Effects of high-intensity interval training and plyometric exercise on the physical fitness of junior male handball players

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Abstract. – **OBJECTIVE:** This study analyzed the effects of high intensity interval training (HIIT) combined with plyometric exercise on the physical fitness of junior male handball players.

PATIENTS AND METHODS: Subjects (age ~17 years) were randomly divided between experimental (n=17) and control (n=15) groups. During the 8-week intervention, the experimental group replaced a part of their regular regimen by HIIT, combined with plyometric exercise. Assessments in both groups before and after the intervention included: squat jump (SJ), countermovement jump (CMJ), sprint performance (5 m, 10 m, 20 m and 30 m), change of direction tests (Illinois modified test [Illinois-MT] and T-half test), 20-m shuttle run, and repeated sprint T-test.

RESULTS: The two-way analyses of variance revealed significant group-time interactions (all $p<0.05$), favoring the intervention group in 5 m, 10 m, 20 m and 30 m sprint (d=0.33, 8.3%; d=0.52, 7.6%; d=0.57, 6.8%; and d=0.58, 8.8%, respectively), T-half (d=0.25, 5.1%), Illinois-MT (d=0.47, 4.2%), SJ and CMJ (d=0.34-0.39, 34-4-34.9%), repeated sprint T-test best time, mean time and total time (d=0.83, 6.9%; d=0.62, 7.4%; and d=0.61, 7.2%, respectively), 20 meter shuttle run test aerobic maximum speed and predicted maximal oxygen intake (d=0.36, 7.5%; d=0.19, 9.4%, respectively).

CONCLUSIONS: HIIT combined with plyometrics can aid in the development of physical fitness abilities, which are extremely important to junior male handball players.

Key Words:
Exercise, Exercise therapy, Human physical conditioning, Resistance training, Circuit-based exercise, Sports.

Introduction

Handball is a sport that demands high-intensity intermittent exercise, with repeated running, jumping, sprinting and changes of direction (i.e., 10- to 12-m sprints of 2.3 s each; 50 turns per game)[1-3]. It requires a combination of aerobic power and anaerobic capacity that will allow the frequent repetition of short-duration high-intensity actions, interspersed with brief recovery intervals (i.e., 825 short duration [2–6 s] high-intensity actions, with 6 s intervals)[2-5]. Playing handball can improve both aerobic and anaerobic performance[3]. However, to maximize their abilities, handball players must engage in additional hand-

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ball-specific training, both physical and technical, to improve intermittent aerobic effort, speed, agility, strength, power, and ball throwing in both offensive and defensive phases of the game[3,6,7]. To improve players' physical fitness, coaches must schedule sessions that combine speed and explosive strength training[3,6-8]. Although power is a very useful quality - especially in shooting - handball also requires very good agility in handling the ball[9,10]. Passing accurately and effectively, knowing how to make a path to the goal by dribbling, and making feints to deceive the opponent are all essential assets, learned by repetition during training[11-14]. Therefore, training sessions must be of high intensity, so that the muscles become accustomed to this rhythm and enable the athlete to repeat these movements during the game[15].

Supplementing standard training sessions by plyometric exercise has proven helpful in developing some of these abilities[6], but it seemed possible that a combination of plyometric exercise with high-intensity interval training (HIIT) [16] might prove even more beneficial. HIIT is a form of timed interval training that alternates periods (e.g., 20-seconds) of high-intensity effort with rest intervals (e.g., 10-second), repeated several times[15,16]. Tabata et al[15] claimed that 4 minutes of HIIT increased both aerobic and anaerobic performance more than 60 minutes of moderate-intensity training. Viano-Santasmarinas et al[16] also reported increases in the countermovement jump performance of handball players after HIIT with either short or long interval durations. However, there is no evidence about the impact of HIIT, combined with plyometric exercise, on the physical fitness of junior male handball players.

Therefore, our aim was to document the effects of a combination of HIIT and plyometric exercise on the physical fitness of junior male handball players. Based on previous findings[16,17], we hypothesized that 8 weeks of HIIT and plyometric exercise would substantially improve the physical fitness (i.e., jumping, sprinting, change of direction speed, repeated sprinting ability, maximal aerobic power) of junior male handball players compared with a standard training program.

Patients and Methods

Participants

Written informed consent was obtained from all subjects' parents or guardians (and assent from the athletes) before participating in the study, approved by the Local Ethics Committee Research Unit (UR17JS01) in conformity with principles identified in the latest version of the Declaration of Helsinki. Thirty-two male junior handball players from a single team participated in this study, assigned randomly between the experimental group (n=17) and control group (n=15) (basal physical characteristics in Table I).

All participants had a minimum competitive experience of 5 y and had reached a medium competitive level within their division (i.e., U-17 National League). During the 4 months preceding the intervention, they trained 5 times per week (~2 h per session) and competed once per week. Goalkeepers were excluded from the study, because they did not participate in the same physical training program as the other players. During the intervention, both the control and the experimental group continued their habitual fitness sessions. However, the experimental group replaced a part of their technical/tactical sessions by HIIT combined with plyometric exercise.

Experimental Protocol

The 8-wk intervention was carried out during the regular season (i.e., in-season). Members of the selected team were matched according to field positions and randomly distributed between an experimental group (n = 17) and a control group (n = 15). Figure 1 presents a depiction of the recruitment and randomization process.

Table I. Physical characteristics of experimental and control groups (mean ± SD).

	Age (years)	Body mass (kg)	Height (m)	% Body fat	APHV (years)	Predicted years from APHV
Experimental group (n=17)	16.6±0.5	69.0±5.4	1.78±0.03	18.4±5.2	15.1±0.6	1.55±0.62
Control group (n=15)	16.5±0.8	68.9±5.3	1.76±0.07	21.4±6.3	15.1±0.6	1.52±0.62

APHV: age of peak height velocity.

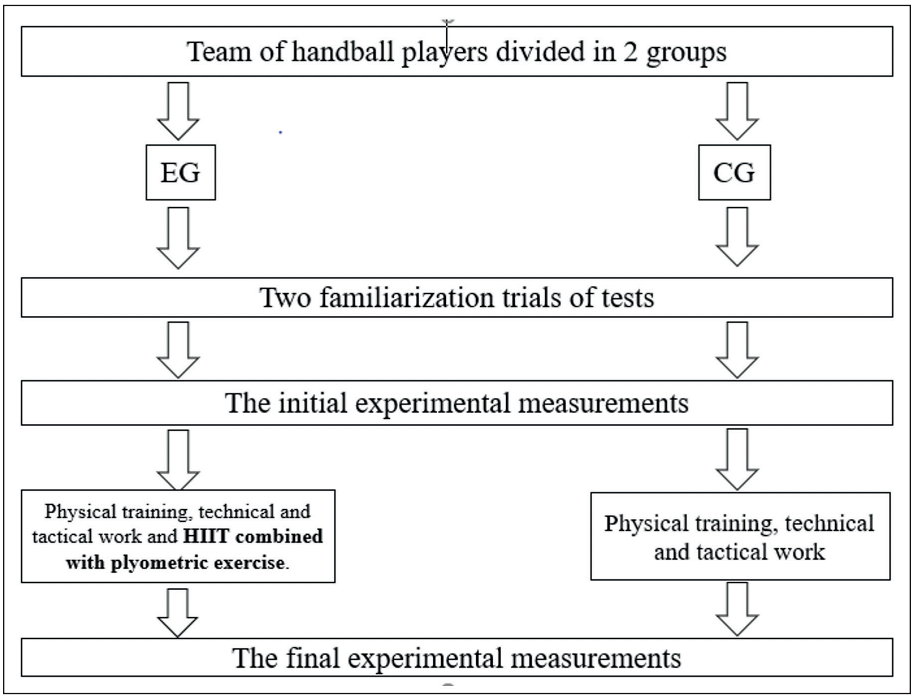

Figure 1. The diagram includes detailed information on the interventions received.

All measures were performed 1-wk before and 4 days after the last plyometric training session. The variables examined included squat (SJ) and countermovement jumps (CMJ), sprint performance (5 m, 10 m, 20 m and 30 m), change of direction tests (Illinois modified test [Illinois-MT] and T-half test), 20 m shuttle run, and repeated sprint T-test. Two familiarizations sessions of 60-70 min preceded definitive testing. Data were collected at the same time of day, under similar environmental conditions, and were separated at least by 48 h from familiarization sessions. During the 24 h prior to testing sessions, players avoided strenuous training and forms were delivered to all players by a certificate nutritionist with instructions regarding what to eat to follow a carbohydrate-rich diet. No caffeine-containing products were consumed for 3 h before testing. Measurements were made in a fixed order over 3 days. A standardized warm-up (10–20 min of low- to moderate intensity aerobic exercise and dynamic stretching) preceded all the tests. On the first test day, a 30 m sprint was carried out, followed by the T-half test and the Illinois-MT. The second day was devoted to jumping (SJ, CMJ), followed by repeated sprint T-test assessments. On the third day, anthropometric measurements were followed by a 20 m shuttle run test.

Testing Procedure

Day 1

30 m Sprint Performance

Subjects ran 30 m, with times over 5 m, 10 m, 20 m and 30 m recorded by paired photocells (Microgate, Bolzano, Italy). Individuals started from a standing position, with the front foot 0.2 m from the first photocell beam. Three trials were separated by 4-6 min of recovery, with the fastest result for each distance being noted. During the recovery period, players maintained readiness for their next maximal attempt by performing low-intensity technical handball drills.

Modified Agility T-test (T-Half test)

The T-half test was used to determine speed with directional changes such as forward sprinting, left and right shuffling, and backward running. Based on the protocol outlined by Sassi et al[17], subjects began with both feet behind the starting line A. At his own discretion, each subject sprinted forward to cone B and touch the base of it with the right hand. Facing forward and without crossing feet, they shuffled to the left to cone C and touch its base with the left hand. Subjects then shuffled to the right to cone D and touch its base with the right hand. They shuffled back to the left to cone B and touch its base. Finally, subjects ran backward as quickly as possible and return to line A. Any subject who crossed one foot in front of the other, failed to touch the base of the cone, and/or failed to face forward throughout had to repeat the test. Time performance was recorded by a single series of paired photocells (Microgate, Bolzano, Italy). Three trials were separated by 6-8 min of recovery, with the fastest result being noted.

Illinois Modified Test (Illinois-MT)

The Illinois-MT times were recorded using an electronic timing system (Microgate, Bolzano, Italy). Two pairs of the electronic timing system sensors mounted on tripods were set at 1 m above the floor and were positioned 3 m apart facing each other on either side of the starting and finishing lines. The Illinois-MT is set up with four cones forming the agility area[19]. On command, from a standing position athlete sprints 5 m, turns and returns back to the starting line, then, he swerves in and out of four markers, completing two 5 m sprints to finish the agility course. No technical advice was given as to the most effective movement technique. Athletes were instructed to complete the test as quickly as possible. They were instructed not to cut over the markers but to run around them. If a subject failed to do this, the trial was stopped and re-attempted after the requisite recovery period. Three trials were separated by 6-8 min of recovery, with the fastest result being noted.

Day 2

Vertical Jump

After a 15-min warm-up, jump height was assessed using an infrared photocell mat connected to a digital computer (Opto-jump System, Microgate SARL, Bolozano, Italy). Contact and flight times were measured with a precision of 1/1000 s. The SJ began at a knee angle of ~90 degrees; avoiding any downward movement, subjects performed a vertical jump by pushing upwards, keeping their legs straight throughout. The CMJ began from an upright position, making a rapid downward movement to a knee angle of ~90 degrees and simultaneously beginning to push-off. Three trials were separated by 6-8 min of recovery, with the highest vertical jump height for each jump being noted.

Repeated Sprint T-test

The aim of the repeated sprint T-test is to simulate parts of a handball game; it includes short, intense efforts separated by recovery periods, and requires running forwards, laterally and backwards. It offers a reliable and valid measurement[20] of the ability to make rapid changes of direction and speed[21]. Seven maximal executions are performed, with 25 s recovery intervals when subjects walked slowly back to the next start point. The indices measured were: best time (BT), mean time (MT), total time (TT), and a fatigue index (FI) calculated as: FI = ((TT / (BT × 7)) ×100) – 100 (11). As this is an exhaustive test, only one maximal effort was performed.

Day 3

Anthropometry

Anthropometric measurements were assessed only at pre-intervention and included: height and sitting height (Holtainstadiometer, Crosswell, Crymych, Pembs, UK, accuracy of 0.1 cm) and body mass (Tanita BF683W scales, Munich, Germany, accuracy 0.1 kg). The overall percentage of body fat was estimated from the biceps, triceps, subscapular, and supra iliac skinfolds, as measured by the Harpenden calipers skinfolds (Burgess Hill, UK) using the equations of Durnin and Womersley[22] for adolescents aged 16-19.9 years:

$$\% \text{ Body fat} = (4.95/(\text{Density} - 4.5)) \bullet 100$$

Where Density = a – b (Log sum of 4 skinfolds); where *a* and *b* are two constants varies by age and sex.

20-Meter Shuttle Run Test

The validity and test-retest reliability of the 20-meter shuttle run test as a means of predicting VO_{2max} was established[23,24]. Players were tested on a flat, non-slip surface; the starting speed was 8.5 km/h and this was increased by 0.5 km/h every minute until the subject could no longer maintain the required pace or failed to reach the lines in time twice in a row[24]. The score was used to predict VO_{2max}[25]. As this is an exhaustive test, only one maximal effort was performed.

Training Protocols

After a common warm-up of 15-min for both the control and the experimental group, the later replaced 25-35-min of technical/tactical training with HIIT combined with plyometric exercise, every Tuesday and Thursday, for 8 consecutive weeks. A depiction of each HIIT-plyometric session is provided in Table II.

Statistical Analysis

Statistical analysis was carried out using the STATISTICA statistical package (Version 8.0;

Table II. High-intensity interval training and plyometric training program.

First set of drills
6 x 40-cm hurdle jumps + 5-s sprint* at 130% of aerobic maximum speed.

Second set of drills
6 x 30-cm hurdle jumps with extended legs + 5-s sprint at 130% of aerobic maximum speed.

Third set of drills
6 x horizontal jumps + 5-s sprint at 130% of aerobic maximum speed.

Fourth set of drills
3 right-leg and 3 left-leg hops + 5-s sprint at 130% of aerobic maximum speed.
Each drills set was performed 2 times in a row. Afterwards, 10 seconds of rest were allowed. Thereafter, this sequence of effort-rest was repeated 8 times. After then, a 3-5 min recovery period was allowed before commencing the next drills set; Each sprint distance included a 180° change of direction so that the athlete could return to his starting position, and the speed was set according to the results obtained in the 20 m shuttle run test, with participants divided in 4 groups according to their performance; Participants were motivated to exert maximal effort (minimal contact time, maximal height or distance) in each jump; All training sessions were conducted on the same surface (indoor gym) were usually athletes trained and compete, using regular handball sport garment.

StatSoft, Inc, Tulsa, USA). Normality of all variables was tested using the Kolmogorov-Smirnov test procedure. Data are presented as mean ± standard deviation. Between-group differences at baseline were examined using independent *t*-tests. The reliabilities of all dependent variables were assessed by calculating intra-class correlation coefficients (ICC) and coefficient of variation (CV). Training related effects were assessed by 2-way analyses of variance (group x time), with Bonferroni post-hoc test. When there were baseline differences between groups, an analysis of covariance (ANCOVA) was run. To evaluate within-group pre-to-post performance changes, paired sample *t*-tests were applied. Percentage changes were calculated as ([post-training value - pre-training value]/ pre-training value) x 100. Effect sizes were calculated by converting partial eta-squared values to Cohen's d; these were classified as small ($0.00 \leq d \leq 0.49$), medium ($0.50 \leq d \leq 0.79$), and large ($d \geq 0.80$) (7). A $p \leq 0.05$ was accepted as a criterion of statistical significance.

Results

No athletes missed more than 10% of the total training sessions and/or more than two consecutive sessions, so it was not necessary to exclude any participants from the study.

Reliability of the Tests

Test-retest reliabilities were generally above the accepted threshold, with intra-class correlation coefficients ranging from 0.846 to 0.986, and coefficients of variation of 1.9 to 13.5% (Table III).

Between-Group Differences at Baseline

Initial measures showed that all physical fitness measures (except 20 m and 30 m sprint) did not differ between experimental and control groups.

Training-Related Effects

Initial measures showed that all physical fitness measures (except 20 m and 30 m sprint) did not differ between experimental and control groups. Significant group x time interactions (all $p<0.05$) were observed, favoring the intervention group (Table IV), with increases in 5m, 10m, 20 m and 30 m sprint (d=0.33, 8.3%; d=0.52, 7.6%; d=0.57, 6.8%; and d=0.58, 8.8%, respectively), T-half (d=0.25, 5.1%), Illinois-MT (d=0.47, 4.2%), SJ (d=0.34, 34.9%), CMJ (d=0.39, 34.4%), repeated sprint T-test best time, mean time and total time

Table III. Reliability and variability of performance tests.

	ICC	95%CI	CV
5 m sprint	0.877	0.748 - 0.940	4.3
10 m sprint	0.896	0.787 - 0.949	3.2
20 m sprint	0.982	0.963 - 0.991	6.5
30 m sprint	0.986	0.972 - 0.993	7.8
T-half test	0.939	0.876 - 0.970	3.9
Illinois modified test	0.954	0.907 - 0.978	1.9
Squat jump	0.846	0.685 - 0.925	13.2
Countermovement jump	0.934	0.866 - 0.968	13.5

CI = confidence intervals; CV = coefficient of variation; ICC = intraclass correlation coefficient.

Table IV. Means and standard deviations for all outcome measures before (Pre) and after (Post) the intervention period in the Experimental and Control groups.

	Experimental Group (n=17)					Control Group (n=15)					
	Pre	Post	%Δ change	Paired *t* test *p*	Paired *t* test d	Pre	Post	%Δ change	Paired *t* test *p*	Paired *t* test d	ANOVA Group x Time interaction F(1, 30), *p*-value (d)
5 m (s)	1.17±0.06	1.07±0.05	8.3±3.9	<0.001	1.87	1.18±0.04	1.16±0.1	2.2±4.8	0.085	0.27	F=15.0, $p<0.001$ (0.33)
10 m (s)	2.04±0.07	1.88±0.06	7.6±2.6	<0.001	2.53	2.05±0.06	2.04±0.1	0.2±4.5	0.780	0.13	F=32.6, $p<0.001$ (0.52)
20 m (s)	3.46±0.24	3.21±0.17	6.8±4.9	<0.001	1.24	3.65±0.18	3.63±0.15	0.3±6.2	0.753	0.12	F=38.1, $p<0.001$ (0.57)*
30 m (s)	4.67±0.36	4.25±0.27	8.8±2.6	<0.001	1.36	5.0±0.34	4.99±0.3	0.3±7.3	0.995	0.03	F=39.9, $p<0.001$ (0.58)*
T-Half (s)	7.05±0.33	6.68±0.26	5.1±4.8	0.001	1.28	7.06±0.21	7.05±0.20	0.5±3.9	0.948	0.05	F=9.74, $p=0.003$ (0.25)
Illinois-MT (s)	13.01±0.27	12.46±0.32	4.2±2.5	<0.001	1.91	13.07±0.23	13.06±0.23	0.1±3.9	0.839	0.05	F=26.4, $p<0.001$ (0.47)
SJ (cm)	28.9±4.5	38.0±3.0	34.9±27.8	<0.001	2.45	27.9±2.7	30.5±2.2	10.0±11	0.003	1.09	F=15.1, $p<0.001$ (0.34)
CMJ (cm)	30.9±4.6	40.6±2.7	34.4±23.1	<0.001	2.65	29.5±3.4	31.8±3.3	8.8±13.5	0.042	0.71	F=19.3, $p<0.001$ (0.39)
RST best time (s)	11.3±0.7	10.5±0.6	6.9±1.3	<0.001	1.26	11.2±0.4	11.1±0.4	1.3±0.6	<0.001	0.26	F=148.3, $p<0.001$ (0.83)
RST mean time (s)	11.6±0.7	10.7±0.6	7.4±2.6	<0.001	1.42	11.6±0.3	11.4±0.3	2.0±0.8	<0.001	0.69	F=47.9, $p<0.001$ (0.62)
RST fatigue index (%)	2.7±2.2	2.1±2.9	3.1± 83.9	0.376	0.24	3.8±2.4	3.0±2.3	23.2±16.8	0.002	0.35	F=0.1, $p=0.81$ (0.0)
RST total time (s)	81.0±4.9	75.0±4.2	7.2±2.5	<0.001	1.36	81.0±2.1	79.7±2.1	2.0±0.8	<0.001	0.64	F=47.6, $p<0.001$ (0.61)
AMS (km. h^{-1})	14.8±0.6	15.9±0.5	7.5±3.3	<0.001	1.89	15.0±0.7	15.3±0.6	2.1±4.3	0.099	0.48	F=17.0, $p<0.001$ (0.36)
PMOI (ml.min-^{1}.kg^{-1})	47.8±2.5	52.2±1.9	9.4±4.1	<0.001	2.04	48.4±2.9	50.0±2.6	3.6±8.2	0.135	0.60	F=7.0, $p=0.013$ (0.19)

*: values derived from ANCOVA; AMS: aerobic maximum speed in the 20-m shuttle run test; CMJ= countermovement jump; d: Cohen effect size; Illinois-MT: Illinois modified test; PMOI: predicted maximal oxygen intake in the 20-m shuttle run test; RST: repeated sprint T test; T-half: T-half test; SJ= squat jump.

(d=0.83, 6.9%; d=0.62, 7.4%; and d=0.61, 7.2%, respectively), 20-meter shuttle run test aerobic maximum speed and predicted maximal oxygen intake (d=0.36, 7.5%; d=0.19, 9.4%, respectively).

Discussion

The main finding from this study was that 8 weeks of a combination of HIIT and plyometric exercise substantially improved sprint performance, change of direction test times, jumping performance, repeated sprint T-test scores and 20-m shuttle run performance of junior male handball players relative to the standard training regimen.

Findings of the present study showed gains in sprint (5 m, 10 m, 20 m, 30 m) performance for the EG relative to the CG (d= 0.33-0.58). Of note, handball activity requires high-levels of speed, particularly over short-and-medium (<30 m) distances[26-28]. In this regard, previous studies[29,30] demonstrated increased sprint acceleration and maximal speed performances following high intensity training. Dello Iacono et al[29] found greater increases in 10 m and 20 m sprint performance after 8 weeks of small-sided games than after high intensity training in handball players. Kelly et al[29] noted that both high-intensity soccer-specific training and a "traditional" aerobic interval training increased the performance of 10- and 30 m sprints and of the CMJ in soccer players. Further, they suggested that high-intensity soccer-specific training improved physiological responses to a greater extent than other currently adopted specific endurance training protocols used in soccer[30]. On the contrary, Buchheit et al[31] found that neither high-intensity interval training nor specific game-based handball training improved 10m sprint time performance in elite young handball players. Similarly, Viano-Santasmarinas et al[16] found no significant change in the 10 m sprint performance of in male handball player using any of 6 high-intensity training protocols with different interval durations (short *vs.* long). The lack of response in these last two studies could reflect differences in the age and type of test population, or the training format (running *vs.* small-sided games). Another factor affecting results is that the majority of studies have been oriented to improving aerobic performance rather than explosive actions such as sprinting, changing direction or jumping vertically. The experimental training program in this study contained a combination of plyometric exercise and HIIT running, and increased sprint performance across all assessed distances. Gains of sprint performance after the current intervention may reflect neural adaptations such as an increased nerve conduction velocity, improved intermuscular coordination, enhanced motor unit recruitment strategy, increased excitability of the Hoffman reflex, as well as changes in muscle size, architecture, or mechanical characteristics of the muscle-tendon complex, and changes in single-fiber mechanics[32].

In team handball training and competition, the players must accelerate and change directions quickly while simultaneously performing physical collisions, passing, throwing, and jumping actions[14]. The current results demonstrate increases in change of direction test performance in the EG relative to the CG (d= 0.25-0.47), denoting the relevance of the intervention for the improvement of sport-specific physical fitness traits. The EG performed many (~56 per session) changes of direction during HIIT sessions (Table II). Although the CG also performed sport-specific change of direction actions during regular training and competition, the specific HIIT-plyometric demands imposed in the EG demonstrated the importance of specific strength and conditioning stimulus, other than playing handball, in already wee-trained athletes. Some authors have seen greater improvement in handball agility specific tests in elite male players following small-sided games training than with high-intensity intermittent training ($p<0.05$)[29]. In line with our results, Katis et al[33] found increases in 30 m sprint and Illinois test performance of amateur young soccer players after 10 bouts of 4-minute duration training with 3-minute passive recovery intervals and with three-a-side small-sided soccer games training. Hermassi et al[7] found increases in T-half test performance after 8 week high-intensity muscular strength and sprint interval training in male handball players. HIIT combined with plyometric exercise is an effective tool for the muscles in terms of the required effort, since the recovery times are very short; this feature has led to significant improvements of lower limb power, as evidenced by substantially improved sprint and change of direction performances.

Another finding of the present study was the significantly greater improvement in jump (SJ, d=0.34; CMJ, d=0.39) performance in the EG compared with the CG. The gains in vertical jumping in our study (SJ and CMJ) are in line with those observed by Dello Iacono et al[29] who found greater improvements in countermovement jumping (7.4 and 10.8%, respectively) and counter-movement jumping with free arms (6.4 and 8.9%, respectively) of elite handball players with small-sided games than with high-intensity intermittent training. Likewise, Hermassi et al[7] reported increases in squat and countermovement jumping scores after combined high intensity strength and sprint interval training in elite handball players. Viano-Santasmarinas et al[16] also found that both short and long high- intensity interval training increased countermovement jump performance in handball players. On the other hand, Petre et al[35] did not observe any increase of countermovement jump performance after either high-intensity interval or continuous training in a group of highly trained individuals. Furthermore, Buchheit et al[4] reported that in elite soccer players explosive strength training increased CMJ (14.8 ±7.7 *vs.* 6.8 ± 3.7%, p=0.02) and hop height (27.5 ± 19.2 *vs.* 13.5 ± 13.2%, p=0.08, ES=0.9) more than did repeated sprint training. The improvement of vertical jump performance is probably attributable to the plyometric component of training[6,32]. Differences between studies remain to be explained, but could reflect details of training (type, intensity, duration, and number of blocks); the study population (gender and age) and the timing of interventions relative to the playing season.

In addition to jumping maneuvers, handball players typically execute many repeated directional changes and linear sprints during matchplay; thus, the repeated sprint T-test seems a highly relevant tool to assess handball players[34]. This study is the first to have examined the effects of a combination of HIIT and plyometric exercises on such test scores, and three (best time d=0.83; mean time, d=0.62, and total time, d=0.61) of four measures showed useful gains in the EG compared to the CG; one possible explanation of the lack of significant change in the fatigue indexes its poor reproducibility[34].

The present study also demonstrated a substantial improvement in 20-meters shuttle run test scores in the EG compared to the CG (d=0.19-0.36). This result is in accordance with previous investigation[36] that found an increase in endurance performance (20-meters shuttle run test) after 6 weeks of plyometric training applied twice weekly in young soccer players. In addition, Hermassi et al[8] previously noted increases in the Yo-Yo test scores of male handball athletes after 10 weeks of explosive strength training, and Iacano et al[29]{Iacono, 2015 #1} found a somewhat greater improvement in the performance of elite handball players on the Yo-Yo intermittent recovery test level 1 after high-intensity intermittent training (+26.3%; p<0.05) than after participation in small-sided games (+23.3%; p<0.05). Short intermittent actions, such as those included in the present training protocol, are of particular interest for team-sport coaches, because they enable athletes to improve both aerobic and anaerobic capabilities with relatively short periods of training[4,31,37].

Conclusions

Eight weeks of a combination of HIIT and plyometric exercises increases handball-related measures of physical performance such as sprinting, maximal and repeated change of direction speed, jumping, and aerobic power in male handball players. Of note, such improvements were observed in well-trained players, attesting the effectiveness of the experimental intervention.

Conflicts of Interest

The authors declare no conflicts of interest.

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