals (Adel et al., 2019; Soylu, Arslan, Sogut, Kilit, & Clemente, 2021). The running pattern resembled an hourglass, with a total distance of approximately 100 meters per lap (17 meters for the short sides and 33 meters for the diagonals). Corner markers on a full-size floorball field were used to indicate directional changes. Participants started with a 1-second interval. During familiarization sessions, distances per interval were measured, and participants were instructed to aim for equal distances in each interval and to increase their distance with each session. Starting positions were adjusted to minimize overlap.

Data collection and analysis

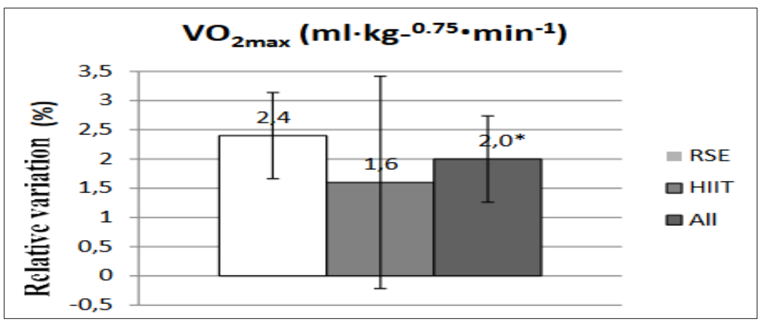
All data are presented in text, tables and figures as mean values for each group and in some cases, also for all participants and with ± standard deviations (SD) and in some cases changes (%) between the pre-post-tests. After the pre-tests, the groups' scores were compared descriptive data and physical capabilities through independent t-tests to ensure that they started the intervention with similar values in the two groups. T-test was used to find statistical significance in changes within the groups. These calculations were performed in SPSS 22. Shapiro-Wilk W test was used to examine the normality of the data and resulted that parametric statistical methods were used (ANOVA). Comparisons between the groups were made with one-way analysis of variance. Post Hoc differences were evaluated by Turkey HSD test. All statistical analyses that resulted in $p < .01$ and $p < .05$ are considered statistically significant.

RESULTS

Table 3. Strength and power development results.

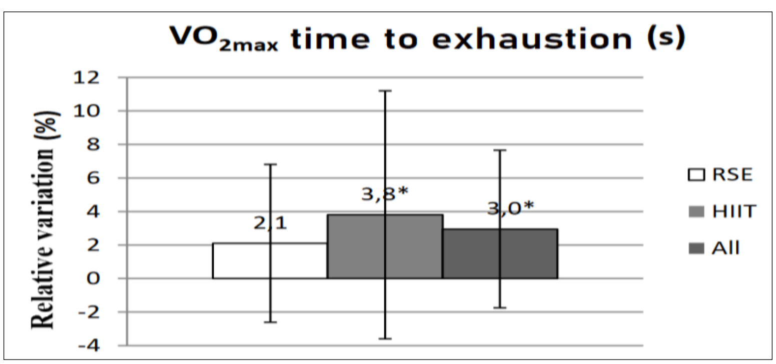
	RSE				HIIT			
Tests	*n*	Pre	Post	*p*	*n*	Pre	Post	*p*
YYIRD (m)	8	1676 ± 212.8	1624 ± 199.2	.13	7	1620 ± 141.3	1720 ± 148.8	.10
Time to exhaustion (s)	7	588.3 ± 33.3	597.5 ± 42.6	.36	7	573 ± 40.4	587.17 ± 41.96	.04(*)
VO_{2max} ($l \cdot min^{-1}$)	7	5.39 ± 0.36	5.33 ± 0.35	.10	7	5.76 ± 0.62	5.82 ± 0.55	.20
VO_{2max} ($ml \cdot kg^{-0.75} \cdot min^{-1}$)	7	161 ± 10.2	165 ± 5.99	.17	7	157.4 ± 4.30	160 ± 4.16	.11
VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	7	56.5 ± 4.28	57.8 ± 1.90	.22	7	55.6 ± 3.30	56.5 ± 1.58	.07(*)

Note. YYIRD = Specific endurance, Yo-Yo test; VO_{2max} = maximum oxygen uptake capacity; Time to exhaustion = total time when performing the VO_{2max} test.



*Note. * = Significant change (p < .05).*

Figure 3. Change in test value/oxygen uptake. Ability calculated in relation to body weight and size.



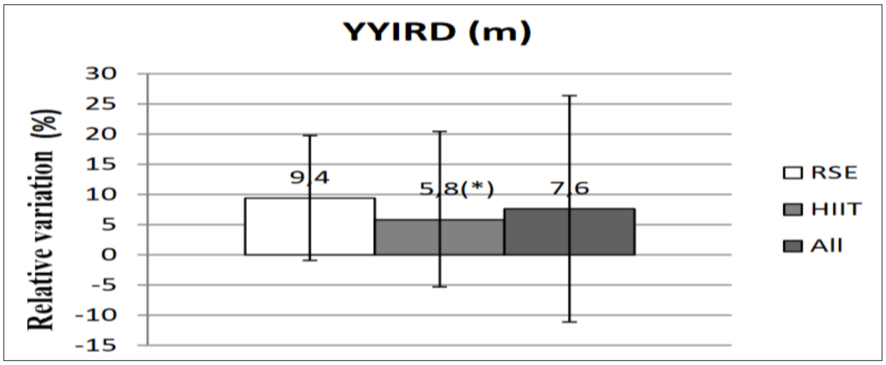
*Note. * = Significant change (p < .05).*

Figure 4. Change in time to exhaustion in VO_{2max} test.

Both groups increased their oxygen uptake capacity and time to exhaustion in the VO_{2max} test, but only the HIIT group's time to exhaustion was significant. Running speed at which VO_{2max} was reached also increased in both groups, by 1.4% for the RSE group and 1.8% for the HIIT group. The test score increased by 2.2 and 1.7 respectively in each group but when calculated in relation to body weight the results are slightly different, see Figure (3,4).

There were no significant differences between the groups. Calculated on the whole group increases in VO_{2max} and increase in time to exhaustion are significant.

The total running distance during the specific endurance test (YYIRT 1) also increased in not significant when calculated separately but significant when calculated separately (Figure 5).



Note. (*) = Trend (p < .10)

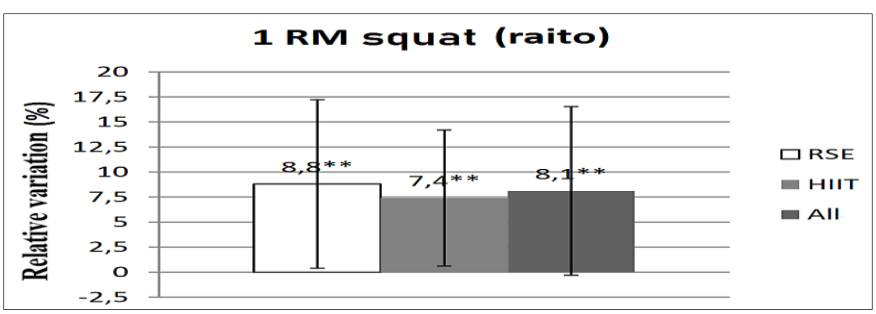
Figure 5. Change in handball-specific endurance in meters sprinted in yoyo test (YYIRT1).

Table 4. Descriptive statistics of the parameters of the Fitness and specific endurance.

	N	Pre	Post	*p*	N	Pre	Post	*p*
Squat 1RM (kg)	8	123.6 ± 23.6	135 ± 19.8	<.01**	7	127.5 ± 24.3	136.7 ± 24.8	< .01**
Squat 1RM (ratio)	8	1.40 ± 0.32	1.53 ± 0.27	<.01**	7	1.45 ± 4.85	1.55 ± 0.29	.01*
RFD (Ns/kg)	8	17.79 ± 3.53	27.81 ± 10.45	.02*	7	16.41 ± 0.29	26.38 ± 4.37	< .01**
5JT (m)	8	12.78 ± 0.41	12.92 ± 0.45	.42	7	12.55 ± 0.60	12.75 ± 0.67	.08(*)

Note. 1 RM (kg) = real weight; 1 RM (ratio) = weight in relation to body weight; RFD = Rate of force development; 5JT = 5 jump test for distance.

All participants increased their strength in the squat both in real weight and in relation to body weight (Table 4), The increases were significant in both groups but there was no significant difference between the groups (Figure 6).



*Note. ** = Significant change (p < .01).*

Figure 6. Change of 1 RM in relation to body weight (kg/kg body weight).

RFD also increased significantly in both groups, with over 56% for RSE and a further 7% for 63.5% in the HIIT group. All participants increased their RFD, by at least 16% and as over 100%. The results were significant in both groups but again there was no significant difference between the groups (Figure 7).

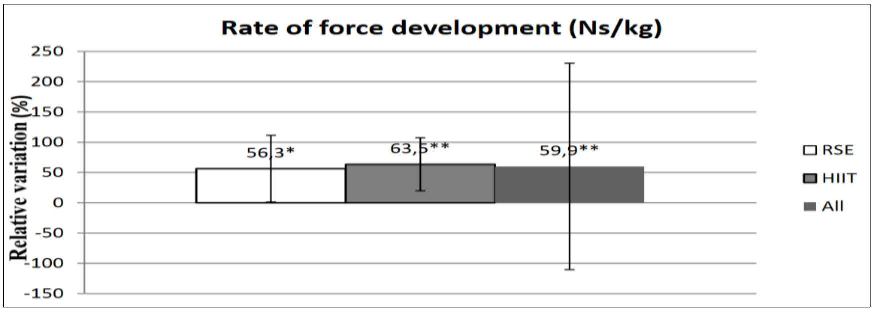


Figure 7. Change in Rate of force development in the lower body.

In 5 JT, the RSE group increased jump length by 1.1% and HIIT by 1.6% and thus 1.35% seen to the whole group. The results showed a trend towards improvement (p < .10) in the HIIT group and calculated for the whole group see (Figure 7).

Table 5. Sprint results.

	n	Pre	Post	*p*	n	Pre	Post	*p*
Acceleration Sprint 5m (s)	8	0.99 ± 0.05	1.05 ± 0.03	.02*	7	0.99 ± 0.05	1.01 ± 0.05	.24
Maximum speed,20-30 m (m/s)	8	8.26 ± 0.31	8.24 ± 0.29	<.01**	7	8.40 ± 0.44	8.34 ± 0.34	<.01*

Note. ** = Significant change (p < .01);* = Significant change (p < .05).

Only the RSE group's slower timing in the 5 m see (Table 5), sprint was substantial, but both groups' significantly faster maximum speed in the final 10 m was. There was no obvious difference between the two groups' performances.

To investigate whether the results of the first post-tests were possibly influenced by neural fatigue due to a period of increased intensity at the match and training during the final game. This test was performed after a period of 10 days of rest followed by 7 days of basic training without explosive elements.

Table 6. Results sprint post-test.

	Sprint (s)	Maximum speed (m/s)	Sprint (s)	Maximum speed (m/s)
Pre	0.9 ± 0.03	8.4 ± 0.29	0.99 ± 0.03	8.34 ± 0.49
Post 1	1.04 ± 0.03(*)	8.36 ± 0.31	1.02 ± 0.05	8.26 ± 0.36
Post 2	0.98 ± 0.03	8.22 ± 0.23*	0.96 ± 0.02	8.21 ± 0.37

*Note. Sprint 5m = acceleration phase; Max speed = average speed 20 -30 m; * = Significant change (p < .05); (*)Significant change = (p < .10).*

These results are calculated on the seven participants who completed all three sprint tests (RSE n = 7, HIIT n = 7). At Post 1, participants in RSE had deteriorated 7.2% and HIIT 3% in the 5 m sprint. At Post 2, the corresponding figures, compared to the pre-tests, were 0.8 deterioration and 2.5% improvement, respectively. None of the changes were significant.

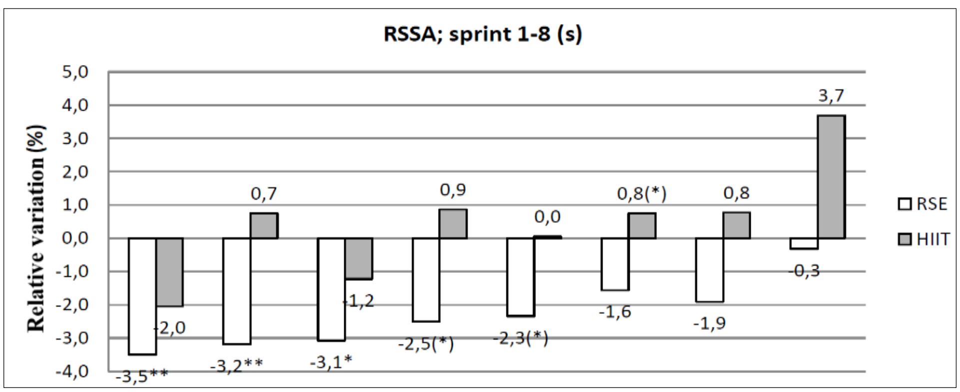
Table 7. Results of RSA.

	n	Pre	Post	*p*	n	Pre	Post	*p*
RSA_{Best} (s)	8	5.44 ± 0.23	5.63 ± 0.12	.01*	7	5.59 ± 0.09	5.64 ± 0.08	.11
RSA_{Sworst} (s)	8	5.91 ± 0.41	5.96 ± 0.14	.46	7	6.15 ± 0.41	5.97 ± 0.10	.24
RSA-$_{Tot}$(s)	8	45.42 ± 1.55	46.46 ± 0.86	<.01**	7	46.65 ± 0.62	46.42 ± 0.44	<.01**
S_{dec} (%)	8	4.48 ± 2.62	3.09 ± 0.83	.09$^{(*)}$	7	4.09 ± 1.76	2.9 ± 0.73	.09$^{(*)}$
FI (%)	8	8.72 ± 3.66	5.8 ± 1.80	.02*	7	8.51 ± 6.83	5.85 ± 0.66	.37

Note. RSA_{Best} = best sprint time; $RSAS_{worst}$ = worst sprint time; RSA_{Tot} = total time for the 8 sprints; S_{dec} = Sprint decrement score; FI = Fatigue index; n = number of participants; p = significance.

Best sprint time, RSABest, worsened (as the time increased) in both groups, more so in the RSE group than in the HIIT group, by 3.6% and 0.9%, respectively. The changes were significant only in the RSE group. The time difference between the groups was also significant ($p < .05$), with the HIIT group showing less deterioration.

Worst sprint time, RSA_{Sworst}, remained similar in the RSE group (-0.9%) but improved in the HIIT group (3%). However, these changes were not significant. In terms of total sprint time, $RSA_{Tot,}$ for the eight sprints, the RSE group deteriorated by 2.3% while HIIT improved by 0.5%. These changes were significant in both groups. Both groups improved S_{dec}, RSE by 30.9% and HIIT by 29.1%. Similarly, FI, RSE improved 33.4% while HIIT improved 31.3%. Of which only the RSE group's changes were significant. There was no difference between the groups in RSA_{Best}, $RSA_{Tot,}$ FI or S_{dec}.



*Note. ** = Significant change (p < .01); * = Significant change (p < .05); (*) = Tendency to change (p < .10).*

Figure 8. Changes in sprint time in the 8 sprints that made up the RSSA test.

DISCUSSION

The purpose of this study was to investigate and compare whether two different interval training methods combined with CCT could result in maintained alternatively changed physical capacity during the competitive season for elite men's handball. More particularly RSA, muscular strength, force development (RFD), power (5JT) and fitness (VO_{2max}) and sport-specific endurance. The primary findings of the current study demonstrated that relatively little but intense cardio training combined with strength training in the form of CCT is enough to maintain a pile fitness level that was affirmed by the study(Saddek et al., 2020; Spiering, Mujika, Sharp, & Foulis, 2021), significantly increase RFD and maintain power, but at the same time to acceleration ability decreased(Berria, Bachir, Eddine, & Adel, 2018; Mohamed, Mohamed, Mohammed, Mokrani, & Belkadi, 2019), likely due to fatigue at the end of the season, as well that HIIT is a better method than RSE for maintaining/developing RSA(Girard et al., 2011). With one exception (RSA_{best}) there were no significant differences between the groups' results ,partly probably on due to the small populations.

Fitness and specific endurance Oxygen uptake increased in both groups RSE (2.9%)and HIIT (1.6%) and seen throughout group (2.0%). Only a few studies have previously investigated the effects of HIIT vs RSE linked to RSA and VO_{2max} (Adel Belkadi, Alia, & Mohammed, 2020; Saddek Benhammou et al., 2022; Zerf, Mokhtar, Kherfane, Adel, & Beboucha, 2021). Of these, only three studies have measured and reported VO_{2max}. The studies that have been carried out in handball (M. Buchheit, Bishop, Haydar, Nakamura, & Ahmaidi, 2010; M. Buchheit et al., 2009; Martin Buchheit et al., 2008)has not reported any figures on changes of VO_{2max}. The results of this study are slightly lower than those of the three studies that all showed similar results between HIIT and RSE; with 5 - 6% increases (Cadenas-Sanchez et al., 2024; Fernandez-Fernandez, Zimek, Wiewelhove, & Ferrauti, 2012). However, these were not carried out during the season as well as with young participants and not with elite-level players, which could be a few reasons the differences. Compared to Gorostiaga et al (2006) on Spanish elite handball players during season, where no changes in endurance were noted, the results of this study show with average 2% improvement still on a good development. In the current study, the result was relatively similar in both groups, but RSE 0.8 percentage points higher increase in VO_{2max} (Boudehri, Belkadi, Dahoune, & Atallah, 2023; Tjønna et al., 2013). The increase can be caused by as well increased strength through CCT and thus running economy (Faude, Schnittker, Schulte-Zurhausen, Müller, & Meyer, 2013; Thomakos, Spyrou, Katsikas, Geladas, & Bogdanis, 2023) as well as increased central and local endurance as a result of high-intensity male ball training which was the same for all participants or one increased anaerobic capacity as a result of HIIT/RSE training.

In the test of maximum oxygen uptake, even greater improvements were noted over time fatigue. Here the HIIT group's increases were significant and greater as they increased 3.8% compared with the RSE group's 2.1%, making the HIIT group's increase 1.7 percentage points greater than RSE group. An increased anaerobic capacity as a result of HIIT training, which was aimed at development of aerobic fitness and buffering capacity could explain this difference, then The RSE group's program was not equally aimed at this type of adaptations but aimed at improvement of neuromuscular factors and increased sprint speed. Both groups increased the distance in the handball-specific endurance test (YYIRT1), The RSE group the most with 9.4%. HIIT increased 5.8%, i.e., 3.6 percentage points less. Similar patterns have also been reported in another study on soccer players where the sport-specific endurance increased more in the RSE group (28.1%) than the HIIT group (12.5) (Viaño-Santasmarinas, Rey, Carballeira, & Padrón-Cabo, 2018). Possible reasons may be that the RSE intervals with direction changes may be an advantage in Yo-Yo testing with 180 degree changes of direction unlike HIIT which did not have to decelerate to the same extent as RSE. In contrast, Mohr et al., (2007) in their 8-week HIIT vs RSE that HIIT was more effective in increasing distance and time to exhaustion in progressive running test (YYIRT2). Also, several studies(Fernandez-Fernandez, Sanz, Sarabia, & Moya, 2017; Sanchez-Sanchez et al., 2019; Viaño-Santasmarinas et al., 2018)reported a higher increase in tennis specific endurance in the HIIT group in their study with an increase of 28.9% compared to RSE's increase of 14.5%. It is difficult to draw any conclusions connected with the results of previous studies as these differ for current participants (age, training status), time on season and training and testing arrangements. But looking at the whole team's increases in VO_{2max} (2%), more time exhaustion (3%) and stretch in the Yo-Yo test (7.6%), this indicates that the team has increased the ability to maintain a high match tempo for longer periods and at match-decisive moments, such as the end of the halves. Furthermore, these results can be linked to an improved ability to recover between intense periods, which is also likely to affect match performances positively. A potentially increased anaerobic capacity, above all in the HIIT group, could it also positively affect the ability to maintain power and high intensity, in front all in defensive games which are more demanding than attacking games.

CONCLUSIONS

CCT is a time-efficient and good method for developing maximal strength and power development (RFD) during season. Despite this, CCT may not have a positive effect on the development of acceleration when it is combined with interval training, especially not at RSE intervals. However, the HIIT-CCT combination can potentially develop acceleration and maximal sprint speed and initial sprint ability at RSA but then in combination with sprint training and possibly in another training phase. HIIT may be a better training method than RSE because maintain or increase the ability to repeat sprints (RSA), probably due to improved anaerobic capacity and peripheral ability. Acceleration ability at 5 meter sprint may decrease with RSE but less (or increased) with HIIT. The training model with combined CCT and HIIT/RSE does not seem to imply anything opposite relationship for simultaneous development of VO_{2max}, specific endurance, maximum sprint speed, strength or RFD (as well as retained power). CCT combined with HIIT training is an effective (more than RSE) training method to maintain and develop physical characteristics relevant to handball performance, such as maximum strength, RFD, fitness, specific endurance and components linked to RSA during competitive season for elite male handball players.

AUTHOR CONTRIBUTIONS

Adel Belkadi: Study design, data collection, data analysis, and manuscript preparation. Wahib Beboucha: Data collection, data analysis, and manuscript preparation. Saddek Benhammou: Data collection, data analysis, and manuscript preparation. Mohammed Moussa: Study design, data analysis, and manuscript preparation. Manar Bouzoualegh: Study design, data analysis, and manuscript preparation. Abdelkader Dairi: Study design and manuscript preparation.

SUPPORTING AGENCIES

Training-University Research Projects (PRFU N° J00L02UN270120230001, Agreement: January 2023).

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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