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Effect of an Intra-Sets Variable Resistance Potentiation Protocol on Throwing Speed in Elite Female Handball Players

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Abstract: The peak velocity of an athlete's throws is a determining factor for sports performance. The aim of this study was to analyze the effects of a post-activation performance enhancement (PAPE) protocol with functional electro-mechanical dynamometry (FEMD) on throwing velocity. Thirteen international-level female handball players voluntarily participated in the study. The PAPE protocol considered four sets of eight repetitions controlled by FEMD (four at 30% of 1RM followed by another four at 60% of 1RM). After each series, the athletes' throwing velocity was measured. Significant differences ($p < 0.01$) were found in the effect size (ES), which measures the strength of the statistical relationship between two variables by group with the repeated measures ANOVA statistic with an effect size $\omega^2 = 0.028$. The effect size analysis identified measurements that are considered null for the baseline—PAPE 1 comparison and small baseline—PAPE 2, baseline—PAPE 3, and baseline—PAPE 4. When resistance is controlled during the run as with an FEMD device, only two sets of eight repetitions (four repetitions at 30% and four repetitions at 60% of 1RM) are required for the improvement of throwing speed in elite handball players.

Keywords: post-activation performance enhancement; resistance training; team sports games; female sport

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1. Introduction

In sports where throws are made overhead, such as handball [1], which became an Olympic sport at the 1972 Munich Olympic Games [2], the maximum throw velocity is a determining factor for athletic performance [1]. The faster the ball is thrown, the less time opponents and the goalkeeper have to stop the shot [3]. There is consensus that the fundamental variables that influence the speed of the ball throw are coordination and coupling of the movement in body segments, the technique implemented, and the power exerted by the upper and lower extremities [4,5]. There is a growing interest in analyzing the effects of new trends in training systems to promote improved performance in specific game actions such as throwing, with post-activation performance enhancement (PAPE) being a method of recent interest in increasing voluntary muscle performance [6].

PAPE [7–9] refers to a warm-up strategy that is widely used by coaches [10]. After a previous series of submaximal or maximal voluntary contractions, an improvement in neuromuscular muscle performance is generated, which stimulates greater muscle power [11]. The exact physiological mechanisms that contribute to the PAPE process are not precisely clear. However, the following have been proposed: (a) an increase in myosin phosphorylation modifies the structure of muscle myosin fibers, modifying the actin–myosin cross-bridge inducing an increase in sensitivity to Ca^{2+} release to the sarcoplasmic reticulum [12]; and (b) an increase in neuronal excitability at the spinal level favors the simultaneous recruitment of motor units [13–15].

One type of training to produce PAPE is variable resistance training (VR), which consists of varying the load or intensity during training sessions [16]. Methods described as VR include the intra-repetition variable resistance or contrast method (I-RVR) [17], intra-session variable resistance (I-SVR) [18], and intra-series variable resistance (IsVR) [19], which have been explored to induce an improvement in post-activation performance, which has been reported in various studies that have analyzed its effect on physical tests [20,21], jumps [22], sprints [23], and throws [24]. These findings reinforce that VR training is an effective conditioning activity to improve performance in different sporting contexts [25]. PAPE protocols with VR have been implemented in previous studies in which changes in load or intensity during repetitions are performed in a poorly controlled manner [26–28]; this makes it difficult to accurately measure physical loading in IsVR models, which could affect the reproducibility of the studies.

For some time now, there have been devices that allow the evaluation of muscle strength in a multi-joint manner with a wide range of movement for any section of the human body [29]. Functional electromechanical dynamometers (FEMD) have demonstrated high validity and reliability for assessing and controlling intensity and load in muscle strength exercises [30–32]. FEMDs allow for adjusting and controlling ranges of motion in analytical and/or functional exercises in single- or multi-joint actions, facilitating the control and manipulation of intensity in each repetition, set of exercises, intensity variations in a set [33], and load adjustment in PAPE protocols with IsVR. In the study by García-Martínez et al. [34], they analyzed the acute effect of PAPE with a protocol of intra-repetition resistance (VIR-R) that consisted of a series of five repetitions at an initial speed of 0.6 $m \cdot s^{-1}$ and a final speed of 0.9 $m \cdot s^{-1}$, and isometrics that consisted of performing a series of 5 s of voluntary maximal isometric exercises. Both pre-activations were performed unilaterally by the dominant upper limb in a standing position, which allowed for analyzing the effect on overhead throwing speed in female handball players and resulted in obtaining a similar increase in the peak speed of the throws after pre-activation with VIR-R as with an isometric pre-activation. Throwing speed in handball is a predictive variable of performance in this sport, considering that it is one of the most relevant factors for scoring points [35]. However, the effect of an FEMD-controlled intra-set variable resistance (IsVR) PAPE protocol on throwing velocity has not been analyzed.

In relation to the background presented, the objective of the study was to analyze the effect of an FEMD-controlled intra-series variable resistance (IsVR) PAPE protocol on the throwing speed of female handball players. Two hypotheses were established: (a) the PAPE IsVR potentiation protocol increases the throwing speed in female handball players, and (b) several potentiation series are required to increase the throwing speed.

2. Materials and Methods

2.1. Design

A repeated measures study was designed to analyze the effect of an IsVR resistance PAPE protocol at intensities of 30% and 60% of 1RM on the 7 m throwing speed in elite female handball players.

2.2. Participants

Thirteen international-level female handball players (Age: 20.01 ± 2.39 years, body mass: 67.08 ± 7.02 kg, height: 1.65 ± 7.86 m, and BMI: 23.44 ± 1.52 kg/m^2) with no experience in the use of FEMD participated voluntarily in the study. All of them had between three and five years of experience in strength training and competitiveness at an international level; Chilean national team members competed in the Santiago 2023 Pan American Games, which served as a qualifying event for the Paris 2024 Olympic Games, and participated in the 2023 IHF Women's World Championship held in Denmark, Norway, and Sweden. They did not present physical limitations, health problems, or musculoskeletal injuries that could compromise the test. A researcher informed the participants and technical staff about the purpose, the research procedures, and possible contraindications that they could experience. All of them gave their written consent to participate in the study. The study and intervention protocol adhered to the principles of the Declaration of Helsinki [36] and was approved by the Institutional Review Board of the University of Granada (IRB approval: 3074/CEIH/2022).

2.3. Instruments

Body mass (kg) and fat mass were assessed with a digital weight (TANITA, model InnerScan BC-554®, Tokyo, Japan), and stature (m) was set with a stadiometer (SECA, model 700®, Hamburg, Germany), respecting the Frankfort plane and in maximum inspiration. Both body mass and stature were assessed in underwear. Body mass index (BMI) was calculated by dividing body mass in kilograms (kg) by stature in meters squared (m^2).

The IsRV PAPE protocol was controlled with an FEMD (Dynasystem, Model Research, Granada, Spain), which was adjusted for displacement, sensed load, and sampling rate as previously described by Andrades-Ramírez et al. [37].

The throwing speed was determined with a radar (Speedster III model Bush-nell® radar gun, Overland Park, KS, USA) with a measuring range of 16–177 km/h over 58 m, a 24.25 GHz radar transmitter, and a 916.68 MHz data transmitter.

2.4. Muscle Strength Assessment

Individual load testing of intensities (30% 1RM and 60% 1RM) for the PAPE protocol was performed at 1RM. The protocol for determining maximum strength consisted of a test of three 5 s isometric strength series separated by 4 to 5 min between sets. The peak value of each set was recorded, and the highest value achieved was used. Intensities were adjusted to 30% and 60% of each repetition of the experimental protocol. Participants were asked to shift their weight vertically as fast as possible at each load performed. In addition, during the test, participants received verbal encouragement from the research team.

2.5. Throwing Velocity Assessment

The participants performed a supported throw, standing behind the penalty line at a distance of 7 m, with both feet flat on the surface and their postural orientation in the direction of the goal. The throw was started from a bipedal position, the feet positioned one next to the other and followed by a step forward, using only one hand; the execution was over the shoulder with the technique of throwing at goal, and it was indicated that the ball should be thrown with maximum effort. The participants were not allowed to cross the throwing line [38].

2.6. Protocol for Familiarization

Two familiarization sessions were conducted 48 h apart using the FEMD for the bilateral bipedal tonic exercise (BSPT) [39] and the PAPE protocol. The familiarization and data collection sessions began with a standardized 10 min (min) general warm-up consisting of 5 min of low-intensity jogging (HR < 120 bpm) and 5 min of mobility for the upper limb muscles, which was self-regulated by the players. Another 10 min of specific warm-up consisted of 3 sets of 5 s isometric exercises at 30–60% of 1RM with a 2 min pause between sets and 20 s between intensities (%).

2.7. Variable Resistance PAPE Intra-Series Potentiation Exercise Protocol

The PAPE protocol comprised 4 sets of 8 repetitions controlled by FEMD (4 at 30% of 1RM followed by another 4 at 60% of 1RM). After each set, the 7 m throwing velocity was measured in three attempts, separated by 15 s. The highest value of each set was recorded for data analysis. The data collection procedure is presented in Figure 1.

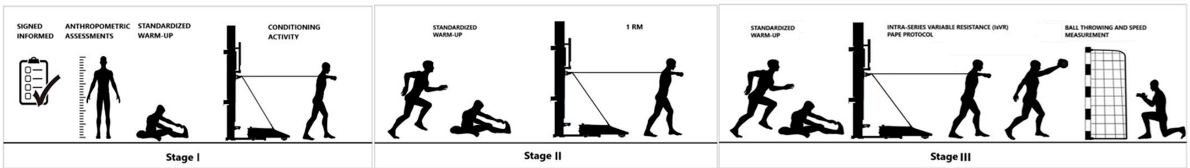


Figure 1. Presents the procedure for the data collection stages (**I–III**) of the study.

2.8. Statistics

All descriptive data were reduced to means and standard deviations (SD). A Shapiro–Wilk test was used for normality distribution analysis. Paired-sample *t*-tests and standardized mean differences (Cohen's d effect size for repeated samples) were used to compare mean and peak force between sets. The criteria for interpreting ES magnitude were as follows: null (<0.20), small (0.2–0.59), moderate (0.60–1.19), large (1.20–2.00), and very large (>2.00) [40]. Comparisons of means between pre- and post-test throwing velocities were determined with one-way repeated measures ANOVA. The effect size calculated with omega square (ω^2) was considered trivial (<0.01), small (0.01), medium (0.06), or very large (0.014) [41]. Statistical significance was accepted at $p < 0.05$. The statistical analyses were conducted using JASP software (version 0.16.4).

3. Results

The values of the peak launch velocity of each participant are presented in Figure 2.

Significant differences ($p < 0.01$) were found in the effect size comparison of means by groups using the repeated measures ANOVA statistic, with an effect size considered large $\omega^2 = 0.028$. In post hoc analysis (Bonferroni), significant differences were reported in the pairwise comparisons (baseline—PAPE 2, baseline—PAPE 3, and baseline—PAPE 4); in addition, significant differences ($p < 0.05$) were reported for the comparison of paired means between peak launch velocities. Cohen's d effect size (ES) was used in a complementary manner to analyze the differences between the control group and the PAPE groups. Measurements that are considered null for the baseline—PAPE 1 comparison and small baseline—PAPE 2, baseline—PAPE 3, and baseline—PAPE 4 were reported as shown in Table 1.

The peak ball throwing speed of each participant and its comparison from the baseline to PAPE 1–4 is presented in Figure 3.

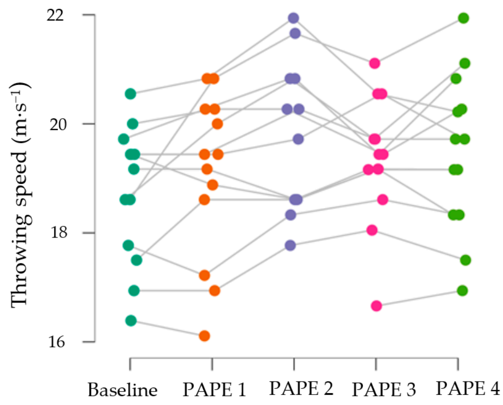
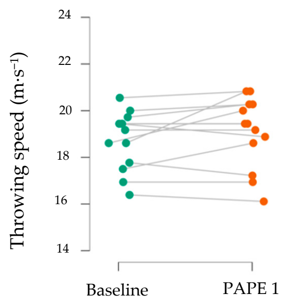


Figure 2. The figure shows the values of the peak launch velocity of each participant and a box plot with their median, maximum, and minimum values for the baseline and PAPE 1–4.

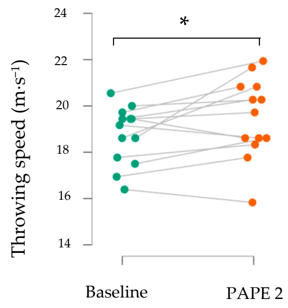
Table 1. Peak ball throw speed post-activation performance enhancement.

	Mean ± SD ($m \cdot s^{-1}$)			
	Baseline	**PAPE 1**	***p*-Value**	**ES**
Peak velocity	18.73 ± 1.25	19.07 ± 1.50	0.152	0.18
		PAPE 2		
		19.48 ± 1.72	0.031	0.35
		PAPE 3		
		19.33 ± 1.14	0.027	0.41
		PAPE 4		
		19.47 ± 1.44	0.039	0.31

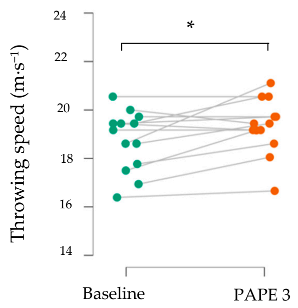
SD: standard deviation; PAPE: post-activation performance enhancement; ES: Cohen's d effect size; m: meter; s: seconds.



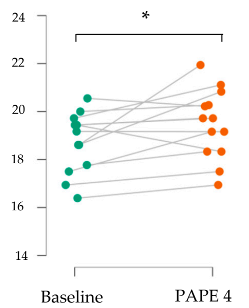
(**a**)



(**b**)



(**c**)



(**d**)

Figure 3. The figure shows the values of the peak throwing velocity of each participant and a box plot for the PAPE with its significance, median, maximum, and minimum values. (**a**) baseline compared to PAPE 1, (**b**) baseline compared to PAPE 2, (**c**) baseline compared to PAPE 3, and (**d**) baseline compared to PAPE 4. *: significance value.

4. Discussion

The purpose of the study was to analyze the effect of an FEMD-controlled intra-set variable resistance PAPE protocol on the throwing velocity of female handball players. Two hypotheses were established: (a) the IsVR PAPE potentiation protocol increases throwing velocity in female handball players, and (b) a number of potentiation sets are required to increase throwing velocity. Our results show that the FEMD-monitored IsVR PAPE protocol significantly increases throwing velocity, and at least two potentiation sets at 30% and 60% of 1RM are required when the PAPE is controlled with an FEMD.

The results of this research are related to the study by Boullosa [8], which suggests that 2–3 sets of six repetitions at an intensity of >70% of 1RM are effective for power and throwing performance in well-trained athletes. The study by Pisz et al. [24] implemented a PAPE protocol of bent-over barbell rows, bench presses, or push-ups with two sets of four repetitions at 60% and 80% of 1RM in professional female softball players, reporting significant improvements similar to those in this study in medicine ball throwing. The choice of sub-maximal intensities is due to the fact that both stronger and weaker individuals respond better to variable CV stimuli when the stimuli are higher [42]. The correct exercise volume should be considered and should be adjusted because there is a significant effect of strength training experience on time under muscle tension and the number of repetitions of each set [43]. For athletes at a competitive level, BP intensity possibly generates increased motor unit recruitment (type II) [25].

In the study by Fu et al. [26] investigating flywheel training, specific inertial loads (0.041 kg m^2, 0.057 kg m^2, and 0.122 kg m^2) were used with three-minute pauses between sets with PAPE occurring between minutes four and eight after the conditioning activity (AC), with significant effects at intermediate and high intensities. Similarly, a study by Pereira et al. [27] evaluated the effect of drop jumps (DJ) on hard and sand surfaces using a crossover design with a fixed height of 60 cm and recovery pauses of seven and 15 min between the AC and subsequent performance measurements, highlighting that the surface did not show significant differences in PAPE responses in elite sprinters due to the high interindividual variation in their responses. In the study by Mina et al. [28], the use of VR with elastic bands adjusted to 85% of 1RM load in back squat exercises showed a significant increase in jump height, power, and the rate of force development, while the use of fixed resistance with free weight at 85% of 1RM did not produce significant changes. Although these studies were able to induce PAPE under certain conditions, they did not implement a specific control for the intensity and load applied during AC, unlike our study using FEMD, in which the physical load and intensity to be used in exercises with IsVR were specifically controlled. This allowed for real-time dynamic adjustments, such as optimizing the load applied in each repetition and maximizing the stimuli to achieve PAPE. Possibly, the control of the physical load and intensity changes can be a determining factor to induce changes in performance to adapt the stimuli to the specific demands and gestures of the sport, such as handball throwing.

The results of our study do not agree with those of Martínez-García et al. [31], where female athletes reported a non-significant improvement in their throwing velocity after using the unilateral standing bench press and a five-repetition protocol with an initial velocity of 0.6 $m{\cdot}s^{-1}$ and a final velocity of 0.9 $m{\cdot}s^{-1}$ in a "unilateral chest press" with the dominant arm in standing position with the FEMD device. Perhaps a strength deficit in the upper limbs of female handball players could affect the average effect of pre-activation on throwing velocity, since it has been shown that stronger individuals have a greater possibility of producing PAPE.

In another study, Asencio et al. [44] implemented a PAPE protocol in amateur male handball players, implementing two different sessions that consisted of three repetitions at 90% of a 1RM bench press. In the other session, three repetitions at maximum intensity were performed with a horizontal press exercise, using one hand on a conical pulley with an inertial workload of 0.16 kg·m^2. This study reported different results to our study; the implemented protocol did not present a significant effect on the throwing velocity in handball after PAPE. The researchers also report that the factor that can influence the result is the strength level of the athletes, which in previous studies was suggested as a key factor for the effects of a PAPE protocol [22,45]. In relation to this, the study by Cuenca-Fernández [46] analyzed the effect of a PAPE protocol after a conditioned eccentric overload exercise, reporting greater effects in athletes with greater muscular strength.

Our study demonstrated that when load allocation and intensity are controlled in PAPE protocols with IsVR, significant effects on 7 m throwing performance are achieved. Future research should consider more comprehensive load controls and intensity controls for sport-specific gestures applicable to PAPE protocols in different sports. It should be considered a limitation for future research projects that small, uncontrolled groups do not allow these results to be extrapolated to other, larger groups of athletes.

5. Conclusions

When resistance is controlled throughout the range as with an FEMD device, a PAPE protocol of only two sets of eight repetitions (four repetitions at 30% and four repetitions at 60% of 1RM) is required to improve throwing velocity in elite female handball players. This type of protocol could help track the progress and development of handball players by providing reliable information on the control of muscle strength and at what intensities, allowing for more exact knowledge of the number of series and intensities at which they are performed which will achieve a better PAPE.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: All relevant data are within the manuscript. The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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

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