Journal of Exercise Science & Fitness 22 (2024) 59–65

Contents lists available at ScienceDirect

Journal of Exercise Science & Fitness

journal homepage: www.elsevier.com/locate/jesf

Accommodating resistance is more effective than free weight resistance to induce post-activation performance enhancement in squat jump performance after a short rest interval

Sebastian Masel [*], Marcin Maciejczyk

Department of Physiology and Biochemistry, University of Physical Education, 31-571, Kraków, Poland

ARTICLE INFO

Keywords:
Variable resistance
Trap bar deadlift
Strength training
Potentiation
Power

ABSTRACT

Background/objectives: Prior work regarding post-activation performance enhancement (PAPE) has shown that various resistance training methods and conditioning activities may induce a PAPE effect such as free weight resistance, accommodating resistance or isoinertial resistance. However, the accommodating resistance and other types of resistance have rarely been directly compared. Thus, the aim of this study was to compare the effects of two different conditioning activities (CA) - a trap bar deadlift with (FW + AR condition) or without (FW condition) accommodating resistance - on subsequent squat jump (SJ) performance after a short rest interval of 90s.

Methods: The study had a cross-over design and fifteen strength trained males (mean age: 22.9 ± 2.1 years; mean relative strength level 2.01 ± 0.27 kg/body mass) participated in one familiarization, two experimental and one control session (CNTR condition). Two CAs were implemented throughout the study - a single set of 3 repetitions of a trap bar deadlift at 80 % of 1RM using solely free weight resistance or with the addition of approximately 15 % of 1RM elastic band tension. The SJ measurements were performed at the baseline and 90s after CAs.

Results: The FW + AR condition significantly improved subsequent SJ performance ($p < 0.05$, effect size 0.34) whereas the FW and CNTR conditions were found to be ineffective to acutely enhance performance.

Conclusions: Our results suggest that the addition of accommodating resistance is superior to free weight resistance in order to acutely improve jump performance after a 90s rest interval. To observe the performance enhancement effect with solely free weight resistance it should be considered to introduce alteration in loading strategies or possibly lengthening the rest interval.

1. Introduction

One of the most frequently used training practices to improve explosive performance is to apply an intense conditioning activity (CA) prior to an explosive exercise such as sprinting or jumping. The phenomenon of an increased power output during subsequent explosive exercise is called post-activation performance enhancement (PAPE).[1] This physiological mechanism has been previously called postactivation potentiation (PAP) but authors recently suggested that using the term PAPE is more appropriate to refer to the enhancement of measures of maximal strength, power and speed following conditioning contractions.[2,3] A training method that is frequently implemented in sports training and incorporates the PAPE phenomenon is contrast training.[4] Although volume[5,6] and intensity[6,7] of the conditioning activity are common attributes that determine the level of performance enhancement effect, other factors must also be considered,[8] including muscle contraction type,[9–12] force vector[13] or range of motion.[14] Nevertheless, the most important requirement for an effective PAPE protocol may be prescribing an appropriate rest interval between both exercises[15] that can be influenced by the parameters of the CA and also characteristics of the individual (e.g. strength level).[16] Despite multiple analyses, no consensus was achieved between the authors considering the optimal rest interval. Some authors suggest 5–7 min to have the biggest effect[17] whereas the others found 6–10 min[18] or 3–7 min considering vertical jump performance.[19] Strength and conditioning coaches tend to use different types of resistance to achieve the desired outcome. Apart from traditional free weight resistance the other commonly used are pneumatic resistance, isoinertial resistance and two types of accommodating

* Corresponding author. Złocieniowa 37/1, 30-798, Kraków, Poland.
E-mail addresses: sebastian.masel@doctoral.awf.krakow.pl (S. Masel), marcin.maciejczyk@awf.krakow.pl (M. Maciejczyk).

https://doi.org/10.1016/j.jesf.2023.12.001
Received 17 July 2023; Received in revised form 1 December 2023; Accepted 1 December 2023
Available online 7 December 2023

resistance - elastic bands and chains. Considering PAPE research, the authors show particular interest in a combination of free weight resistance and accommodating resistance[20–30] that was proven to be effective in generating muscle potentiation.[31] However, the researchers seem to focus in their studies solely on accommodating resistance - a training method that involves using elastic bands or chains and challenges athletes to constantly accelerate through a given range of motion.[32] Only four studies compared the accommodating resistance with other types of resistance: two with isoinertial resistance[22,25] and two with traditional free weight resistance.[24,26] One additional study compared the sport-specific CAs[28] where the participants used an elastic resistance CA or punch-specific isometric CA and the results of the study indicate that both types of CAs improved punch-specific performance. Each of the comparison studies[22,24–26] proved that a combination of free weight and accommodating resistance was more effective than the other type of resistance (isoinertial or free weight) to induce the PAPE effect. Isoinertial resistance is an interesting subject for future research but it is worth mentioning that this type of resistance is expensive whereas free weight and accommodating resistance are more affordable for a general audience. Additionally, the use of accommodating resistance can be exceptional as it may also allow the reduction of the rest interval between two exercises to 90–120s and still produce a performance enhancement effect.[20,21,23,26,29] According to meta-analysis by Wilson et al.[18] the duration of the PAPE effect can last up to 10 min, which can be beneficial for some sport events that would require a delayed post warm-up PAPE effect (e.g. swimming or sprinting start). However, strength and conditioning coaches frequently have limited time for a session and implementing accommodating resistance may be beneficial in case of time management. Therefore, comparing the efficacy of these two types of resistance to induce the PAPE should be the main focus of the researchers as they are most commonly used in strength training.

A back squat is the most frequently used training exercise in PAPE research and was used in all of the comparison studies.[22,24–26] However, the authors suggest that a trap bar deadlift could be an effective training alternative to a back squat[33] and there is growing evidence regarding the use of a trap bar deadlift as a CA.[28,29,34–36] Three of the studies focused on comparing the performance enhancement effects between a back squat and a trap bar deadlift[34–36] and all these studies used solely free weight resistance. One of the studies indicated no PAPE effect in both exercises,[34] in the other study both exercises improved sprint performance[35] and the last one proved that a trap bar deadlift was superior to a back squat in improving subsequent vertical jump performance.[36] Three other trap bar deadlift studies focused on the efficacy of a combination of free weight and accommodating resistance on the PAPE.[28,29,36] The results of these studies are inconsistent as the first one showed no performance enhancement effect,[36] the other suggested that a trap bar deadlift may be more effective for squat jump than counter-movement jump[28] and the last one indicated the performance enhancement effect in subsequent squat jump.[29] Therefore, a trap bar deadlift was proved to be effective in inducing PAPE in both manners: using free weight resistance[35,36] and a combination of free weight and accommodating resistance.[29]

Even though a trap bar deadlift can be an effective CA, comparing the efficacy of free weight resistance and a combination of free weight and accommodating resistance was not the authors' objective. So far, all of the comparison studies[22,24–26] considering back squat indicated that a combination of free weight and accommodating resistance was superior to the other types of resistance. Our previous research[29] showed that a trap bar deadlift with accommodating resistance can induce PAPE in 90s after CA. Thus, the main purpose of this study was to compare the efficacy of two CAs - a trap deadlift with or without accommodating resistance - on subsequent SJ performance. The meta-analysis suggests using rest intervals of at least 3 min considering vertical jump performance[19] but the performance enhancement effect may also occur in less than 3 min when accommodating resistance is added to free weight resistance.[20,21,23,26,29] We hypothesized that both types of CAs could provide sufficient stimuli to subsequently enhance SJ performance.

2. Methods

2.1. Study design

This study had a cross-over design and the participants took part in four sessions: one familiarization, two experimental and one control. The sessions were performed in the morning (from 8 a.m. to 12 a.m.) and an obligatory break between sessions of 48–72 h was introduced. The study began with a familiarization session that included somatic measurements, one-repetition maximum determination (1RM) in a trap bar deadlift and familiarization with a SJ test. Afterwards, in the main part of the study, the participants took part in two experimental and one control session in a random order (Fig. 1). The experimental sessions included a standardized warm-up, baseline SJ, PAPE condition with CA (with or without accommodating resistance) and post-CA SJ after 90s, whereas the control one included a standardized warm-up, baseline SJ, control condition without CA and post-CA SJ after 90s. There were two types of conditioning activity used in the study - the first was a single set of 3 repetitions of a trap bar deadlift at 80 % of 1RM solely from free weight (named FW), whereas the second was a single set of 3 repetitions of a trap bar deadlift at 80 % of 1RM with approximately 15 % of 1RM of an elastic band and the rest of the load was provided by free weight (named FW + AR).

To take part in the study, the participants were required to meet the following inclusion criteria: a) relative strength level in a trap bar deadlift $\geq$ 1.5 kg/body mass; b) regular participation in resistance training (at least 3 times a week); c) free from injuries or other musculoskeletal disorders in the last 6 months. The participants were instructed to maintain their usual training, dietary and sleeping habits throughout the study. They voluntarily took part in the study and provided signed informed consent after being informed about the study protocol and potential risks and benefits of the study. The study protocol was accepted by the Bioethics Committee (Regional Medical Chamber in Kraków, opinion no: 1/KBL/OIL/2022) and was performed in accordance with the ethical standards of the declaration of Helsinki in 2013. The sample size was calculated a priori using G*Power statistical software (Dusseldorf, Germany). The calculation was based on the following variables: the ANOVA with repeated measures, an effect size (f) of 0.5, an alpha value of 0.05, a statistical power of 0.95 (95 %) and a correlation between measurements of 0.50. A sample size of at least 15 individuals was obtained.

2.2. Participants

Fifteen strength-trained males participated in the study. The average age of the participants was 22.9 ± 2.1 years, body height 182 ± 6.5 cm, body mass: 80.4 ± 9.8 kg; body fat 15.8 ± 7.0 %; BMI 24.1 ± 2.8; lean body mass 67.5 ± 8.8 kg. The participants had an experience in various sports: 6 in volleyball, 3 in football, 1 in powerlifting, 1 in fencing, 1 in sprinting, 1 in cycling, 1 in crossfit, 1 in calisthenics. One additional participant was willing to participate in the study but his relative strength level (approximately 1.4 kg/body mass) was insufficient and was excluded from the study after 1RM measurements.

2.3. Warm-up protocol

The warm-up protocol was standardized and was performed at the beginning of each session. Total duration of the warm up was approximately 15 min and it consisted of two parts. The first part was a general warm-up to raise body temperature and it included 10 min of cycling on a cycle ergometer (Monark, Sweden) at a heart rate of 100–120 bpm. The second part took approximately 5 min and the participants performed dynamic stretching. It consisted of a set of 3 exercises of 10 repetitions each: knee to chest with calf raise; heel to buttocks with calf

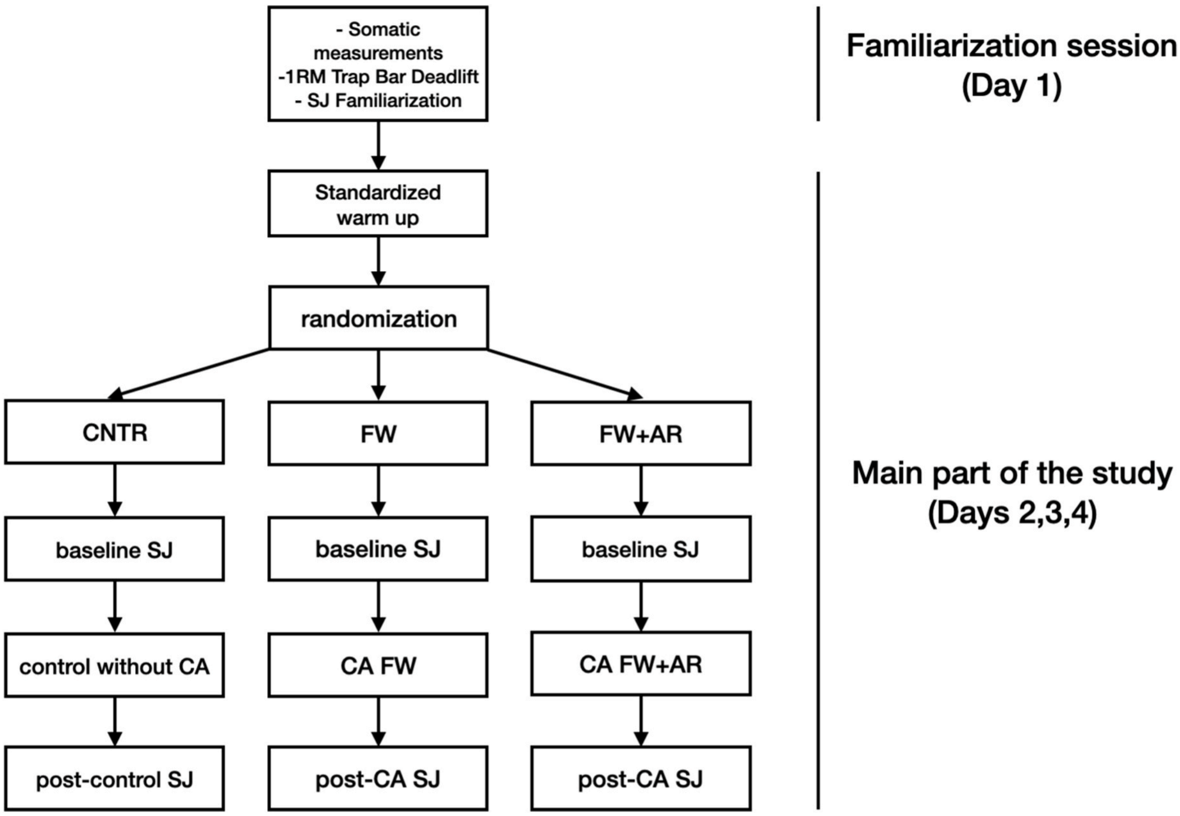

Fig. 1. Study design. 1RM - one repetition maximum; CA - conditioning activity; SJ - squat jump; FW + AR - condition with the addition of accommodating resistance; FW - condition with solely free weight; CNTR - control condition.

raise; hip external rotation with calf raise.

2.4. Familiarization session

The familiarization session consisted of three parts - somatic measurements, 1RM determination in a trap bar deadlift and familiarization with the SJ test. The somatic measurements were performed barefoot and participants were instructed to distribute their body weight evenly on the platform. Their body height was measured by a stadiometer (SECA, Germany), whereas body mass and body composition (body fat and lean body mass) were measured using the JAWON scale (Korea, bioelectrical impedance analysis).

The second part of the familiarization session included 1RM determination in a trap bar deadlift. Participants performed a standardized warm-up and the subsequent 1RM determination was executed in the same manner as previously described.[26] All repetitions were performed with high handles of a trap bar and the participants were instructed to perform each repetition with a maximal velocity in a concentric part of the lift and approximately 2s of the eccentric phase. The result of the 1RM measurements was the mean relative of 2.01 ± 0.27 kg/body mass.

The third part of that session was familiarization with the squat jump test. After the 1RM determination, the participants executed the SJ test several (3–5) times - the exact number of executions was based on the participant's ability to learn the movement pattern with the correct technique.

2.5. Squat jump measurements

Squat jump measurements were executed in the same manner as previously described.[28] The participants were instructed to perform a downward movement to reach approximately 90° of knee flexion, followed by an isometric hold of 2 s (that were counted by the supervisor of the study) and a jump from an isometric position. The measurements were performed with OptoJump (Italy) - a measurement system that was proved to be valid and reliable in assessing vertical jump height.[37]

2.6. Experimental and control sessions

The participants performed two experimental sessions that took approximately 30 min and one control session that took approximately 25 min. Each session began with the standardized warm-up (as in familiarization session) and 90s after the warm-up they performed baseline SJ. 90s after baseline SJ the participants performed a single set of 3 repetitions at 50 % of 1RM. During the control session (CNTR condition) they performed post-control SJ 90s after this set and it was the final part of the measurements for the day. During experimental sessions, after 180s of recovery after this set, the participants performed a CA of the study - a single set of 3 repetitions of a trap bar deadlift at 80 % of 1RM. One day it was performed only with traditional resistance (FW condition) and on the other day with the use of accommodating resistance (FW + AR condition) - approximately 15 % of 1RM of an elastic band. Then, in both experimental protocols, the participants performed post-CA SJ after 90s (Fig. 2). Throughout the protocols, in all of the measurements, two repetitions of SJ were performed and the one with a higher value of jump height (JH) was kept for further statistical analysis.

In the TR condition all the resistance was coming from traditional plates. In the TR + AR condition total resistance of the intended percentage of 1RM was divided into 65 % of 1RM of traditional resistance and approximately 15 % of 1RM of an elastic band. Four types of brand new elastic bands (Domyos, Germany) of different thickness were used throughout the study to assess an adequate accommodating resistance. The resistance of the band was calculated as the median of the range of the resistance suggested by the producer.

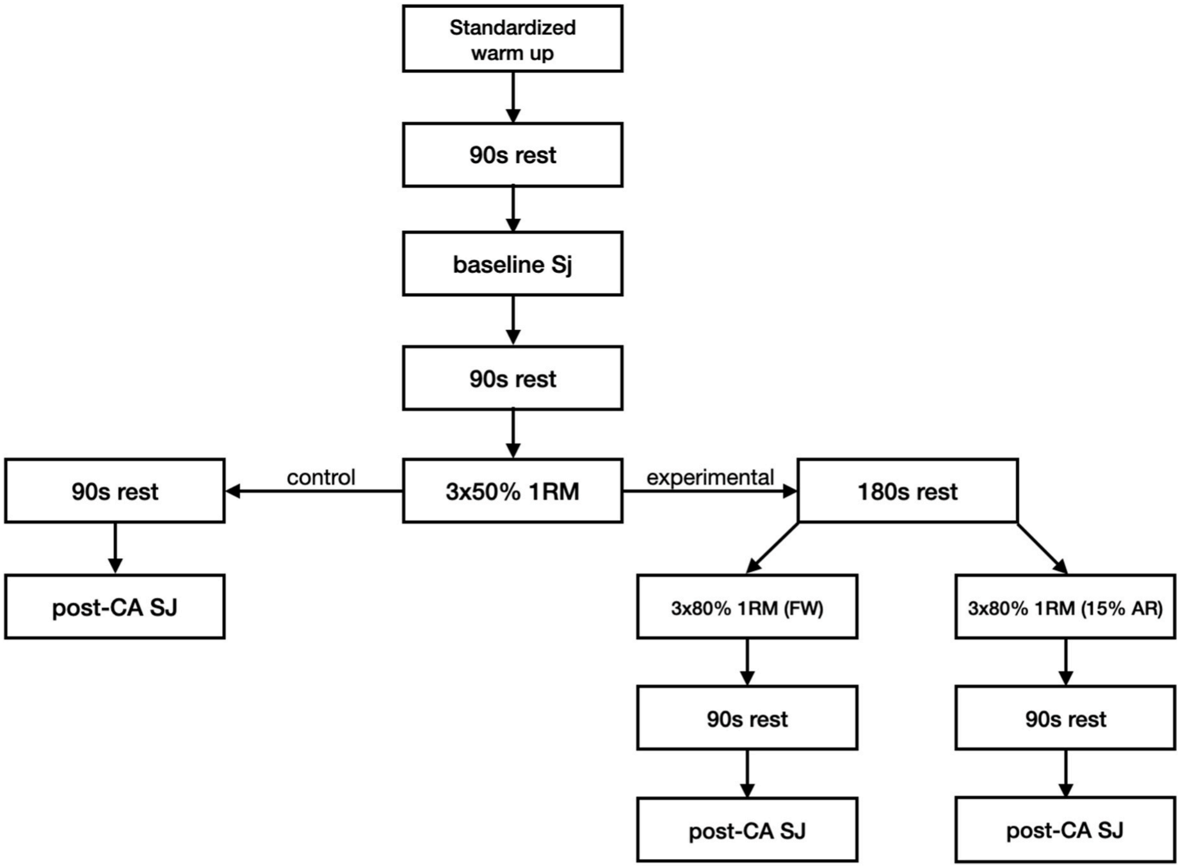

Fig. 2. Study flow.

2.7. Statistical methods

All data is presented as mean and standard deviation (SD). The distribution of variables was checked with the Shapiro–Wilk test. To assess the significance of the CA used in the study on jump performance the three-way ANOVA with repeated measures was implemented (analyzed factors: condition [FW vs. FW + AR vs CNTR], time [pre vs. post] and interaction between these factors). Post hoc analysis was performed using the LSD test. Levene's test was used to check the homogeneity of variance within the groups. The differences were considered statistically significant for $p < 0.05$. The effect size (Cohen's d) was calculated and interpreted as small (0.20), medium (0.50), or large (0.80).[38] The STATISTICA 13.1 PL (StatSoft, Inc., Tulsa, OK, United States) was implemented for statistical calculations.

3. Results

Analyzing the data, the FW + AR condition was found to induce PAPE response - all the parameters of the jump significantly improved after applying CA. Both FW and CNTR conditions were ineffective as pre to post-CA changes did not indicate a significant difference (Table 1 and Table 2).

During an individual analysis, it was found that in FW + AR condition most of the participants acutely increased their performance in post-CA SJ. In FW + AR condition for 11 out of 15 participants (73 %) a CA was sufficient to induce PAPE, and additionally 2 of them had nearly the same performance (−0.3 % and −0.2 %). On the contrary, in CNTR condition only 9 of 15 (60 %) acutely improved their performance and in FW 8 of 15 (53 %) (Table 2).

Table 1
Results of jumping tests after applicated CA with 90s rest interval (presented as mean ± SD).

Variable	Condition	Pre	Post	Effect: Group F p ηp^2	Effect: Time F p ηp^2	Interaction F p ηp^2	Post hoc Pre vs. Post p	Pre vs. Post ES
JH	FW	36.9 ± 4.8	37.2 ± 5.4	0.09	2.49	2.84	0.756	0.06
	FW + AR	36.6 ± 4.3	38.1 ± 4.4	0.91	0.12	0.69	0.007	0.34
	CNTR	36.7 ± 4.7	36.6 ± 5.0	0.004	0.055	0.119	0.694	0.02
FT	FW	0.547 ± 0.036	0.549 ± 0.040	0.09	2.49	2.84	0.756	0.05
	FW + AR	0.545 ± 0.032	0.557 ± 0.033	0.91	0.12	0.69	0.007	0.37
	CNTR	0.546 ± 0.036	0.544 ± 0.038	0.004	0.055	0.119	0.694	0.05
RAP	FW	15.3 ± 1.3	15.4 ± 1.5	0.175	4.696	2.704	0.554	0.07
	FW + AR	15.2 ± 1.0	15.8 ± 1.0	0.84	0.03	0.08	0.003	0.6
	CNTR	15.3 ± 1.0	15.3 ± 1.3	0.008	0.100	0.114	0.972	0

JH - jump height; FT - flight time; RAP - relative average power.

Table 2
Individual analysis of jump height changes through various conditions.

N°	FW + AR		Pre to post change in cm	Change in %	CNTR		Pre to post change in cm	Change in %	FW		Pre to post change in cm	Change in %
	pre JH (cm)	post JH (cm)			pre JH (cm)	post JH (cm)			pre JH (cm)	post JH (cm)		
1	35.2	37.1	1.9	5.4 %	32.9	31.1	−1.8	−5.5 %	34.3	35.7	1.4	4.1 %
2	30.2	30.4	0.2	0.7 %	28.6	29.6	1	3.5 %	29.7	30.9	1.2	4.0 %
3	33.7	38.2	4.5	13.4 %	36.5	37.6	1.1	3.0 %	37.6	38.4	0.8	2.1 %
4	37.6	38.9	1.3	3.5 %	37.9	38.6	0.7	1.8 %	38.3	36.5	−1.8	−4.7 %
5	38.3	39.6	1.3	3.4 %	41.4	37.2	−4.2	−10.1 %	38.2	37.4	−0.8	−2.1 %
6	36.8	39.1	2.3	6.3 %	36.7	40	3.3	9.0 %	41	41.8	0.8	2.0 %
7	44	44.7	0.7	1.6 %	44.1	45.6	1.5	3.4 %	43.8	45.8	2	4.6 %
8	44.6	43.7	−0.9	−2.0 %	42.4	44.3	1.9	4.5 %	43.4	42	−1.4	−3.2 %
9	35.9	34	−1.9	−5.3 %	36.7	35	−1.7	−4.6 %	35.2	33.8	−1.4	−4.0 %
10	31.5	33.6	2.1	6.7 %	31.4	32.4	1	3.2 %	34.3	33.1	−1.2	−3.5 %
11	37.4	42.4	5	13.4 %	37.8	40.2	2.4	6.3 %	40.4	43.5	3.1	7.7 %
12	39.5	41.9	2.4	6.1 %	41.8	40.5	−1.3	−3.1 %	41	41.7	0.7	1.7 %
13	34.6	39.1	4.5	13.0 %	34.3	31.1	−3.2	−9.3 %	31.5	29.8	−1.7	−5.4 %
14	29.2	29.1	−0.1	−0.3 %	28.2	28.6	0.4	1.4 %	26.8	26.5	−0.3	−1.1 %
15	40.1	40	−0.1	−0.2 %	40	36.8	−3.2	−8.0 %	38	40.8	2.8	7.4 %
x	36.6	38.1	1.5	4.4 %	36.7	36.6	−0.1	−0.3 %	36.9	37.2	0.3	0.6 %
sd	4.3	4.4	1.9	5.5 %	4.7	5.0	2.2	5.8 %	4.8	5.4	1.6	4.2 %

JH - jump height; FW + AR - a condition with free weight and accommodating resistance; CNTR - a control condition; FW - a condition with solely free weight.

4. Discussion

The results of this study indicate that a short rest interval of 90s was sufficient to induce the performance enhancement effect in subsequent SJ in a trap bar deadlift with accommodating resistance. Our results are in agreement with other studies - a combination of free weight and accommodating resistance is effective in inducing PAPE with a short rest interval of only 90s.[20,21,23,29] However, a single set of a trap bar deadlift with free weight resistance and 90s rest interval was not effective in inducing PAPE. Thus, the combination of free weight and accommodating resistance is superior to solely free weight resistance in a trap bar deadlift when the short rest interval is applied.

To our knowledge, this is the first study that has compared two types of resistance in a trap bar deadlift regarding PAPE response. So far, only two studies[24,26] have compared free weight resistance and a combination of free weight and accommodation resistance, but the CA used in these studies was back squat. Different rest intervals were implemented by different authors - our study used a 90s rest interval, whereas the study by Mina et al.[24] used various post-CA rest intervals (30s, 4, 8, 12 min) and the study by Popp Marin et al.[26] also used various rest intervals (within 15s, 2, 4, 6, 8 min). These studies provided similar results as ours - using accommodation resistance is superior to solely free weight resistance with a short rest interval. An interesting fact is that despite introducing various post-CA rest intervals a combination of free weight and accommodating resistance was found to be effective up to 120s–30s[24] or 120s.[26] The training intensities of the CAs used in these studies were similar - 3 repetitions with 80 % of 1RM in our study, 3 repetitions with 85 % in the other study[24] and 5 repetitions with 85 % of 1RM in the third study.[26] The differentiating factor between the studies was the volume of the CA, as our study and the study by Mina et al.[24] used a single set whereas Popp Marin et al.[26] used 3 sets of CA before implementing post-CA counter-movement jump. Even though the volume of the CA was high,[26] it still allowed the athletes to express the performance enhancement effect in the subsequent counter-movement jump just after 120s in accommodating resistance condition, and the performance increase was spectacular - 5.8 % increase in CMJ height and 1.53 ES.

So far, data regarding the influence of a trap bar deadlift with free weight resistance on subsequent explosive performance is limited - only 3 studies have examined it.[34–36] The conclusions of these studies are inconsistent - two of them indicated a beneficial effect of the CA on a subsequent 40 m sprint,[35] or CMJ[36], whereas the study by Leyva et al.[34] did not support it. All these studies, similarly to our study, used the same volume of the CA as 3 repetitions of a trap bar deadlift were performed. However, a higher training intensity was introduced during these interventions - our study used 80 % of 1RM and others used 85 %,[34] 90 %[35] or 93 % of 1RM.[36] In our study a rest interval of 90s was introduced before post-CA measurements and other authors used different rest intervals – 7[35] or 8 min[34] and Scott et al.[36] used a wide range of rest intervals - 2, 4, 6, 8, 10, 12, 14, 16 min. Despite implementing various rest intervals, the performance of an explosive exercise increased exclusively after 2, 6[36] or 7 min.[35] The appropriate rest interval was indicated to be the most important factor to be determined while projecting a PAPE protocol[19] and the original recommendations suggest using prolonged rest intervals such as 5–7,[17] 6–10[18] or 3–7 min considering vertical jump performance.[19] However, in this study we decided to use the rest interval of 90s for both types of CAs because in one of the studies[36] 120s was sufficient to induce PAPE despite very high training intensity of the CA (1 set of 3 repetitions at 93 % of 1RM). Thus, we used the rest interval of 90s as the volume of the CA was the same and the intensity introduced was lower - 80 % of 1RM in our study versus 93 % of 1RM in the study by Scott et al.[36] These two protocols had visible similarities but our approach was inappropriate as no improvement in post-CA SJ was observed. Therefore, more research is needed to optimise PAPE response in a trap bar deadlift using solely free weight resistance.

Our study confirmed that the addition of accommodating resistance is efficient when the short rest interval is introduced between the CA and a subsequent explosive exercise. Strength and conditioning coaches, especially in team sports, frequently have limited time for sessions and proper time management is particularly important. Therefore, when the PAPE protocols are implemented to develop muscle power the addition of accommodating resistance seems to be rational, as it may allow avoidance of prolonged rest intervals that could negatively influence both training motivation and duration of the training session. Despite the time management benefit we can also expect performance enhancement regarding a whole training block.[39] Apart from the PAPE protocols the addition of accommodating resistance was also found to be more effective than solely free weight resistance training to develop lower body power[40] or maximal strength.[41] Additionally, several systematic reviews and meta-analyses[42–44] proved that the accommodating resistance may be superior or equally effective in improving maximal muscle strength and power. Wallace and Bergstrom[45] also highlighted other benefits of the accommodating resistance such as matching strength curves of multi-joint resistance exercises, greater eccentric loading or reducing the large deceleration of the concentric phase of the lift. Another benefit of accommodating resistance is to force an individual to a higher force production as total resistance of the lift increases in concentric phase with the lengthening of an elastic band.[46] This can apply not only to typical exercises used in resistance training but also to sport-specific actions where elastic resistance is implemented in addition to body-weight dynamic movements e.g. punch,[30] roundhouse kick[47] or arm-pull thrust in swimming.[48] Thus, the practitioners should seriously consider adding accommodating resistance to free weight resistance while projecting the training protocols to improve muscle power.

Even though the FW protocol was ineffective, the researchers should consider designing various protocols with a trap bar deadlift and free weight resistance as some authors found that they can also potentiate subsequent explosive performance.[35,36] Because the PAPE response is highly individual, manipulating variables of the CA such as volume, intensity and rest interval seem to be crucial for optimal PAPE effect. It may be possible that within the same training intensity the addition of accommodating resistance may generate lesser fatigue.[26] Therefore, in future research the authors could focus on prescribing different volumes and intensities of CAs or solely manipulating the rest interval. So far, the rest intervals of 2, 6 or 7 min were found to be effective for a trap bar deadlift with free weight[35,36] so there is a broad area to seek other waysto implement this type of CA successfully. Lengthening the rest interval after introducing a CA with solely free weight resistance could be the first suggestion to be introduced. Various types of resistance, volume and intensity within a CA could potentially lead to the enhancement effect after a proper implementation of an adequate rest interval. This allows more efficient control of the fatigue generated by a CA to not inhibit the enhancement effect of a given CA. Thus, both researchers and practitioners should place special interest in implementing proper rest intervals based on a CA introduced to a given individual.

As the PAPE response is highly individual and dependent on many factors[6] we decided to introduce an additional individual analysis of the results of this study. We found different numbers of participants acutely enhancing their post-CA SJ performance in different conditions (73 % in FW + AR, 60 % in CNTR, 53 % in FW). Also, the highest percentage of performance varies between the conditions - in FW + AR the highest reported increase was 13.4 %, in CNTR 9 % and in FW 7.4 %. An interesting observation is that nearly all of the participants (7 out of 8) who improved their performance in FW condition also improved their performance in FW + AR condition. One could speculate that if an individual can improve their performance with a given rest interval and volume and intensity of a CA they should also expect an improvement when accommodating resistance is introduced within the same parameters of a CA. Additionally, it was observed that 60 % of the participants (9 out of 15) responded positively to various conditions - 33 % of the participants (5 out of 15) responded positively to all three conditions and 27 % (4 out of 15) to two conditions. Therefore, it could be possible that having a performance increase with one type of CA could increase the likelihood of having the same effect in another CA.

Our study provided a practical recommendation in implementing the addition of accommodating resistance to free weight resistance in order to enhance explosive performance after a relatively short rest interval of 90s. However, strength and conditioning coaches should apply the results of this study with caution as the participants were not professional athletes and had different sport backgrounds. Before implementing successful protocol of this study to the training routine of the athletes, they should check if the athletes respond to these kind of stimuli in a similar way. Also, to appropriately implement PAPE protocols, a coach should be aware that they fulfill various objectives[49] e.g. warming up before a swimming competition or complex training during a strength and conditioning session. Thus, one must decide what kind of CA is optimal for a given individual to achieve the enhancement effect. Every effort should be made to have a better understanding of a given situation and use the PAPE phenomenon appropriately.

5. Limitations of the study

The study protocol did not involve professional athletes that are usually a target group to implement the PAPE protocols. Additionally, only two types of CAs with the same volume, intensity and rest interval were compared throughout the study. A further investigation could compare various loading strategies with a special interest in multiple free weight resistance protocols and relatively short rest intervals. Even slightly lengthening the rest interval could be the first suggestion for future research. Also, in order to achieve a desired band tension of the accommodating resistance, the investigators should introduce force plates measurements to calculate vertical ground reaction force.

6. Conclusions

A single set of 3 repetitions of a trap bar deadlift with 80 % of 1RM with the addition of accommodating resistance was found to be superior in enhancing SJ performance to free weight resistance after a 90s rest interval. In order to acutely improve explosive performance using solely free weight resistance, different loading strategies or lengthening the rest interval could be introduced.

Funding

The study and APC was funded by the University of Physical Education in Krakow, Poland, grant number: 157/MN/INB/2022.

Credit author statement

Sebastian Masel - Conceptualization; Data curation; Formal Analysis; Investigation; Methodology; Writing - original draft.

Marcin Maciejczyk - Conceptualization; Formal Analysis; Methodology; Writing - review & editing.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

Acknowledgments

Not applicable.

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