Baltic Journal of Health and Physical Activity

Volume 16 | Issue 1 Article 11

2024

The effects of complex elastic band training on physical fitness components in junior female handball players

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Recommended Citation

Hammami M, Morgans R, Zmijewski P. The effects of complex elastic band training on physical fitness components in junior female handball players. Balt J Health Phys Act. 2024;16(1):Article11. https://doi.org/10.29359/BJHPA.16.1.11

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Abstract

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Keywords

standing long jump, 1-RM half squat, force-velocity test, change of direction, resistance training, repeated sprint ability

Baltic Journal
of Health and Physical Activity
e-ISSN 2080-9999

Article

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Keywords: standing long jump; 1-RM half squat; force-velocity test; change of direction; resistance training; repeated sprint ability.

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Academic Editor:
Agnieszka Maciejewska-Skrendo

Received: December 2023
Accepted: February 2024
Published: March 2024

1. Introduction

Handball is a team activity that requires high levels of physically demanding actions such as jumping, throwing and sprinting [1–4]. A key factor in handball is the ability to execute these actions, which necessitates the best possible combination of force and velocity to produce maximum power output [2, 3]. In handball, elite female players perform ~3500 m of total distance, cover ~423 m at moderate speed and ~141 m of high-speed running [5]. Young female handball players must possess strength and power as these qualities can enhance on-court ability and lower injury risk [1, 6]. The ability to generate more energy and perform quick, precise movements is only possible with strong muscles and powerful movements that are crucial components for success in the sport [1–3]. As a result, physical trainers, coaches, and sport physicians may utilize pertinent information to develop more effective strength and conditioning programs for female handball players to increase strength and power [7]. Furthermore, these training plans may be created for female handball players at all competition levels, from amateur to elite [7].

Heavy-load resistance and plyometric training are two of the most investigated strength training methods, despite the fact that a variety of methods have been proposed to enhance physical fitness [7–11]. Heavy-load resistance training emphasizes strength, while plyometric training emphasizes velocity, resulting in distinct physiological adaptations [7]. Through neural (motor unit activation/recruitment and synchronization), morphological (cross-sectional area), cellular, as well as metabolic adaptations (fibre-type composition), both training methods have the potential to increase maximal strength and power to varying degrees [12, 13]. These adaptations serve as the foundation to advance the required increase in physical fitness, such as performance in vertical and horizontal jumps, linear sprinting speed, and/or change-of-direction speed (CoD) [7, 12, 13].

A single training session may result in extra gains in physical fitness if heavy-load resistance exercises and plyometric exercises are combined [7]. Comparing exercise regimens using either only high-load resistance or plyometric training, the combination of these two exercise regimes may lead to adaptation along the force-velocity continuum [7]. Complex training is a form of combined exercise that entails the set-by-set alternate application of high-intensity resistance exercise and low-intensity plyometric exercise during a single training session [14]. Complex strength training involves combining two or more exercises into a single movement, which helps improve neuromuscular co-ordination and may lead to greater strength gains [9, 15]. In handball, complex strength training can support players to improve explosive power and multi-directional movements, both of which are essential for success in this sport [9, 10, 16]. Recently Hammami et al. [16] incorporated elastic band exercises during the implementation of complex strength training, replacing heavy-load training with elastic band training. These exercises enhanced sprinting, jumping and repeated CoD. However, no previous studies have examined the effects of combining elastic band training and plyometric training on repeated sprint ability (RSA) and force-velocity of the upper and lower limbs.

Therefore, the aim of the present investigation was to evaluate the effects on performance-related abilities of young female handball players when part of the normal in-season training regimen was replaced with complex elastic band training (CEBT). The measured abilities included CoD, jump height, upper and lower limb force-velocity, 1-RM bench press, 1-RM half squat, and RSA performance. The tested hypothesis was that replacing a part of regular in-season training with a 10-week program of bi-weekly CEBT would enhance CoD, jump height, upper and lower limb force-velocity, 1-RM bench press, 1-RM half squat, and RSA performance relative to the control players that maintained the normal, standard in-season training regimen.

2. Materials and methods

2.1. Ethical approval

The study was approved by the Local Ethics Committee of the Research Laboratory (LR23JS01) in conformity with principles identified in the latest version of the Declaration of Helsinki. Written informed consent was obtained from all participants' parents or guardians (and consent from the athletes) prior to participating in the study.

2.2. Participants

Thirty female, junior handball players from two teams (i.e., both teams played in the Tunisian first handball league and followed the same training program) were divided by playing position, and players from each position were then randomly assigned to the intervention (IG; n = 16) and control group (CG; n = 14) (See Table 1 for participant physical characteristics).

Table 1. Physical characteristics of the intervention and control groups (mean ± SD).

	Age (years)	Body mass (kg)	Height (m)	% Body fat	APHV (years)	Predicted years from APHV
Intervention group (n = 16)	16.0 ± 0.3	63.4 ± 5.1	168 ± 3.9	21.9 ± 2.8	3.0 ± 0.4	13.0 ± 0.3
Control group (n = 14)	16.3 ± 0.5	63.3 ± 3.8	167 ± 3.5	22.4 ± 1.2	3.0 ± 0.4	13.3 ± 0.5

APHV: age of peak height velocity.

All participants had a minimum competitive experience of six years and had attained a medium performance level within the division (i.e., U-17 National League). The participants trained six times per week during the four months preceding the intervention (~2-hours per session) and officially competed once per week. Goalkeepers were excluded from the study due to the specific nature of match activity and low running demands and did not participate in the same physical training program as outfield players. During the intervention, both the CG and the IG continued with regular fitness sessions. However, the IG replaced a section of the technical/tactical training sessions with CEBT. Figure 1 illustrates the interventions performed.

The study was designed to examine the effects of a 10-week CEBT program on selected fitness measures in young female handball players. The 10-week intervention was conducted during the regular season (i.e., in-season 2018–2019).

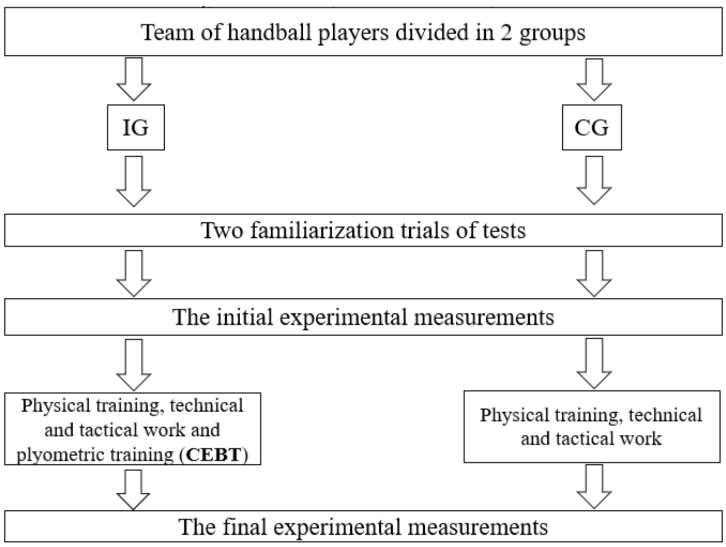

Figure 1. Detailed information on the interventions received.

In the week prior to the intervention, two 80- to 90-minute sessions were planned to familiarize players with all test procedures. Initial and final test measurements were made at the same time of day (5:00–7:00 PM), under approximately the same environmental conditions (temperature: 16–19 C), at least three days following the most recent competition, and 5–9 days following the last CEBT session. Measurements were conducted in a standardized sequence across four days, immediately prior to and four days following the last strength training session. The examined variables included CoD [Modified agility T-test (T-half)], three jumping tests [squat jump (SJ), countermovement jump (CMJ) and standing long jump (SLJ)], RSA, muscular strength [1-RM bench press and 1-RM half squat] and muscular power [force-velocity test for both upper and lower limb]. During the 24-hours prior to testing, players were asked to avoid strenuous training, and documented information was provided to all players by a certificated nutritionist with instructions regarding what items to consume to ensure a carbohydrate-rich diet. No caffeine-containing products were consumed for 3-hours prior to testing. A standardized warm-up (10–20 minutes of low- to moderate-intensity aerobic exercise and dynamic stretching) preceded all tests.

2.3. Testing procedures

2.3.1.Anthropometry

Anthropometric measurements included standing and sitting height, body mass and body fat were measured by an ISAK trained sports science staff member. The definitions and instructions for each measurement are consistent with the International Society for the Advancement of Kinanthropometry (ISAK) guidelines. Standing height and sitting height were measured to the nearest 0.1 cm using a stadiometer (Holtain, Crosswell, Crymych, Pembs, United Kingdom), and body mass to 0.1 kg (Tanita BF683W scales, Munich, Germany).

The participants stood with the feet together and the heels, buttocks and upper part of the back touching the Stadiometer. The measurer placed a hand along participants' jaw with the fingers reaching to the mastoid processes. The participant was instructed to take a deep breath and hold while keeping the head in the Frankfort plane the measurer applied a gentle upward lift through the mastoid processes. Another member of staff placed the head-board firmly down, compressing the hair as much as possible. Measurement was collected at the end of a deep inspiratory manoeuvre.

Sitting height is the height from the table or box (where the participant is sitting) to the vertex when the head is held in the Frankfort plane. Participants sat on the anthropometry box in an erect position, while the measurer placed the hands along the participants' jaw with the fingers reaching to the mastoid processes. The participant was instructed to take and hold a deep breath keeping head in the Frankfort plane, while the measurer applied gentle upward lift through the mastoid processes.

Body mass can be affected by hydration status and prolonged standing. In an effort to minimize these effects, body mass measurements for each participant were performed on a single day between 08.00–12.00. Participants were asked not to eat after 22.00 the night before testing, to refrain from exercise for 12-hours prior to testing, and to abstain from alcohol 24-hours prior to testing. Participants came to the laboratory refraining from exercise and alcohol or stimulant beverages and fasting for at least 3-hours. Body mass was measured using a calibrated electronic scale without shoes and wearing minimal clothes, to the nearest 0.01kg.

The overall percentage of body fat was estimated from the biceps, triceps, subscapular, and suprailiac skinfolds, using the equations of Durnin and Womersley [17] for children and adolescent females:

$$\% \text{ Body fat} = (495/D) - 450$$

where D = 1.1369 – 0.0598 (Log sum of 4 skinfolds)

Maturity offset status was calculated from peak height velocity [18]:

$$\text{Maturity offset} = -9.38 + (0.000188 \times \text{leg length} \times \text{sitting height}) + (0.0022 \times \text{age} \times \text{leg length}) + (0.00584 \times \text{age} \times \text{sitting height}) + (0.0769 \times \text{weight/height ratio})$$

2.3.2.Change of direction

Five minutes following the sprint trials, the modified T-test test was conducted. The players started in a two-point athletic stance, with the preferred foot on the start-line. On instruction, the participants accelerated as quickly as possible, speed with directional changes including forward sprinting, left and right shuffling, and backpedalling, as previously described by Haj-Sassi et al. [19]. Commercially available timing gates (paired photocells Microgate, Bolzano, Italy) were utilized to conduct this test. The result was recorded with an accuracy of 0.01 s. The Microgate Srl system had been previously validated [20].

2.3.3.Vertical jump

Following the CoD test, the SJ and CMJ without arm-swing were performed. All participants were familiar with the jumping protocols, having completed jumps regularly as part of regular club assessments and participating in several practice testing sessions. All jump tests were conducted at an indoor facility to avoid any external variations in surface that might affect results. For each jump test, three attempts were made, and the best result was recorded in centimetres (cm) for further analysis. A recovery interval of 2 minutes between jumps was provided. A commercially available jump mat (Optojump System, Microgate SARL, Bolzano, Italy) was used to perform the test. The OptoJump system had been previously validated [20]. Participants performed the tests in normal sports shoes in an indoor facility with a non-slip, flat surface at a room temperature of 18–20°C.

2.3.4.Standing long jump

From the starting position, participants were instructed to stand with feet shoulder-width apart behind a line drawn on the ground and arms in a neutral stance. Participants performed a countermovement with arms and legs as soon as the command ready, set, go was provided prior to jumping horizontally forward. Participants were instructed to not fall forward or backward, and had to land with both feet at the same time, without taking an additional step. With a tape measure, the horizontal distance to the closest millimetre (mm) between the starting line and the heel of the back foot was measured and recorded for future analysis.

2.3.5.Repeated sprint ability

The RSA consisted of recording six sets of two 20-m shuttle sprints (approximately 7 second running time) using paired photocell (Microgate Srl; Race time 2. Light Radio, Bolzano, Italy). Each sprint was performed every 20 seconds. There were four scores determined: best, and total sprint times and fatigue index (100-(Total time/6x best sprint time × 100)) [21].

2.3.6.One-repetition maximum

To determine the maximum load multiple series of exercises were performed, with each series separated by 4 minutes of recovery time. The loads were systematically increased during these series, ranging from 5% to 10% of the 1-RM for bench press and 10% to 20% of the 1-RM for half squats. The progression continued until the maximum load was reached. This protocol had been previously validated [22].

2.3.7.Force–velocity

The test involved the use of a Monark Exercise AB 894 E ergocycle (Vansbro, Sweden). It aimed to measure the power of both upper and lower limbs during intense sprint runs lasting a maximum of 7-seconds. Pedalling was performed against loads set at 1.5%, 2%, 2.5%, 3%, 4.5%, and 2.5% of body mass for the upper limbs and 7.5%, 8.5%, 9.5%, 10.5%, and 11.5% of body mass for the lower limbs. Performance metrics included Peak

Power (W), Peak Power per kilogram of body mass (W/kg), Maximum Pedalling Velocity (rpm), and Maximum Braking Force (N) [23, 24].

2.3.8.Complex strength training program

The training intervention consisted of a progressive 10-week CEBT program. The CEBT program was completed during the mid-portion of the 2018/2019 competitive season (from January to March). The design of the CSTEB intervention was based on the players' previous training history and research results [25–27] (Table 2). Bi-weekly CEBT sessions (Tuesday and Thursday) included eight workshops:

- Workshop 1: Six dumb-bell flies into six push-ups.
- Workshop 2: Six knee extensions into six hopping on one foot (three on the right and three on the left side) at 30 cm.
- Workshop 3: Six rows with a high elbow into six push-ups.
- Workshop 4: Six knee flexions into six hurdle jumps at 35 cm.
- Workshop 5: Six trunk rotations into six push-ups.
- Workshop 6: Six half squats into six hurdle jumps (30 cm height) with extended legs.
- Workshop 7: Six standing presses into six push-ups.
- Workshop 8: Six hip adductions (three at the right limb and three at the left limb) into six horizontal jumps.

The numbers of sets are presented in Table 2. The workshops were alternated (upper limb exercise and lower limb exercise). Four different bands were used, red (week 1), green (week 2, 3 and 4), blue (week 5, 6 and 7), and black (week 8, 9, and 10). The elastic band was folded to double its resistance on extension of the lower limb exercise, but not doubled for the upper limb exercise. The necessary amplitudes of movement during each exercise were calculated individually, thus determining appropriate attachments of the bands to the wall and the player's body part. Recovery between sets was 30-seconds. All exercises were performed with maximal effort. The initial length of the elastic band was 120 cm for all exercises. Players stood at a distance from the wall attachment equal to the required elongation of the elastic band (100% or 250% elongation) minus the amplitude of motion. The CEBT was not added to the regular handball training programme although was performed immediately following the warm-up [26], replacing some low-intensity technical-tactical handball drills. The CEBT replacement activity accounted for <10% of the total handball-training load (competitive and friendly matches not considered). The CG followed the regular handball training schedule (i.e., mainly technical-tactical drills, small-sided and simulated games, and injury prevention drills). The overall handball training load was comparable between both groups. Notably, this was due to all players following similar handball training routines consisting of six sessions per week with 90 to 120 minutes each. The CG maintained the normal, standard in-season training regimen.

Table 2. Complex elastic band training program.

Exercises	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
Upper limb	Red elastic band at 250 % elongation (3.2 kg)			Green elastic band at 250 % elongation (4.4 kg)		Blue elastic band at 250 % elongation (6 kg)			Black elastic band at 250 % elongation (8 kg)	
	Sets × Reps	Sets × Reps	Sets × Reps	Sets × Reps	Sets × Reps	Sets × Reps	Sets × Reps	Sets × Reps	Sets × Reps	Sets × Reps
Flies	3 ×10	3 ×10	4 ×10	5 ×10	3 ×10	4 ×10	5 ×10	3 ×10	4 ×10	5 ×10
Row with high elbows	3 ×10	3 ×10	4 ×10	5 ×10	3 ×10	4 ×10	5 ×10	3 ×10	4 ×10	5 ×10
Trunk rotation	3 ×10	3 ×10	4 ×10	5 ×10	3 ×10	4 ×10	5 ×10	3 ×10	4 ×10	5 ×10
Standing press	3 ×10	3 ×10	4 ×10	5 ×10	3 ×10	4 ×10	5 ×10	3 ×10	4 ×10	5 ×10
Lower limb	Red elastic band « Folding» at 250 % elongation (6.4 kg)			Green elastic band « Folding» at 250 % elongation (8.8 kg)		Blue elastic band « Folding» at 250 % elongation (12 kg)			Black elastic band « Folding» at 250 % elongation (16 kg)	
	Sets × Reps	Sets × Reps	Sets × Reps	Sets × Reps	Sets × Reps	Sets × Reps	Sets × Reps	Sets × Reps	Sets × Reps	Sets × Reps
Knee extension	3 ×10	3 ×10	4 ×10	5 ×10	3 ×10	4 ×10	5 ×10	3 ×10	4 ×10	5 ×10
Knee flexion	3 ×10	3 ×10	4 ×10	5 ×10	3 ×10	4 ×10	5 ×10	3 ×10	4 ×10	5 ×10
Half squat	3 ×10	3 ×10	4 ×10	5 ×10	3 ×10	4 ×10	5 ×10	3 ×10	4 ×10	5 ×10
Hip adduction	3 ×10	3 ×10	4 ×10	5 ×10	3 ×10	4 ×10	5 ×10	3 ×10	4 ×10	5 ×10

N.B.: The overall handball training load was comparable between the groups (using the Borg Rating of Perceived Exertion (RPE)).

2.4. Statistical analysis

Statistical analyses were conducted using the SPSS 23 program for Windows (SPSS, Inc., Armonk, NY: IBM Corp). Normality of all variables was tested using the Kolmogorov–Smirnov test procedure. Specific results (1-RM bench press, 1-RM half squat, PPLL and F0 performance) showed elements of skewing the data. Therefore, both means and medians were reported for these measurements. Data are presented as mean and standard deviation (SD). Between-group differences at baseline were examined using independent t-tests, and the effect of the intervention was determined by 2-way analyses of variance [Intervention vs Control and Test vs Re-test]. 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 [classified as small ($0.00 \le d \le 0.49$), medium ($0.50 \le d \le 0.79$), and large ($d \ge 0.80$)] [28]. Training-related effects were assessed by 2-way analyses of variance (group × time). The criterion for statistical significance was set at $p < 0.05$ (two-tailed). The reliabilities of all dependent variables were assessed by calculating 2-way mixed intra-class correlation coefficients (ICC) and coefficients of variation (CV).

No athlete missed more than 10% of the total training sessions or more than two consecutive sessions, so it was unnecessary to exclude any participant from the study.

3. Results

3.1. Test reliability

Intra-session reliabilities were generally above the accepted threshold, with ICCs of 0.913-0.926 and CVs of 2.2 to 8.9% (Table 3).

Table 3. Reliability and variability of performance tests.

	ICC	95%CI	%CV
T-half	0.915	0.827–0.959	2.2
SLJ	0.926	0.848–0.964	8.5
SJ	0.922	0.839–0.962	8.9
CMJ	0.913	0.821–0.957	7.9

CI = confidence intervals; CV = coefficient of variation; ICC = intraclass correlation coefficient; T-half = Modified change of direction T-test; SLJ = standing lang jump; SJ = squat jump; CMJ = countermovement jump

3.2. Baseline between-group differences

There were no significant initial intergroup differences for any of the dependent variables.

Table 4. Means and standard deviations for CoD, jump, 1-RM, and repeated sprint ability measures before (Pre) and after (Post) the intervention period in the Intervention and Control groups.

	Intervention Group (n=16)					Control Group (n=14)					
	Pre	Post	%Δ change	Paired t test		Pre	Post	%Δ change	Paired t test		ANOVA Group x Time interaction
Change of direction				p	d				p	d	p-value (*d*)
T-half (s)	7.45±0.15	6.58±0.19	11.7±2.9	<0.001	5.25	7.46±0.18	7.41±0.18	0.7±0.8	0.002	0.29	<0.001 (2.40)
Jump											
SJ (cm)	22.4±1.9	27.1±2.5	21.3±2.9	<0.001	-2.19	22.8±2.1	23.8±1.7	4.5±4.4	<0.001	-0.54	0.001 (0.94)
CMJ (cm)	23.8±1.7	29.7±2	24.8±1.7	<0.001	-3.28	24.1±2.1	25±1.9	4.0±3.4	<0.001	-0.46	<0.001 (1.34)
SLJ (cm)	145±9	171±6	17.9±7.5	<0.001	-3.51	147±12	154±13	4.9±2.4	<0.001	-0.58	0.001 (0.91)
RSA											
RSA-BT (s)	7.55±0.10	7.25±0.08	3.9±0.2	<0.001	3.42	7.54±0.07	7.50±0.06	0.5±0.4	<0.001	0.63	<0.001 (1.70)
RSA-MT (s)	7.68±0.10	7.38±0.10	3.8±0.2	0.000	3.10	7.70±0.07	7.66±0.06	0.5±0.5	0.001	0.63	<0.001 (1.59)
RSA-TT (s)	46.1±0.6	44.3±0.6	3.8±0.2	<0.001	3.10	46.2±0.4	46±3	0.5±0.5	0.001	0.10	<0.001 (1.59)
RST-FI (%)	1.66±0.33	1.81±0.35	9.7±15.5	0.019	-0.46	2.06±0.63	2.10±0.54	5.2±23.9	0.770	-0.46	0.615 (0.12)
1-RM											
1-RM Bench press (kg)	36.4±4.8	50.1±5	39±15	<0.001	-2.89	35.8±9.7	39.3±9.9	10.4±4.8	<0.001	-0.37	0.010 (0.68)
1-RM Half squat (kg)	54.3±7.3	74.3±10.1	37.2±10.8	<0.001	-2.34	54.9±13.4	61.1±13.8	11.9±6.5	<0.001	-0.47	0.020 (0.61)

T-half = Modified agility T-test; SJ = squat jump; CMJ = countermovement jump; SLJ = standing long jump; RSA = repeated sprint ability ; BT = best time ; MT = mean time; TT = total time ; FI = fatigue index ; RM = repetition maximal.

Training-related effects

All outcomes for both groups significantly improved over the 10-week intervention With a group × time interaction the IG improved more than CG in T-half performance [$p < 0.001$; $d = 2.40$ (large)]; jump performance [SJ ($p = 0.001$, $d = 0.94$ (large)), CMJ ($p < 0.001$, $d = 1.34$ (large)), and SLJ ($p = 0.001$, $d = 0.91$ (large))]; three of four RSA scores [$p < 0.001$, $d = 1.70$ (large); $p < 0.001$, $d = 1.59$ (large); and $p < 0.001$, $d = 1.59$ (large), the best time (RSA-BT), mean time (RSA-MT) and total time (RSA-TT) respectively]; strength [1-RM bench press ($p = 0.010$, $d = 0.68$ (medium)) and 1-RM half squat ($p = 0.020$, $d = 0.61$ (medium))] (Table 4).

Also force-velocity scores for the upper limb performance improved more in IG, in the peak power in these two forms (W and W·kg-1), maximal pedalling velocity (V0) and maximal braking force (F0) [$p < 0.001$, $d = 2.30$ (large); $p < 0.001$, $d = 1.99$ (large); $p = 0.024$, $d = 0.60$ (medium); and $p < 0.001$, $d = 1.13$ (large), respectively]; and three of four force velocity scores for the lower limb performance [$p < 0.001$, $d = 1.35$ (large); $p < 0.001$, $d = 1.40$ (large) and $p < 0.001$, $d = 1.33$ (large) for the peak power in these two forms (W and W · kg^{-1}) and maximal braking force (F0) respectively] compared to the CG (Table 5).

Table 5. Means and standard deviations for upper and lower force-velocity measures before (Pre) and after (Post) the intervention period in the Intervention and Control groups.

	Intervention Group (n=16)					Control Group (n=14)					
	Pre	Post	%Δ change	Paired t test p	d	Pre	Post	%Δ change	Paired t test p	d	ANOVA Group x Time interaction p-value (*d*)
Upper limb											
PP_{UL} (W)	154.4±16	268±35	74.7±25.4	<0.001	-4.99	146.1±22.8	151.6±18.3	5.9±18.5	0.424	-0.27	<0.001 (2.30)
PP_{UL} (W.kg^{-1})	2.44±0.20	3.72±0.42	54.1±24.4	<0.001	-4.02	1.90±0.25	2.00±0.31	6.4±18.8	0.301	-0.37	<0.001 (1.99)
$V_{0\text{-}UL}$ (rpm)	93.9±14.1	107.5±12.1	16.8±21.1	0.003	-1.07	85.9±16.6	84.4±8	1.4±20.5	0.717	0.12	0.024 (0.60)
$F_{0\text{-}UL}$ (N)	6.74±0.95	9.73±1.23	46.5±23.7	<0.001	-2.81	6.79±1.33	7.30±0.95	10.4±22.5	0.092	-0.46	<0.001 (1.13)
Lower limb											
PP_{LL} (W)	319.7±30.8	420±26.7	31.9±8.5	<0.001	-3.59	337.1±35.4	353.8±33.7	5.1±2.9	<0.001	-0.50	<0.001 (1.35)
PP_{LL} (W.kg^{-1})	5.06±0.44	6.38±0.32	26.8±8.6	<0.001	-3.38	5.28±0.51	5.43±0.43	2.9±3.3	0.003	-0.33	<0.001 (1.40)
$V_{0\text{-}LL}$ (rpm)	171.5±18.5	153.2±14.4	10.1±9.7	0.001	1.14	165.8±23.4	164.3±21.7	0.4±9.4	0.737	0.07	0.094 (0.43)
$F_{0\text{-}LL}$ (N)	7.45±0.92	10.83±1.11	45.9±10.4	<0.001	-3.42	7.72±0.63	8.86±1.01	12.9±13.2	0.001	-1.18	<0.001 (1.33)

PPUL = peak power for the upper limb; V0-UL = maximal pedalling velocity for the upper limb; F0-UL = maximal braking force for the upper limb; PPLL = peak power for the lower limb; V0-LL = maximal pedalling velocity for the lower limb; F0-LL = maximal braking force for the lower limb.

4. Discussion

The aim of this study was to identify the effects of complex elastic band training on athletic physical fitness among junior female handball players. The results indicated that ten weeks of complex elastic band training can improve CoD, jump ability, RSA, and strength and power for both upper and lower limbs.

This study applied optimal time in the complex training program based on previous scientific literature [14]. The results of this study demonstrated that following ten weeks of complex elastic band training during the in-season period, participants significantly increased CoD performance (i.e., T-half; IG: +11.7%; CG: +1%; p < 0.001; d = 2.24 (large)). Studies suggest that a complex training [29] or resistance training with elastic band program [16, 29] may enhance the CoD performance. Our result is consistent with the results of Hammami et al. [10], indicating that CoD (i.e., T-half agility test and modified Illinois test) performance significantly increased in the IG compared to the CG following eight weeks of complex training in junior female handball players. Moreover, the study by Chaabene et al. [8] demonstrated that T-test performance increased following eight weeks of complex training in young female handball players. A systematic review and meta-analyses concluded that complex training supplementation is an effective method to improve CoD performance [9]. Several mechanisms may contribute to the in-creased CoD following complex training, including the neuromuscular aspects underlying these positive adaptations that may be related to changes in physiological mechanisms (i.e., storage and utilization of elastic energy or stretch-shortening cycle function), in morphological factors (muscle architecture or fibre type), and neural factors (motor unit recruitment, synchronization, firing frequency, intermuscular coordination) [9, 30, 31].

In terms of jump performance, findings of the present study showed that the CEBT intervention induced a large improvement in performance in both vertical [SJ (p = 0.001; d = 0.94); and CMJ (p= 0.000; d = 1.34)] and horizontal [SLJ (p = 0.001; d = 0.91)] jumping. Similarly to our results, the review (87 studies with 1,355 patients ranging in age from 10 to 26.4 years) by Wang et al. [15] revealed an increase in jump performance following complex strength training (p = 0.001; d = 0.85). Likewise, these authors found a small (ES = 0.41) positive effect on vertical jump performance following complex strength training [9]. Similarly to our training program, the authors found increases in jump performance (SJ (p < 0.001), CMJ (p < 0.001), CMJ with arms (p < 0.001), and the five-jump test (p < 0.01)) in young female handball players [16]. Adaptations to complex strength training are initially considered a neuronal result in greater recruitment, enhanced activation frequency, im-proved synchronization and a greater discharge frequency [9, 31, 32].

An examination of the existing literature highlights discrepancies regarding jump performance adaptations to complex training. Due to these discrepancies, the sub-group analysis was conducted with the aim of identifying potential moderating factors that may account for the various adaptations that occurred following complex training (age and level, training frequency, duration of intervention and total number of sessions, intensity of the conditioning activity, intra complex rest interval, and team-sport modality).

There was a medium improvement in 1-RM bench press ($p = 0.01$; $d = 0.68$) and 1-RM half squat ($p = 0.02$; $d = 0.61$) performance in the IG following the 10-week complex elastic band training. Our result is consistent with Chaabene et al. [33], who reported a large ES for the 1-RM half squat in the complex training group following an 8-week, two sessions per week intervention. Similarly, Hammami et al. [10] found a greater improvement in 1-RM half squat in the complex training group compared with the CG over an 8-week training intervention (two sessions per week). Contrastingly, these authors found no significant group × time interactions for the back squat 1-RM ($F = 0.209$; $p = 0.653$) following an 8-week resistance training program with complex training and two sessions per week in collegiate basketball players [34]. Recently, the review of Wang et al. [15] reported a large main effect ($p < 0.001$; $d = 1.53$) of maximum strength following complex training. This is arguably due to the sophisticated training (i.e., complex elastic band training) involving resistance training that enhances maximum muscle strength. Independently of the practice level, the current study revealed that junior handball players exhibited larger ESs for 1-RM bench press and 1-RM half squat adaptations following CEBT interventions. Nota-bly, the examined junior athletes may not have had a strong foundation in strength training, and as a result, any training stimulus, including post activation potentiation (PAP) or a mixture of loads, would likely lead to significant performance enhancements [32]. An-other mechanism that may help to explain the development of maximum force due to CEBT training is the phenomenon of muscle hypertrophy. Unfortunately, in this study the muscle volume of the upper and lower limbs was not measured, thus, this may be considered among the limitations of this research.

Complex strength training, which involves combining multiple exercises into one continuous movement, may improve RSA performance [35, 36]. This type of training may enhance neuromuscular co-ordination, improve muscle power and endurance, and increase anaerobic capacity, all of which are important for performing repeated sprints [9, 15, 31]. However, the specific effect of complex strength training on RSA performance may vary depending on factors such as the duration and intensity of the training program, the individual's baseline fitness level, and the specific exercises employed in the training programme [9, 15, 31]. Our findings regarding the RSA scores showed significant improvements in the IG compared to the CG in three for four parameters [RSA-BT ($p < 0.001$, $d = 1.70$); RSA-MT ($p < 0.001$, $d = 1.59$); and RSA-TT ($p < 0.001$, $d = 1.59$)]. Our results concur with previous studies [35, 36]. Abade et al. [36] found a moderate improvement in RSA performance following 12-weeks of complex strength/power training in male handball players. Controversy, Hammami et al. [10] revealed no significant change in both RSA and repeated CoD ability following eight weeks of complex training in junior female handball players. The improvement in RSA following complex strength training may partly be explained by several factors. Firstly, complex strength training may enhance neuromuscular co-ordination, which improves the efficiency of muscle activation and co-ordination during sprints [11, 37–40]. This may lead to improved sprinting technique and faster sprint times. Secondly, complex strength training may increase muscle power and endurance, allowing an individual to sustain high-intensity efforts for a longer peri-od. This may result in less fatigue during repeated sprints, allowing an individual to maintain performance across multiple efforts [11, 37–40]. Lastly, complex strength training may increase anaerobic capacity, which is essential for performing repeated sprints. Anaerobic capacity refers to the ability of the body to produce energy without the need for oxygen, and is critical for high-intensity efforts like repeated sprints [11, 37–40]. By in-creasing anaerobic capacity, an individual can perform more sprints at a higher intensity before fatiguing.

Power is a critical component in handball, as it allows players to generate explosive movements such as sprinting, jumping, and throwing with greater speed and force. There are many methods to evaluate power. Our findings evaluated power using force-velocity testing, revealing increases in both upper and lower scores except maximal pedalling velocity for the upper limb (V0UL; $p = 0.09$, $d = 0.43$). To our knowledge, this is the first study that investigated the effect of complex elastic band training on both upper and lower force-velocity profiling. Indeed, using similar elastic band training, Aloui et al. [41] revealed an increase in both absolute and relative peak power ($p < 0.001$; 49.3 ± 22.9% and 47.9 ± 24.6%, respectively) evaluated by the force-velocity test following eight weeks of elastic band training in junior handball players. Complex strength training that involves performing multiple exercises in a sequence with minimal rest in between can have a positive effect on force-velocity results and other physical abilities in youth handball players [42]. This type of training has previously been shown to improve both maximal strength and power output, which are key components of force-velocity performance [9, 15, 32]. However, the specific effects will depend on the training program and individual factors such as fitness level and training history [9]. Among various forms, elastic bands can effectively enhance conditioning workouts. Previous studies indicated that incorporating medicine ball exercises into the training of pre-adolescent female athletes improved crucial aspects of physical performance, optimizing exercise effects [43].

5. Conclusions

Compared to other types of resistance training equipment, elastic resistance bands are less expensive, easy to implement, portable, and simple to incorporate into regular handball training sessions. Following a 10-week complex elastic band training program, added to the regular training schedule of junior female handball players, handball-related performance markers such as jumping, CoD speed, upper and lower body strength, and RSA were improved. Therefore, when training junior female handball players during the season, coaches should consider including components of contrast strength and elastic band training. It appears that substantial improvements in performance-related characteristics are safe to achieve without requiring more training time.

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Author Contributions: Study Design, MH; Data Collection: MH; Statistical Analysis: MH; Data Interpretation: MH, RM, and PZ; Manuscript Preparation: MH, RM, and PZ; Literature Search: MH, RM, and PZ. All authors have read and agreed to the published version of the manuscript.

Funding: The research obtained no external funding.

Institutional Review Board Statement: The study was approved by the Local Ethics Committee of the Research Laboratory (LR23JS01) in conformity with principles identified in the latest version of the Declaration of Helsinki.

Informed Consent Statement: Written informed consent was obtained from all participants parents or guardians (and consent from the athletes) prior to participating in the study.

Data Availability Statement: Data available from the corresponding author on request.

Conflicts of Interest: The authors declare no conflict of interest.