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Effects of Post-Activation Performance Enhancement on Jump Performance in Elite Volleyball Players

Sebastian Masel * and Marcin Maciejczyk *

Department of Physiology and Biochemistry, Faculty of Physical Education and Sport, University of Physical Education, 31-571 Kraków, Poland
* Correspondence: sebastian.masel@gmail.com (S.M.); marcin.maciejczyk@awf.krakow.pl (M.M.)

Abstract: Post-activation performance enhancement (PAPE) is a widely described phenomenon, but the majority of studies tend to evaluate the response of various parameters of a conditioning activity (CA) on the same explosive exercise. The aim of this study was to evaluate the PAPE response of the same CA—trap bar deadlift with an accommodating resistance—on jump height in two different jumping tests: squat jump (SJ) and countermovement jump (CMJ). Study participants included twelve elite volleyball players (age 23 ± 2 years; body height, 194.7 ± 5.9 cm; body mass, 89.8 ± 7.9 kg; body fat, 14.7 ± 3.7%) experienced in resistance training (relative 1RM of a trap bar deadlift with accommodating resistance 1.92 ± 0.12 kg/body mass). Each participant performed tests under four conditions: two conditions for both SJ and CMJ—experimental with CA and control without CA. Jumps were performed at the baseline and 90 s after CA. The protocol did not increase jump power significantly in either SJ or CMJ. However, individual analysis showed that more participants responded positively to the CA in SJ (73%) than CMJ (50%), implying that PAPE response may depend on the similarity of the muscle-type contraction between CA and an explosive exercise.

Keywords: potentiation; accommodating resistance; trap bar deadlift; power; PAP; PAPE

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1. Introduction

Post-activation potentiation (PAP) is a widely described physiological phenomenon that was originally described as an increased power output after previous activation of the muscle as a result of phosphorylation of myosin regulatory light chains [1,2]. Although PAP was used for years to describe the phenomenon, recent data [3] suggest that the terminology should distinguish between post-activation potentiation and post-activation performance enhancement (PAPE). PAP refers to increases in twitch forces evoked by prior muscle activity and phosphorylation of myosin regulatory light chains, whereas PAPE refers to increases in voluntary force production (or exercise performance) evoked by prior muscle activity and mechanisms such as potential increases in muscle temperature, muscle and muscle fiber water content and muscle activation [3].

There are several concerns to consider when designing a protocol to induce PAPE. In training practice, PAPE is achieved by applying conditioning activity (CA) prior to an explosive exercise (e.g., jump or sprint). The first parameter to consider is the type of conditioning activity (CA), which should be movement-specific with respect to an explosive exercise to obtain greater effects [4]. A key consideration is to identify an appropriate connection between the following parameters: the volume and intensity of CA and the rest interval between CA and explosive exercise [2]. To improve performance in explosive exercise, a balance must be struck between type and parameters of CA and fatigue induced by CA to determine potential PAPE [5]. Apart from variables strictly related to performed movements, individual characteristics, such as gender, muscle fiber type, training status, training experience and relative strength level, should also be considered when developing an optimal protocol [2,5,6]. To determine optimal parameters to induce PAPE, accommodating resistance should also be considered for CA. Using chains and elastic bands as a form of accommodating resistance are two training modalities commonly used by strength training specialists. Using a combination of accommodating and free weight resistance has been shown to improve maximal strength and power to a greater extent than using only free weight resistance [7,8]. Using elastic bands can challenge athletes to accelerate through a given range of motion [9] and can result in improvements in the rate of force development [10,11], which is related to increased jumping performance [12]. The use of accommodating resistance has been suggested to induce PAPE as strongly as using only free weight resistance and simultaneously allowing for a reduction in the rest interval between CA and explosive exercise [13]. Accommodating resistance has been used in numerous studies to optimize PAPE, with results consistently showing that accommodating resistance is an effective method to induce PAPE [14–20] that can be achieved with a relatively short rest period (1.5–2 min) between CA and subsequent explosive tasks [14,15,17,20]. In some cases, using accommodating resistance was found to be superior to free weight resistance, which did not induce PAPE in either male [16,18] or female [20] participants in previous studies.

In most studies, authors tend to use back squat as CA, and an increasing number of studies involve trap bar deadlift as CA [21–24]. Results are not consistent, as some studies report no PAPE, one study reported the advantage of a trap bar deadlift compared to a back squat [23]. Only one study has simultaneously evaluated the use of accommodating resistance and trap bar deadlift, with no PAPE reported [24]. However, some parameters in the abovementioned studies are not in agreement with the results of previously published studies [2,4–6]. For example, sprinting is not movement-specific to a trap bar deadlift [22], and some authors claim that the training experience of the subjects may be insufficient to demonstrate increased performance [21]. Furthermore, very high intensity of CA (70% of free-weight resistance and 23% of accommodating resistance) and short rest periods (30, 90 and 180 s) could generate a high level of fatigue [24]. Taking into consideration methodological inadequacies, trap bar deadlift as a CA should be evaluated with caution.

Over the years, PAPE response has been shown to be highly individual [25,26], depending on both the parameters of CA and individual characteristics, such as muscle fiber type, gender, training status, training experience and relative strength level [2,5,6]. However, it was hypothesized that a response to a given CA could be highly specific to a motor activity performed after CA, e.g., an individual after performing a CA could show no PAPE in a given jumping exercise but show PAPE in another jumping exercise that is more specific to a given CA. An improved response could be observed in a case in which both activities are as specific as possible. Therefore, choosing adequate parameters of CA may be insufficient if an explosive exercise performed afterwards is not specific enough to indicate PAPE.

Given the general agreement that accommodating resistance is an effective method to induce PAPE, the aim of this study was to evaluate the effects of PAPE on jump performance in elite volleyball players and, in particular, whether the same CA induces similar PAPE responses in two jumping tests with different movement characteristics: countermovement jump (CMJ) and squat jump (SJ). CMJ is an eccentric–concentric type of movement, whereas SJ is solely a concentric type of movement, as it starts from an isometric position, as well as a CA. Our hypothesis was that this protocol can induce PAPE in both exercises, given the existing movement direction specificity, which could be even stronger while performing SJ, as it is more specific to the used CA than CMJ, considering muscle-type contraction. Moreover, another aim of the present study was to analyze players' individual responses to the CA used in the protocol.

2. Materials and Methods

2.1. Study Design

Twelve elite male volleyball players took part in the study. The following inclusion criteria were used: (a) professional level of competition (Polish Volleyball League (PLS—Polska Liga Siatkówki) divisions); (b) valid medical examination; and (c) lack of injuries or other health contraindications in the last 6 months. Initially, fourteen players were supposed to participate in the study, but two participants were excluded from taking part in the study due to low back pain in prior weeks. CMJ was performed by all twelve participants; one participant did not perform SJ due to an ankle injury during a volleyball session. Participants were instructed to follow their normal dietary, supplement and sleeping habits during the study. All participants were informed about the study protocol, voluntarily took part in the experiment and signed informed consent. The study protocol was approved by the Bioethics Committee (Regional Medical Chamber in Kraków, Poland; opinion no: 1/KBL/OIL/2022) and performed according to the ethical standards of the Declaration of Helsinki (2013).

Before the main part of the study, on day 1, somatic parameters were measured, and one repetition maximum (1RM) was determined. In the main part of the study, for four days, the participants performed a standardized warmup, baseline CMJ or SJ (depending on the day), two experimental sessions (one for CMJ and one for SJ) with CA (PAPE condition) and two control conditions (one for CMJ and one for SJ) without CA (CNTR condition) (Figure 1). Four conditions were performed in a random order; on days 2 and 3, participants performed PAPE and CNTR conditions of the same jump, and on days 4 and 5, PAPE and CNTR of the second jump (e.g., on day 2, SJ PAPE; on day 3, SJ CNTR; then, on day 4, CMJ CNTR; on day 5, CMJ PAPE). Six participants performed SJ conditions first, and the other six performed CMJ conditions first. The conditioning activity used in the study comprised 3 repetitions of a trap bar deadlift with a load of 80% 1RM and an accommodating resistance of approximately 25 kg provided by an elastic band (yellow band, Corength, Domyos) (18 ± 2% of 1RM); the remainder of the load was provided by traditional resistance. There was no familiarization session, as the players were familiar with a trap bar deadlift with accommodating resistance and jumping tests. All daily sessions were performed at the same time of day (from 9 a.m. to 11 a.m.). Apart from experimental days, players participated in their volleyball training schedule (afternoon training sessions).

As the magnitude of the response to CA may be individual, after completing all tests, for further statistical analysis, based on the obtained data, players were divided into two groups: positive responders to the CA and non-responders. Because Optojump has an 0.8 cm standard error of measurement [27], positive responders were defined as athletes exhibiting improvement in absolute values by $\geq$0.8 cm between baseline and post-CA jumps, whereas non-responders were defined as players whose changes between baseline and post-CA jumps were $<$0.8 cm. Statistical analysis was performed for all subjects and separately for positive responders and non-responders.

2.2. Participants

Study participants comprised twelve elite male volleyball players (age: 23 ± 2 years; volleyball training experience: 11 ± 3 years) competing in the second highest volleyball division in Poland (Tauron 1. League). Volleyball players participating in the study included players competing in every volleyball position: setters, outside hitters, opposite hitters, middle blockers and libero. The mean participant body height was 194.7 ± 5.9 cm; body mass, 89.8 ± 7.9 kg; body fat, 14.7 ± 3.7%; BMI, 23.9 ± 1.5; lean body mass, 76.5 ± 6.8 kg.

2.3. Somatic Measurements

All somatic measurements were performed on day 1 of the study; body mass and body composition (body fat and lean body mass) were measured using a JAWON scale (Korea) (bioelectrical impedance analysis), and body height was measured using a stadiometer (SECA, Hamburg, Germany).

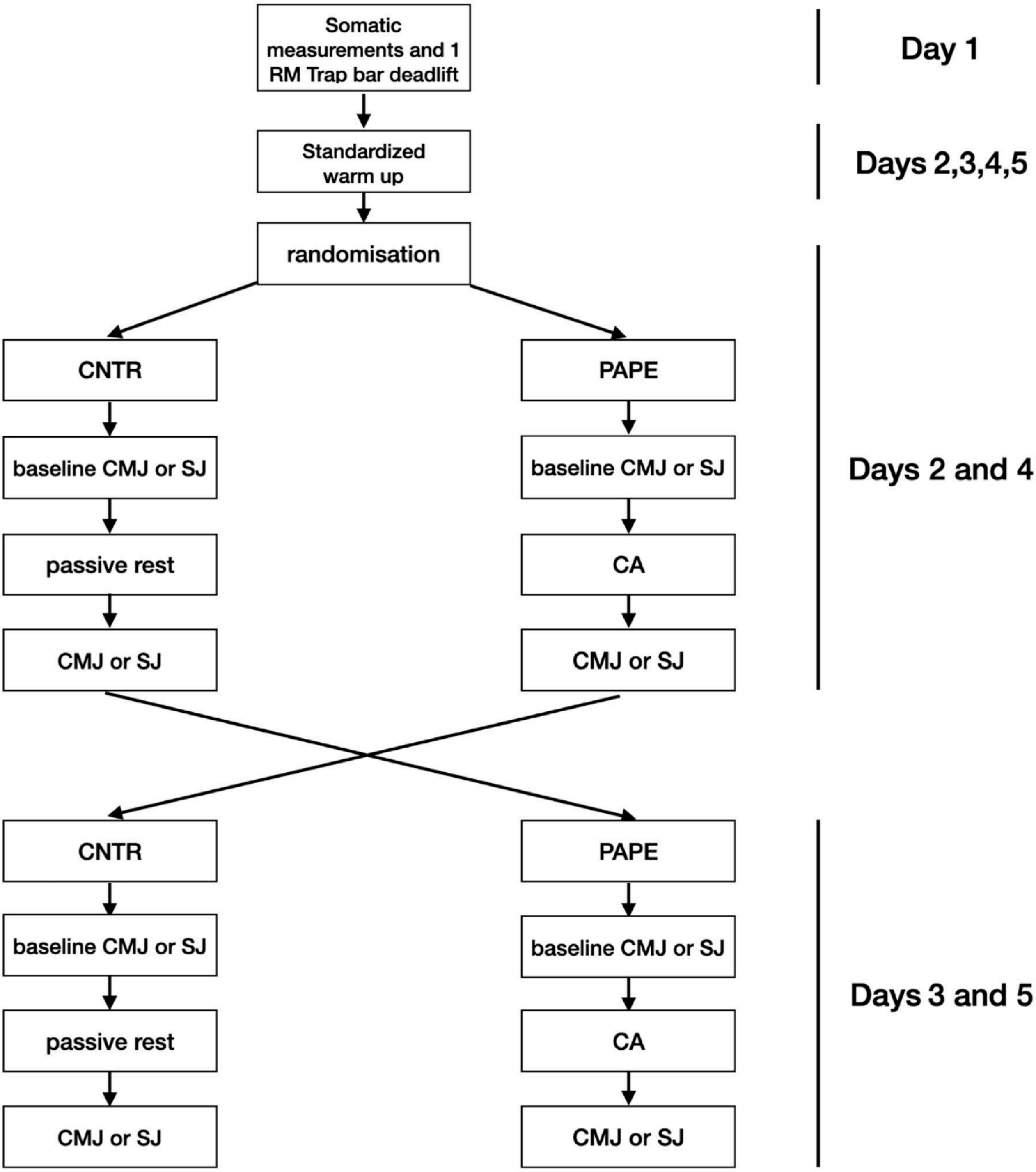

Figure 1. Study design. 1 RM—one-repetition maximum; CNTR—control condition; PAPE—experimental condition, CA—conditioning activity; CMJ—countermovement jump; SJ—squat jump.

2.4. Warmup

Each day started with a standardized warmup that included 6 min of light jogging at a heart rate of 100–120 bpm. Then a set of dynamic stretching was performed while walking, which consisted of 4 exercises of 10 repetitions each: knee to chest with calf raise, heel to buttocks with calf raise, hip external rotation with calf raise, and leg swings, ending with 2 all-out sprints at 10 m length. The total duration of the standardized warmup was approximately 12 min.

2.5. 1RM Measurement

The group of twelve participants was divided in two groups of six participants each to avoid excessive rest periods between sets. Participants were instructed to perform repetitions with a maximal velocity in concentric phase and controlled eccentric phase (approximately 2 s of eccentric phase). All repetitions were performed from floor level. 1RM in a trap bar deadlift was determined using accommodating resistance (an elastic band with approximately 25 kg of resistance). Participants performed the standardized warm up and after two minutes they performed a specific trap bar deadlift warmup, starting with 10 repetitions with a load of 20 kg and approximately 25 kg band resistance. Next, participants performed 3 repetitions with a load increase of 10–15% each set until they reached approximately 80% of an estimated 1RM. Then, participants performed 1 repetition with an increased load until they reached their 1RM (i.e., unable to perform a lift with proper technique). An elastic band with approximately 25 kg resistance was used for all sets; participants exclusively increased the traditional resistance load. For 1RM measurements, accommodating resistance was approximately 15 $\pm$ 1% of an achieved 1RM. Sets of 3 repetitions consisted of rest periods of 3 minutes, with sets of 4–5 min to assess 1RM. Mean relative 1RM in a trap bar deadlift with accommodating resistance amounted to 1.92 $\pm$ 0.12 kg/kg body mass.

2.6. Conditioning Activity and PAPE Protocol

Participants were split into four groups of three people to adequately control rest periods and avoid potential interruptions. Every group took approximately 25 min per day. All repetitions of trap bar deadlift were performed using an elastic band with an accommodating resistance of approximately 25 kg. The remainder of the load was provided by traditional resistance to obtain the intended percentage of 1RM.

Participants performed a standardized warmup. Then, after a 90 s recovery period, participants performed baseline CMJ or SJ. Then, 90 s after baseline CMJ or SJ, participants performed a specific warmup: 3 repetitions with a load of 50% 1RM, followed by a 180 s recovery period and 3 repetitions with a load of 70% 1RM. In the protocol with CA (PAPE), after another 180 s of recovery, participants performed a set of 3 repetitions with a load of 80% 1RM, which was CA. After another 90 s, CA participants performed another CMJ to determine whether a post-CA PAPE effect occurred. In the protocol without CA (CNTR), participants did not perform a set of 3 repetitions with a load of 80% 1RM (CA); they solely performed CMJ 270 s after a set of 3 repetitions with a load of 70% 1RM (Figure 2).

The protocols for CMJ and SJ were identical; randomization, load, repetitions, percentages of 1RM and recovery periods were not changed.

2.7. Jumping Tests

Jumping tests were performed using OptoJump (Italy) technology, an optical measurement system consisting of a transmitting and receiving bar that is a valid and reliable tool for the assessment of vertical jump heights [28]. The participants entered the area between two bars and performed a jumping test. During the study, all tests were performed with arms placed on the hips, and participants were forbidden to move their arms during the test. Participants performed a single jump under two conditions: at baseline and post-CA. During CMJ, participants were instructed to perform a fast downward movement followed by a fast upward movement with the intention to jump as high as possible. Depth of the downward movement was individual for each participant; they were instructed to perform the task as naturally as possible. During SJ, participants performed a downward movement to approximately 90° of knee flexion, followed by an isometric hold of approximately 2 s and a jump from an isometric position. As SJ is a test from an isometric position, participants were forbidden to perform another downward movement after an isometric hold. During both tests, participants were allowed independently choose the width of their feet for the jump. The following parameters were measured: jump height (JH), flight time (FT) and total energy (TE). To calculate average power (AP) and peak power (PP) a formula by proposed by Johnson and Bahamonde was used [29]. Furthermore, relative average power (RAP) and relative peak power (RPP) were calculated as the values of AP or PP, respectively, divided by the participant's body mass.

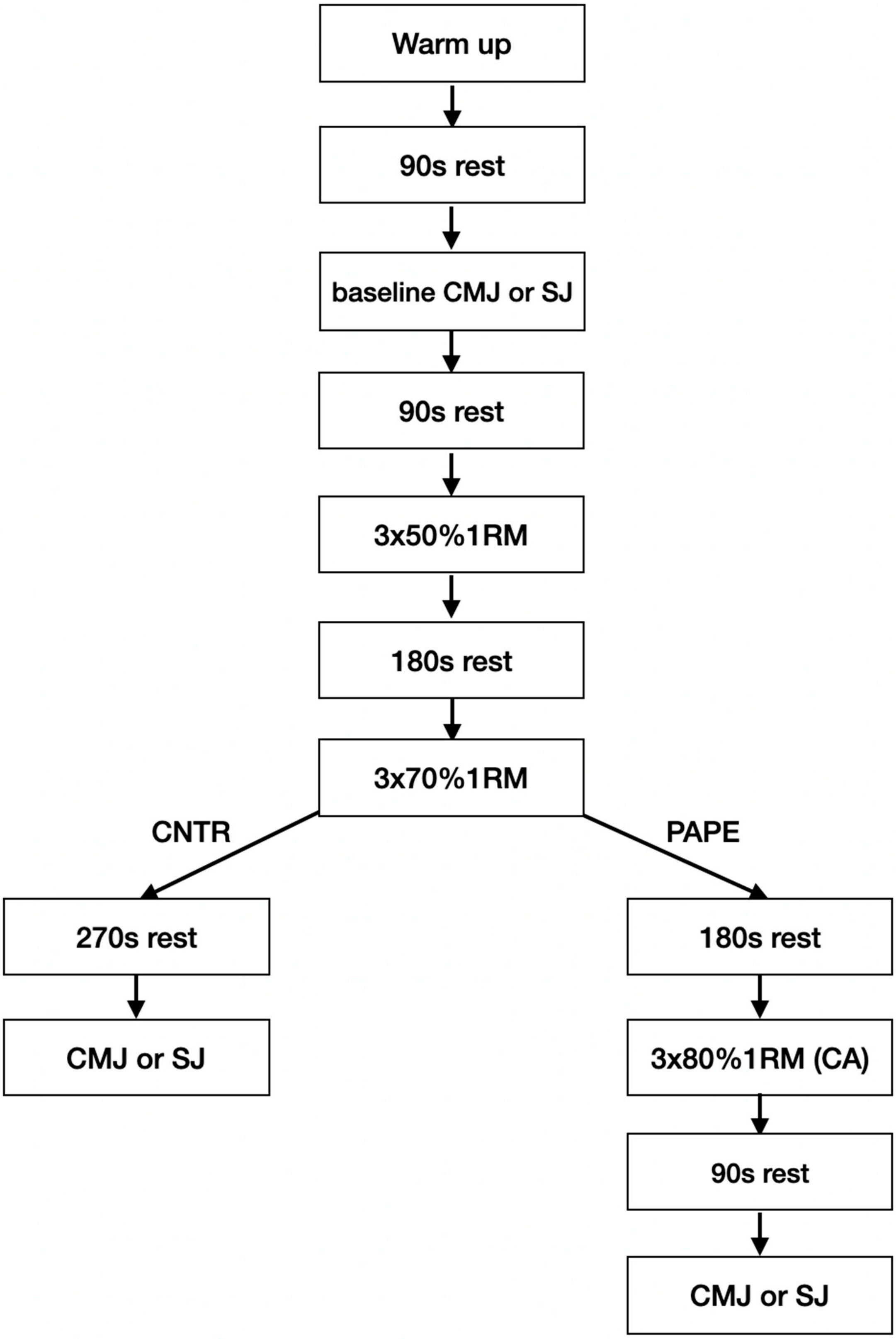

Figure 2. Flow chart of the investigated protocols.

2.8. Statistical Methods

All data are presented as mean and standard deviation (SD). An ANOVA with repeated measures (analyzed factors: condition (PAPE vs. control), time (pre vs. post) and interaction between these factors) was used to assess the significance of the effect of CA on changes in jump performance. In the case of a significant influence of the main factor (ANOVA, $p < 0.05$), post hoc analysis was performed using Tukey's test. Data distribution was checked using the Shapiro–Wilk test. Homogeneity of variance within groups was tested via Levene's test (variance of the analyzed parameters was similar between groups). The differences in all analyzed indices were considered statistically significant at the level of $p < 0.05$. The effect size (Cohen's d) was calculated and interpreted as small (0.20), medium (0.50) or large (0.80) [30]. Statistical analysis was performed using Statistica 12.0 software (StatSoft, Tulsa, OK, USA).

3. Results

According to analysis of the mean data for all volleyball players, the CA used in this study was not effective to induce an increase in jump height. No significant effects between conditions in time changes (baseline vs. post measurements) and interactions between analyzed factors were observed for either CMJ or SJ (Table 1).

Taking into consideration mean values only for participants who positively responded to the CA, significant interactions between factors were noted for all measured variables. Post hoc analysis indicated significant time changes in all parameters only in association with the PAPE condition, both for SJ and CMJ; the control condition resulted in no significant change in baseline vs. post measurement. A larger effect size was observed for SJ than CMJ. Individual analysis showed that more participants positively responded to a CA in SJ (8 of 11; 73%) than CMJ (6 of 12; 50%) (Table 2).

According to analysis of mean values for non-responders, there were no statistically significant differences between conditions, time change and interactions in any parameter of CMJ or SJ (Table 3).

Table 1. Results of jumping tests for all participants at the baseline and after CA (presented as mean ± SD).

CMJ							
Variable	**Condition**	**Baseline**	**Post**	**Effect: Condition F(p)**	**Effect: Time F(p)**	**Interaction F(p)**	**p: Post Hoc Pre–Post (Cohen's d)**
JH (cm)	CNTR	45.1 ± 6.2	44.7 ± 6.4	0.024 (0.88)	0.118 (0.73)	1.62 (0.21)	NS
	PAPE	44.9 ± 4.3	45.3 ± 4.6				NS
FT (s)	CNTR	0.605 ± 0.040	0.602 ± 0.041	0.04 (0.84)	0.10 (0.75)	1.57 (0.22)	NS
	PAPE	0.604 ± 0.028	0.609 ± 0.03				NS
E (J)	CNTR	396.6 ± 63.4	392.8 ± 61.1	0.02 (0.88)	0.01 (0.92)	1.4 (0.24)	NS
	PAPE	396.1 ± 59.2	400.6 ± 60.6				NS
AP (W)	CNTR	2082.6 ± 350.7	2065.8 ± 334.7	0.01 (0.91)	0.11 (0.73)	1.62 (0.21)	NS
	PAPE	2074.5 ± 330.9	2103.7 ± 340.2				NS
RAP (W/kg)	CNTR	23.2 ± 3.1	23 ± 3.1	0.01 (0.92)	0.16 (0.69)	1.40 (0.24)	NS
	PAPE	23 ± 2.2	23.4 ± 2.4				NS
PP (W)	CNTR	5987.1 ± 664.8	5957 ± 635.1	0.01 (0.91)	0.12 (0.73)	1.62 (0.21)	NS
	PAPE	5972.7 ± 645.1	6025.1 ± 659.8				NS
RPP (W/kg)	CNTR	66.8 ± 5.6	66.5 ± 5.8	0.00 (0.98)	0.26 (0.61)	1.02 (0.32)	NS
	PAPE	66.5 ± 3.6	67.1 ± 3.8				NS

Table 1. *Cont.*

SJ							
Variable	**Condition**	**Baseline**	**Post**	**Effect: Condition F(p)**	**Effect: Time F(p)**	**Interaction F(p)**	**p: Post Hoc Pre–Post (Cohen's d)**
JH (cm)	CNTR	43.2 ± 3.3	42.5 ± 4	0.04 (0.84)	0.13 (0.72)	3.52 (0.07)	NS
	PAPE	42.6 ± 4.2	43.7 ± 3.6				NS
FT (s)	CNTR	0.593 ± 0.021	0.588 ± 0.026	0.04 (0.84)	0.11 (0.74)	3.74 (0.06)	NS
	PAPE	0.589 ± 0.028	0.596 ± 0.023				NS
E (J)	CNTR	382.2 ± 41.6	375.9 ± 45.8	0.02 (0.87)	0.05 (0.81)	2.80 (0.10)	NS
	PAPE	378.2 ± 55.5	386.6 ± 48.3				NS
AP (W)	CNTR	2014.5 ± 251.5	1983.4 ± 274.3	0.01 (0.90)	0.13 (0.72)	3.52 (0.07)	NS
	PAPE	1990.2 ± 324.9	2036 ± 278.7				NS
RAP (W/kg)	CNTR	22.3 ± 1.7	22 ± 2	0.025 (0.87)	0.18 (0.67)	4.27 (0.05)	NS
	PAPE	22 ± 2.2	22.5 ± 1.8				NS
PP (W)	CNTR	5866.9 ± 507.2	5811.2 ± 545	0.01 (0.91)	0.13 (0.72)	3.52 (0.07)	NS
	PAPE	5823.3 ± 631.2	5905.5 ± 557.1				NS
RPP (W/kg)	CNTR	65.1 ± 3.2	64.5 ± 3.7	0.02 (0.87)	0.18 (0.67)	4.27 (0.05)	NS
	PAPE	64.5 ± 3.7	65.5 ± 3.2				NS

JH—jump height; FT—flight time; E—total energy; AP—average power; RAP—relative average power; PP—peak power; RPP—relative peak power; NS—non-significant.

Table 2. Results of jumping tests for positive responders (six participants in CMJ, eight in SJ) at the baseline and after CA (presented as mean ± SD).

CMJ							
Variable	**Condition**	**Baseline**	**Post**	**Effect: Condition F(p)**	**Effect: Time F(p)**	**Interaction F(p)**	**p: Post Hoc Pre–Post (Cohen's d)**
JH (cm)	CNTR	45.6 ± 5.8	44.8 ± 5.2	0.01 (0.90)	2.92 (0.12)	13.32 (0.004)	0.54 (0.15)
	PAPE	44.4 ± 4.2	46.8 ± 4.4				0.01 (0.56)
FT (s)	CNTR	0.609 ± 0.039	0.603 ± 0.034	0.02 (0.88)	3.03 (0.11)	12.54 (0.005)	0.59 (0.16)
	PAPE	0.601 ± 0.028	0.617 ± 0.029				0.01 (0.56)
E (J)	CNTR	399.2 ± 70.2	392 ± 66.1	0.002 (0.96)	1.88 (0.20)	10.65 (0.008)	0.56 (0.11)
	PAPE	388.8 ± 58.1	406.5 ± 58.5				0.035 (0.30)
AP (W)	CNTR	2092.5 ± 364.8	2055.2 ± 341.7	0.00 (0.93)	2.92 (0.11)	13.32 (0.004)	0.54 (0.11)
	PAPE	2039.2 ± 312.4	2142.1 ± 314				0.01 (0.33)
RAP (W/kg)	CNTR	23.5 ± 3.1	23 ± 2.7	0.01 (0.91)	2.83 (0.12)	13.08 (0.004)	0.54 (0.17)
	PAPE	22.9 ± 2.42	24 ± 2.46				0.016 (0.45)
PP (W)	CNTR	5992.4 ± 671.4	5925.6 ± 636.8	0.00 (0.94)	2.92 (0.11)	13.32 (0.004)	0.54 (0.10)
	PAPE	5896.8 ± 587.7	6081.5 ± 590.8				0.01 (0.31)
RPP (W/kg)	CNTR	67.3 ± 5	66.5 ± 4.3	0.01 (0.90)	2.83 (0.12)	13.08 (0.004)	0.54 (0.17)
	PAPE	66.2 ± 3.6	68.3 ± 3.7				0.02 (0.58)
SJ							
Variable	**Condition**	**Baseline**	**Post**	**Effect: Condition F(p)**	**Effect: Time F(p)**	**Interaction F(p)**	**p: Post Hoc Pre–Post (Cohen's d)**
JH (cm)	CNTR	43.5 ± 3.5	42.7 ± 3.9	0.001 (0.98)	8.87 (0.009)	35.48 (<0.001)	0.19 (0.22)
	PAPE	41.8 ± 4.1	44.3 ± 3.8				0.0002 (0.63)

Table 2. *Cont.*

SJ							
Variable	**Condition**	**Baseline**	**Post**	**Effect: Condition F(p)**	**Effect: Time F(p)**	**Interaction F(p)**	**p: Post Hoc Pre–Post (Cohen's d)**
FT (s)	CNTR	0.595 ± 0.024	0.589 ± 0.026	0.002 (0.96)	8.31 (0.01)	34.35 (0.001)	0.19 (0.24)
	PAPE	0.583 ± 0.029	0.6 ± 0.026				0.0003 (0.62)
E (J)	CNTR	379.1 ± 38.4	371.8 ± 38.2	0.000 (0.99)	7.82 (0.01)	32.142 (<0.001)	0.22 (0.19)
	PAPE	354.6 ± 44.3	386.1 ± 46.9				0.0003 (0.69)
AP (W)	CNTR	1973.1 ± 220.6	1937.5 ± 222.1	0.000 (0.98)	8.87 (0.009)	35.48 (<0.001)	0.19 (0.16)
	PAPE	1899.7 ± 248.1	2006.5 ± 257.7				0.0002 (0.42)
RAP (W/kg)	CNTR	22.2 ± 1.8	21.8 ± 2	0.002 (0.96)	9.43 (0.008)	37.69 (<0.001)	0.18 (0.21)
	PAPE	21.4 ± 2.1	22.5 ± 2				0.0002 (0.54)
PP (W)	CNTR	5799.7 ± 428.8	5735.9 ± 430.3	0.00 (0.98)	8.87 (0.009)	35.48 (<0.001)	0.19 (0.15)
	PAPE	5668.1 ± 472.7	5859.6 ± 494.4				0.0002 (0.40)
RPP (W/kg)	CNTR	65.1 ± 3.4	64.6 ± 3.8	0.002 (0.96)	9.43 (0.008)	37.69 (<0.001)	0.18 (0.14)
	PAPE	63.8 ± 3.8	65.9 ± 3.4				0.0002 (0.58)

JH—jump height; FT—flight time; E—total energy; AP—average power; RAP—relative average power; PP—peak power; RPP—relative peak power; NS—non-significant.

Table 3. Results of jumping tests for non-responders (six participants in CMJ, three in SJ) at the baseline and after CA (presented as mean ± SD).

CMJ							
Variable	**Condition**	**Baseline**	**Post**	**Effect: Condition F(p)**	**Effect: Time F(p)**	**Interaction F(p)**	**p: Post Hoc Pre–Post (Cohen's d)**
JH (cm)	CNTR	44.5 ± 6	44.6 ± 7	0.007 (0.93)	0.86 (0.37)	1.20 (0.29	NS
	PAPE	45.3 ± 4	44.3 ± 4.1				NS
FT (s)	CNTR	0.601 ± 0.041	0.601 ± 0.047	0.01 (0.90)	1.06 (0.32)	1.17 (0.30)	NS
	PAPE	0.608 ± 0.027	0.601 ± 0.028				NS
E (J)	CNTR	394 ± 55.6	393.6 ± 55.6	0.02 (0.88)	1.06 (0.32)	0.90 (0.36)	NS
	PAPE	403.5 ± 59.1	394.7 ± 62.1				NS
AP (W)	CNTR	2072.7 ± 303.6	2076.3 ± 297.2	0.004 (0.94)	0.86 (0.37)	1.20 (0.29)	NS
	PAPE	2109.9 ± 317.3	2065.4 ± 332.6				NS
RAP (W/kg)	CNTR	22.9 ± 2.8	23 ± 3.2	0.0001 (0.99)	0.71 (0.41)	1.58 (0.23	NS
	PAPE	23.2 ± 1.7	22.7 ± 1.8				NS
PP (W)	CNTR	5981.9 ± 599.5	5988.4 ± 576.2	0.03 (0.95)	0.86 (0.37)	1.20 (0.29)	NS
	PAPE	6048.7 ± 637.2	5968.8 ± 665.3				NS
RPP (W/kg)	CNTR	66.2 ± 5.7	66.4 ± 6.6	0.00 (0.99)	0.71 (0.41)	1.58 (0.23)	NS
	PAPE	66.8 ± 3.3	65.9 ± 3.2				NS
SJ							
Variable	**Condition**	**Baseline**	**Post**	**Effect: Condition F(p)**	**Effect: Time F(p)**	**Interaction F(p)**	**p: Post Hoc Pre–Post (Cohen's d)**
JH (cm)	CNTR	42.2 ± 1.2	41.9 ± 3.6	0.39 (0.56)	2.59 (0.18)	1.34 (0.31)	NS
	PAPE	44.8 ± 2.4	42.1 ± 1.1				NS
FT (s)	CNTR	0.588 ± 0.008	0.584 ± 0.025	0.39 (0.56)	2.85 (0.16)	1.27 (0.32)	NS
	PAPE	0.604 ± 0.016	0.586 ± 0.007				NS

Table 3. *Cont.*

SJ							
Variable	**Condition**	**Baseline**	**Post**	**Effect: Condition F(p)**	**Effect: Time F(p)**	**Interaction F(p)**	**p: Post Hoc Pre–Post (Cohen's d)**
E (J)	CNTR	390.7 ± 48	386.9 ± 60.1	0.05 (0.83)	2.66 (0.17)	1.50 (0.28)	NS
	PAPE	414.6 ± 65	388.1 ± 51.7				NS
AP (W)	CNTR	2124.9 ± 253.5	2105.9 ± 314.1	0.03 (0.85)	2.59 (0.18)	1.34 (0.31)	NS
	PAPE	2231.5 ± 328.2	2114.7 ± 270.6				NS
RAP (W/kg)	CNTR	22.6 ± 0.6	22.4 ± 1.7	0.344 (0.58)	2.82 (0.16)	1.24 (0.32)	NS
	PAPE	23.7 ± 1	22.5 ± 0.5				NS
PP (W)	CNTR	6046.2 ± 568.2	6012.1 ± 663.8	0.02 (0.87)	2.59 (0.18)	1.34 (0.31)	NS
	PAPE	6237.4 ± 704.7	6027.8 ± 601.6				NS
RPP (W/kg)	CNTR	64.6 ± 1.6	64.1 ± 2.9	0.44 (0.54)	2.82 (0.16)	1.24 (0.32)	NS
	PAPE	66.4 ± 0.7	64.3 ± 0.9				NS

JH—jump height; FT—flight time; E—total energy; AP—average power; RAP—relative average power; PP—peak power; RPP—relative peak power; NS—non-significant.

4. Discussion

The aim of this study was to evaluate the effects of PAPE on jump performance in elite volleyball players and whether the same CA induces similar PAPE responses in two jumping tests with different movement characteristics: CMJ and SJ. Although the applied accommodating resistance protocol was not effective in improving power output of all players, our study results indicate that the response to the same PAPE protocol may behave differed between the CMJ and SJ group. The study results show that (a) the response to CA is individual, and the obtained data should be evaluated individually; (b) for the same athlete, the effects of CA may be differ between CMJ and SJ; (c) thus, an individualized protocol should be applied to induce PAPE; (d) the data indicate that the protocol used in this study may be more effective for power enhancement in SJ. Additionally, the results of the study indicate that CA was more successful (8 of 11 participants; 73% of) than CMJ (6 of 12 participants; 50%) with respect to inducing PAPE in SJ, confirming our hypothesis. Although the protocol used in the present study to induce PAPE was not efficient for all 12 volleyball players who participated, the results indicate that there the response to a CA in both jumping tests may be individual and that a given CA may induce higher response to an explosive exercise with the same muscle type contraction.

The results of this study are not in agreement with those reported in previous research [14–20] on accommodating resistance and PAPE that found accommodating resistance to be appropriate to induce PAPE. In contrast, in the present, we found that the use of accommodating resistance seemed to be partially appropriate. To induce PAPE effectively, the applied protocol needs to be properly adjusted by choosing an intensity and volume of CA and an appropriate rest interval between CA and explosive exercise. Therefore, to create an optimal protocol, we used parameters that were previously reported as efficient. Results of a study by Naciero et al. [31] suggest that moderate (three repetitions with 80% of 1RM) and high (three sets of three repetitions with 80% of 1RM) volume of CA can be effective to induce PAPE compared to low training volume (one repetition with 80% of 1RM), which was found to be inappropriate. The intensity used in studies [14–20] in which accommodating resistance was investigated generally ranged from 80% to 85% of 1RM, with 55–70% of resistance provided by free weight and the rest provided by accommodating resistance. Therefore, we decided to use a CA of three repetitions with 80% of 1RM, with approximately 15% (band tension of 18 ± 2% of 1RM in CA) of resistance provided by an elastic band. The average level of relative strength level of the participants in this study was 1.92 ± 0.12 kg/kg body mass in trap bar deadlift with accommodating resistance, which is close the standard for strong individual (relative 1RM ≥ 2 kg/kg body mass) suggested by

Seitz et al. [32]. However, in a systematic review with meta-analysis by Seitz and Haff [6] a strong individual was classified according to a >1.5 relative back squat strength. In the previous studies [6,32], relative strength level was suggested for a back squat; in the present study, we used a trap bar deadlift, although participants can still be classified as strong individuals. Additionally, it was suggested that strong individuals are able to express potentiation effect earlier than weaker individuals and that accommodating resistance may result in induction of PAPE after approximately 90 s [13]. In previous studies involving elite athletes (rugby players), accommodating resistance was used in addition to classic resistance and shorter rest intervals than usually suggested (90 s), resulting in the induction of a PAPE effect [14,15,17]. Analysis of the research described above and the conclusions thereof informed our choice of CA parameters in the present study, i.e., three repetitions with 80% 1RM and a 90 s rest interval between CA and explosive exercise.

Taking into consideration details of previous studies [14–20] in which PAPE was investigated, it is not clear why PAPE was not achieved in the present study. Parameters of a CA were similar or identical to those implemented in previous studies, and accommodating resistance was used, calling into question the efficacy of a trap bar deadlift as a CA. The other issue could be group selection or the gender of the participants; to the best of our knowledge, this is the first study on PAPE in elite male volleyball players. Although parameters of CA and rest intervals differed from those used in the present study, PAPE was previously observed in volleyball players at different levels of competition—collegiate [33,34] and elite [35,36]—although these studies involved female volleyball players. In a study by Gołaś et al. [26], the authors suggested that a rest interval seems to be the most important component to consider. These data agree with a systematic review and meta-analysis [37], which indicated that the rest interval between CA and explosive exercise is the most important factor with respect to inducing potentiation in an explosive vertical jump. Much longer rest periods were originally suggested to induce a PAPE effect (7–10 min by Wilson et al. [2]), especially for vertical jump performance (3–7 min by Dobbs et al. [37]). This may explain why some of the participants were categorized non-responders in this study. Conclusions of previous studies [2,26,37] indicate that using the same CA parameters and different rest intervals (reduced or extended) may be appropriate to induce PAPE in elite volleyball players. Therefore, in future research other variables could be adjusted to optimize PAPE in elite volleyball players, i.e., by solely manipulating rest intervals between CA and an explosive exercise and either keeping CA or parameters constant or manipulating them as well.

A possible explanation for the higher efficacy of CA in SJ than CMJ is the specific range of motion of a trap bar deadlift, which is similar to that of SJ. According to Krzysztofik et al. [38] the range of motion of the CA has a significant effect on the magnitude of the PAPE response, with the most considerable effect achieved when the range of motion of the CA is similar to that of the subsequent explosive task. In the present study, the depth of SJ was set to approximately 90 degrees of knee flexion, whereas the depth of CMJ was individual determined for each athlete. Analysis of the biomechanics of a trap bar deadlift revealed 78.8 $\pm$ 11.2 degrees of knee flexion in the starting position [39]. Taking into consideration that every athlete likely did not perform the SJ with exactly 90 degrees of knee flexion, as we did not measure this value with a device, it could be debated whether the level of knee flexion is similar between SJ and a trap bar deadlift. It has been proven that when performing CMJ, countermovement depth affects vertical jump performance [40–45]. As the athletes in the present study self-selected countermovement depth and this parameter was not measured using a device, we speculate that CMJ depth could play a role in the achievement a potentiation response after CA. Therefore, in the future, researchers should consider first measuring CMJ depth of an individual and then prescribing an appropriate squat depth or height of the bar lifted from the floor to achieve a similar level of knee flexion, possibly inducing PAPE more effectively. A possibly explanation as why participants turned were either responders or non-responders is a somatic component expressed in the body height. As previously mentioned, the accommodating resistance used in the present study was an elastic band with approximately 25 kg band tension, amounting to 18 ± 2% of 1RM in CA. Therefore, the use of the same band for all participants rather than choosing a distinct band for every participant to achieve the intended percentage of 1RM may have influenced the results of the present study. For taller participants, the band provides more tension during the concentric phase, as it stretches for a greater distance, likely resulting in a 1–2% difference in 1RM. Participant mean body height in CMJ was 194 ± 6.8 cm for responders and 195.3 ± 4.9 for non-responders; in SJ, mean body height 195.8 ± 5.7 for responders and 193 ± 5.9 for non-responders, suggesting that the body height of the participants and the resulting differences in tension of the elastic band was not a limiting factor that could have influenced the results of the study. Additionally, volleyball position was not a limiting factor, as the players of every volleyball position were both responders and non-responders in both tests.

Although the protocol applied in the present study was partially appropriate to induce PAPE in elite volleyball players, CA was more effective in terms of potentiating SJ than CMJ (8 of 11 players responded in SJ vs. 6 of 12 in CMJ). A possible explanation for this phenomenon is that performing SJ is more specific to a trap bar deadlift than performing CMJ. Both explosive exercises are movement-specific, involving a vertical displacement of the bar, although SJ is more specific to a trap bar deadlift, considering the type of muscle contraction. Performing SJ requires an isometric hold followed by a solely concentric action, as in a trap bar deadlift; an individual sets a starting position while the bar is on the floor and performs a solely concentric portion of the lift. CMJ is an eccentric–concentric type of movement, which is similar to a back squat, wherein an individual also performs an eccentric–concentric movement. This may be an explanation why in the present study, more participants exhibited PAPE while performing SJ than CMJ. To the best of our knowledge, similar observations have not been reported in previous studies, and the selection of a similar muscle contraction type for a CA to that of the corresponding explosive exercise could be an additional component to consider when developing a protocol to induce PAPE. However, this observation should be applied with caution, as further research is required before conclusions can be drawn. Furthermore, we advise that an appropriate training protocol should be developed prior to implementation in a training program with elite athletes.

5. Limitations of the Study

A potential limitation of the present study could be the sample size, as only 12 participants were included. Furthermore, in our study, some of the players were identified as non-responders. The study design did not allow for determination of the reasons for this finding. In the future, the exact band tension should be determined and individualized, in addition to applying different recovery intervals for the design of similar protocols. Additionally, only one experimental protocol was performed by the volleyball players; it is possible that other study protocols (i.e., different workload, rest intervals between CA and explosive exercises) could be more effective to induce a PAPE response.

6. Conclusions

A single set of a heavy trap bar deadlift (three repetitions with 80% 1RM) with the use of accommodating resistance failed to induce PAPE in both jumping tests (CMJ and SJ) in elite volleyball players. However, the response to CA was individualized. Individual analysis revealed that more participants responded positively to the CA in SJ (73%) than CMJ (50%), and effect size values were larger for SJ than CMJ according to all analyses. This result could imply that PAPE response may be dependent on the similarity of the muscle type contraction between CA and the corresponding explosive exercise. These results could inform strength and conditioning coaches with respect to the development of a training program for a given individual.

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

Data Availability Statement: The datasets analyzed during the study are available from the corresponding author (S.M.) upon reasonable request.

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

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