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Effect of an 8-week combined isometric-plyometric and sprint training programme on the physical performance of junior handball players

Hédi Allègue[1], Mohamed-Souhaiel Chelly[1,2].

1: Research Laboratory (LR23JS01) « Sport Performance, Health & Society», Higher Institute of Sport and Physical Education of Ksar Said, University of Manouba, Tunis, Tunisia.

2: Higher Institute of Sport and Physical Education of Ksar Said, University of Manouba, Tunis, Tunisia.

mohamedsouhaiel.chelly@issep.uma.tn

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I/ Introduction

Handball is an Olympic sport played worldwide with approximately 18 million players in over 150 international federations(Raeder, Fernandez-Fernandez, & Ferrauti, 2015). From a physical point of view, handball is an intermittent and vigorous contact sport requiring high intensity efforts in a short duration where players jump, run and throw the ball at high speed, followed by a very short rest period (Gorostiaga, Granados, Ibañez, González-Badillo, & Izquierdo, 2006). On the other hand, the combination of a high demand for muscular strength and power with a well-developed aerobic capacity (i.e. relatively high oxygen consumption) will allow better recovery during periods of low intensity or rest, which is decisive for the success of top-level handball players(Granados, Izquierdo, Ibáñez, Ruesta, & Gorostiaga, 2013).

Players alternate between short periods of intense activity with longer periods of moderate intensity actions and movements such as turning, stopping, jumping, throwing, changing direction and individual offensive and defensive play (Luteberget & Spencer, 2017). Agility is particularly important for optimal handball performance (Massuça, Fragoso, & Teles, 2014). Other important attributes such as: dynamic balance, spatial awareness, rhythm and visual processing ability (Sheppard & Young, 2006), in addition to sprint, strength and power are also essential elements of general training (Hammami, Negra, Shephard, & Chelly, 2017; Keiner, Sander, Wirth, & Schmidtbleicher, 2014) and are very important for performance not only in adults but also in adolescent players (Chelly et al., 2011; Gorostiaga et al., 2006; Šbila, Vuleta, & Pori, 2004).

Combined training, under the umbrella of complex training, switches between a heavy-load exercise and a rapid or plyometric drill that is similar in how it affects the body. This method is supported by the hypothesis of post-activation performance enhancement which is defined as a physiological phenomenon that describes the enhancement in performance following high-intensity specific conditioning activities (Blazevich & Babault, 2019; Chulvi-Medrano et al., 2025). The idea is to use slow, heavy movements to recruit the nervous system as much as possible and to take advantage of this recruitment during subsequent fast-paced exercises (Ronnestad, Kvamme, Sunde, & Raastad, 2008). In rugby men, significant improvements in speed were identified after four training sessions (Comyns, Harrison, & Hennessy, 2010).

Given the specific demands of handball in terms of jumping, Change-of-Direction, and sprinting, integrating plyometric training appears to be an effective solution for optimizing player performance. It is common to include plyometric exercises in a regular training programme to increase strength and explosiveness (Chelly, Hermassi, Aouadi, & Shephard, 2014) or the ability to repeat sprints (RSA) (Chtara et al., 2017). Furthermore, Hammami et al.(Hammami, Gaamouri, Aloui, Shephard, & Chelly, 2019a) showed that 10 weeks of combined training (dynamic strength exercise, plyometric, sprint) increased numerous performance variables: sprint, Change-of-Direction, Repeated Change-of-Direction and vertical jump (CMJ and SJ) performances in young female handball players (Hammami, Gaamouri, et al., 2019a). In addition, several studies have shown the positive effect on physical performance of integrating a short-distance run after a plyometric exercises (Hammami, Gaamouri, Aloui, Shephard, & Chelly, 2019b; Hammami, Gaamouri, Shephard, & Chelly, 2019; Neves et al., 2025).

Although plyometric exercises are essential for developing dynamic performance, the inclusion of isometric training could further optimize muscular power and strength, both critical for handball athletes. Firstly, it allows tightly controlled application of force within the joint angles without pain in various rehabilitation programmes (Hasler, Denoth, Stacoff, & Herzog, 1994; Krebs, Staples, Cuttita, & Zickel, 1983). Secondly, a practitioner who understands the physical demands of sport can use isometric training to focus on their weaknesses in a more specific way which could have a positive impact on performance (Abbott & Wilkie, 1953) and injury prevention (Tsoukos, Bogdanis, Terzis, & Veligekas, 2016). Thirdly, isometric training makes it possible to induce a greater force overload since the force of maximum isometric contraction is greater than that of concentric contraction (van Beijsterveldt, van de Port, Vereijken, & Backx, 2013). Integrating isometric contractions into a combining training framework therefore holds promise for amplifying the neuromuscular adaptations typically sought through dynamic strength and plyometric methods alone.

To the best of our knowledge, although some recent studies have explored the combination of isometric and plyometric training (Pietraszewski, Gołaś, Zając, Maćkała, & Krzysztofik, 2025), only a limited investigations (Allégue et al., 2023) have specifically examined its effects when integrated with sprinting exercises in the context of a comprehensive complex training program targeting young handball players. We hypothesized that the experimental group undergoing the Combined isometric-plyometric and sprint Training (CIPST) would exhibit significantly greater improvements in all measured physical performance variables (sprinting, Change-of-Direction ability, repeated sprint with Change-of-Direction, vertical jump, lower-limb isometric strength, and upper-limb strength) compared to the control group after the 8-week intervention.

II/ Materials and methods

1. <u>Study population:</u>

All the participants in this protocol were in good health and did not suffer from musculo-tendinous pathologies, or hearing or visual disorders. Our study population consisted of 31 junior handball players. This population was divided into two groups; Experimental Group (GExp) (age = 14.7 years; weight = 70.8 kg; height = 176.8 cm; % body fat = 14.9; number of years of practice = 5.1 years) and Control Group (CG) (age = 14.2 years; weight = 61.8 kg; height = 171.7 cm; % body fat = 13.9; number of years of practice = 4.4 years).

2. <u>Experimental protocol:</u>

2.1- Anthropometric measurements:

The anthropometric measurements that were carried out were: height, body mass and the four skin folds: bicipital, tricipital, subscapular and supra-iliac. All measurements were taken by the same examiner. Body mass was measured on a Tanita scale (Tanita corp, Arlington Heights, IL 6005). Height was measured (accuracy 0.1cm) on a measuring tape. Skin folds were measured using skin fold forceps (Harpenden).From the 4 measurements, we calculated the body fat density (Durnin & Womersley, 1974):

Dc = C-[M x (log10 x sum of 4 skinfolds)]

Dc: Corporel Density

C and M : Constants depending on sex and age.

C= 1.1533

M= 0.0643

The Dc value was then converted into a percentage of body fat (% BF):

% BF = (495/Dc) – 450

2.2- Description of the tests:

The tests consisted of various events during which the subjects were strongly encouraged to perform at their best. After a standardised warm-up, the subjects performed the tests below on two occasions, the test before and the retest after an 8-week CIPST training programme.

A) Vertical Jump tests

The two jumps, the Squat Jump (SJ) and the Counter Movement Jump (CMJ) were measured by an Opto-Jump (Microgate, Bolzano, Italy). One minute's rest was allowed between the 3 trials of each test.

- Squat jump (SJ):

The jump starts from a squat position. The knees are bent and the angle formed by the thighs and legs is approximately 90°. The hands are placed on the hips to avoid any swinging movement with the arms that would allow you to jump higher. Once in the squat position, the

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subject pauses for three seconds, then pushes explosively to take off and jump as high as possible, then lands gently, controlling the descent to return to the standing position.

- Counter Movement Jump (CMJ):

The jump starts from a standing position. The instructions are the same as those given for the SJ, except that the subject does not pause between the flexion and extension movements of the knees. The subject performs a downward counter-movement to a knee angle of 90° (a flexion of the lower limbs) immediately followed by a complete extension of the lower limbs.

B) Sprint performance: 5m, 20m and 30m

The athlete must perform a maximum linear sprint of 40m on flat, unobstructed ground. The photocells are placed at the start, 5m, 20m and 30m respectively. The four pairs of photocells are placed 30-50 cm from the ground and aligned. The athlete could start when he was ready, thus eliminating the time taken to react to a visual or audible signal. He ran as fast as he could to the finish line, making sure not to slow down before crossing the finish line. Three trials were separated by 6 to 8 minutes recovery time. Performance was recorded by photoelectric cells (Microgate, Bolzano, Italy).

- Planned agility test: T test

The subject starts at cone A. On the timer's command, the subject sprinted to cone B and touched the base of the cone with his right hand. He then turns left and moves sideways to cone C, also touching its base, this time with his left hand. Then he swings sideways to the right for cone D and touches the base with his right hand. He then climbs back up to cone B, touching it with his left hand, and runs backwards around A(Pauole, Madole, Garhammer, Lacourse, & Rozenek, 2000). The trial was not counted if the subject crossed one foot in front of the other while walking, did not touch the base of the cones, or did not face forward throughout the trial. Take the best time from three successful trials. The performance was taken by photoelectric cells (Microgate, Bolzano, Italy).

C) Repeated Change-of-Direction Test: RCOD

The repeated sprint with change of direction (RCOD) consisted of 6 sprints of 20m, each starting from a standing position, 0.2 m behind the sensor, with active recovery intervals of 25 seconds(Wong del, Chan, & Smith, 2012). Times were measured using infrared sensors (Microgate, Bolzano, Italy) located 0.5 m above the ground at the start and finish lines. Four 100° changes of direction were made at 4-metre intervals. During the active recovery phase, the subject returned slowly to the start line. The best time in a single trial (RCOD-Best Time), the average time for the 6 x 20 m (RCOD-mean Time), the total time for the 6 sprint repetitions (RCOD-Total Time) were recorded, and the RCOD fatigue index was calculated according to the formula:

RCOD-Fatigue index = 100 x (RCOD-Total Time / RCOD-Ideal Sprint Time) -100

Ideal-Sprint Time = Number of sprint x RCOD-Best Time

D) Maximal strength test: medicine ball throw (3kg)

- Medicine ball backward throw

Participants should stand with his back to the direction of the throw, feet parallel to each other, heels on the line, medicine ball held at arm's length with both hands. The second test consist of starting with the medicine ball at knee height, throw it backwards, over the head as far as possible into the throwing area. After the throw, the participant can step over the line (i.e. backwards). Each participant has three tries.

- Throwing a medicine ball from a seated position:

The participant sits on a chair, feet together, holding the medicine ball to his chest with both hands. He then leans back and throws the medicine ball (3 kg) by extending his arms forward as far as possible, while remaining seated.

- Throwing a medicine ball from a standing position:

Stand behind the indicated line and hold the medicine ball against the chest. Then throw the medicine ball (3 kg) as far forward as you can with the arms outstretched.

E) Isometric leg strength test:

A calibrated dynamometer (Takei) (Hannibal, Plowman, Looney, & Brandenburg, 2006) measures the isometric force of the muscle, recorded in kilograms (kg). When an external force is applied to a handle which is attached to an adjustable chain, a steel spring compresses and a pointer moves. The dial ranges from 0 to 300 kg. The length of the chain was adjusted to the height of the participants by asking the subject to stand on the base of the dynamometer. The handle was then placed at the height of the intra-auricular space of the knee joint. Participants were asked to stand on the base with their knees and hips slightly flexed while the lower back maintained an appropriate lordotic curve. Subjects were asked to lift themselves in a vertical direction by providing a continuous isometric contraction of the knee extensors, hips and lower back while holding the handle. Participants were asked to increase traction in a progressive manner and reach maximum force in three seconds.

2.3-Training programme

The four selected workshops are described in Table 1.

Table 1: Workshops of the training programme

Workshop Numbers	Time (s) x Isometric exercise	Dynamic exercise
Workshop-1	10-20 s x half-squat with 90° thigh-leg angle	Six hurdle jumps (30cm height) + 10m sprint
Workshop-2	10-20 s x bench press with 90° forearm angle	Six horizontal throws of a medicine ball (2kg) at chest level to the wall + Four handball javelin throw
Workshop-3	10-20 s x Bulgarian split-squat (with bench): leg on bench vs support leg with 90° thigh-leg angle	Six Hurdle jump (25 cm height) with single leg (3 right leg + 3 left leg) + 10m sprint
Workshop-4	10-20 s pull-over with 130° trunk-arm angle	Touch throw with medicine ball (2kg) + Four handball javelin throw

The training programme was carried out twice a week for 8 consecutive weeks (Table 2 and Table 3). Participants were also familiarized with the 1RM test procedure and a theoretical

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maximal load for half-squat, bench press, pull-over and Bulgarian split-squat were determined for each subject (Hermassi, Wollny, Schwesig, Shephard, & Chelly, 2019). Each session lasted 45 minutes and began with a 15-minute warm-up. Each workshop consisted of 3 exercises (4 sets with 1 to 2 minutes recovery time): The first exercise is an isometric contraction, the second is a plyometric exercise, and the third and final exercise is a short-distance sprint.

Table 1 : Training programme load for experimental group.

	Week	**%1-RM**	**Time in isometric contraction (s)**	**Numbers of de set**	**Recovery (min)**
	1	60%	10	4	1 to 2
Cycle 1	2	65%	10	4	1 to 2
	3	70%	10	4	1 to 2
	4	70%	10	2	1 to 2
	5	75%	10	4	1 to 2
Cycle 2	6	75%	15	4	1 to 2
	7	75%	20	4	1 to 2
	8	75%	20	2	1 to 2
					4min between set

Table 2 : One-week training schedule

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
GExp	H	CIPST +H	H	CIPST +H	H	Recovery	Competition
CG	H	H	H	H	H	Recovery	Competition

H : Habitual handball training; CIPST: Combined isometric-plyometric and sprint Training

3) <u>Statistical analysis:</u>

Statistical analyses were carried out using the SPSS 26 program for Windows (SPSS, Inc., Chicago, IL, USA). The normality of data was tested using the Kolmogorov-Smirnov test. Descriptive data are presented as adjusted group means and standard deviations. Between-group

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differences at baseline were examined using independent t-tests, and the effect of the intervention was determined by 2-way analyses of variance [Experimental vs Control, Test vs Retest]. 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. 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 ($d \geq 0.80$) (Cohen, 1988). The significance level was set at $p < 0.05$ throughout.

IV/ Results

The performance of the sprint tests and the Change-of-Direction ability showed no significant difference between the 2 groups after the training period ($p>0.05$) (Table 4). On the other hand, vertical jump, assessed by SJ and CMJ, improved significantly in Gexp ($p<0.05$), unlike isometric strength of the lower limbs (Table 5), which stagnated. On the other hand, all the performances of the medicine ball throw (standing, sitting and backward) improved statistically under the effect of our training programme (Table 6).

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Table 3: Comparison of sprint and agility performance before (pre) and after (post) the 8-week trial in the two groups

	CG			GExp				Anova interaction (group x time)	Ancova interaction (group x time)
	pre	post	Δ (%)	pre	post	Δ (%)	Cohen's d	p	p
Sprint time (s)									
5m	1.12 ± 0.11	1.08 ± 0.13	4.35	0.98 ± 0.11	0.94 ± 0.88	1.13 ± 0.11	-1.24		0.571
20m	3.37 ± 0.27	3.42 ± 0.24	1.54	3.27 ± 0.18	3.17 ± 0.14	3.4 ± 0.27	-1.27	0.166	
30m	5.03 ± 0.31	4.93 ± 0.34	1.95	4.60 ± 0.42	4.51 ± 0.30	5.03 ± 0.31	-1.30		0.153
Planned agility test (s)									
T test	11.29 ± 0.53	10.96 ± 0.56	2.85	10.69 ± 0.58	10.12 ± 0.41	5.34	-1.68		0.003
RCOD-Best Time	6.40 ± 0.57	6.51 ± 0.61	1.72	5.94 ± 0.30	5.97 ± 0.29	-0.49	-079	0.735	
RCOD Total Time	40.04 ± 3.15	40.83 ± 3.21	1.97	37.20 ± 1.92	36.95 ± 0.20	0.7	-0.90	0.441	
RCOD-Mean Time	6.67 ± 0.52	6.80 ± 0.54	0.8	6.20 ± 0.31	6.16 ± 0.33	-1.96	-0.90	0.445	
RCOD-Fatigue Index	4.49 ± 3.91	4.82 ± 5.25	7.23	4.38 ± 3.91	3.113 ± 5.24	28.89	-0.03	0.397	

Δ: Difference in percentage; RCOD : Repeated Change-of-Direction

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Table 4 : Comparison of CMJ, SJ and Isometric leg strength performance before (pre) and after (post) the 8-week trial in the two groups

	CG			GExp				Anova interaction (group x time)	Ancova interaction (group x time)
	pre	post	Δ (%)	pre	Post	Δ (%)	Cohen's d	p	p
CMJ (cm)	23.8 ± 4.7	25.8 ± 5.9	7.7	28.6 ± 5.3	36.0 ± 4.2	25.77	1.99		<0.001
SJ (cm)	23.64 ± 5.73	24.5 ± 5.9	3.5	27.2 ± 6.4	33.0 ± 5.1	24.23	1.74	0.049	
Lower limbs isometric force (kg)	77.9 ± 14.7	76.0 ± 12.1	2.5	91.43 ± 24.88	99.0 ± 23.5	8.24	1.24	0.344	

Δ (%): difference in percentage

Table 5: Comparison of standing, sitting and backward medicine ball throwing performance before (pre) and after (post) the 8-week trial in the two groups

	CG			GExp				Anova interaction (group x time)	Ancova interaction (group x time)
	pre	post	Δ (%)	pre	post	Δ (%)	Cohen's d	p	p
Standing throw (m)	7.21 ± 0.83	7.58± 0.88	4.92	8.00 ± 0.92	9.60 ± 1.05	16.70	1.98		<0.001
Sitting throw (m)	4.931 ± 0.77	5.313 ± 0.75	6.02	5.08 ± 0.76	6.62 ± 0.84	23.31	1.69	0.004	
Back throw (m)	10.0 ± 1.30	10.47 ± 1.28	4.57	10.29 ± 1.86	12.22 ± 2.09	15.81	1.01	0.099	

Δ (%): difference in percentage.

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V/ Discussion

Our study examined the effect of 8 weeks of complex isometric training programme on the few physical qualities (sprinting, ability to change direction, repeated sprinting with change of direction, vertical expansion, lower limb isometric strength and upper limb explosive strength) in junir adolescent handball players. The main results of this work showed that replacing part of the standard handball training with complex isometric training programme resulted in beneficial gains only in vertical expansion performance. For the other tests, moderate to no effects were recorded.

1) Vertical jump and maximal strength of the upper limbs

The results of our study showed an improvement in CMJ and SJ performance in the GExp, with Δ%=25.77 and Δ%=24.23 respectively. In contrast a small improvement was observed in CG (Δ%=7.74) and (Δ%=3.47). These gains were associated with an improvement in lower limb maximal isometric strength performance in GExp (Δ%=8.24), compared with a decrease (Δ%= -2.46) in CG. The gains in vertical jump are consistent with those of Maio Alves et al. (Maio Alves, Rebelo, Abrantes, & Sampaio, 2010), who found a 9.6% improvement in CMJ for junior football players after 8 weeks of combined strength and plyometric training.

Furthermore, the results of the present study revealed an improvement in standing, sitting and backward medicine ball throwing performance in GExp (Δ%=16.70, Δ%23.31 and Δ%15.81, respectively), compared to a small improvement in CG (Δ%=4.92, Δ%=6.02, Δ%=4.57, respectively). In general, the improvements in these performances following our CIPST programme could be attributed to structural and neural factors, such as an increase in nerve conduction velocity, better recruitment of motor units, maximal electromyography and improved Hoffman reflexes(Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002; Impellizzeri et al., 2008).

2) Change-of-Direction ability (Planned agility)

Despite a large improvement in the T-test (Δ%=5.34) in GExp compared to CG (Δ=2.85%) (p=0.003 ANCOVA group x time interaction) , we found no gain in the RCOD test in response to CIPST, which is in agreement with the results found by Hammami et al.(Hammami, Gaamouri, et al., 2019a). In contrast, Buchheit et al. (Buchheit, Mendez-Villanueva, Delhomel, Brughelli, & Ahmaidi, 2010) also found that repeated sprint training (shuttle) induced greater improvements than maximal strength training: better times (-2.90 ± 2.1 vs. -0.08 ± 3.3%, p = 0.04) and mean times (2.61 ± 2.8 vs. -0.75 ± 2.5%, p = 0.10, effect size [ES] = 0.70). One possible reason could be that aerobic power is a major factor in recovery for intermittent exercise, and that this quality was not developed by the CIPST.

Another possible explanation for these results could be that this training regime did not include any form of exercise where the athletes had to change direction. Indeed, Hammami et al. (Hammami, Gaamouri, et al., 2019a) showed that the effects of a combined programme between plyometrics and Change-of-Direction were significant with gains of 5.28% (ES=0.093) and 4.2% (ES=0.205) respectively for T-half test and Modified-Illinois test.

3) Sprint performance

Explosive actions such as sprinting are important in handball (Luteberget & Spencer, 2017). The results of our study showed a slight improvement in 20m (Δ%=3.18) and 30m (Δ%=2.11) performances in GExp compared to CG (20m :Δ%=1.54 and 30m :Δ%=1.95), with no significant difference between the two groups after CIPST. In contrast Hammami et al.(Hammami, Gaamouri, et al., 2019a) found a significant increase in 20m and 30m sprint performance after 10 weeks of complex strength training program. This contradiction could be explained by the difference between the two training protocols. Hammami et al. (Hammami, Gaamouri, et al., 2019a) chose 4 workshops with 6 repetitions specifically oriented for the lower limbs: half-squat, thigh press, isometric half-squat and calf extension. Each exercise was followed by a polymetric workout and then a 10-m sprint. However, our study contains 4 workshops with only 4 repetitions, including: 2 upper-limb workshops followed by medicine ball throws and then shooting; and 2 lower-limb workshops: half-squat and split squat followed by a polymetric exercise and then a 10-m sprint. For Hammami et al. (Hammami, Gaamouri, et al., 2019a) the training programme contains one sprint × 6 repetitions × 4 workshops = 24 sprints per session for a training period of 10 weeks. In contrast, in the present study our programme contains one sprint × 2 workshops × 4 repetitions = 8 sprints per session. This difference in the volume of training sessions between the two programmes may account for the discrepancy in the results found.

Study limitations

This experimental study has certain limitations. Indeed, the stagnation of performance in certain physical test such as the sprint and the RCOD could be explained either by the relatively low load in certain workshops, or by the short duration of the training period (8 weeks). Electromyography (EMG) measurements associated with some of the physical tests performed (such as vertical jump, Lower limbs isometric strength and ball throwing velocity) could have enriched the results and the discussion of all the current investigation.

VI/ Conclusion

Modern handball requires a high level of motor and functional fitness. These requirements consider the development of the player's physical aptitude to be a necessary condition for high-level sport. To achieve this, the development of the various physical qualities must be triggered at an early age. Our experiment minimised the risk of dynamic work with load and replaced it with safer isometric work. The results of this study showed that CIPST led to an improvement in a number of physical qualities, principally vertical jump and maximal strength in the upper limbs and planned agility. However, the content of our training programme induced a moderate and non-significant improvement in the Repeated Change-of-Direction ability and short-distance sprinting, thus constituting the limits of this study. Adding a Repeated Change-of-Direction situations to the content of our training programme, improving aerobic fitness to recover better between repeated sprints and increasing the volume of sprints for each session are likely to induce additional gains and constitute a major perspective of the present work.

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