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Short-term in-season ballistic training improves power, muscle volume and throwing velocity in junior handball players. A randomized control trial

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ABSTRACT: This study investigated the effects of a ballistic training programme using an arm/shoulder specific strength device (ASSSD) on the upper body peak power (PP), muscle volume (MV) of the dominant arm and throwing velocity in junior handball players. Twenty-six players were randomly assigned to an experimental (EG = 15, age 17.6 ± 0.51 years) and control (CG = 11, age 17.36 ± 0.50 years) group. Over an 8-week in-season period, the EG performed a ballistic training programme (2 sessions/week) immediately before their normal team handball training. Both groups underwent tests on the ASSSD, which operates in consecutive accelerative and decelerative actions, for throwing characteristics determination. Peak power (PP), peak force (PF), peak velocity (PV), peak rate of power development (PRPD), muscle volume (MV), throwing velocity with run-up, standing throw, and jump throw were also assessed before/after the training programme. The EG group showed significant post-training improvements in PP (52.50% – $p < 0.001$), PF (26.45% – $p < 0.01$) and PRPD (78.47% – $p < 0.001$) better than the CG (1.81, 0.67 and 1.64%, $p > 0.05$, respectively). There was also a post-training improvement in the velocity at PP (22.82% – $p < 0.001$) and PF (42.45% – $p < 0.001$) in the EG compared to the CG (4.18 and 8.53%, $p > 0.05$ respectively). There was a significant increase in acceleration at PP (51.50% – $p < 0.01$) and PF (69.67% – $p < 0.001$). MV increased (19.11% – $p < 0.001$) in the EG, with no significant change (3.34% – $p = 0.84$) in the CG. Finally, significant increases were obtained in the three throw types (3.1–6.21%, $p < 0.05$- < 0.001) in the EG compared to the CG. The additional ASSSD training protocol was able to improve muscle strength/volume and ball throwing velocity in junior handball players.

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INTRODUCTION

Handball is an Olympic sport characterized by short intermittent high-intensity efforts such as sprinting, jumping, blocking, pushing between players and throwing the ball at high velocities [1]. Indeed, overarm throwing is one of the main handball skills that enables a successful offensive game phase [2]. This complex motion was defined as a fast (between 0.3 to 0.4 seconds), and discrete [3] skill. The faster the ball is thrown, the less time defenders and goalkeepers will have to save the shot [1, 2]. A great deal of literature has shown that three factors are the main determinants of the efficiency of throwing: technique, coordination of consecutive actions of body segments, and upper and lower extremity muscle strength and power [4,5,6,7,8].

An athlete's power may be improved by adding more force, increasing the range of motion, or decreasing the time of the movement [5]. Toji and Kaneko [3] stated that training protocols designed to improve muscle-power development must emphasize the strength or the velocity adaptations. In this regard, a consistent number of protocols have tested different strength training programmes to improve the muscle power (i.e., peak power), and throwing velocity in handball players. Eight weeks of bi-weekly heavy strength training (i.e., intensities higher than 80% of 1-RM of bench press) have provided an improvement in handball players throwing velocity [8,9,10,11]. But despite these positive effects, this type of training is unusual to better replicate the kinematic movement in the field because it is not as effective for non-matching sport-specific movement where kinetic and/or kinematic characteristics are not respected.

Significant improvements in throwing velocity and muscle volume were reported after 8 weeks of an upper body plyometric training programme in adolescent handball players [12]. Hermassi et al. [11] recorded power and throwing performance enhancements after 10 weeks of weightlifting in male handball players. Furthermore, other reports stated that maximal power output has been shown to occur through the use of ballistic exercises such as bench throw with lower loads (30% of 1-RM BP) [2, 8]. However, the direction of resistance movement is less relevant to the specific tasks encountered in a sport condition of throwing exercising. In addition, Ettema et al. [14] observed no significant increases in throwing velocity in female handball players after the introduction of tri-weekly pulley device training during eight consecutive weeks. Such findings may be due to the lack of specificity of the training exercises, which may have hindered any performance improvements. Medicine ball throws have also been used to assess upper-limb strength and power, and as resistance training to enhance throwing velocity [15, 16, 17, 18, 19]. However, to date, there is no consensus on the optimal load for developing maximal strength, power and thus throwing velocity [18].

Recently, elastic band training was suggested as a training method to enhance throwing velocity in young female handball players [20]. Aloui et al. [21] documented improvements in peak power, muscle volume of the dominant arm, and throwing velocity after 8 weeks of bi-weekly elastic band training in male junior handball players. Nevertheless, it has been argued that the best improvements in athletic tasks involving significant power output are obtained with the use of loads that maximize an individual's power output [22] and through the use of exercise similar to their actual athletic activity [23]. These studies have suggested the use of ballistic exercises with loads that maximize power output as the most recommended training strategy to achieve power improvements [23, 24].

Taking the above into consideration, an innovative arm/shoulder specific strength device (ASSSD) was proposed as an appropriate testing and training device. This apparatus mechanically mimics kinetic and kinematic characteristics of ballistic throwing movements in a handball game. It has been conceived for seeking power output adaptations, athletic performance [25], and as an injury risk reduction tool for both muscles and joints.

To the best of the author's knowledge, no previous reports have explored the effectiveness of an additional and specific ballistic training programme using this innovative device for regular in-season handball training. Thus, the present study aimed to investigate the outcome effects of bi-weekly ASSSD ballistic training added to a regular in-season training programme during 8 weeks on peak power (PP), muscle volume of the dominant arm (MV), and throwing velocity in male junior handball players.

MATERIALS AND METHODS

Experimental approach

A randomized longitudinal controlled design (i.e., pre-test and post-test) was used to investigate the outcome effects of an 8-week ballistic training programme using an arm/shoulder specific strength device (ASSSD) on peak power (PP), muscle volume (dominant arm), and on throwing velocity. The experimental group (EG) performed a ballistic training programme twice a week for a total of eight consecutive weeks. The training sessions focused on handball's specific movement patterns using an ASSSD to best mimic the handball shot. The training sessions were performed in conjunction with the player's regular training programme to fully allow for the transfer of the effects of the additional training on PP, muscle's structure, and functional performance. The EG ($n = 15$) and the control group (CG) ($n = 15$) followed the same handball training programme, 5 times per week lasting 1 h 30 min for each one. During the experimental period, no additional strength, power, or plyometric training was completed for both groups. To avoid the interference of uncontrolled variables, all subjects were asked to refrain from strenuous workouts on the day before each test.

Participants

At the start of this investigation, 30 male junior handball players (a single team handball player) with an average of ~7 years of training experience volunteered to participate in this study. They were randomly (balanced from the baseline measurements) assigned to an experimental group EG ($n = 15$) and a control group CG ($n = 15$) (Table 1). During the study, four players in the CG were excluded because of injury and assiduity. A total of 26 male athletes continued in this study. Subjects were divided into two groups: an experimental ($n = 15$) and a control group ($n = 11$). A minimum sample size of 26 was determined from an a priori power analysis using G*Power (Version 3.1, University of Dusseldorf, Germany) [26]. The power analysis was computed with an assumed power at 0.80 at an alpha level of 0.05, and an effect size of 0.3. The inclusion criterion was playing in the Tunisian handball championship. The exclusion criterion was having reported injuries of the upper or lower extremities within the 6 months before the beginning of the study. The experimental procedures, the potential risks, and the benefits of the study were fully explained to the players before the beginning of the testing sessions. The participants provided written informed consent and were free to withdraw from the trial at any time. Parental consent was obtained for the < 18 years old players. This study was approved by the institutional review committee for the ethical use of human subjects, according to current national laws and regulations.

Testing and training routine

The subjects were tested over a period of 12 weeks. During weeks 1 and 2, all the subjects were familiarized with the ASSSD training and the assessment procedures. All the tests were completed over two consecutive days. During the first testing day, anthropometric

TABLE 1. Subject's characteristics

Variables	EG (n = 15)	CG (n = 11)	p-value	Cohen's d
Age (yrs)	17.6 ± 0.51	17.36 ± 0.50	0.11	Small
Body height (cm)	181.53 ± 6.72	184.45 ± 5.37	0.20	Small
Body mass (kg)	79.05 ± 9.89	82.36 ± 3.07	0.24	Small
Arm Length (cm)	60.67 ± 0.94	60.82 ± 0.79	0.33	Small
Weekly training (hour-min)	7.30 (5X1.30)	7.30 (5X1.30)	1.00	Trivial
Training experience (yrs)	7.6 ± 2.79	7.36 ± 1.69	0.50	Small

assessments were collected, followed by ball throwing velocity evaluation in a standing throw, a throwing with run up and jump throw. On the second testing day, peak power (PP), and throwing values indicating the initial individual optimal load (IOL) with which the EG was trained for the first mesocycle (MESO-1) spread over 4 weeks were collected. After 3–5 days of recovery following their last training session of MESO-1, players underwent a mid-test session in the transition period for the redefinition of the IOL used for training in the second mesocycle (MESO-2). A resting period of 3 to 5 days was allowed between the final training session and the post-test testing session in an attempt to maximize the response to the training intervention while minimizing fatigue (Figure 1). The three testing sessions were made by the same researchers, at the same time of the day from 6:00 to 8:00 p.m. and under the same experimental conditions.

Anthropometric measurements

For all participants, anthropometric measurements were collected during the pre- and post-test sessions, and prior to power measurements. Body mass (± 0.1 kg) was measured using a portable digital scale (Tanita body fat analyser, model TBF 105), with the participants standing barefoot, with feet together, in their normal daily attire. The body height (± 0.1 cm) was measured in a standing position, with the shoulders and heels adjacent to a wall using a height meter (220 Seca, Germany) following the guidelines proposed by the International Society for the Advancement of Kinanthropometry (ISAK). Arm length was measured from the acromial to the radial with the arms hanging by the sides. Arm span was measured from the right to the left middle fingertip with the arms extended and abducted. Hand spread was measured from the fingertip of the thumb to the fingertip of the fifth finger with all fingers abducted. Hand length was considered as the distance from mid-stylion to dactylion. The muscle volume of the upper limbs was estimated by measuring circumferences and skinfold thicknesses using calibrated skinfold calipers (Holtain LTD, Crymych, UK) at different levels of the arm and the forearm, the length of the upper limb, and the breadth of the humeral condyles [9].

Muscle volumes were estimated as follows:

$$\text{Muscle volume} = \text{total limb volume} - (\text{fat volume} + \text{bone volume})$$

The 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) according to the following formula:

$$\text{Total limb volume} = \Sigma\,(C^2)\cdot L\,/\,62.8$$

where $\Sigma\ C^2$ is the sum of the squares of the five 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 follows:

$$(\Sigma C/5)\cdot[\Sigma S/2n]\ L$$

where ΣS is the sum of three skinfolds 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 follows:

$$\pi\cdot(F\cdot D)\ 2\cdot L$$

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.

Throwing velocity

Throwing performance was tested after a general warm-up of 15 min including jogging, flexibility exercises for shoulders, and warming-up throws to prepare for maximal throws. Throwing velocity was evaluated by performing three types of overarm throw on an indoor team handball court: a standing throw (STh), a throw with run-up (Thr), and a jump throw (JTh) according to the recent literature [27]. Each subject performed a series of three consecutive throws using a standard ball (mass 480 g, circumference 58 cm) as fast as possible through a standard goal, using one hand and with their proper technique. Participants were given 10 to 15 s of passive recovery between each trial [9, 10]. Players were informed about their velocity values immediately after each throw. The best velocity value achieved by each player in each type of throw was chosen for the statistical analysis. In the standing throw (also called a penalty throw), which means keeping the front foot on the floor the whole time during throwing at the 7 m line, while throwing with a run-up, the participants performed three preliminary steps before throwing the ball from 9 m. In the jump shot, players made a preparatory 3-step run before jumping vertically 9 m from the goal, releasing the ball while in the air. The starting position was holding the ball with both hands in front [18]. The ball velocity was measured using a portable radar Stalker ATS System (Radar Sales, Minneapolis, MN, USA) held behind the goal in front of the subject.

ASSSD test description

Subjects were placed in a standing position with the dominant arm abducted to approximately 90° and the elbow flexed to 90° where the inner face of the hand is positioned just in contact with the force transducer placed in the ball. The front foot opposite to the DA and the other foot is placed on either side of a line drawn on the floor just at the neutral position (0°) of the suspended device's bar attached to the ball. Both feet were kept in contact with the floor at all times for the standing throws. Throwing exercises were conducted in the standing position with DA, then after a 3-step run-up generating controllable speed to get the feel of the ASSSD and to develop the so-called kinaesthetic sense of the body, arms and feet position. For the throws with run-up, players received the descending ball after a 3-step forward run-up exerting a braking force followed by propelling the ball explosively. Once the ball was released, the subject took 3 steps back, initiating another throwing act (Figure 2).

The throwing exercise consisted of five repeated sequences of ball propulsion and reception against loaded ball inertia involving the active muscle chain and moving multiple joints in dynamic throwing motions. Both negative and positive work characterized by a combination of both eccentric and concentric muscle actions (i.e., a stretch-shortening cycle (SSC) are shackled in fast and explosive throws respecting correct throwing pattern. The given instruction to the subject was as follows: "Throw as fast and hard as you can!" Online visual feedback of the performance accomplished was provided to the subjects on a computer screen.

IOL and power assessments

The individual optimal load (IOL) assessments were collected using an ASSSD with a sample rate of 1000 Hz (Higher Institute of Technological Studies, Department of Mechanics. Nabeul, Tunisia) which was designed for allowing the simultaneous assessment of relevant throwing exercise variables. The relative reliability was calculated using the intraclass correlation coefficients (ICCs), showing strong agreement between trials. The absolute reliability was analysed using standard error of measurement (SEM) (0.03–2.75), and coefficients of variation (CVs) (2.84–4.59%), revealing excellent intraday reliability. Validity was assessed using linear regressions, *r* and *p* values showing a good relationship between PF and PP gathered from ASSSD and isokinetic peak torques at different angular velocities (60°, 180° and 300°) of the dominant arm [25]. Kinematic data were recorded from applying force on the ball attached to the device's bar from:

a. An industrial force transducer (Model DBBP Series – S-Beam with a Smart Powered Strain Bridge/Load 1600B). The force transducer was connected to an interface for analogue signals analysis, converting and transferring measurement data to a personal computer where a customized software calculates, displays and stores all values presented in an Excel spreadsheet.
b. A certified tachometer (DOGA DO162.4102.2B00/3025 12V DC Motor 2000RPM 0.20NM) fitted to the bar displayed velocity and acceleration.
c. A multi-turn wires wound potentiometer (WXD3-13-2W 2.2 K ohms) investigated the range of bar displacement and specified the angle at which PF, PP and PV were achieved.
d. An electromagnetic brake (COMBISTOP N 20 Nm 30.13X) actuated a dual-surface spring-applied DC brake and a bridge rectifier (INTORQ 6-pole bridge rectifier BEG-16) for full-wave rectification.
e. A connector block, cable-connected to a PC via a USB cable, includes: filtering and conditioning unit (FCU) with control unit and digital processing (CUDP). The CUDP ensures the data reading collected by the sensors, and controls the electromagnetic brake through the interface unit (IU) respecting the bar rotation limits. For the accurate IOL definition giving peak power (PP) achievement [22, 24] for the dominant arm (DA), each subject was asked to perform 3 X 5 repetitions quickly and explosively [23] at the progressive augmented weight (3–5 kg) and at different ten height levels of 10 cm each plotted on a graduated bar (1 m) of the ASSSD. Three minutes were given between trials for rest and arm-shoulder stretching exercises. At each height level, power, force and velocity were instantaneously calculated throughout the movement from trials and displayed to assess positive and negative work peak force (PF), peak power (PP), peak velocity (PV) only, rate of force development (RFD) on positive and negative work (slope of the force-time curve) [13], and rate of power development (RPD) (slope of the power-time curve) associated with resistance exercise [29]. Impulse (time-integrated force) at different time epochs [14] relative to the force onset (30 ms, 50 ms, 100 ms, 150 ms, and 200 ms) was also recorded. Time variables were assessed by overlaying the force, power, and velocity-time curves for different peaks' determination times [30]. Concentric (CON) and eccentric (ECC) variables during overhead throws – force, power, velocity, and acceleration

when there occurred peak force (PF), power (PP) and velocity (PV) – were also assessed and were termed velocity at PF, velocity at PP, acceleration at PP and acceleration at PF. PP was defined as the power at which additional loading or exceeding the level with the same workload induced a decrease in power output. Thus, the highest load and the level at which the participant elicited his PP was recorded and used as the reference to assign participants to different training groups and sub-groups at the beginning of the intervention [31] to facilitate the training process.

Training programme

Following baseline testing, the EG underwent an eight-week ballistic training programme consisting of 16 sessions, divided into 2 sessions per week on Tuesdays and Thursdays, immediately before their handball training sessions (Table 2). All training sessions lasted for 45 minutes and began with a 15-minute specific warm-up including general joint mobilization, stretching, and some push-ups. Intensity for Pmax1 was individualized for each participant according to the IOL predefined (IOL1) in test-1 (pre-test) before beginning the first training mesocycle (MESO-1). This IOL was assessed in test-2 (in-test) and redefined (IOL2) for training at the Pmax2 in the second mesocycle (MESO-2). Training sessions included a stepwise increase of sets throughout the first three weeks of the study mesocycles (1 set more every week) and then decreased in the last two sessions of the last week (4th week), to minimize muscle damage, which often occurs in unaccustomed ECC exercise [32]. The number of repetitions remained the same for all the training sessions. Each set consists of 8 repeated consecutive sequences of ball propulsion and reception

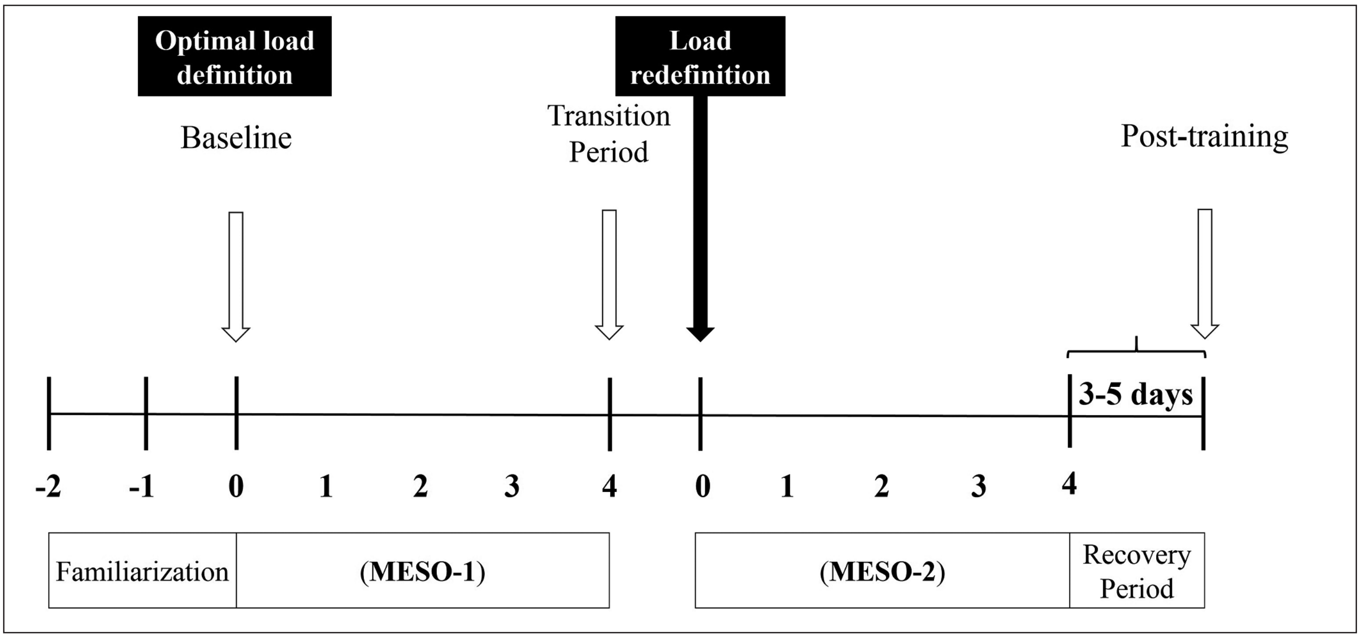

FIG. 1. Experimental design scheme.

TABLE 2. Ballistic training schedule during the 8-week training period.

Week	Test	Session 1 Reps × Sets/Rest	Session 2 Reps × Sets/Rest	Volume	Intensity
1	P max 1	8 × 4/3	8 × 4/3	64	Load 1
2		8 × 5/3	8 × 5/3	80	
3		8 × 6/3	8 × 6/3	96	
4		8 × 5/3	8 × 4/3	72	
5	P max 2	8 × 4/3	8 × 4/3	64	Load 2
6		8 × 5/3	8 × 5/3	80	
7		8 × 6/3	8 × 6/3	96	
8		8 × 5/3	8 × 4/3	72	

FIG. 2. 3D Illustration of the ballistic training exercise.

against loaded ball inertia, simulating a handball shot. Subjects were instructed to perform all exercises with maximal effort, totalling 312 virtual shots for each mesocycle. Recovery time between sets was three minutes [33] with arm-shoulder stretching exercises. Each session was followed by performing a throwing protocol including the three types of throw using a regular handball [29]. No injuries occurred over the 16 workouts. Participants were verbally instructed and encouraged to perform each repetition as fast as possible without receiving performance feedback.

Statistical analyses

Means ± standard deviations (SD) were used to describe all variables. Before using parametric tests, the assumption of normality was verified using the Kolmogorov-Smirnov test. The data were then analysed using a multivariate analysis of variance (2X2) with repeated measures on the second factor. The factors included two separate groups of training (EG and CG) and repeated measures of time (pre- and post-training). If significant main effects were present, Bonferroni post-hoc analysis was performed. The effect size was calculated for all ANCOVAs using a partial eta-square (η^2). The eta-square values of 0.01, 0.06 and 0.15 were considered as small, medium and large cut-off points, respectively [34]. Effect size (ES) was also calculated for all paired comparisons and evaluated with the method described by Cohen [33] (small < 0.50, moderate = 0.50–0.80 and large > 0.80). The reliability of the measures (ECC-CON PP, ECC-CON PF, CON PV) was assessed twice over a number of days with a Cronbach's model intra-class correlation coefficient (ICC) and the coefficient of variation (CV) according to the method of Hopkins [35]. Relationships between muscle volume and throwing performance were assessed using Pearson's product-moment correlation. According to Hopkins [36], the magnitude of correlation coefficients was considered as trivial (< 0.1), small (from 0.1 to < 0.3), moderate (from 0.3 to < 0.5), large (from 0.5 to < 0.7), very large (from 0.7 to < 0.9), nearly perfect (from 0.9 to < 1) and perfect (= 1). Statistical analyses were performed using the software statistical package SPSS 20.0 (SPSS Inc., Chicago, IL), and statistical significance was set at $p<0.05$.

RESULTS

All data were normally distributed ($p > 0.05$) and reliability tests showed good to excellent reliability (ICC = 0.87–0.96) and acceptable variability (CV < 5%).

Kinetic variables

Significant group by time interactions were noted for PF [$F_{(1,25)} = 8.68$; $p < 0.01$; $\eta^2 = (0.26)$ large], PP [$F_{(1,25)} = 29.99$; $p < 0.001$; $\eta^2 = (0.53)$ large], PV [$F_{(1,25)} = 4.20$; $p < 0.04$; $\eta^2 = (0.17)$ large] and peak RPD [$F_{(1,25)} = 37.21$, $p < 0.001$, $\eta^2 = (0.61)$ large]. The EG achieved significantly larger improvements more than the CG in PF (26.45 vs 0.67%; ES = large), PP (52.50 vs 1.81%; ES = large), PV (6.49 vs 3.58; ES = large) and peak RPD (78.47 vs 1.64%;

ES = large). No significant group by time interactions were observed in peak RFD [$F_{(1,25)} = 0.70$; $p < 0.41$; $\eta^2 = (0.02)$ trivial], and peak impulse [$F_{(1,25)} = 1.55$; $p < 0.22$; $\eta^2 = (0.06)$ trivial].

In addition, group by time interactions for peak negative RPD indicated significant differences between groups [$F_{(1,25)} = 21.15$; $p < 0.001$; $\eta^2 = (0.47)$ large]. In the same way, a post-hoc analysis indicated that the EG achieved significantly larger improvements more than the CG in negative RPD (12.69 vs -6.21%; ES = large). No significant differences were observed between groups in negative PF, negative PP, and peak RFD [$p > 0.05$; $\eta^2 = (0.01)$ trivial] (Table 3).

Mechanical variables

ANCOVA analysis revealed a significant between-group differences for time to reach PF [$F_{(1,25)} = 14.665$; $p < 0.001$; $\eta^2 = (0.392)$ large], time to reach PV [$F_{(1,25)} = 4.201$; $p < 0.05$; $\eta^2 = (0.150)$ moderate] and time to reach negative PF [$F_{(1,25)} = 18.403$; $p < 0.001$; $\eta^2 = (0.443)$ large]. The EG achieved significantly larger improvements more than the CG in time to reach PF (-8.37 vs -2.00%; ES = large), time to reach PV (-10.18 vs -1.53%; ES = large), and time to reach negative PF (-11.93 vs -3.27%; ES = large). No significant differences were observed between groups in time to reach PP and negative PP ($p > 0.05$; η^2 = trivial).

Velocity and acceleration variables

The ANOVA analysis revealed a significant group by time interactions for velocity at PP [$F_{(1,25)} = 12.65$; $p < 0.001$; $\eta^2 = (0.34)$ large], and at PF [$F_{(1,25)} = 20.25$ with $p < 0.001$, $\eta^2 = (0.48)$ large]. In addition, the ANOVA analysis of the acceleration at PP [51.50%; $F_{(1,25)} = 1{,}55$ with $p < 0.01$, $\eta^2 = (0.24)$ large] and at PF [69.67%; $F_{(1,25)} = 10.37$ with $p < 0.001$, $\eta^2 = (0.36)$ large] showed significant differences between groups. Post-hoc analysis revealed that the EG achieved significantly greater improvements more than the CG in velocity at PP (22.82 vs 4.18%; ES = large), velocity at PF (42.45 vs 8.53%; ES = large), acceleration at PP (51.50 vs 13.34%; ES = large) and acceleration at PF (69.67 vs 18.91%; ES = large).

Anthropometric variables

A significant group by time interaction in anthropometric variables was found only in MV [$F_{(1,25)} = 124.92$; $p < 0.001$; $\eta^2 = (0.65)$

TABLE 3. Effects of 8-weeks of ballistic training on kinetic variables.

Variables	Group	Baseline	Post-training	Change%	Cohen's d	Effect time p-value (η^2)	Interaction p-value (η^2)
Peak Force (N)	EG	74.41 ± 10.20	93.20 ± 14.46**‡	26.45	1.84	**0.00**1	**0.01**
	CG	77.66 ± 18.46	78.18 ± 18.89	0.67	0.03	(0.28)	(0.26)
Peak negative Force (N)	EG	-45.67 ± 7.64	-48.40 ± 7.86	5.98	0.36	0.53	0.19
	CG	-44.64 ± 11.49	-44.27 ± 7.23	-0.83	0.03	(0.02)	(0.07)
Peak Power (W)	EG	430.11 ± 58.20	655.92 ± 98.90**‡	52.50	3.88	**0.001**	**0.001**
	CG	475.55 ± 107.20	484.18 ± 97.16	1.81	0.08	(0.59)	(0.53)
Peak negative Power (W)	EG	-71.33 ± 7.47	-76.00 ± 10.79	6.55	0.62	0.47	0.09
	CG	-69.09 ± 10.76	-67.73 ± 11.07	-1.97	0.13	(0.02)	(0.12)
Peak Velocity ($m \cdot s^{-1}$)	EG	6.32 ± 0.28	6.73 ± 0.34**†	6.49	1.46	**0.001**	**0.03**
	CG	6.15 ± 0.50	6.37 ± 0.36	3.58	0.44	(0.43)	(0.18)
PRFD ($N \cdot s^{-1}$)	EG	601.65 ± 139.88	709.05 ± 196.88	17.85	0.77	0.20	0.47
	CG	649.06 ± 24.56	655.86 ± 83.24	1.05	0.05	(0.07)	(0.02)
Peak negative RFD ($N \cdot s^{-1}$)	EG	-836.40 ± 381.10	-965.25 ± 386.16	15.41	0.34	0.34	0.90
	CG	-903.63 ± 389.09	-957.57 ± 383.66	5.97	0.14	(0.04)	(0.00)
PRPD ($W \cdot s^{-1}$)	EG	3205.33 ± 1048.85	5720.00 ± 1250.46**‡	78.47	2.40	**0.001**	**0.001**
	CG	3248.48 ± 761.78	3301.82 ± 757.65	1.64	0.07	(0.49)	(0.61)
Peak negative RPD ($W \cdot s^{1}$)	EG	-577.78 ± 41.15	-651.11 ± 41.53**‡	12.69	1.78	**0.001**	**0.001**
	CG	-449.09 ± 107.80	-421.21 ± 91.64	-6.21	0.26	(0.44)	(0.60)
Peak Impulse (N·s)	EG	281.51 ± 167.77	384.08 ± 193.95	36.44	0.61	0.31	0.22
	CG	317.09 ± 146.67	303.50 ± 131.07	-4.29	0.09	(0.04)	(0.06)

EG, experimental group; CG, control group; PRFD, peak rate of force development; PRPD, peak rate of power development; η^2, effect size. **Sig. differences $p < 0.01$ from baseline and after the training period; "†" Sig. differences $p < 0.05$, "‡" $p < 0.01$ between EG and CG.

large]. Significantly larger improvements in MV were found in the EG compared to the CG (19.11 vs 3.34%, respectively).

Throwing performance

A significant group by time interaction was observed for STh [$F_{(1,25)}$ = 5.77; $p < 0.05$; η^2 = (0.15) large], and ThR [$F_{(1,25)}$ = 25.48; $p < 0.001$; η^2 = (0.52) large]. Significantly larger improvements in STh and ThR were found in the EG (5.55 and 6.21% respectively) compared to CG (-0.18 and 0.81% respectively). No significant differences were observed between groups for JTh ($p > 0.05$; η^2 = (0.001) trivial).

Relationship between muscle volume and throwing velocity

Analyses revealed significant large positive correlations between muscle volume and the three types of throw: STh (r = 0.57, ES = large), ThR (r = 0.64, ES = large), and JTh (r = 0.54, ES = large).

DISCUSSION

This study aimed to investigate the effects of adding an 8-week in-season ballistic training programme on power, muscle volume of the dominant arm and ball throwing velocity using an ASSSD on a handball team during the regular training programme. The results showed an increase in PP of 52.50% (*d* = 3.88) in the EG but only a 1.81% (*d* = 0.08) effect size in the CG. This strong enhancement in PP was probably related to an increased maximal dynamic force (r = 0.96, $p < 0.001$), 26.45 vs. 0.67%, as well as a significant increase in peak velocity (r = 0.80, $p < 0.001$), 6.49 vs. 3.58%, in the EG compared to the CG respectively. The EG group showed increases of 78.47% in peak RPD ($p < 0.001$), 12.69% in peak negative RPD ($p < 0.001$), and 17.85% in RFD vs 1.05%, in comparison to the CG group. A large gain (36%) in peak impulse was recorded in the EG group in comparison to the CG group (-4.29%) (Table 3).

In comparison to the CG where only a 1.81% improvement in PP values was observed (*d* = 0.08), the EG demonstrated a consistent increase (52.50%) in PP values (*d* = 3.88) (Table 3). These findings are consistent with those of previous investigations. Indeed, Chelly et al. [12] reported increases of upper limb power (both absolute (27.4 %; $p < 0.001$) and relative to body mass (28.7%; $p < 0.001$) following an 8-week bi-weekly course of upper limb plyometric training in junior male handball players. Furthermore, Aloui et al. [21] recorded a significant increase of upper limb power (both absolute (36%; $p < 0.001$) and relative to body mass (34%; $p < 0.001$) following an 8-week biweekly course of upper limb elastic band training for junior male handball players. Hence, despite the difference in strategies for improving power output, it appears that this

TABLE 4. Effects of 8-weeks of ballistic training on mechanical variables.

Variables	Groups	Baseline	Post-training	Change %	Cohen's d	Effect time p-value (η^2)	Interaction p-value (η^2)
Time to peak Force (s)	EG	0.215 ± 0.02	0.197 ± 0.01**§	-8.37	0.90	**0.01**	**0.001**
	CG	0.200 ± 0.03	0.196 ± 0.01	-2.00	0.13	(0.23)	(0.39)
Time to peak Power (s)	EG	0.248 ± 0.04	0.225 ± 0.01**	-9.27	0.58	**0.01**	0.36
	CG	0.231 ± 0.05	0.216 ± 0.06	-4.35	0.20	(0.25)	(0.03)
Time to peak Velocity (s)	EG	0.275 ± 0.09	0.247 ± 0.06*†	-10.18	0.31	0.54	**0.05**
	CG	0.199 ± 0.05	0.196 ± 0.07	-1.53	0.04	(0.02)	(0.15)
Time to peak negative Force (s)	EG	0.218 ± 0.02	0.193 ± 0.01**§	-11.93	1.30	**0.001**	**0.001**
	CG	0.214 ± 0.02	0.207 ± 0.01	-3.27	0.7	(0.44)	(0.44)
Time to peak negative Power (s)	EG	0.234 ± 0.02	0.217 ± 0.01	-7.26	0.92	0.51	0.13
	CG	0.231 ± 0.02	0.223 ± 0.01	-3.46	0.43	(0.02)	(0.10)
Velocity at peak Power ($m \cdot s^{-1}$)	EG	5.04 ± 0.52	6.19 ± 0.98**§	22.82	2.21	**0.001**	**0.001**
	CG	4.78 ± 0.69	4.98 ± 0.51	4.18	0.28	(0.34)	(0.34)
Velocity at peak Force ($m \cdot s^{-1}$)	EG	4.24 ± 0.31	6.04 ± 0.83**§	42.45	5.81	**0.001**	**0.001**
	CG	4.34 ± 0.58	4.71 ± 0.55	8.53	0.64	(0.66)	(0.48)
Acceleration at peak Power ($m \cdot s^{-2}$)	EG	15.63 ± 12.08	23.68 ± 5.17**§	51.50	0.67	**0.04**	**0.01**
	CG	15.74 ± 5.78	17.84 ± 5.76	13.34	0.36	(016)	(0.24)
Acceleration at peak Force($m \cdot s^{-2}$)	EG	12.99 ± 7.67	22.04 ± 5.99**§	69.67	1.18	**0.001**	**0.001**
	CG	12.32 ± 6.39	14.65 ± 3.28	18.91	0.36	(0.30)	(0.36)

EG, experimental group; CG, control group; η^2, effect size. Significant differences from baseline conditions "*" $p < 0.05$ and "**" $p < 0.01$. Significant differences between EG and CG "†" $p < 0.05$; "‡" $p < 0.01$ and "§" $p < 0.001$.

TABLE 5. Effects of 8-weeks of ballistic training on muscle volume of the dominant arm and the three types of throwing performance of handball players.

Variables	Group	Baseline	Post-training	Change %	Cohen's d	Effect time p-value (η^2)	Interaction p-value (η^2)
Muscle volume of the	EG	2211.75 ± 273.19	2634.50 ± 329.16**‡	19.11	1.55	**0.001**	**0.001**
dominant (ml)	CG	3144.04 ± 549.18	3248.93 ± 542.92	3.34	0.19	(0.84)	(0.65)
Standing throw	EG	21.26 ± 1.86	22.44 ± 2.29**†	5.55	0.63	**0.04**	**0.05**
($m \cdot s^{-1}$)	CG	21.85 ± 1.60	21.81 ± 1.25	-0.18	0.03	(0.16)	(0.15)
Throw with run-up	EG	22.77 ± 1.74	24.14 ± 0.92**‡	6.21	0.81	**0.001**	**0.001**
($m \cdot s^{-1}$)	CG	22.78 ± 1.45	22.90 ± 0.96	0.81	0.08	(0.36)	(0.35)
Jump throw	EG	22.29 ± 1.84	23.00 ± 0.48*	3.19	0.39	**0.05**	0.94
($m \cdot s^{-1}$)	CG	22.22 ± 1.50	22.57 ± 1.04	1.76	0.23	(0.15)	(0.00)

EG, experimental group; CG, control group; η^2, effect size. Significant differences respect to the baseline condition "*" $p < 0.05$ and "**" $p < 0.01$. Significant differences between EG and CG "†" $p < 0.05$ and "‡" $p < 0.001$.

ballistic training which entails exercise with prescribed IOL using an ASSSD is an efficient and novel strategy to develop muscular power of the upper limbs.

According to the force-velocity relationship, it is thought that maximum power output is the product of optimum force and optimum shortening velocity [2, 36]. Indeed, the higher significant improvement in PP observed in the present study was probably due to an increased maximal dynamic force (26.45 vs. 0.67%), as well as a significant increase in peak velocity (6.49 vs. 3.58%) in the EG compared to the CG, respectively (Table 3). These results are in agreement with previous studies that have used a force-velocity test to investigate the effects of dynamic resistance training [1, 10, 11], plyometric training [12], and elastic band training [21], and they have reported a significant change in power which may be dependent on improvements in maximal dynamic force and/or velocity. It is worth noting that, based on the specificity of muscle power development in explosive actions such as throwing in handball, which has been shown to last approximately 180–240 ms [38], the ballistic training exercise using the ASSSD with prescribed IOL seems to be a more suitable stimulus to enhance the player's maximum peak power. This is the first study to highlight the outcome effects of a ballistic training exercise which virtually mimics a handball shot using this novel tool on RFD and RPD in adolescent handball players. In the current study, the EG showed a substantial increase in RFD (17.85%) and RPD (78.47%) (Table 3). These results seem in relative accord with Gruber et al. [39], who noted a significant increase in RFD after 4 weeks of ballistic strength training, and Mangine et al. [13], who observed significant improvement after 8 weeks of bench press training. Moreover, Oliveira et al. [6] recorded a substantial increase in RFD after 8 weeks of fast eccentric resistance training on an isokinetic device. Comparisons between the aforementioned studies are difficult because of differences in variables such as the type of contraction (isometric vs. dynamic), the limb trained and tested (upper or lower), the device used to measure (force plate, bench press, isokinetic dynamometer, linear position transducer), the specific RFD variable (peak RFD, time to peak RFD), RFD at particular time intervals, the player's age and gender [40]. Nevertheless, and concerning the necessity for players to produce a high rate of force and power development during explosive actions, the improvement observed in the current study would explain the optimized transfer of adaptation from the ballistic exercise based on explosive actions [41]. These results could have been induced by various neuromuscular adaptations, such as an increased neural drive to the agonist muscles [16], improved intermuscular coordination, changes in the muscle-tendon and mechanical-stiffness characteristics, changes in muscle size and/or architecture, as well as in single-fibre mechanics [42], but because no physiological measurements were made, only speculations are possible and the underlying adaptations induced by this specific training exercise remain hypothetical.

The individual optimal load (IOL) incorporated in the ballistic training exercise would appear to offer the individual an optimal stimulus, in which the muscles are required to produce the greatest amount of force in the shortest time possible for the development of muscle power. The current study showed that the EG increased the impulse significantly more than the CG (36.44 vs -4.29%). This effect is greater than those obtained by previous research [14, 43]. Although the prescription of an IOL using an ASSSD, based on maximizing mechanical power output, appears to be an attractive strategy for rapid power development [44], performance may be critically dependent on the ability to exert force at speeds specific to a given athletic discipline. Interestingly, these findings lead us to consider that in specific ballistic exercise on this innovative device where agonist and antagonist muscles contracted simultaneously, as in the current study, peak acceleration and peak velocity have been shown to increase intensively in the EG compared to the CG. Nevertheless, the neurophysiological mechanisms contributing to the increased velocity and acceleration are unknown. Possible factors include more effective neural activation [29], a selective recruitment increase of the fast-twitch fibres [29], changes in intrinsic muscular properties [37], an increase in myosin–adenosine triphosphatase activity, better synchronization and a higher firing frequency of motor units [29].

In terms of time to reach peak kinetic and kinematic variables, the ballistic training exercise decreased significantly times to peak positive and negative force and power, which in turn elicited a substantial increase in velocity and acceleration at peak force and power of the movement in the EG compared to the CG after the 8-week training programme (Table 4). One possible explanation of these adaptations could be the reduction of the contraction duration in the movement, benefiting from the elastic energy stored in the active muscle chain, tendons, and ligaments during eccentric contraction to potentiate the concentric movement [45]. This novel device represents a field tool for fast interpretation of data related to throwing exercise. Hence, an additional novelty of the present investigation suggests that the ballistic training exercise using the ASSSD would appear to offer for scientists, conditioning coaches, and practitioners an ideal approach to acquire more specific details relative to strength and power components. Such findings of this investigation could provide a great deal to assess and improve explosive strength components, for designing individual training programmes.

Neural adaptations were not possible to measure, but anthropometric adaptations were found in this study that could explain the performance changes after the training period. Greater muscle mass is often an advantageous characteristic in sports, as in team handball, where speed and explosiveness are the essences of the sport [4]. The current study showed that the EG significantly increased muscle volume of the upper limb, whereas the control group did not show any changes after 8 weeks (Table 5). This indicates that the EG, because of the optimal training load, physically adapted to withstand the extra training load. Our findings are also in line with the results of other studies [10, 12, 43]. However, Aloui, et al. [21] did not record a significant increase in muscle volume in the EG compared to the CG after 8 weeks of elastic band training in junior handball players, suggesting that the improvement in muscle power was related to neural adaptations. Although these studies were not the same as ours, this might suggest that the gain in muscle power was largely attributable to an increase in regional muscle volume [9]. This positive morphological changes of the muscle structure and architecture may be related to neuromuscular adaptations and mechanical adaptations elicited by the augmented eccentric muscle actions such as greater motor unit discharge rates in conjunction with possible selective recruitment of higher-order motor units and improved synchronization [29].

In addition to the improvements in PP and related variables, it is of great interest to see whether these neuromuscular adaptations may translate to an enhancement of in-field performance (i.e., throwing velocity). It should be mentioned that this study is the first to have examined the value of ballistic and specific training using an innovative ASSSD in enhancing the throwing performance of junior handball players. Our results revealed that the increase in throwing performance was significantly related to an enhancement of muscle volume after 8 weeks of the trial. Only the EG sustained this improvement in both the standing throw ($r = 0.537$ with $p = 0.039$, 5.5%) and standing throw with run-up ($r = 0.645$ with $p < 0.008$ with 6.21% increase), and jump throw ($r = 0.548$; $p < 0.034$, but only a 3.19% change was obtained). The CG showed a non-significant increase in the three types of throws. Although the standing throw with run-up is considered as the second most popular throwing technique (14 < 18%) in handball team [19], our findings agree with Wagner et al. [46], who concluded that it is the throwing technique which produces the highest ball release speed (Table 5).

Comparisons with previous research are difficult because of differences in study design, throwing techniques (standing throw, 3-step running throw, and jump shot), measurement methods (photoelectric cells, radar, or cinematography) [1, 12], the age and skill level of players (amateur or professional), gender (men or women) and the intensity of training. However, our results were in accordance with previous studies [12, 15, 20, 21]. On the other hand, team handball training alone also increased throwing velocity. This can be explained by the principle of specificity, which in this context implies that training at throwing is useful for enhancing throwing performance.

It was reported that specific resistance training with underweight balls also increased throwing velocity in well-conditioned players [47]. In contrast, different results were obtained by Ettema et al. [14], who found no significant improvement in standing throwing velocity after 8 weeks of a resistance training programme of three weekly sessions using a pulley device system that mimicked overhand throwing at 85% of 1-RM. The control group focused on throwing as fast as possible for 81 throws per session. While no statistically significant differences were found between the groups, it appeared that throwing velocity improved more in the control group (6.1%) compared to the resistance training group (1.4%). The fact that the control group performed better than the resistance training group can be explained by the concept of specificity. On the other hand, considering the necessity to achieve maximal throwing velocity for success in team handball, players should possess a proper technique characterized by optimal coordination and timing of consecutive actions of body segments (i.e., intermuscular coordination), together with good levels of muscle strength and power in both the upper and lower limbs [1, 43]. Chelly et al. [9] found that the peak power of both the upper and the lower limbs was closely correlated with throwing velocity. Specifically, the throwing exercise, when performed on the ASSSD, promotes kinetic energy transfer from the legs through the torso to the arm, thus improving throwing movement patterns. Therefore, it can be speculated that a certain amount of power production improvement is needed with a ballistic training programme using this novel device to see a transference to in-field performance.

Despite the large number of variables analysed, the present findings should be interpreted cautiously because of the short-term character of the training intervention (eight weeks), and the relatively small sample size. Furthermore, this study was limited to only one age group of handball players with the exclusion of female players and only one training method was used (ballistic training exercise using the ASSSD). Further investigations should introduce different ages, gender, level of experience, and performance to compare the cumulative effect of each one on the physical capabilities of handball players.

CONCLUSIONS

This study showed that an 8-week in-season ballistic training programme using an ASSSD with (IOL) induced greater improvements in variables related to sports performance such as peak power, muscle volume, and throwing velocity compared with regular handball training in junior handball players. Given the importance of both power output and throwing velocity to team handball success, any training intervention generating greater (or earlier) utility is of particular interest for handball players and strength and conditioners. Due to the limited weeks available in several sports preparatory periods, these results are useful in terms of time-efficiency. Therefore, the results that emerged from this study showed that the ballistic training exercise using this innovative device seems to be an optimal stimulus to improve physical abilities and throwing performance in junior handball players. This improvement demonstrated that the specific explosive-type actions of junior handball players can be enhanced during the competitive period with a short-term ballistic training programme implemented and combined with a regular one.

Conflict of interest

The authors declare no conflict of interest.

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