Article

The Effects of an 8-weeks in-season Loaded Plyometric Exercise by Elastic Band Training Program on the Peak Power, Strength, and Throwing Velocity of Junior Male Handball Players

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Abstract: This study examined the effects of incorporating 8 weeks of biweekly upper limb loaded plyometric training (elastic band) into the in-season regimen of handball players. Participants were randomly allocated to a control (n = 15, age: 18.1±0.5 years, body mass: 73.7±13.9 kg), or experimental (n = 14, age: 17.7±0.3 years, body mass: 76.8±10.7 kg) group. Measures obtained pre- and post-intervention included a cycle ergometer force-velocity test, ball throwing velocity in three types of throw, 1-RM bench press and pull-over, and anthropometric estimates of upper limb muscle volumes. Gains in the experimental group relative to controls included absolute muscle power (W) (Δ23.3%; p=0.032; d=0.083), relative muscle power ($W\cdot kg^{-1}$) (Δ22.3%; p=0.024, d=0.091), and all 3 types of ball throw (Δ18.6%, p=0.019, d=0.097 on jumping shot; Δ18.6%, p=0.017; d=0.101 on 3-step running throw; and Δ19.1%, p=0.046, d=0.072 on standing throw). Furthermore, a improvement was observed in both groups in 1-RM bench press and pull-over performance. However, upper limb muscle volumes remained unchanged in both groups. We conclude that adding biweekly elastic band plyometric training to standard training improves muscle strength and power. Accordingly, such exercises should be adopted as a part of a pragmatic approach to handball training.

Keywords: Stretch-shortening cycle; Peak power; Plyometric with load; Team sports; Throwing.

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1. Introduction

Team handball is a sport characterized by intermittent effort with periods at various intensities [1, 2]. Although most match time is at lower intensities, most decisive actions such as throwing, jumping, accelerations, sprinting, and tackles demands a high level of explosiveness and strength [3-5]. Therefore, optimal conditioning programs should incorporate strength training sessions to promote these characteristics. There are several possible types of muscle strengthening training, including isometrics, dynamic, plyometric, and isokinetics. In addition, other options are dynamic

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strength training combined with variable resistance such as elastics (also known as elastic bands, rubber bands and tubing) [6-10] and weightlifting chain [11, 12], and plyometric training combined with variable resistance such as a Smith machine [13, 14] and weight vest [15, 16]. Several studies have reported dynamic strength training combined with elastic resistance is an effective tool for improving strength and power of upper and lower limbs in athletes [6, 16, 17]. The most pertinent feature of this training is the progressive increase in external resistance due to the instability of the band, which could induce a greater stimulus for strength gains [18], and a high neuromuscular demand, improving both motor unit recruitment and rate coding [19]. A further characteristic of elastic resistance is that, besides improving velocity, it increases the eccentric stimulus of training, and therefore the strength required to decelerate or stop the load at the end of the eccentric phase, increasing myoelectric activity in the muscles [20].

Despite the efficacy of elastic resistance, there has been no previous investigation examining loaded plyometric training (elastic resistance) on athletic performance. Plyometric exercise involves stretching a muscle immediately before executing a rapid concentric contraction, commonly called a stretch shortening cycle (SSC) [21]. The incorporation of SSC into handball training is intuitively logical, as handball players often throw, push, jump, sprint, and change direction. Furthermore, several studies have shown an improvement of athletic performance after loaded plyometric training using other type of resistance. Indeed, Lyttle et al. [13] noted a significant increases in 1RM bench press and medicine ball throw performance, after 8 weeks of biweekly loaded plyometric training (weighed bench-press throw at 30% 1RM), in adult male athletes. Moreover, Khalifa et al. [22] showed increased vertical and horizontal jump performance after 10-weeks of loaded plyometric training (weight vest), in elite male basketball players. However, equipment used for loaded plyometric training in these studies is more expensive, heavy, and sophisticated than elastic resistance such as the elastic band, which is prohibitive for some athletes.

To our knowledge, no previous investigations have examined the effects of loaded plyometric training using elastic bands on relevant physical abilities in male handball players. Therefore, the aim of the present investigation was to evaluate the effects of replacing some normal in-season training by loaded plyometric training (elastic band) for upper limbs in junior male handball players. Outcome measures included the maximal muscular strength and power of the upper limbs, muscle volume, and throwing ball velocity. We hypothesized *a priori* that an 8-week program of elastic band plyometric training would enhance muscular power of the upper limbs, and ball throwing ball velocity scores, when compared to the control group who maintained their standard in-season regimen.

2. Materials and Methods

2.1. Experimental approach to the problem

Two familiarization sessions were held 2 weeks prior to testing and measurements began 2 months into the competitive season. Performance data were collected before and after the experimental subjects had completed the 8-week period of added elastic band plyometric training. Initial and final test measurements were performed at the same time of day (17:00-19:00 h), under approximately the same environmental conditions (temperature: 16-19°C), at least 3 days after the most recent competition, and 5 to 9 days after the last elastic band plyometric training session. A pretest 1RM determined the approximate 1RM value. A standardized battery of warm-up exercises was performed before maximal efforts. On the first test day, anthropometric assessments were followed by the force-velocity test. On the second day, the ball throwing velocity was assessed. On the third day, 1RM pull-over (1RMPO) and 1RM bench press (1RMBP) performance were assessed. Subjects were asked to maintain their habitual intake of food and fluids, to abstain from physical exercise for 1 day, do not drink caffeine-containing beverages for 4 hours, and do not eat food for 2 hours before testing. Verbal encouragement ensured maximal effort throughout all tests.

2.2. Subjects

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Twenty-nine elite adolescent handball players (age: 17.7 ± 0.4 years, body mass: 75.7 ± 16.2 kg, height: 1.81 ± 0.06 m, body fat: 14.1 ± 4.9%) were drawn from a single national handball team that were competing in the first national division. Their mean experience of handball competition was 6.3 ± 0.76 years. They were examined by the team physician, with a particular focus on conditions that might preclude elastic band plyometric training, and all were found to be in good health. Players were characterized by playing position, and players from each position were then randomly assigned between experimental and control groups. They were well-matched in terms of their initial characteristics: (experimental group age: 17.7 ± 0.3 years, body mass: 76.8.4 ± 10.7 kg, height: 1.83 ± 0.04 m, body fat: 13.4 ± 3.8%; control group age: 18.1 ± 0.5 years, body mass: 73.7 ± 13.9 kg, height: 1.82 ± 0.06 m, body fat: 14.4 ± 6.0%); a Student's non-paired t-test showed no inter-group differences in all anthropometric characteristics at the $p \leq 0.05$ level.

The habitual regimen for participants included Tuesday sessions which incorporated moderate resistance training (body weight squats, jump squats, overhead lunges, push-ups, and pull-ups), plus light weight resistance training (40–60% 1RM exercises such as bench presses, pull-overs, and half back squats), and Thursday sessions which included technical and tactical routines. Every Tuesday and Thursday for 8 weeks, the experimental group replaced their standard regimen with the elastic band training program by the loaded plyometric training.

2.3. Testing Schedule

Day 1

Anthropometry.

Muscle volume of the upper limbs was estimated as detailed previously, using circumferences and skin-fold thicknesses measured at different levels of arm and the forearm, length of the upper limb, and the breadth of the humeral condyles [4]:

Muscle volume = total limb volume - (fat volume + bone volume)

Total limb volume was estimated as the volume of a cylinder, based on its length (L), corresponding to the distance from the acromion to the minimum wrist circumference, and the mean of 5 limb circumferences (axilla, maximum relaxed biceps, minimum above the elbow, maximum over the relaxed forearm, and minimum above the styloid process):

$$\text{Total limb volume} = (\sum C2) / L/62.8$$

where $\sum C2$ is the sum of the squares of the 5 circumferences of the corresponding limb. Skin folds were assessed using a standard Harpenden caliper (Baty International, Burgess Hill, Sussex, United Kingdom). The fat volume was calculated as:

$$(\sum C/5) \,.\, [(\sum S/2n)]L$$

where $\sum S$ is the sum of 3 skin folds for the upper limb (biceps, triceps, and mid-forearm), and n represents the number of skin folds measured on each limb. Bone volume was calculated as:

$$\pi \,.\, (F \,.\, D)\, 2 \,.\, L$$

where D is the humeral intercondylar diameter, F is a geometric factor (0.21 for the upper limb), and L is the limb length as measured above. Standard equations predicted the percentage of body fat from measurements of biceps, triceps, subscapular, and suprailiac skinfolds [23]:

$$\%\text{Body fat} = a \log (\sum 4\text{folds}) - b$$

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where ∑S is the sum of the 4 skinfolds (in mm), a and b are constants dependent on sex and age.

The Force-Velocity Test

Upper limb force-velocity measurement was performed on a standard Monark cycle ergometer (model 894 E, Monark Exercise AB, Vansbro, Sweden) as detailed previously [4]. Briefly, instantaneous maximal pedaling velocity during a 7-second all-out sprint was used to calculate the maximal anaerobic power for each braking force, and the subject was judged to have reached peak power (Wpeak) if an additional load induced a decrease in power output. Parameters obtained included Wpeak, maximal braking force (F0) and maximal pedaling cadence (V0). The test began with a braking force equating to 1.5% of subject's' body mass [4]. After a 5-min recovery, resistance was sequentially increased to 2, 3, 4, 5, 6, 7, 8 and 9% of the subject's body mass. For more details of the force-velocity test, see [4].

Day 2

Handball Throwing

Throwing velocity was evaluated by making three types of over-arm throw on an indoor handball court: a standing (penalty) throw, a 3-step running throw and a jump shot. The standing and 3-step throws have been described previously [24]. In the jump shot, players made a preparatory 3-step run before jumping vertically and releasing the ball while in the air, behind a line 9 m from the goal. Throwing times were recorded by digital video camera (Sony Handycam DCR-SD1000, frame rate: 25 Hz, Tokyo, Japan), positioned on a tripod 1.5 m above and parallel to the player. Data processing software (Regavi and Regressi, Micrelec, Coulommiers, France) converted measures of ball displacement-time data to velocities. Throws with the greatest starting velocity were selected for further analysis. The reliability of the data processing software has been reported previously [24] and the test–retest coefficient of variations in throwing velocity was 1.9%.

Day 3

One Repetition Maximum Pull-Over

The barbell was positioned 0.2 m above subjects' chests and was supported by the bottom stops of the device. Players performed successive eccentric–concentric actions from the starting position. The eccentric action took the weight over and behind the head, with the elbow fully extended. At the end of the backward movement, when the upper limbs were approximately parallel to the ground and the elbows were slightly flexed, subjects pushed the barbell to bring it back to the starting position, keeping their abdominal muscles contracted and their body stable, without bouncing or arching of the back. Subjects were familiar with the required technique, having used it in their weekly training sessions. A pretest assessment of 1RMPO was made during the final standard training session. For 1RMPO as for the 1RMBP, warm-up for the definitive test comprised 5 repetitions at loads of 40–60% of the pretest 1RMPO and 1RMBP. Thereafter, 4-5 separate attempts were performed until the subject was unable to extend the arms fully on 2 occasions. The load noted at the last acceptable extension (similar to starting position) was considered as the 1RMPO. Two minutes of rest was allowed between trials.

One Repetition Maximum Bench-Press

The 1RMBP (kg) was performed in a Smith machine; the barbell was attached at both ends, and linear bearings on 2 vertical bars allowed only vertical movements. The bar was positioned above the players' chests (about 0.3 m from the ground) and was supported by the bottom stops of the measuring device. Successive elbow flexion extensions were performed from the starting position. To ensure consistent positioning of the shoulder and elbow joints throughout, the participant held

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their shoulders in 45° abduction during the concentric contractions. No bouncing or arching of the back was allowed. A more detailed description of the bench press is provided elsewhere [4].

Loaded Plyometric Training (Elastic Band) Program

Subjects avoided any training other than that associated with the handball team throughout the study. Every Tuesday and Thursday for 8 weeks, the experimental group replaced part of the standard regime (technical-tactical part) with elastic band plyometric training (Table 1). The elastic band (Thera-Bands®; Hygenic Corporation; Akron, Ohio, USA) system includes 2 latex bands of differing elasticity: black (Special Heavy) and silver (Super Heavy). Subjects were instructed to perform exercises with maximal effort (maximal concentric velocity). The loaded plyometric training (elastic band) program comprised 2 exercises: plyometric standard push-up (Figure 1) and plyometric diamond and wide arm push-up (Figure 2). Training sessions began with a 15-minute warm-up and lasted for 20 minutes (a total of 35 minutes).

A standardized battery of warm-up exercises was performed prior to plyometric training, which included exercises such as running, coordination exercises, trunk rotation, internal and external rotary movements of the hip and knee, abdominal and oblique exercises, back exercises, sheathing, knee elevation, heel to bum, lateral displacement forward and backward, jump exercises, skipping and tapping and sprinting in a straight line and with directional changes over short distances (15-20 m). Internal and external rotary, flexion and extension movements of the shoulders, normal and plyometric push-ups with both hands on the ground, 8-10 free-medicine ball throws, and 8-10 free-ball throws were also performed. Two black elastic bands, two silver elastic bands, two silver plus one black elastic bands, and two silver plus two black elastic bands were used respectively for the first and second week, the third and fourth week, the sixth and seventh weeks, and the seventh and twelfth week, to ensure progression.

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Table 1 Details of loaded plyometric (elastic band) training program performed by the experimental group over the 8-week trial.

Exercices	**Session 1**	**Session 2**	**Session 3**	**Session 4**	**Session 5**	**Session 6**	**Session 7**	**Session 8**
	With 2 black elastic bands at 150 % elongation (11.2 kg)				With 2 silver elastic bands at 150 % elongation (15.6 kg)			
Plyometric standard push-up	4 x 6	4 x 6	5 x 6	5 x 6	4 x 6	4 x 6	5 x 6	5 x 6
Plyometric diamond and wide arm push-up	4 x 6	4 x 6	5 x 6	5 x 6	4 x 6	4 x 6	5 x 6	5 x 6
Exercises	**Session 9**	**Session 10**	**Session 11**	**Session 12**	**Session 13**	**Session 14**	**Session 15**	**Session 16**
	With 2 silver plus 1 black elastic bands at 150 % elongation (21.2 kg)				With 2 silver plus 2 black elastic bands at 150 % elongation (26.8 kg)			
Plyometric standard push-up	4 x 6	4 x 6	5 x 6	5 x 6	4 x 6	4 x 6	5 x 6	5 x 6
Plyometric diamond and wide arm push-up	4 x 6	4 x 6	5 x 6	5 x 6	4 x 6	4 x 6	5 x 6	5 x 6

(sets x repetitions)

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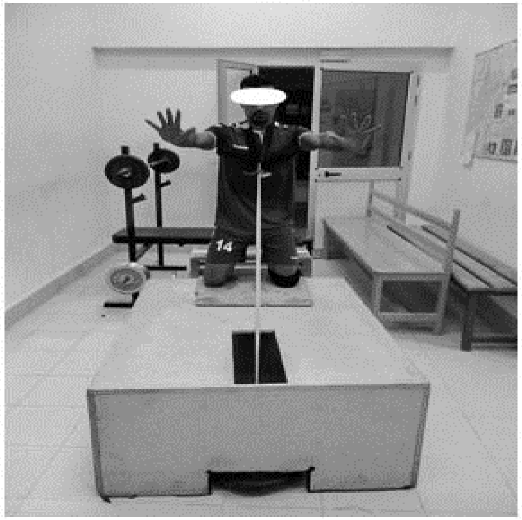
A. Starting position of plyometric standard push-up

B. Reception phase of plyometric standard push-up



C. Final position of plyometric standard push-up

Figure 1 Phases of plyometric standard training exercise.

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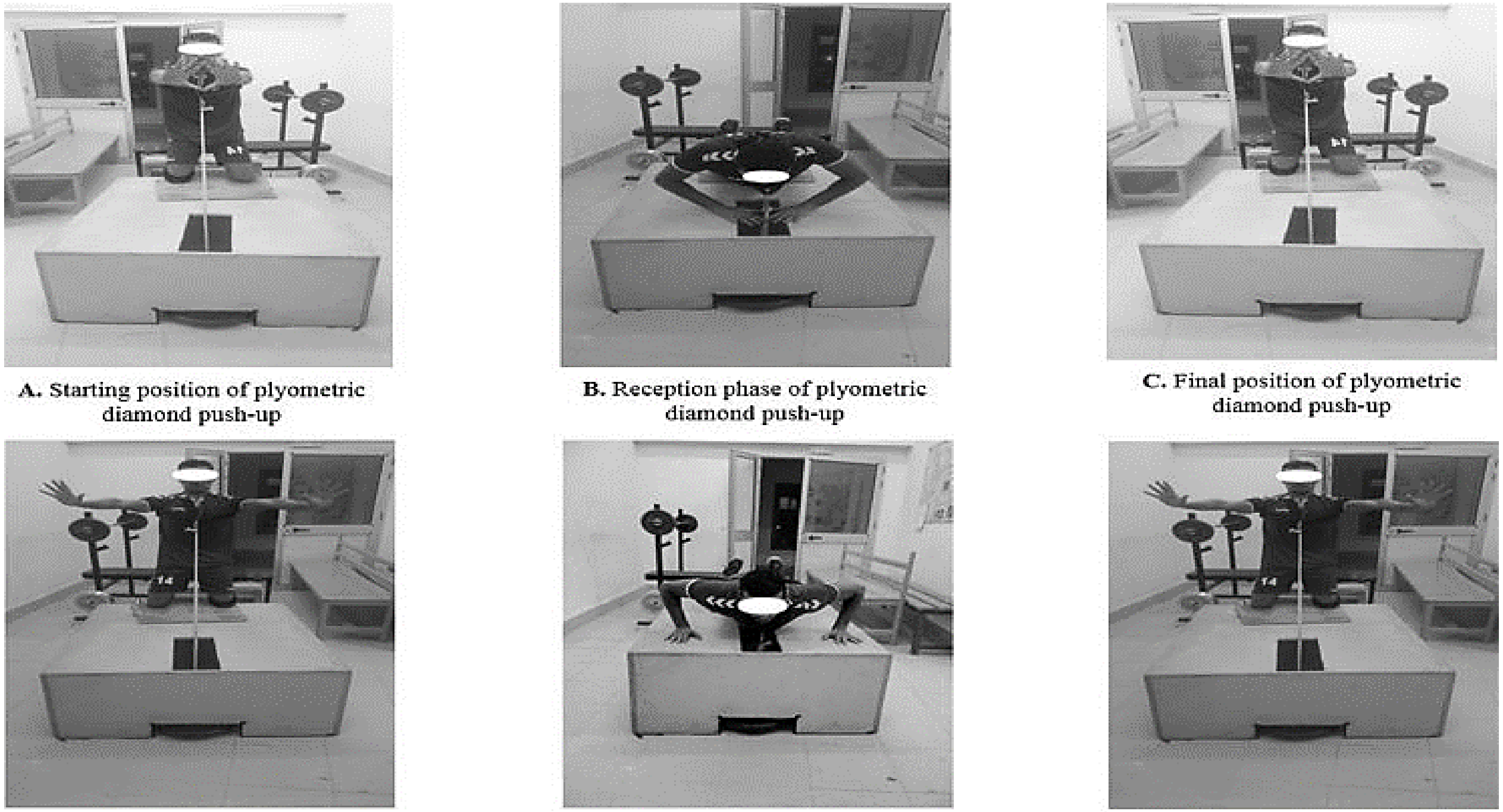

A. Starting position of plyometric diamond push-up

B. Reception phase of plyometric diamond push-up

C. Final position of plyometric diamond push-up

D. Starting position of plyometric wide arm push-up

E. Reception phase of plyometric wide arm push-up

F. Final position of plyometric wide arm push-up

Figure 2 Phases of plyometric diamond and wide arm push-up training exercise.

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For both exercises the knees and feet remained in contact with the top of a wooden box, which participants exercised upon height of 50 cm, length of 120 cm, and a width of 90 cm). The elastic band was attached to the chest (upper part of the sternum) via a strap, and vertically to the through a rectangular hole in the wooden box (opening 30 cm long and 15 cm wide). The hole in the box was in front and parallel to subjects' chests when in a standard push-up position. The initial length of the elastic band was 35 cm for both exercises and ~90 cm when participants were in the initial standard push-up position.

Plyometric Standard Push Up:

Subjects were kneeling, with the trunk vertical, knees and feet remaining in contact with the floor, shoulders in antepulsion (90°), elbows extended, and palms facing forward, and trunk vertical. They then allowed themselves to fall forward (under the effect of gravity), extending their arms forward with slight elbow flexion, in preparation for contact with the box, stopping movement when with elbows will be flexion at approximately 90°. They then immediately reversed the action by extending the arms rapidly, propelling the upper body as high as possible towards its starting position. Subjects then initiated the next push-up immediately (i.e. no pause between repetitions) and continued until the prescribed number of repetitions had been achieved.

Plyometric Diamond and Wide Arm Push Up:

Exercises were completed in a similar fashion to the plyometric standard push-up except that in the diamond push-up participants had their hands close together, thumbs and index fingers touching to form a shape of a diamond. For the wide arm push-up, hands were held approximately double shoulder width apart.

The elastic band plyometric raining began at a resistance of 11.2 kg, with an increase of 4 to 5 kg every 4 sessions to reach a final a resistance of 26.8 kg, and resistance was derived from the manufacturer's manual, based on the elongation of the band. The number of sets was increased after every two sessions (from 4 to 5 sets) for each level of resistance. The number of repetitions per set was maintained throughout training (6 repetitions). No injuries were encountered over the 16 workouts.

3.3. Statistical Analyses

Statistical analyses were conducted using the SPSS 20 program for Windows (SPSS, Inc, Chicago, IL, USA). Normality of all variables was tested using the Kolmogorov-Smirnov procedure. Levene's test determined the homogeneity of variance. Means and SDs were calculated, and independent t-tests examined between-group differences at baseline. Training-related effects were assessed by repeated measures 2-way (group x time) analyses of variance (ANOVA). Subsequently, Tukey's post hoc procedure was applied to locate pair-wise differences. An analysis of covariance (ANCOVA) was also run for variables with baseline inter-group differences. Effect sizes were calculated using Cohen's d, and were classified as trivial ($d < 0.2$), small ($0.2 \leq d \leq 0.6$), moderate ($0.6 \leq d \leq 1.2$), large ($1.2 \leq d \leq 2.0$), or very large ($d > 2.0$) [25]. Reliability of measures was assessed using intra-class correlation coefficients (ICC) [26] and the coefficients of variation (CV) over consecutive pairs of intra-subject trials [10]. An ICC of more than 0.90 is considered as high, between 0.80 and 0.90 as moderate, and less than 0.80 as insufficient for physiological field tests [26]. Three types of throwing velocity showed an ICC > 0.80 and a CV < 5%). Alpha level is reported as exact P values as suggested by Hurlbert et al. [27].

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3. Results

Intra-class correlation coefficients, the confidence intervals, and coefficients of variation assessing the reliability for all 3 types of throwing velocity are shown in Table 2. No initial inter-group differences existed at baseline.

Table 2 Intra-class correlation coefficient and coefficient of variation showing acceptable reliability for measures of throwing ball velocity.

	ICC	95%CI	CV (%)
Throwing ball velocity ($m.s^{-1}$)			
Jumping shot	0.956	0.906-0.979	3.1
3-step running throw	0.947	0.888-0.975	3.2
Standing throw	0.958	0.910-0.980	3.6

ICC = Intraclass correlation coefficient; CI = Confidence interval; CV = Coefficient of variation.

3.1 Effect of Training on Anthropometric Measures

No interaction effect (i.e. group × time) was present in anthropometric measures at the $p<0.05$ level (Table 3). However, paired samples t-tests indicated an improvement in arm muscle volumes (L) (Δ 13.8%; t-test $p = 0.001$; $d = 0.619$) in the experimental group. All other anthropometric changes were trivial.

3.2 Effect of Training on Power Performance

For the force-velocity test, a group × time interaction existed at the $p<0.05$ level for peak power (W) and relative peak power ($W.kg^{-1}$). No interaction effect was noted for muscle quality ($W.L^{-1}$), peak cadence (rpm) or peak force (N). In terms of magnitude, the experimental group experienced a large increase in absolute peak power and relative peak power, and a moderate increase in muscle quality and peak cadence. A small improvement was noted in peak force (Table 4).

3.3 Effect of Training on Maximum Muscular Strength Performance

No interaction effect was observed in ANOVA in 1RMPO or 1RMBP. In post-hoc analyses, the experimental group experienced a large improvement in 1RMPO, whilst the control group experience a moderate improvement. In regards to the bench press, the experimental group experienced a moderate improvement in performance, whilst the control group experience a trivial improvement (Table 5).

3.4 Effect of Training on Throwing Performance

No interaction effect was observed in ANOVA in the jumping shot, the 3-step running throw, or standing throw. In post-hoc analyses, the experimental group experienced a very large improvement in 3-step running throw, and large improvements in jumping shot and standing throw. The control group experienced a small improvement in 3-step running throw and jumping shot and a large improvement in standing throw (Table 5).

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Table 3 Comparison of muscle volume of arm and body fat % between experimental and control groups before and after 8-week intervention.

	Experimental (n=14)			Paired t-test		Control (n=15)			Paired t-test		ANOVA (group x time)	
	Pre	Post	% Δ	p value	d (Cohen)	Pre	Post	% Δ	p value	d (Cohen)	p value	d (Cohen)
Arm muscle volume (l)	3.5 ± 0.74	4.0 ± 0.73	13.8 ± 11.5	0.001	0.619	3.7 ± 0.55	3.8 ± 0.60	2.4 ± 5.6	0.141	0.162	0.293	0.020 (small)
Body fat %	13.4 ± 3.8	13.2 ± 3.5	-0.5 ± 8.4	0.562	0.045	14.4 ± 6.0	14.6 ± 5.8	0.17 ± 5.0	0.260	0.029	0.899	0.063 (small)

Table 4 Force-velocity test data for upper limbs for experimental and control groups before and after 8-week intervention.

	Experimental (n=14)			Paired t-test		Control (n=15)			Paired t-test		ANOVA (group x time)	
	Pre	Post	% Δ	p value	d (Cohen)	Pre	¨Post	% Δ	p value	d (Cohen)	p value	d (Cohen)
Force–velocity test												
Warm.peak (W)	416 ± 60	511 ± 72*	23.3 ± 3.6	0.001	1.448	405 ± 51	433 ± 52	7.1 ± 10.0	0.016	0.530	0.032	0.083 (small)
Warm.peak($W.k^{-1}$)	5.6 ± 0.52	6.9 ± 0.73*	22.3 ± 4.1	0.001	1.990	5.3 ± 1.1	5.4 ± 1.2	2.6 ± 11.6	0.461	0.102	0.024	0.091 (small)
Warm.peak (W/L)	119 ± 12	130 ± 18	9.3 ± 10.6	0.006	0.716	110 ± 16	115 ± 18	5.2 ± 14.0	0.146	0.304	0.488	0.009 (small)
V0 (rpm)	135 ± 11	142 ± 11	4.9 ± 1.5	0.001	0.607	138 ± 13	141 ± 14	2.8 ± 4.9	0.046	0.274	0.660	0.004 (small)
F0 (N)	111 ± 17	119 ± 18	6.8 ± 1.3	0.001	0.437	114 ± 24	116 ± 23	3.0 ± 13.9	0.720	0.082	0.609	0.005 (small)

V0 represents the maximal pedaling velocities for upper limbs. F0 represents the maximal braking force for the upper limbs. Warm.peak represent the maximal power output for upper limbs. Note: A the 2-way analysis of variance (group x time) assessed the statistical significance of training-related effects: * $p \leq 0.05$.

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Table 5 Comparison of ball throwing velocities and 1RM strength of upper limbs for experimental and control groups before and after 8-week intervention.

	Experimental (n=14)			Paired t-test		Control (n=15)			Paired t-test		ANOVA (group x time)	
	Pre	Post	% Δ	p value	d (Cohen)	¨Pre	Post	% Δ	p value	d (Cohen)	p value	d (Cohen)
Ball throwing velocities (m.s^{-1})												
Jumping shot	22.4 ± 2.4	26.5 ± 2.7*	18.6 ± 2.0	0.001	1.608	21.7 ± 2.6	22.5 ± 2.8	3.8 ± 5.2	0.012	0.315	0.019	0.097 (small)
3-step running throw	23.0 ± 1.9	27.4 ± 2.0*	19.1 ± 3.3	0.001	2.229	22.1 ± 2.8	23.1 ± 3.2	4.8 ± 6.0	0.001	0.365	0.017	0.101 (small)
Standing throw	21.6 ± 2.6	26.0 ± 3.1*	20.4 ± 2.1	0.001	1.529	20.7 ± 2.8	22.0 ± 2.9	6.4 ± 9.1	0.001	1.529	0.046	0.072 (small)
1RM strength (kg)												
1RM pull-over	29.3 ± 4.1	35.5 ± 4.9	22.5 ± 2.8	0.001	1.368	28.0 ± 4.8	30.8 ± 6.3	9.6 ± 6.7	0.001	0.499	0.170	0.035 (small)
1RM bench-press	73.4 ± 14	85.0 ± 17	15.9 ± 1.1	0.001	0.973	72.4 ± 16	75.2 ± 18	3.7 ± 4.9	0.001	0.165	0.303	0.020 (small)

Note: A 2-way analysis of variance (group x time) assessed the statistical significance of training-related effects: * p≤0.05.

4. Discussion

The aim of this study was to assess the effectiveness of an 8-week elastic band plyometric training program for improving muscular strength and power, and ball throwing velocity in elite adolescent handball players. Data presented here suggest that replacing some aspects of typical training with elastic band upper body plyometric training produces moderate to large improvements in muscle power of the upper limbs without meaningfully altering anthropometrics. Moreover, and possibly more pertinent to coaches and practitioners, large to very large improvements were noted in ball throwing velocities, which would likely improve sport-specific performance.

4.1. Effect of Training on power performance

The experimental group showed gains of absolute and relative muscle power in the upper limbs, although there was no significant change if power was expressed per liter of muscle volume (i.e. muscle quality). Previous investigations concerning plyometric training [28] or resistance training [29-31] have seen improvements in both the absolute and the relative power of the lower limbs, but no change if power was expressed per liter of muscle volume, in elite male handball players. Chelly et al. [28] noted a gain in absolute (27%) and relative (28%) upper limb power during a force-velocity test following plyometric training without added load in elite junior handball players. Also, Hermassi et al. [30] noted improved absolute (12%) and relative (11%) upper limb power during force-velocity testing after resistance training in elite male handball players. Mechanisms explaining increased absolute power in the present study and studies discussed here could be explained by increased myofiber length (number of sarcomeres in -series) [32] and/or the stress-related overload placed on the body during plyometric training [33]. Moreover, plyometric training induces neuromuscular adaptation (e.g. increased motor unit recruitment, rate coding, synchronization, and intermuscular coordination [33-35]) that may have contributed to increased power production [33, 36].

4.2. Effect of training on anthropometric measures

The current study showed only a moderate change in upper limb muscle volumes in the experimental group, implying the large increase in muscle power were driven primarily by neural adaptations described in the previous paragraph rather than muscular hypertrophy. This is encouraging for the practitioner, as increasing power output in the absence of mass increase enhance the power:mass ratio, and may enhance other attributes such as jumping, change of direction, and sprinting, whereby individuals are required to accelerate their own body mass. However, whether improvements in upper and lower body power in the present study translate to improvements in sprints and/or jumping requires further investigation.

4.3. Effect of training on maximum muscular strength performance

Handball performance depends not only on strength, but also on ability to exert force at speed [30]. A powerful action is often associated with high velocity movements (e.g., in sprinting, jumping, and throwing) [37]. The current study showed moderate to large improvements in strength performance in the experimental group, measured by bench press (15.9%) and pullover (22.5%). Improvements we observed were in line with those reported by Lyttle et al. [13] who observed improved 1RM bench press (13%) after 8 weeks of a biweekly loaded plyometric training (weighed bench-press throw at 30% 1RM), in adult male athletes. However, a recent study [38] reported greater improvements of upper body strength (68% and 27% for pull-over and bench press, respectively) than those observed in our study in elite male handball players after 10 week of a biweekly resistance circuit training. Differences in the training program (intensity, duration, frequency, and type of exercise) and in methodology (competitive level of players; age of players; period of studies) could contribute to divergences between studies. Yet, it is clear that a combination of resistance training,

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handball technique training, and competitive skills training enhance maximal and explosive strength of the upper limbs, giving players an advantage in sustaining the forceful muscle actions required during such actions such as throwing [4, 28, 39].

4.5. Effect of training on maximum ball throwing performance

This study is the first to have examined the effect of elastic band plyometric training on throwing performance of junior handball players. Throwing velocity is of importance to successful play, since elite handball players exhibit substantially higher throwing velocities than lower level competitors (8–9% advantage in men [40] and 10–11% advantage in women [41]). We observed improved ball velocity in the experimental group compared to the control group in all 3 types of ball throw. The mean velocity of jumping shot was increased by 18.6% for experimental group, while the control group enhanced their throwing velocity by only 3.8%. Similarly, the mean velocity of 3-step running throw was improved by 19.1% for the intervention group, whereas the control group enhanced their throwing velocity by only 4.8%.

In the same way, the mean velocity of the standing throw increased by 20.4% in the experimental group, but the control group enhanced their throwing velocity by only 6.4%. These results are in accordance with Chelly et al. [28] who noted enhanced throwing velocities (28.5% on jumping shot; 21.5% on 3-step running throw; and 18.9% on standing throw) following an 8-week bi-weekly course of lower and upper limb plyometric training without added load (plyometric push up). Similarly, Mascarin et al. [42] noted increased handball throwing velocities (6.3% on standing shot and 7.8% on jumping throw) in young female handball players after 6 weeks of a tri-weekly dynamic elastic band training for the shoulder. Also, Hermassi et al. [29] reported improved handball throwing velocities (42.5% on 3-step running throw after heavy loaded resistance training; 37.8% on 3-step running throw after moderate loaded resistance training) following 8-weeks of upper limb resistance training.

In contrast Buccheit et al. [43] reported no improvement after a 10-week bi-weekly course of two different training regimens (high-intensity interval- and specific game-based handball) in handball throwing velocity of elite adolescent handball players. Using an identical force-velocity protocol to the present investigation, Bouhlel et al. [44] reported significant correlations between javelin performance and the peak power output of both the upper and lower limb muscles. Similarly, Chelly et al. [45] reported that the peak power of both the upper and the lower limbs were closely correlated with throwing velocity. It is difficult to compare these results with previous trials because of differences in study design, measurement methods (photoelectric cells, radar, or cinematography), throwing techniques (standing throw, 3-step running throw and jump shot), [28, 39], (amateur or professional), the intensity and type of training, and the age and skill level of players..

4.6. Practical applications

This controlled study shows that 8 weeks of bi-weekly in-season upper limb loaded plyometric training enhances peak power output and throwing ball velocity in junior handball players. Thus, it appears pragmatic to incorporate this form of plyometric training into traditional in-season technical and tactical male handball training sessions to enhance performance of players. The elastic band presents a new material for plyometric training with load like weight machines, but less expensive and simple to implement. It also activates all relevant muscle groups (upper and lower limbs), and it requires little allocation of time. Current results indicate that handball coaches should consider including in-season loaded plyometric training for upper limbs to enhance the performance of their players. It remains to be seen how much plyometric training with added load adds to other methods of training, such as heavy resistance training. Moreover, the neuromuscular mechanisms which underpin improvements reported herein may also be an area for future research. Our observations to date are primarily applicable to one particular category of elite junior handball players. Future studies should extend these observations to female players, other age groups, and to other skill levels. There is also a need to compare the gains in test performances with the improvement of actual play on the handball field. Finally, increased training intensity or volume should be considered in future as a tactic to increase the likelihood of a gain in this important physical quality.

5. Conclusions

In conclusion, adding biweekly elastic band plyometric training to standard training improves muscle strength and power, and ball throwing velocity, without significantly altering muscle mass, suggesting improvements were neurally-dependent. Therefore, handball coaches and practitioners should incorporate elastic band plyometric training into handball training as a pragmatic approach to enhance specific and non-specific fitness.

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