AKADEMIA WYCHOWANIA FIZYCZNEGO W KRAKOWIE

im. Bronisława Czecha w Krakowie

Szkoła Doktorska

Autoreferat rozprawy doktorskiej

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Wpływ różnych protokołów Postactivation Performance Enhancement (PAPE) na poziom mocy beztlenowej u osób aktywnych fizycznie i wyczynowych siatkarzy

Rozprawa napisana w Zakładzie Fizjologii i Biochemii

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Kraków, 2024

Serdeczne podziękowania dla mojego promotora
***prof. Marcina Maciejczyka** za poświęcony czas*
i nieocenioną pomoc w tworzeniu tej pracy.
Pracę dedykuję moim bliskim, którzy stanowili
dla mnie wsparcie w rozwoju naukowym.

Spis treści

1. Artykuły wchodzące w skład cyklu publikacyjnego

Przedmiotem przedstawionej rozprawy doktorskiej jest cykl czterech tematycznie powiązanych publikacji naukowych. We wszystkich z przedstawionych prac jestem pierwszym autorem i autorem korespondencyjnym, a jedynym współautorem tych publikacji jest promotor rozprawy doktorskiej. Poniżej przedstawiono wspomniane, powiązane tematycznie publikacje naukowe, wchodzące w skład dysertacji doktorskiej:

1. Masel, S. & Maciejczyk, M. Effects of Post-Activation Performance Enhancement on Jump Performance in Elite Volleyball Players. *Appl. Sci*. **12**, 9054 (2022).

Punktacja: 100 pkt MEiN, 2.7 Impact Factor

2**.** Masel, S. & Maciejczyk, M. Post-activation effects of accommodating resistance and different rest intervals on vertical jump performance in strength trained males. *BMC Sports Sci. Med. Rehab.* **15** (2023).

Punktacja: 100 pkt MEiN, 2.1 Impact Factor

3. Masel, S. & Maciejczyk, M. Accommodating resistance is more effective than free weight resistance to induce post-activation performance enhancement in squat jump performance after a short rest interval. *J. Exer. Sci. Fit.* **22**, 59-95 (2024).

Punktacja: 40 pkt MEiN, 2.4 Impact Factor

4. Masel, S. & Maciejczyk, M. No effects of post-activation performance enhancement in elite male volleyball players under complex training. *Sci. Rep.* **14** (2024).

Punktacja: 140 pkt MEiN, 3.8 Impact Factor

Sumaryczna punktacja publikacji wchodzących skład cyklu powiązanych tematycznie publikacji wynosi 380 punktów MEiN, a ich łączny Impact Factor to 11,0. Badania, na podstawie których powstała rozprawa doktorska, zostały sfinansowane przez Akademię Wychowania Fizycznego w Krakowie, projekt nr. 157/MN/INB/2022.

Pozostałe publikacje naukowe autora rozprawy doktorskiej, niewchodzące w skład cyklu publikacyjnego:

1. Masel, S. & Maciejczyk, M. Changes in Countermovement Jump Height in Elite Volleyball Players in Two Competitive Seasons: Consideration on the Technique of Execution of the Jump. *Appl. Sci.* **12**, 4463 (2024).

Punktacja: 100 pkt MEiN, 2.5 Impact Factor

2. Maciejczyk, M., Pałka, T., Więcek, M., Masel, S. & Szyguła, Z. The Effects of Intermittent Hypoxic Training on Anaerobic Performance in Young Men. *Appl. Sci.* **14**, 676 (2024).

Punktacja: 100 pkt MEiN, 2.5 Impact Factor

3. Maciejczyk, M., Pałka, T., Więcek, M., Szymura, J., Kuśmierczyk, J., Bawelski, M., Masel, S. & Szyguła, Z. *Appl. Sci.* **13**, 9954 (2023).

Punktacja: 100 pkt MEiN, 2.5 Impact Factor

Łączna punktacja pozostałych publikacji wynosi 300 punktów MEiN oraz Impact Factor wynoszący 7,5. Całkowity dorobek autora rozprawy doktorskiej to 18,5 IF oraz 680 punktów MEiN.

2. Wstęp

Zjawisko Post-Activation Performance Enhancement (PAPE) polega na zwiększeniu mocy mięśniowej w ćwiczeniu o charakterze dynamicznym (np. bieg, skok rzut) następującym po wykonaniu ćwiczenia dynamicznego z wysoką intensywnością (wyrażonej np. jako % jednego powtórzenia maksymalnego (%1RM)), najczęściej o charakterze siłowym [1]. Pierwotnie, stosowano sformułowanie PAP (Post-Activation Potentiation), które zostało zaproponowane raz pierwszy przez Burke i wsp. [2] w 1976 r. Tillin i Bishop [3] w 2009 roku jako pierwsi obszernie opisali zjawisko PAP i przedstawili dwa główne potencjalne mechanizmy odpowiedzialne za występowanie PAP - fosforylacja łańcuchów lekkich miozyny oraz zwiększona rekrutacja wysokoprogowych jednostek motorycznych. Przez wiele lat prace opisujące to zjawisko używały terminologii PAP. W 2017 roku Cuenca-Fernandez i wsp. [4] po raz pierwszy zaproponowali wprowadzenie określenia PAPE. Kolejni autorzy [1, 5, 6, 7] podkreślali potrzebę rozgraniczenia tych dwóch terminów od siebie z racji na występujące pomiędzy nimi różnice (Tabela 1).

Tabela 1. Charakterystyka zjawisk PAP i PAPE [1, 4, 5, 6].

	PAP	**PAPE**
rodzaj bodźca	elektryczny lub MVC (maksymalny skurcz izometryczny) lub ćwiczenie o wysokiej intensywności	wolicjonalny submaksymalny skurcz mięśniowy tj. ćwiczenie o wysokiej intensywności (np %1RM)
czas trwania	krótki (od kilku sekund do <3 minut), efekt stopniowo malejący	długi, nawet do 10 minut, w zależności od CA
główny mechanizm	fosforylacja łańcucha lekkiego miozyny	zwiększona temperatura/przepływ krwi/zawartość wody w mięśniach
weryfikacja efektu	warunki laboratoryjne	testy mocy/szybkości
spodziewany efekt	zwiększona siła skurczu mięśniowego	wzrost mocy mięśniowej, zwiększona wydajność w skokach/sprintach/rzutach

Mechanizmy działania PAPE nie zostały jeszcze dokładnie zbadane, jednak na obecny moment zdają się one być odmienne od mechanizmów PAP, a pozytywny efekt PAPE jest przypisywany zwiększonej aktywności mięśniowej, zwiększonemu przepływowi krwi, wzrostowi zawartości wody wewnątrz pracujących mięśni oraz podniesionej temperaturze mięśni [1]. Jako wspólny czynnik inhibitujący wystąpienie zjawiska PAP/PAPE uznać można nadmierne zmęczenie nerwowo-mięśniowe [1]. Generalizując, aktualnie PAPE jest terminem powszechniej stosowanym w związku z możliwością większej aplikacji przez praktyków w warunkach codziennej pracy.

Tworzenie protokołów badawczych z użyciem fenomenu PAPE i weryfikacja jego efektów zazwyczaj odbywa się w następujący sposób:

ćwiczenie o charakterze dynamicznym jako test mocy/szybkości (baseline testing)

↓

ćwiczenie aktywacyjne (conditioning activity - CA)

↓

przerwa wypoczynkowa (intra-complex recovery interval - ICRI)

↓

ćwiczenie o charakterze dynamicznym jako ponowny test mocy/szybkości weryfikujący wystąpienie PAPE (post-CA dynamic exercise)

Ćwiczenia dynamiczne, jako testy mocy/szybkości, zazwyczaj obejmują podstawowe formy lekkoatletyczne tj. skoki (zazwyczaj counter movement jump (CMJ) - skok ekscentryczno-koncentryczny z zamachem lub bez zamachu ramion lub squat jump (SJ) - skok z pozycji izometrycznego półprzysiadu), sprinty lub rzuty [8]. Ćwiczenie aktywacyjne powinno być wykonywane z wysoką intensywnością i zwykle przybiera formę ćwiczenia siłowego wykonywanego z intensywnością $\geq$ 75% 1RM [9], jednakże badacze równie skutecznie aplikowali inne formy CA jak np. obciążony sprint [10] czy ćwiczenia plyometryczne [11].

Powodzenie aplikacji danego protokołu treningowego z użyciem fenomenu PAPE jest zależne od wielu czynników, a warunkiem podstawowym jest dobranie odpowiedniego połączenia objętości [12, 13] i intensywności ćwiczenia aktywacyjnego [13, 14]. Ponadto, czas przerwy wypoczynkowej między ćwiczeniem aktywacyjnym a ćwiczeniem o charakterze dynamicznym (ICRI), może być najważniejszym czynnikiem warunkującym skuteczność danego protokołu PAPE [15]. Wśród autorów nie istnieje jednolity konsensus odnośnie optymalnego czasu ICRI - niektórzy wskazują na zasadność zastosowania przerwy o długości 3-7 minut w przypadku badania możliwości skocznościowych [15], inni sugerują wydłużenie czasu do 5-7 minut [8], lub nawet 6-10 minut [9].

Ponadto, aby zwiększyć prawdopodobieństwo wystąpienia efektu PAPE rekomendowane jest podobieństwo ćwiczenia aktywacyjnego i następnie wysiłku o charakterze dynamicznym (np. oba ćwiczenia o takim samym wektorze wertykalnym) [16] i zastosowanie podobnego rodzaju pracy mięśniowej i zakresu ruchu między dwoma ćwiczeniami [17]. Badania odnośnie PAPE wskazują na duże różnice interpersonalne i indywidualną odpowiedź na zastosowany bodziec [18], a czynniki takie jak płeć, staż treningowy, oraz charakterystyka włókien mięśniowych również mogą odgrywać rolę w efektywności międzyosobniczej protokołów PAPE [3, 8]. Dodatkowym czynnikiem, który jest wyróżniany przez autorów jako kluczowy, jest poziom siły mięśniowej - autorzy wskazują, że sportowcy o wysokim relatywnym poziomie siły mięśniowej (>1,5 kg/kg masy ciała [8] lub >2 kg/kg masy ciała [19] w przysiadzie ze sztangą) osiągają lepsze efekty niż osoby mniej wytrenowane w kontekście siły mięśniowej [19, 20]. Mimo szerokiego spektrum czynników wpływających na efektywność protokołów PAPE, aby zamaskować efekt zmęczenia występujący bezpośrednio po wykonaniu CA [3], szczególne znaczenie zdaje się odgrywać znalezienie odpowiedniego balansu między parametrami CA a dobraniem odpowiedniej przerwy wypoczynkowej.

Z uwagi na występujące różnice interpersonalne w reakcji fizjologicznej na dany protokół PAPE, protokoły z różną objętością i intensywnością CA mogą skutkować różną odpowiedzią w treningu sportowym. Badacze dowiedli, że zastosowanie różnych metod i środków treningowych (z obszaru treningu siłowego) może być efektywne do wywołania efektu PAPE. Zarówno tradycyjne CA o charakterze ekscentryczno-koncentrycznym z użyciem wolnego ciężaru [13], CA o charakterze izometrycznym[21, 22] czy CA tylko o charakterze ekscentrycznym [23], jak i bardziej nowoczesne metody jak użycie oporu inercyjnego [24] czy dopasowującego się obciążenia [25] mogą pozytywnie wpłynąć na efektywność późniejszego ćwiczenia dynamicznego. Metoda dopasowującego obciążenia (accommodating resistance - AR), nazywana również czasem zmiennego obciążenia (variable resistance - VR) jest powszechnie używaną na świecie, skuteczną metodą treningu siłowego do kształtowania siły i mocy mięśniowej, która zakłada użycie łańcuchów lub gum oporowych [26, 27, 28]. Założone na sztangę gumy lub łańcuchy, są obciążeniem dopasowującym - oznacza to, że podczas fazy ekscentrycznej ruchu (np. zejście w przysiadzie ze sztangą) obciążenie, któremu się przeciwstawia jest mniejsze, ale podczas fazy koncentrycznej (np. wstanie ze sztangą z dołu przysiadu) się zwiększa, co wymusza stałe przyspieszanie ruchu [29]. Wallace i Bergstrom [30] wskazują również, że zastosowanie AR pozwala lepiej odwzorować krzywą siły w wielostawowych ćwiczeniach siłowych, a także może zredukować znaczny spadek prędkości w fazie koncentrycznej.

Efektywność metody AR w kontekście zjawiska PAPE została wielokrotnie potwierdzona przez różnych badaczy [31-40]. Przy użyciu tej metody badacze zazwyczaj decydowali się na użycie intensywności 80-85% 1RM, z którego 55-70% stanowiło tradycyjne obciążenie, a pozostała część była uzupełniona przez obciążenie dopasowujące. Czynnikiem odróżniającym metodę dopasowującego obciążenia względem innych metod używanych w kontekście protokołów PAPE jest występowanie efektu PAPE po czasie krótszym niż sugerowany w meta-analizach [8, 9, 15]. Czas ICRI wynoszący 3 minuty jest podawany jako dolna granica [8, 9, 15], a użycie AR pozwalało na powtarzalne zredukowanie czasu do 1,5-2 minut z zachowaniem efektu PAPE [31-40]. Trenerzy przygotowania fizycznego często używają protokołów PAPE w swojej pracy do treningu mocy mięśniowej i możliwość skrócenia czasu ICRI wydaje się być kluczowa do powszechniejszego zastosowania szczególnie w sportach zespołowych, w których czas na wykonanie jednostki treningowej jest ograniczony. Tradycyjne protokoły mogą okazać się zbyt czasochłonne, a wydłużony czas oczekiwania po zastosowaniu CA może wpłynąć negatywnie na motywację zawodnika. Oprócz przywołanych zalet stosowania AR [30], istotną kwestią w kontekście PAPE wydaje się być generowanie mniejszego zmęczenia w porównaniu z użyciem tylko tradycyjnego obciążenia, gdy intensywność treningowa (% 1RM) jest taka sama [37].

Zastosowanie zjawiska PAPE jest szerokie - protokoły mogą być stosowane jako element pobudzający przed zawodami sportowymi (aplikowany od kilku do kilkudziesięciu godzin przed zawodami), część rozgrzewki przed zawodami lub ponowną rozgrzewkę podczas zawodów [41]. Jednakże, najczęstszą formą aplikacji PAPE zdaje się być metoda treningu kompleksowego, gdzie ćwiczenie z wysoką intensywnością jest aplikowane jako CA, a po CA wykonywane jest ćwiczenie plyometryczne lub ukierunkowane na moc [42, 43]. Następnie występuje przerwa wypoczynkowa i zazwyczaj wykonywanych jest kilka serii ćwiczeń. W kontekście zastosowania PAPE metoda ta bywa również niepoprawnie nazywana treningiem kontrastowym [44], podczas gdy trening kontrastowy różni się od treningu kompleksowego, ponieważ zakłada on wykonanie najpierw serii ćwiczeń o wysokiej intensywności treningowej, a następnie przejście do ćwiczeń plyometrycznych lub ukierunkowanych na moc [43]. Istnieją dowody naukowe na skuteczność treningu kompleksowego w zwiększaniu zdolności wysiłkowych [42, 43, 45, 46], a Freitas i wsp. [42] sugerują, że zastosowanie tego typu treningu może być szczególnie zasadne u sportowców startujących w dyscyplinach, w których zdolności skocznościowe są kluczowe dla odniesienia sukcesu sportowego. Wprowadzenie treningu kompleksowego jako element treningowy u siatkarzy wydaje się być racjonalne z racji na wysokie wymagania w kontekście zdolności skocznościowych [47] - zwiększenie wysokości wyskoku może wpływać na skuteczność działań techniczno-taktycznych [48]. Pomimo niewątpliwej użyteczności zastosowania zjawiska PAPE w treningu wyczynowych siatkarzy liczba dowodów naukowych jest ograniczona - dotychczas autorzy skupiali się na badaniu wyczynowych siatkarek [49, 50, 51], a zgodnie z moją wiedzą publikacje wchodzące w cykl tej dysertacji doktorskiej były pierwszymi w tej tematyce, które zostały przeprowadzone na wyczynowych siatkarzach [52, 53].

3. Uzasadnienie podjęcia badań i cel pracy

3.1 Uzasadnienie podjęcia badań

Głównym powodem podjęcia badań było wypełnienie luki w badaniach naukowych dotyczących zastosowania zjawiska PAPE w treningu sportowym. Zastosowanie treningu kompleksowego w siatkówce, która opiera się na zdolnościach skocznościowych jest w pełni racjonalne [42], jednak jak dotąd autorzy badań nie poświęcali mu szczególnej uwagi pomimo mnogości badań w tematyce PAPE. Zastosowanie zjawiska PAPE w treningu sportowym zgodnie z dotychczasowymi doniesieniami naukowymi [8, 9, 15] jest trudne ze względu na konieczność zastosowania długiej przerwy wypoczynkowej między CA a ćwiczeniem dynamicznym. Trenerzy (szczególnie w profesjonalnym sporcie) mają często ograniczony czas na realizację danej jednostki treningowej i przerwy wypoczynkowe 5-minutowe lub dłuższe, aby zaobserwować zjawisko PAPE wykluczają zastosowanie treningu kompleksowego zgodnie z obowiązującymi wytycznymi. Biorąc pod uwagę powyższe aspekty zdecydowano się na badanie zjawiska PAPE i treningu kompleksowego z użyciem dopasowującego obciążenia, które wielokrotnie było stosowane w badaniach w kontekście PAPE [31-38]. Zastosowanie dopasowującego obciążenia może pozwolić na skrócenie czasu ICRI do 1,5-2 minut, co w kontekście zarządzania czasem i konstruowania jednostki treningowej może wpłynąć na decyzję trenerów i finalne wdrożenie tej metody treningowej. Z racji na trudności organizacyjne w przeprowadzaniu badań w grupie wyczynowych sportowców, część badań została przeprowadzona w grupie osób aktywnych fizycznie charakteryzujących się wysokim poziomem siły relatywnej, żeby możliwie jak najbardziej odwzorować ich charakterystykę [19]. Plan badań zakładał weryfikację skuteczności różnych protokołów PAPE u osób aktywnych fizycznie i następnie wykorzystanie najbardziej efektywnego protokołu w treningu wyczynowych siatkarzy.

3.2 Cel badań

Ogólnym celem przeprowadzonych badań była ocena skuteczności wybranych protokołów PAPE, z wykorzystaniem jako CA martwego ciągu ze sztangą trapezową i dopasowującego obciążenia, w zwiększeniu wysokości (i mocy) wyskoku u wyczynowych siatkarzy i osób aktywnych fizycznie (z wysokim poziomem siły relatywnej). Celem aplikacyjnym pracy było określenie skuteczności PAPE w treningu sportowym oraz opracowanie protokołu treningowego z użyciem PAPE do zastosowania w treningu sportowym. Szczegółowe cele badań zostały przedstawione przy opisie poszczególnych publikacji stanowiących pracę doktorską.

4. Metodyka i wyniki poszczególnych publikacji

4.1 Publikacja nr 1

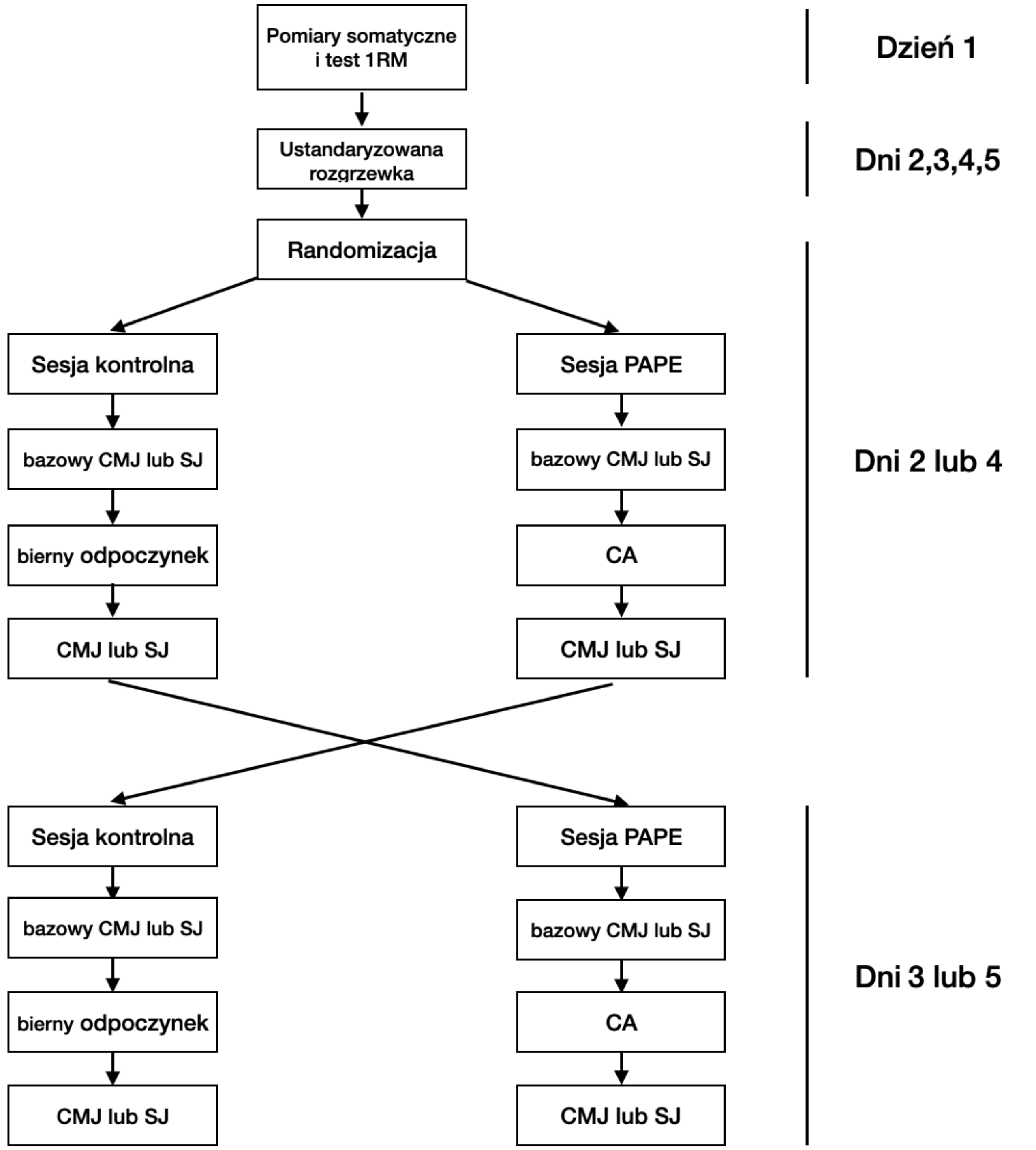
Masel, S. & Maciejczyk, M. Effects of Post-Activation Performance Enhancement on Jump Performance in Elite Volleyball Players. Appl. Sci. ***12****, 9054 (2022).*

Celem tej pracy było zbadanie efektywności opracowanego protokołu indukującego PAPE na wysokość wyskoku podczas dwóch rodzajów skoków tj. CMJ i SJ, a hipotezy badawcze zostały sformułowane następująco:

1. Zastosowane CA pozwoli na wywołanie efektu PAPE w grupie siatkarzy, zarówno w CMJ i SJ;
2. Obserwowana odpowiedź na CA wśród siatkarzy będzie zindywidualizowana.

W badaniach uczestniczyło 12 wyczynowych siatkarzy (wiek 23±2 lata; wysokość ciała 194,7±5,9 cm; masa ciała: 89,8±7,9 kg; zawartość tkanki tłuszczowej 14,7±3,7%) o wysokim poziomie siły relatywnej (1,92±0,12 kg/kg masy ciała). Badania były przeprowadzone w układzie naprzemiennym (cross-over) i trwały 5 dni, a badani uczestniczyli w jednej sesji, zawierającej pomiary somatyczne i testowanie 1RM, dwóch sesjach eksperymentalnych i dwóch sesjach kontrolnych (Ryc 1.).

Tworząc protokół badawczy wzięto pod uwagę dotychczasowe doniesienia naukowe dotyczące dopasowującego obciążenia w kontekście PAPE [31-37], w których użyte CA pozwoliło na wywołanie efektu PAPE. W pracy oceniono efekt PAPE na wysokość (i moc) skoku wertykalnego w dwóch odmiennych ćwiczeniach skocznościowych - SJ i CMJ, co było przedmiotem badań również w innej pracy [54], w której wykazano, że przy użyciu CA, opartego na pracy izometrycznej, podobny efekt PAPE na wysokość skoku był obserwowany w obu rodzajach wyskoku. Elementem innowacyjnym w tej pracy doktorskiej było zastosowanie martwego ciągu z użyciem sztangi trapezowej jako CA. Ten środek treningowy jest uznawany jako efektywna alternatywa do powszechnie stosowanego przysiadu ze sztangą [55] i jest powszechnie stosowany w treningu ze sportowcami. Niewątpliwą zaletą użycia tego środka treningowego jest wykonanie ćwiczenia w identycznym zakresie ruchu (każde powtórzenie rozpoczyna się uniesieniem ciężaru z podłogi), co jest ważne dla efektu PAPE [17]. Udowodniono również, że w przysiadzie ze sztangą na plecach głębokość przysiadu może determinować efekt PAPE [56]. Głębokość przysiadu (tj. zakres zejścia w dół) ze sztangą utrudnia również kontrolę wykonania technicznego przez trenującego. Liczba badań, gdzie zaimplementowano martwy ciąg z użyciem sztangi trapezowej jako CA jest niewielka, a ich wyniki nie są spójne [38, 57, 58, 59]. Jednocześnie tylko w jednym z przytoczonych badań [38] użyto jednocześnie tego środka treningowego i dopasowującego obciążenia i nie zaobserwowano efektu PAPE. W niniejszym badaniu CA polegało na wykonaniu 3 powtórzeń z intensywnością 80% 1RM, gdzie elastyczna guma, która została zaimplementowana jako AR, stanowiła ok. 15% 1RM. Przerwa wypoczynkowa przed wykonaniem ćwiczenia dynamicznego została zaplanowana na 90s. Do pomiaru wysokości skoku i mocy wykorzystano system Optojump (Włochy), bazujący na sensorach optycznych zlokalizowanych w listwie nadawczej i odbierającej, którego rzetelność została udowodniona naukowo [60].



Ryc. 1. Plan badań (1RM – jedno powtórzenie maksymalne; CA – conditioning activity; CMJ – countermovement jump; SJ – squat jump)

Normalność rozkładu została sprawdzona przez test Shapiro-Wilka, a jednorodność wariancji przez test Levena. Istotność różnic określono za pomocą ANOVA z powtarzanymi pomiarami i analizą post-hoc. Wielkość efektu została obliczona przy użyciu d Cohena.

Wyniki naszych badań nie potwierdziły hipotezy nr. 1 i wskazują na brak efektu PAPE dla grupy siatkarzy dla obu testów skocznościowych (CMJ i SJ). Jednakże, została potwierdzona hipoteza nr. 2 - wystąpiła indywidualna odpowiedź na zastosowane CA, a ten sam sportowiec może reagować odmiennie w różnych skokach przy użyciu tego samego CA. Ponadto, pomimo braku istotności statystycznej dla całej grupy, nasze badania wskazują na większą skuteczność użytego CA na wysokość skoku w SJ niż w CMJ. Większa liczba badanych zaprezentowała pozytywną odpowiedź na CA w SJ (8 z 11, 73%; jeden badany nie wykonał tego protokołu ze względu na uraz stawu skokowego) niż CMJ (6 z 12, 50%). Wyniki naszych badań wskazują na potencjalnie silniejszy efekt PAPE, jeśli ćwiczenie dynamiczne, polegało na wykonaniu takiego samego rodzaju pracy mięśniowej, jak podczas zastosowanego CA. Praca mięśniowa podczas SJ jest koncentryczna, wykonywana z pozycji izometrycznej, co idealnie odwzorowuje pracę mięśniową w martwym ciągu przy użyciu sztangi trapezowej. Natomiast praca mięśniowa podczas CMJ jest ekscentryczno-koncentryczna i możliwe jest, że bardziej efektywnym środkiem treningowym do wywołania efektu PAPE dla CMJ, mógłby być przysiad ze sztangą ze względu na ten sam charakter pracy mięśniowej. Pomimo braku istotności statystycznej wyniki tej pracy były istotne dla dalszej części badań, ponieważ pozwoliły na odrzucenie CMJ i wybranie SJ jako testu, który następnie był używany jako weryfikacja efektu PAPE.

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

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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

Citation: Masel, S.; Maciejczyk, M. Effects of Post-Activation Performance Enhancement on Jump Performance in Elite Volleyball Players. *Appl. Sci.* **2022**, *12*, 9054. https://doi.org/10.3390/app12189054

Academic Editors: Mark King and Mickey Scheinowitz

Received: 30 June 2022
Accepted: 6 September 2022
Published: 8 September 2022

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 deadlifts 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 deadlifts 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. A trap bar deadlift with accommodating resistance was used as a second conditioning activity. 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 ≥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.

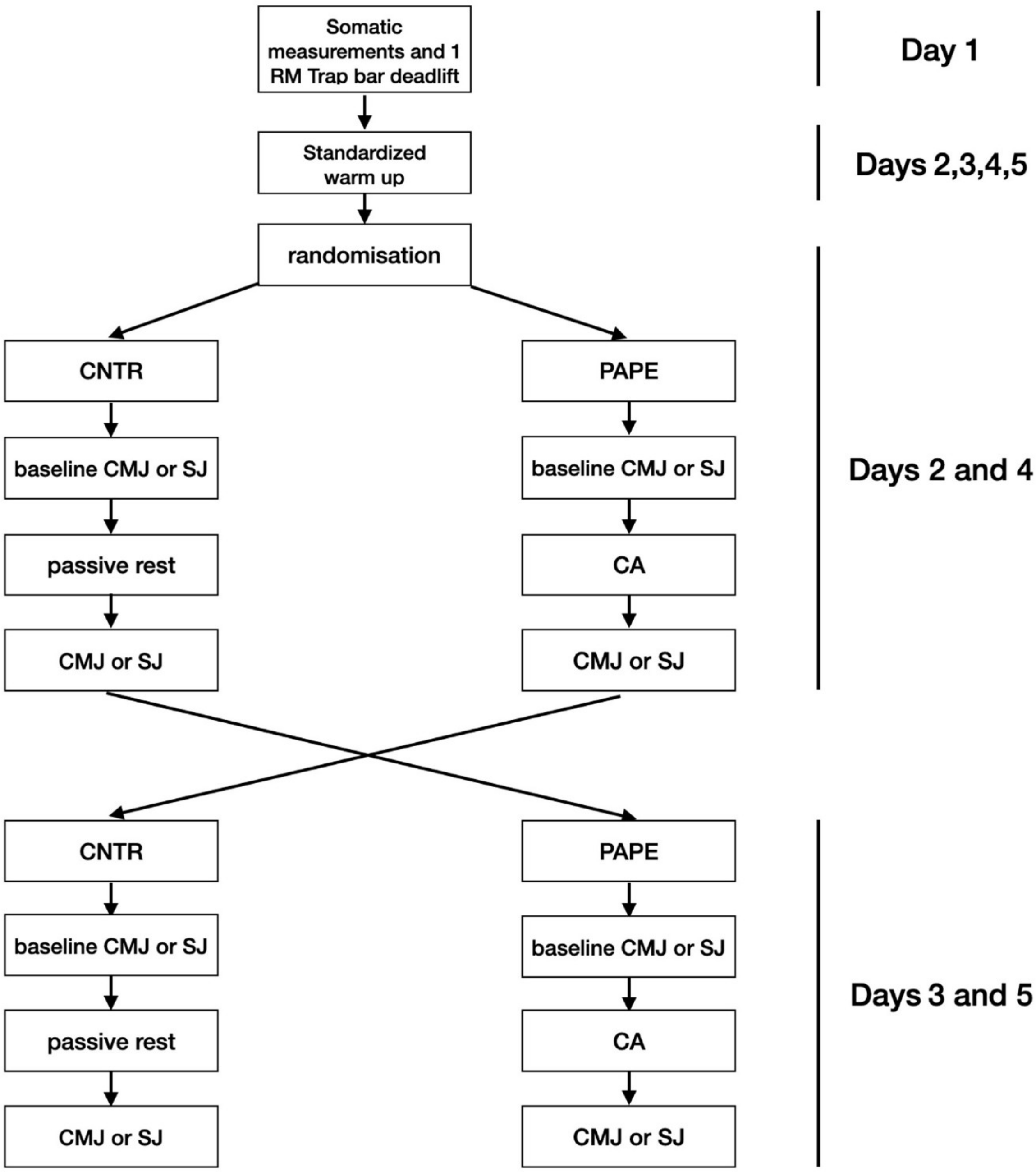

Figure 1. Study design. 1 RM—one-repetition maximum; CNTR—control condition; PAPE—experimental condition, CA—conditioning activity; CMJ—countermovement jump; SJ—squat jump.

2.2. 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, Germany).

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 warmup for two minutes, at which point 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 ± 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 ± 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 deadlifts 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.

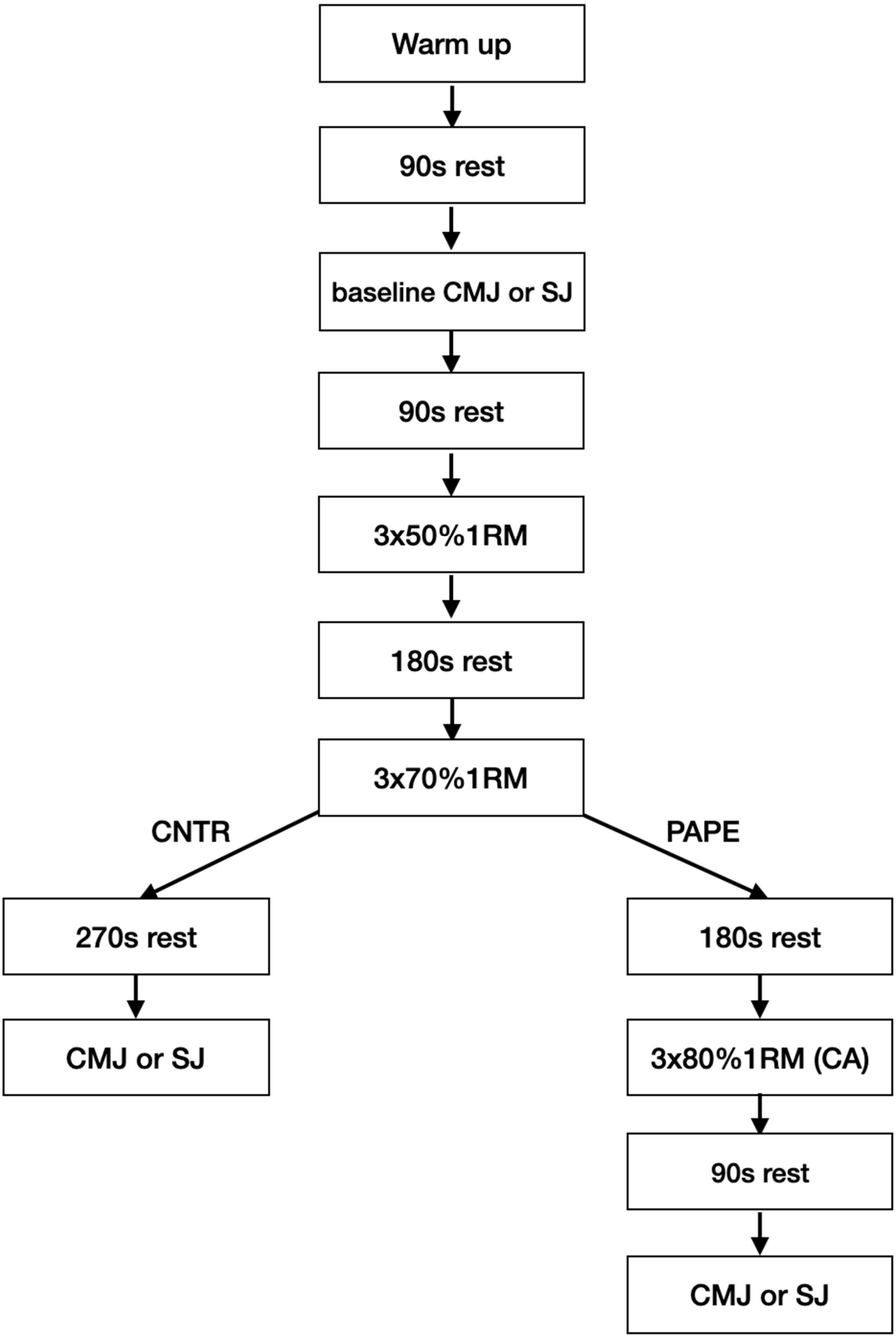

Figure 2. Flow chart of the investigated protocols.

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.

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).

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

Variable	Condition	Baseline	Post	Effect: condition F(p)	Effect: Time F(p)	Interaction F(p)	p: Post Hoc Pre–Post (Cohen's d)
	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
				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.

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).

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)
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.

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 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
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 ± 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 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.

Author Contributions: Conceptualization, S.M. and M.M.; formal analysis, S.M. and M.M.; investigation, S.M.; methodology, S.M. and M.M.; supervision, M.M.; writing—original draft, S.M. and M.M.; writing—review and editing, S.M. and M.M. All authors have read and agreed to the published version of the manuscript.

Funding: The APC was funded within the framework of a program of the Ministry of Science and Higher Education under the name, 'Regional Initiative for Perfection' during the period of 2019–2022 (Project No. 022/RID/2018/19; total funding: PLN 11,919,908).

Institutional Review Board Statement: 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 in accordance with the ethical standards of the Declaration of Helsinki (2013).

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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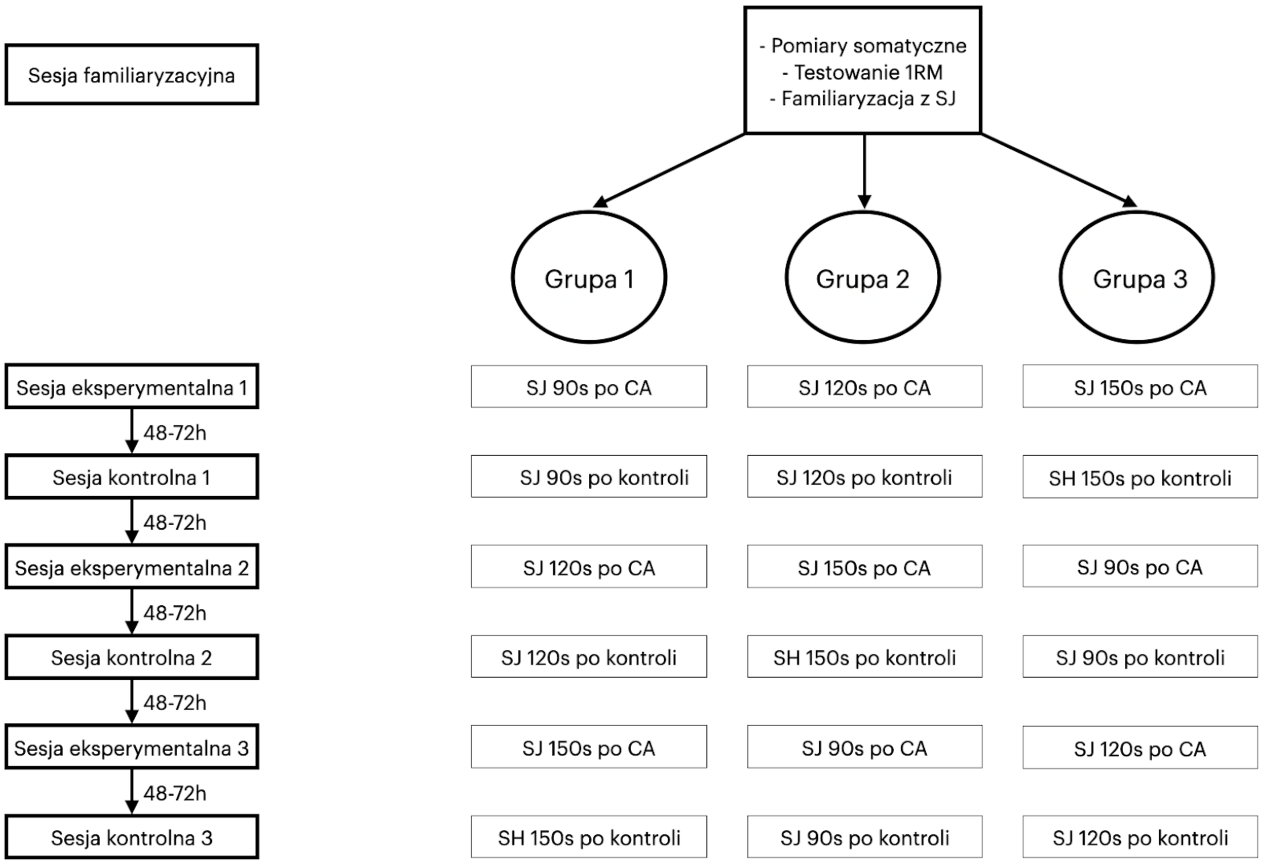
4.2 Publikacja nr 2

Masel, S. & Maciejczyk, M. Post-activation effects of accommodating resistance and different rest intervals on vertical jump performance in strength trained males. BMC Sports Sci. Med. Rehab. ***15*** *(2023).*

Przygotowując kolejny protokół badawczy do drugiej części badań wykorzystano doświadczenia zebrane z pierwszej części badań. Celem tej pracy było zbadanie efektywności protokołu PAPE z różnymi przerwami wypoczynkowymi na wysokość wyskoku w SJ i wyłonienie najskuteczniejszego protokołu do dalszej części badań. Przyjęto hipotezę, że efekt PAPE będzie obserwowany u badanych mężczyzn przy przerwach wypoczynkowych krótszych niż 180 sekund.

Badania zostały przeprowadzone w grupie osób aktywnych fizycznie, charakteryzujących się wysokim poziomem siły relatywnej. Założeniem było to, aby badana grupa była względnie zbliżona pod tym względem do grupy z pierwszej części badań. Zastosowane CA pozostało niezmienione, ale w związku z lepszą odpowiedzią na SJ w pierwszej części badań, postanowiono pozostawić tylko SJ do weryfikacji efektu PAPE. Główną zmianą w metodyce tej części badań było wprowadzenie różnych ICRI - oprócz 90s z części pierwszej zaimplementowane zostały również przerwy 120s i 150s.

W publikacji nr 2 wzięło udział 15 mężczyzn aktywnych fizycznie, regularnie uczestniczących w treningu siłowym (wiek 22,9±2,1 lata; wysokość ciała 182 ±6,5 cm; masa ciała: 80,4±9,8 kg; zawartość tkanki tłuszczowej 15,8±7,0%) o wysokim poziomie siły relatywnej (2,01 ±0,27 kg/kg masy ciała). Badanie miało charakter krzyżowy (cross-over) i badani uczestniczyli w jednej sesji familiaryzacyjnej, trzech sesjach eksperymentalnych i trzech sesjach kontrolnych w okresie 3 tygodni. Badania odbywały się o podobnej porze dnia (od 8 do 12), a po sesji zapoznawczej badani zostali podzieleni na 3 grupy po 5 osób i wykonywali kolejne sesje eksperymentalne i kontrolne w różnej kolejności (Ryc. 2)



Ryc. 2. Plan badań (1RM – jedno powtórzenie maksymalne; CA – conditioning activity; SJ – squat jump)

Rozkład danych został sprawdzona za pomocą testu test Shapiro-Wilka, a jednorodność wariancji z wykorzystaniem testu Levena. Do określenia istotności statystycznej użyto ANOVA z powtarzanymi pomiarami (istotność określono na poziomie $p < 0,05$), a w przypadku istotności statystycznej analiza post-hoc została przeprowadzona testem NIR. Wielkość efektu została określona przy użyciu d Cohena.

Wyniki naszych badań częściowo potwierdziły naszą hipotezę: efekt PAPE wystąpił tylko przy przerwie wypoczynkowej wynoszącej 90 sekund. Ponadto, została zauważona następująca tendencja - im dłuższy czas odpoczynku między CA a SJ tym mniejszy był obserwowany efekt PAPE. Istotne statystycznie zmiany ($p=0,046$) w wysokości skoku wystąpiły tylko w próbie z 90-sekundowym wypoczynkiem, natomiast nieistotne zmiany odnotowano w próbie ze 120-sekundową przerwą pomiędzy CA a testem ($p=0,166$) oraz w próbie ze 150-sekundową przerwą ($p=0,745$). Wyniki naszych badań wskazują, że przy użyciu tego rodzaju protokołu, przerwa wypoczynkowa wynosząca 90 sekund, wydaje się być optymalna do wywołania efektu PAPE. Wydłużenie odpoczynku do 120s może potencjalnie również być skuteczne, lecz nie ma wskazań do dalszego wydłużania przerwy ponad 120s. Co ciekawe, próba 90-sekundowa, która okazała się nieskuteczna dla grupy do wywołania efektu PAPE w pierwszej części badań była jedyną próbą, która okazała się być efektywna w indukowaniu PAPE.

Masel *et al. BMC Sports Science, Medicine and Rehabilitation* (2023) 15:65
https://doi.org/10.1186/s13102-023-00670-y

BMC Sports Science, Medicine and Rehabilitation

RESEARCH

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Post-activation effects of accommodating resistance and different rest intervals on vertical jump performance in strength trained males

Sebastian Masel[1*] and Marcin Maciejczyk[1]

Abstract

Background Post-activation potentiation performance (PAPE) is a physiological phenomenon that has been studied numerously but the researchers are still seeking for the optimal application methods. The accommodating resistance was found to be an effective training method to acutely enhance subsequent explosive performance. The purpose of this study was to evaluate the effects of performing a trap bar deadlift with accommodating resistance on squat jump (SJ) performance with different rest intervals (90, 120, 150s).

Methods The study had a cross-over design and fifteen strength-trained males (age 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) participated in one familiarization, three experimental and three control sessions within three weeks. The conditioning activity (CA) used in the study was a single set of 3 repetitions of a trap bar deadlift at 80% 1RM with approximately 15% 1RM of an elastic band. The SJ measurements were performed at the baseline and post-CA after 90 or 120 or 150s.

Results The 90s experimental protocol significantly improved ($p < 0.05$, effect size 0.34) acute SJ performance whereas 120 and 150 s experimental protocols did not significantly improve performance. The following tendency was observed - the longer the rest interval, the smaller the potentiation effect; p value for 90s (0.046), 120s (0.166), 150s (0.745).

Conclusions A trap bar deadlift with accommodating resistance and 90s rest interval can be used to acutely enhance jump performance. A 90s rest interval was found to be optimal to enhance subsequent SJ performance, but the potential rest interval extension to 120s could also be taken by strength and conditioning coaches as the PAPE effect is highly individual. However, exceeding the rest interval to more than 120s may not be effective in optimising the PAPE effect.

Keywords Variable resistance, Strength training, Post-activation performance enhancement, Trap bar deadlift, Power

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Introduction

Strength and conditioning coaches are constantly seeking optimal training methods to enhance power performance and one of them is using post-activation performance enhancement (PAPE) effect - a specific conditioning activity (CA) is applied prior to a similar movement task to obtain increased acute power. The enhancement is associated with potential mechanisms such as increased muscle temperature, muscle fiber water content and muscle activation [1] and is usually observed after 6–10 min after CA [1, 2] or 3–7 min considering specifically vertical jump performance [3]. However, the PAPE effect is highly individual and many factors need to be considered [2, 4, 5] to make it effective regarding training intervention (e.g. volume of a CA [6]) and characteristics of the individual (e.g. strength level [7]).

A variety of PAPE application methods were found to enhance performance. Any type of muscle contraction can be effective (only eccentric [8–10], isometric [10–14], eccentric-concentric [15] and only concentric [16]) as well as using additional training equipment such as flywheel devices [17, 18] or accommodating resistance [18–25]. It is important to determine the most efficient one for the individual as it should be as specific as possible to its sport. It could vary from e.g. an athlete warming up for a swimming competition having all possible training equipment (e.g. using a flywheel) or no equipment at all (e.g. using isometrics) to an athlete executing a strength and conditioning session in the gym to improve his power performance (e.g. using accommodating resistance). Introducing training intervention with a prolonged rest interval as suggested in the studies [1–3] between CA and a subsequent explosive task could diminish any potential benefits of PAPE as it could be too time-consuming and also influence training motivation. It was proved that an individual could effectively implement active recovery during an extended rest interval without losing the potentiation effect [26] but using accommodating resistance is also a well-described method that may allow reduction of the rest interval between CA and an explosive exercise [27]. Because time management is one of the crucial components of the training process, reducing the length of the rest interval to less than 3 min (suggested by Dobbs et al. [3] to be a minimum value for enhancing jump performance) may be especially important for strength and conditioning coaches. Therefore, the current evidence [19, 20, 22, 25] suggests that designing PAPE protocols with the use of accommodating resistance seems to be an optimal method in obtaining the potentiation effect with the simultaneous time management benefit.

The accommodating resistance method was repeatedly found to be effective in inducing PAPE [18–25]. With its ability to achieve greater velocity in the concentric portion of the lift and greater power output than using traditional resistance [28], it may allow enhanced performance with a relatively shorter rest interval of 90-120s between CA and a subsequent explosive task [19, 20, 22, 25]. Moreover, certain studies proved that the accommodating resistance was more effective in comparison to free weight resistance [21, 23, 25] in inducing PAPE. Even though a trap bar deadlift was suggested as being an effective training alternative to a squat, [29] there is little evidence of a trap bar deadlift inducing PAPE [30–34]. The results of the studies using only traditional resistance are not consistent - two of them showed no PAPE effect [30, 31], whereas one of them enhanced subsequent explosive performance. Furthermore, a trap bar deadlift was more effective compared to a back squat [32]. Additionally, there are two studies [33, 34] where the accommodating resistance was used while performing a trap bar deadlift. Both of them [33, 34] involve a vertical jump component as an explosive exercise. It may be especially important as monitoring vertical jump height is a method for evaluating the effectiveness of the training program [35]. The first one [33] was not effective in enhancing subsequent countermovement jump (CMJ) performance and the second [34] was partially effective and showed a higher effect for a squat jump (SJ) than CMJ as a higher percentage of the players responded positively (improvement in absolute values by ≥0.8 cm between baseline and post-CA jumps) in SJ (73%) than CMJ (50%). Therefore, more studies are necessary to evaluate the real potential of a trap bar deadlift with accommodating resistance as a CA to reduce the rest interval between CA and a subsequent explosive task.

Even though a trap bar deadlift is a frequently used exercise, the current evidence of its use with accommodating resistance on PAPE is very limited and so far the outcome has been negative. Therefore, the main objective of this study was to evaluate the effects of performing a trap bar deadlift with accommodating resistance as a CA on jump performance with rest intervals shorter than 3 min between CA and a subsequent explosive task. An additional purpose of the study was to determine if a trap bar deadlift combined with accommodating resistance could be an effective CA as the current evidence did not support it [33, 34]. SJ was implemented in the study as it starts from an isometric position as well as a trap bar deadlift. It was hypothesized that PAPE could be induced with rest intervals shorter than 3 min.

Materials and methods

Study design

It was a cross-over study and the participants took part in one familiarization, three experimental and three control sessions within three weeks. After the familiarization session, to introduce randomization, participants were divided into three groups of five participants and performed the study in three different orders (Fig. 1). Randomization was carried out in a following manner: during the familiarization session each of the participants chose one of three scraps of paper with unseen “G1”, “G2” or “G3” and was assigned to perform the study in that order. All daily sessions were performed at a similar time of day (from 8 a.m. to 12 a.m.) with 48-72 h apart and it was the first participants’ physical activity of the day. The first experimental session was performed after 72-96 h after a familiarization session due to intensity of the measurements. The familiarization session included somatic measurements, determination of one-repetition maximum (1RM) in a trap bar deadlift and familiarization with a squat jump (SJ) test. The experimental sessions included a standardized warm-up, baseline SJ, PAPE condition with CA and post-CA SJ (after 90 or 120 or 150s); the control sessions included a standardized warm-up, baseline SJ, control condition without CA and post-control SJ (after 90 or 120 or 150s). Conditioning activity used in the study was a single set of 3 repetitions of a trap bar deadlift at 80% 1RM with approximately 15%1RM of an elastic band and the rest of the load was provided by traditional resistance.

There were the following inclusion criteria: (a) regular participation in strength training (at least 3 times a week); (b) relative strength level in a trap bar deadlift ≥ 1.5 kg/body mass; c) lack of injuries or other health contraindications in the last 6 months. Participants were recruited in the following manner: an announcement of the recruitment of volunteers was carried out with the aims of the study and inclusion criteria and therefore, the participants eligible for the study were chosen to participate. Participants were instructed to follow their normal dietary, supplement, training and sleeping habits during the study. All participants were informed about the study protocol, benefits and potential risks of the study. They voluntarily took part in the experiment, providing signed informed consent and were allowed to withdraw from the experiment at any moment. The Bioethics Committee accepted the study protocol (Regional Medical Chamber in Kraków, opinion no: 1/KBL/OIL/2022) which was performed according to the ethical standards of the declaration of Helsinki 2013.The sample size was calculated a priori using G*Power 3.1 statistical software (Dusseldorf, Germany) with 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

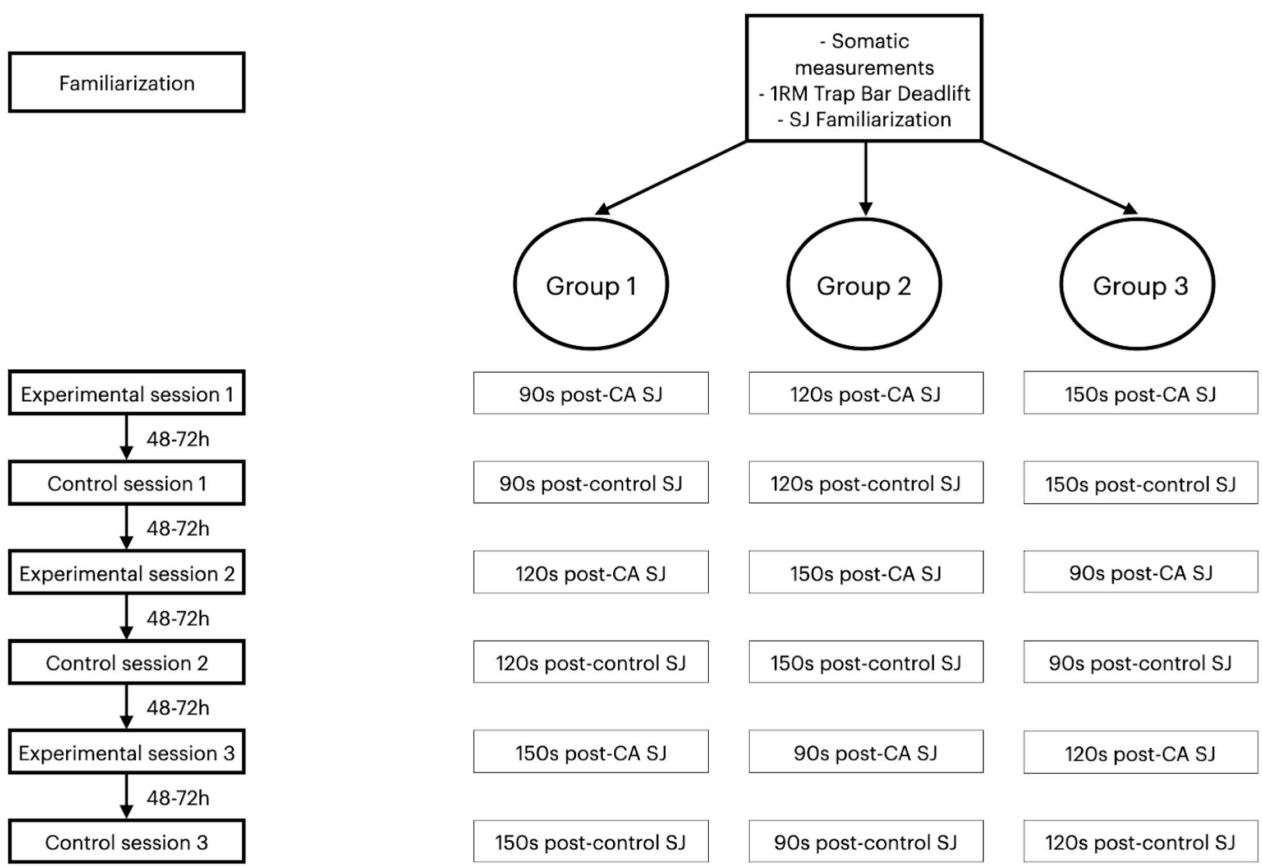

Fig. 1 Study design. 1 RM - one repetition maximum; CA - conditioning activity; SJ - squat jump

between measurements of 0.50. A minimum sample size of 15 individuals was obtained.

Participants

Participants of the study were fifteen strength-trained males (age 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) with various sport backgrounds (6 in volleyball, 3 in football, 1 in powerlifting, 1 in fencing, 1 in sprinting, 1 in cycling, 1 in crossfit, 1 in calisthenics). Originally, sixteen participants were willing to participate in the study but one participant was excluded from taking part in the study after 1RM measurements due to an insufficient relative strength level (approximately 1.4 kg/body mass).

Warm-up

Each session started with a standardized warm-up that included: 10 min of cycling on a cycle ergometer (Monark, Sweden) at a heart rate of 100–120 bpm; then a set of dynamic stretching was performed which consisted of 3 exercises of 10 repetitions each: knee to chest with calf raise; heel to buttocks with calf raise; hip external rotation with calf raise. Total duration of the standardized warm up was approximately 15 min.

Familiarization session

The familiarization session began with the somatic measurements - body height was measured using 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). All the measurements were performed barefoot and participants were instructed to stand still and distribute their body weight evenly on the platform.

After somatic measurements, 1RM determination in a trap bar deadlift was executed as previously described [34]. Participants performed a standardized warm-up and one minute after the standardized warm-up participants began performing a trap bar deadlift warm-up, starting with 10 repetitions with a load of 25 kg. After that, participants performed 3 to 4 sets of 3 repetitions, increasing the load with each set by 10–15% until they reached approximately 80% of an estimated 1RM. Then participants performed solely 1 repetition with an increased load by 5–10 kg for each subsequent attempt until they reached their 1RM (were unable to perform a lift with a proper technique). Sets of 3 repetitions included rest intervals of three minutes, whereas rest intervals between single repetition sets were 4–5 min. The participants were instructed to perform each repetition with a maximal velocity in the concentric phase of the lift and controlled eccentric phase (approximately 2s of eccentric phase). All repetitions were performed from the floor level (with high handles of a trap bar). The mean relative 1RM in a trap bar deadlift amounted to 2.01±0.27 kg/body mass.

After the 1RM determination, the participants performed the familiarization with the squat jump test. Each of the participants executed the SJ test 3 to 5 times depending on how quickly the participant learned the movement pattern.

Squat jump measurement

Jumping tests were performed using OptoJump (Italy) technology - an optical measurement system that consists of a transmitting and receiving bar and was shown to be a valid and reliable tool for the assessment of vertical jump height [36]. SJ testing was performed as previously described [34]. During SJ, participants were instructed to perform a downward movement until they reach approximately 90° of knee flexion, then an isometric hold of 2 s and a jump from an isometric position. All the jumps were performed with arms placed on the hips and participants were forbidden to move them during the test. Because SJ is a test from an isometric position, participants were forbidden to perform another downward movement after an isometric hold of 2 s. The participants were allowed to choose the width of their stance while performing a test. During the familiarization with the test and throughout the whole duration of the study, the isometric hold at the bottom of the squat was counted and the jumping command was verbalized ("1… 2… JUMP") by the supervisor of the study to avoid improper execution of the test (34).

Experimental and control sessions

After the familiarization session, the participants performed three experimental and three control sessions. Control sessions took approximately 25 min and experimental sessions approximately 30 min. The participants began each session with an identical standardized warm-up and 90s after the warm-up performed baseline SJ. Then, 90s after baseline SJ, they performed a single set of 3 repetitions at 50% 1RM. In control protocols, depending on the day, participants performed post-control SJ after 90 or 120 or 150 s. In experimental protocols, after 180 s of recovery, participants performed a conditioning activity of the study - a single set of 3 repetitions of a trap bar deadlift at 80% of 1RM with approximately 15% 1RM of an elastic band. Then, depending on the day, participants performed post-CA SJ after 90 or 120 or 150 s (Fig. 2).

To assess an adequate accommodating resistance, four types of brand new (to avoid potential loss of band tension) elastic bands of different tension were used throughout the study. The resistance of the band was

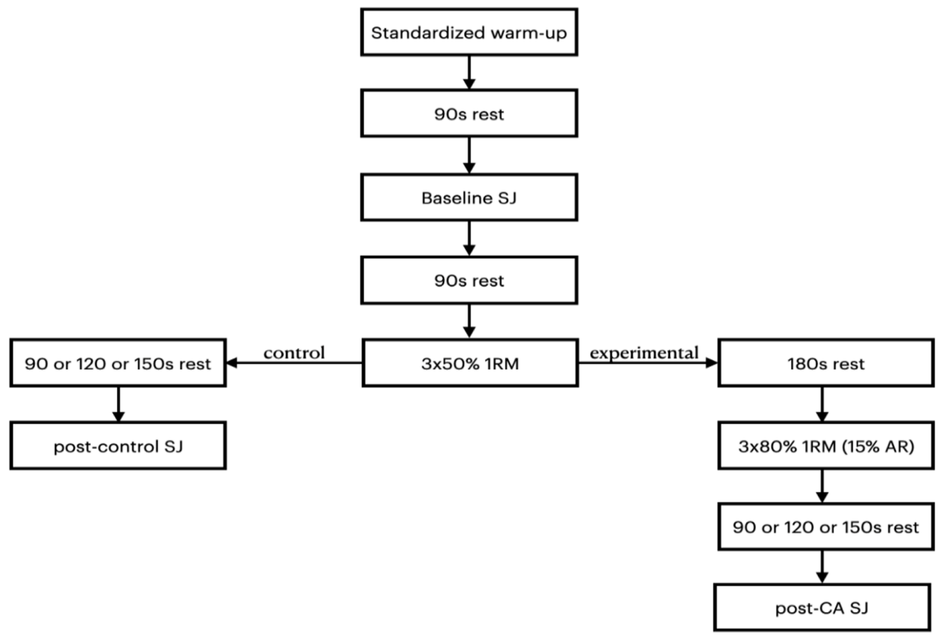

Fig. 2 Study flow

calculated as the median of the range of the resistance suggested by the producer. The thickness of a band was appropriate to a participant performing a CA in addition to a traditional resistance in obtaining the intended percentage of 1RM. Throughout the protocols, two repetitions of SJ were performed in the same manner as described in the section before and the repetition with a higher value of jump height (JH) was kept for the statistical analysis.

Statistical methods

All data is presented as mean and standard deviation (SD). Data distribution was checked using the Shapiro–Wilk test. Homogeneity of variance within the groups was tested via Levene's test (variance of the analyzed parameters was similar in both groups). The ANOVA with repeated measures (analyzed factors: condition [PAPE vs. control], time [baseline vs. post] and interaction between these factors) was used to assess 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 the LSD test. 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) [37]. Statistical analysis was performed using Statistica 12.0 software (StatSoft, Tulsa, OK, USA).

Results

Analyzing the data, a significant interaction was observed in all the parameters of the jump in PAPE condition with a 90s rest interval ($p=0.046$). Conditions with 120s ($p=0.166$) and 150s ($p=0.745$) did not significantly improve JH. Post-hoc analysis indicated significant changes in baseline versus post measurements in the PAPE condition, whereas the control condition did not indicate it (Table 1).

However, it is worth noting that the results of PAPE showed the following tendency - the longer the rest interval, the smaller the potentiation effect. Also, pre to post-CA changes in mean values in JH are similar for 90s (1.5 cm; 36.6±4.3 to 38.1±4.4) and 120s PAPE conditions (1.2 cm; 36.4±4.5 to 37.6±4.4).

Discussion

The results of our study showed that the rest interval of 90s was effective in enhancing subsequent jump performance but the extension of the rest interval to 120-150s was not effective. A single set of a trap bar deadlift with accommodating resistance as a CA can be an effective way to enhance subsequent explosive performance with a relatively short rest interval (90s) between these activities.

To our knowledge, this is the first study that examined the use of accommodating resistance and various rest intervals shorter than 3 min (90, 120, 150s) between CA and a subsequent explosive exercise. Additionally, a trap bar deadlift was used as a CA that at this point was not excessively studied regarding PAPE. Our results

Table 1 Results of jumping tests after applicated CA with different (90, 120, 150s) rest intervals (presented as mean ± SD)

Variable	Condition	Baseline	Post	Effect: condition F(p)	Effect: Time F(p)	Interaction F(p)	p: post-hoc pre-post (Cohen's d)
			90s				
JH (cm)	PAPE	36.6 ± 4.3	38.1 ± 4.4	0.174 (0.680)	3.030 (0.092)	4.342 (0.046)	0.01 (0.34)
	CNTR	36.7 ± 4.7	36.6 ± 5.0				0.81 (0.02)
FT (s)	PAPE	0.545 ± 0.032	0.557 ± 0.033	0.204 (0.655)	2.484 (0.126)	4.371 (0.046)	0.01 (0.37)
	CNTR	0.546 ± 0.036	0.544 ± 0.038				0.72 (0.05)
RAP (W/kg)	PAPE	15.2 ± 1.0	15.8 ± 1.0	0.429 (0.517)	4.406 (0.044)	4.212 (0.049)	0.01 (0.6)
	CNTR	15.3 ± 1.0	15.3 ± 1.3				0.97 (0)
			120s				
JH (cm)	PAPE	36.4 ± 4.5	37.6 ± 4.4	0.076 (0.785)	3.286 (0.079)	2.022 (0.166)	NS
	CNTR	36.5 ± 4.6	36.6 ± 4.6				NS
FT (s)	PAPE	0.544 ± 0.033	0.553 ± 0.033	0.090 (0.766)	2.884 (0.100)	2.095 (0.158)	NS
	CNTR	0.545 ± 0.034	0.545 ± 0.0.34				NS
RAP (W/kg)	PAPE	15.2 ± 1.3	15.6 ± 1.3	0.111 (0.741)	3.582 (0.068)	1.312 (0.261)	NS
	CNTR	15.2 ± 1.3	15.3 ± 1.4				NS
			150s				
JH (cm)	PAPE	36.7 ± 5.1	36.8 ± 4.6	0.021 (0.885)	0.489 (0.490)	0.107 (0.745)	NS
	CNTR	36.3 ± 5.0	36.7 ± 5.1				NS
FT (s)	PAPE	0.546 ± 0.038	0.547 ± 0.035	0.028 (0.867)	0.453 (0.506)	0.042 (0.839)	NS
	CNTR	0.543 ± 0.037	0.545 ± 0.038				NS
RAP (W/kg)	PAPE	15.4 ± 1.3	15.5 ± 1.2	0.086 (0.771)	0.831 (0.369)	0.153 (0.699)	NS
	CNTR	15.3 ± 1.4	15.3 ± 1.4				NS

JH - jump height; FT - flight time; RAP - relative average power; NS (non-significant).

are in agreement with multiple studies proving a positive influence of the use of accommodating resistance in enhancing subsequent explosive performance [18–25]. Originally, the meta-analysis by Wilson et al. [2] suggests using rest intervals of 6–10 min for the PAPE effect to occur and the meta-analysis by Dobbs et al. [3] 3–7 min, considering subsequent vertical jump performance. However, this study confirms the other data [19, 20, 22, 25] where the use of accommodating resistance allowed reduction of the rest interval between the CA and the subsequent explosive task to less than 180 s. One of the potential explanations of this phenomenon may be that the use of accommodating resistance generated the lesser fatigue than with traditional resistance and therefore allowed the potentiation effect to occur faster.

Our study also proved that extending the rest interval, between a CA and subsequent vertical jump to more than 90s had the following tendency - the longer the rest interval, the smaller the potentiation effect. A significant difference was detected between the baseline and post-CA jumps for 90s condition, close to a significant difference for 120s condition and far from being significant for 150s condition. The use of accommodating resistance and the rest interval of 90s was already proved to be effective using a squat as a CA [19, 22] and not effective using a trap bar deadlift as a CA [33, 34]. The rest interval of 120s was effective once [21] and not effective once [25], whereas the rest interval of 150s was not studied at this point. Even though the performance improvements using a rest interval of 120s were not statistically significant, it can be observed that there is a small difference between pre to post-CA changes in mean values for 120s and 90s (1.5 to 1.2 cm).

An interesting observation is that the exact rest interval (90s) with the same CA proposed in the other study [34] that was not effective in inducing PAPE turned out to be the only one significantly improving performance in this study. The authors suggested that a potential limitation was a sample size, as only 11 participants performed a condition with SJ. However, in this study the required sample size was calculated and the number of 15 individuals was obtained. In the above-mentioned study [34] it was impossible to calculate the required sample size as the participants needed to perform the same type of a training program to meet the criteria of the homogeneity of the group. The other difference between these studies is the use of four types of elastic bands in this study in contrast to only one used in the previous one [34]. That could allow adjusting more effectively a load to a given individual that is a key element in optimizing PAPE as the intensity of a CA is an important component of an effective PAPE protocol [2]. Additional considerations were made regarding the results of the second study that examined the use of a trap bar deadlift and accommodating resistance [33]. That study [33] used very high intensity of a CA (70% of free-weight resistance and 23%

of accommodating resistance) that could generate excessive fatigue with a combination of short rest intervals (30, 90, 180s) in subsequent CMJ. Also, one could speculate if the group was sufficiently homogenous as there is a wide discrepancy considering 1RM measurements. The relative strength level in a trap bar deadlift was presented as 1.78±0.41 meaning there could be individuals not having sufficient relative strength level suggested by Seitz and Haff [7] to enhance PAPE. It was suggested that stronger individuals are able to express the PAPE effect earlier than weaker individuals [27]. That is exceptionally important considering the use of accommodating resistance and potential reduction of the rest interval between CA and a subsequent explosive task. Thus, the improved methodology of this study seems to be a critical reason for achieving a positive outcome with this type of CA.

As the use of accommodating resistance in PAPE was confirmed in the previous studies [19, 20, 22, 25] in reducing the rest interval in comparison with original recommendations [1–3], an idea to reduce the length of the rest interval to less than 90s could be an interesting direction for future research. Previous research by Wyland et al. [21] reported that a 60s rest interval with a CA of 5 sets of 3 repetitions of a back squat at 85% of 1RM (with 30% of the total resistance coming from elastic bands) did not enhance subsequent sprinting performance. On the contrary, the study by Mina et al. [23] where the same type of a CA was used as in the study by Wyland et al. [21] allowed to enhance subsequent CMJ after only 30s. The study by Scott et al. [33] also used the 30s rest interval but there was no PAPE effect. Possibly, the ideal combination for strength and conditioning practitioners would be to limit the rest interval to a minimum, optimally performing a subsequent explosive task right after a CA with the potentiation effect. Two studies [21, 25] investigated an immediate response (within 15 s) after a CA and both of them failed to show PAPE effect after such a short rest interval.

Accommodating resistance was proved to acutely enhance subsequent explosive performance in less than 180 s [19, 20, 22, 25] but there is no evidence which mechanisms allow shortening of the rest interval. Tillin and Bishop [4] stated that to determine potential PAPE response, an appropriate balance is necessary between type and parameters of the CA and fatigue induced by the CA. Excessive fatigue induced by the CA seems to be detrimental for subsequent explosive performance. Training status, load, mode and sets all potentially influence the PAPE response, but the length of the rest interval may be the most important component of the PAPE protocols [3]. Thus, the rest interval needs to be applied appropriately depending on the type of a CA. Wallace and Bergstrom [38] proposed potential mechanisms of accommodating resistance efficacy and one of them is reducing the large deceleration period of the concentric phase. It could explain why the use of accommodating resistance in the CA seems to generate less fatigue and allows us to observe the potentiation response in less than 180 s. In this study we did not evaluate the possible mechanisms of the observed phenomenon and that could be the subject of future studies.

This study has a practical recommendation for the practitioners that an enhancement effect is likely to occur in the 90-120s window after this type of CA and the additional extension of the rest interval seems to be sub-optimal. PAPE has an individual response and in fact various loading strategies may be effective in enhancing performance This is an important recommendation as it may allow avoidance of testing different protocols on the athletes before implementing this type of training method into their training program. However, despite the PAPE effect occurring in this study, the results should be applied with caution as the participants were not professional athletes. Their relative strength level (2.01±0.27 kg/body mass) matches the recommendations made by Seitz et al. [7] but not an ideal homogeneity of the group (different sport background) could be a potential limitation of the study. Additionally, in any further investigation researchers should consider determining the exact band tension in addition to having brand new elastic bands to match the intended training intensity as accurately as possible.

Limitations of the study

The study protocol did not involve the exact determination of the band tension. Even though the bands used in the study were new, the band tension could slightly vary between the participants due to different anthropometrics (body height). Additionally, in future studies researchers should try to recruit the participants within the same sport. A further investigation is needed to examine if the use of accommodating resistance could also be effective with rest intervals shorter than 90s. This type of research project would probably require testing different loading interventions such as various volumes and intensities of a CA and different percentages of 1RM coming from elastic bands.

Conclusions

A single set of a trap bar deadlift (three repetitions at 80% 1RM) with the use of accommodating resistance and 90s rest interval was effective in enhancing SJ performance in strength-trained males. Additionally, the following tendency could be observed - the longer the rest interval, the smaller the potentiation effect; p value for 90s (0.046), 120s (0.166), 150s (0.745). Thus, strength and conditioning specialists should consider not exceeding 120s rest interval with this type of CA in order to optimise the PAPE effect.

List of abbreviations

PAPE Post-activation potentiation enhancement
CA Conditioning Activity
1RM One repetition maximum
CMJ Counter-movement jump
SJ Squat jump

Acknowledgements
Not applicable.

Author contributions
SM collected data; SM and MM designed the research, analyzed and interpreted data, drafted, edited and revised the manuscript. Both authors approved the final paper version.

Funding
The authors declare there was no external funding.

Data availability
The datasets analyzed during the study are available from the corresponding author (SM) on reasonable request.

Declarations

Ethics approval and consent to participate
All participants were informed about the study protocol, voluntarily took part in the experiment and signed informed consent. All experimental protocols were 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.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Received: 26 January 2023 / Accepted: 10 April 2023
Published online: 24 April 2023

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Publisher's note

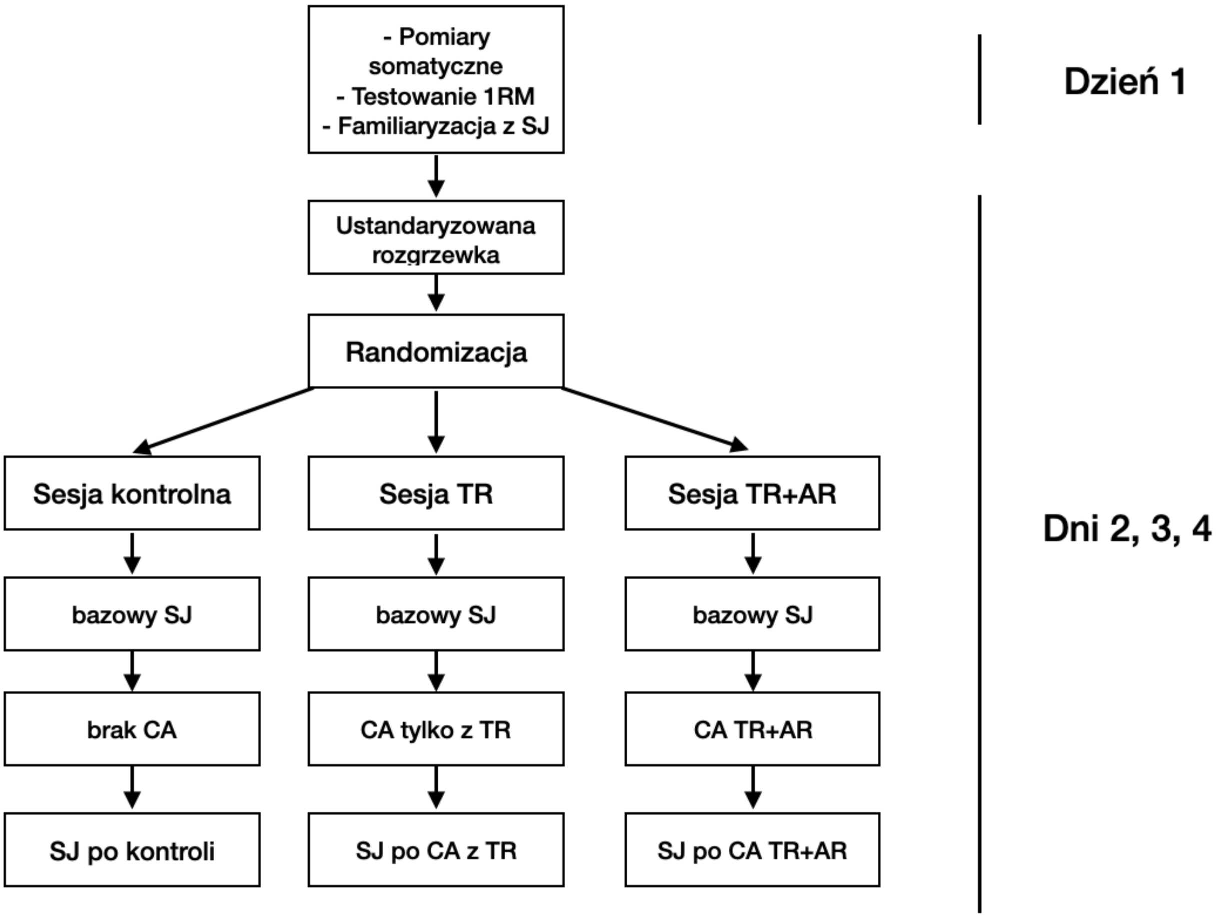
4.3 Publikacja nr 3

Masel, S. & Maciejczyk, M. Accommodating resistance is more effective than free weight resistance to induce post-activation performance enhancement in squat jump performance after a short rest interval. J. Exer. Sci. Fit. ***22****, 59-95 (2024).*

Protokół, który okazał się skuteczny dla grupy w drugiej części badań (z przerwą wypoczynkową pomiędzy CA a testem wysiłkowym wynoszącą 90s) stanowił podstawę do przeprowadzenia kolejnej części badań, w której zdecydowano się porównać odpowiedź PAPE w protokole z użyciem dopasowującego obciążenia (AR) z protokołem, w którym użyto tylko tradycyjnego obciążenia. Dotychczasowe doniesienia skupiały się na porównaniu odpowiedzi AR z obciążeniem inercyjnym [33, 36] i obciążeniem tradycyjnym [35, 37] i wszystkie z nich wykazały wyższość AR nad innym rodzajem obciążenia. Jednakże, wszystkie z nich używały przysiadu ze sztangą jako CA, a jak dotąd nie sprawdzono odpowiedzi przy użyciu martwego ciągu na sztandze trapezowej jako CA.

Celem tej pracy było porównanie skuteczności tego samego protokołu badawczego z wykorzystaniem tylko tradycyjnego obciążenia (TR) lub części obciążenia dobranego jako obciążenie dopasowujące (AR). Przyjęto hipotezę, że oba protokoły będą efektywne w wywołaniu PAPE z przerwą wypoczynkową pomiędzy CA a SJ wynoszącą 90 sekund.

W badaniach uczestniczyło 15 mężczyzn aktywnych fizycznie, regularnie uczestniczących w treningu siłowym (wiek 22,9±2,1 lata; wysokość ciała 182±6,5 cm; masa ciała: 80,4±9,8 kg; zawartość tkanki tłuszczowej 15,8±7,0%) charakteryzujących się wysokim poziomem siły relatywnej (2,01±0,27 kg/kg masy ciała). Badanie było zaplanowane jako cross-over study (badanie naprzemienne). Badani uczestniczyli w jednej sesji familiaryzacyjnej, jednej sesji kontrolnej i dwóch eksperymentalnych. Badania odbywały się o podobnej porze dnia (od godziny 8 do 12), a badani wykonywali próby w losowej kolejności (Ryc. 3).



Ryc. 3. Plan badań (1RM – jedno powtórzenie maksymalne; TR – użycie tradycyjnego obciążenia; TR+AR –użycie obciążenia dopasowującego; CA – conditioning activity; SJ – squat jump).

Wyniki badań nie potwierdziły postawionej hipotezy. Protokół z wykorzystaniem AR okazał się skuteczny w poprawie wysokości wyskoku w SJ, a użycie jedynie tradycyjnego obciążenia przy zastosowaniu relatywnie krótkiej przerwy wypoczynkowej (90s) nie pozwoliło na wywołanie efektu PAPE. Potwierdzone zostały również obserwacje innych autorów, gdzie wprowadzenie dopasowującego obciążenia dawało lepsze rezultaty niż użycie innego rodzaju obciążenia w kontekście odpowiedzi PAPE [33, 35, 36, 37].

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

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A R T I C L E I N F O

Keywords:
Variable resistance
Trap bar deadlift
Strength training
Potentiation
Power

A B S T R A C T

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

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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

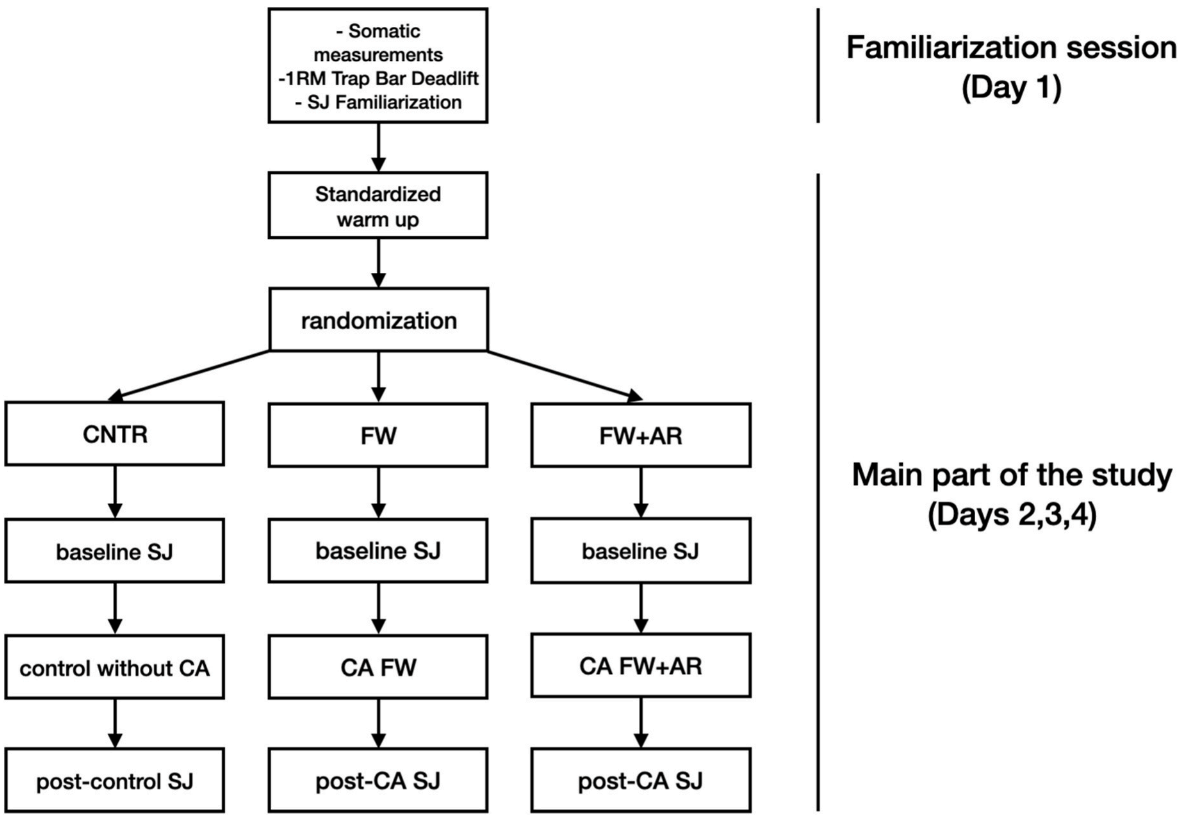

Fig. 1. Study design. 1RM - one repetition maximum; CA - conditioning activity; SJ - squat jump; FW + AR - condition with the addition of accommodating resistance; FW - condition with solely free weight; CNTR - control condition.

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.

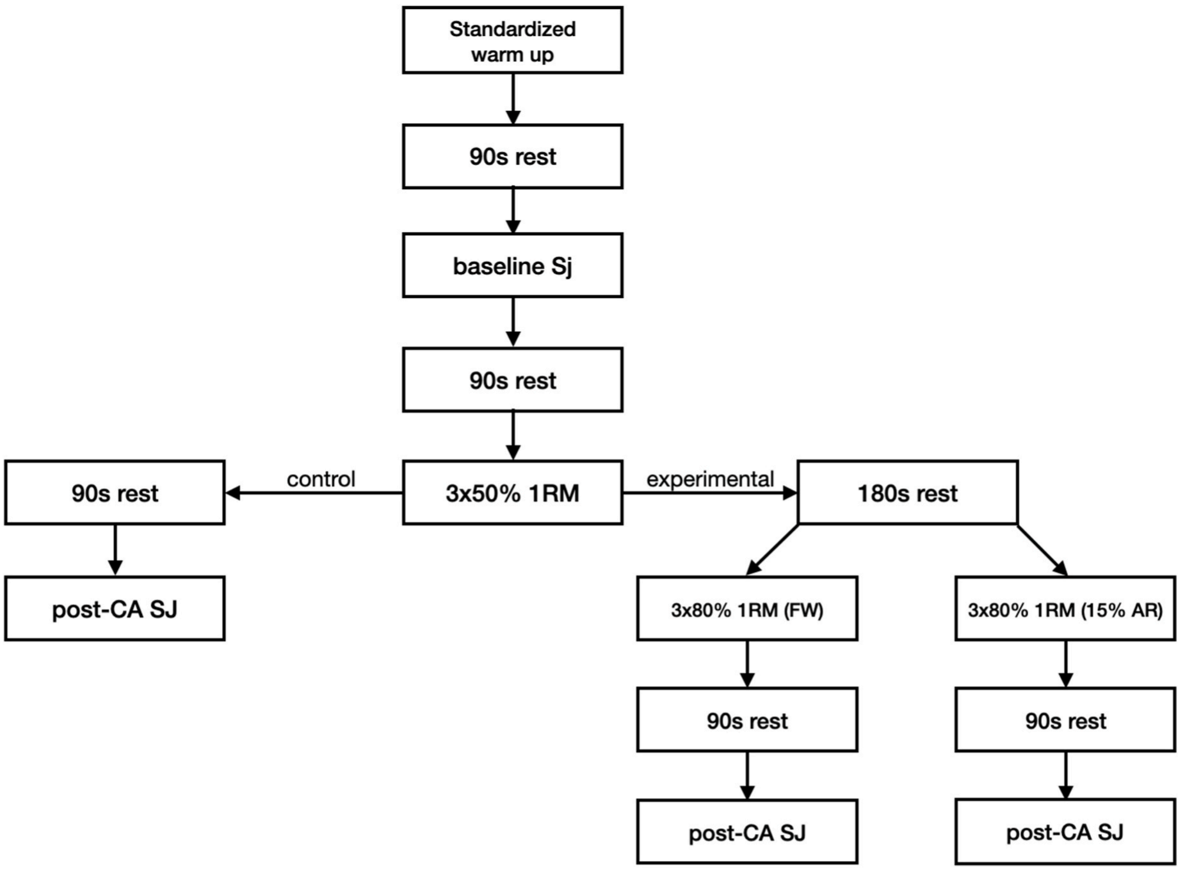

Fig. 2. Study flow.

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

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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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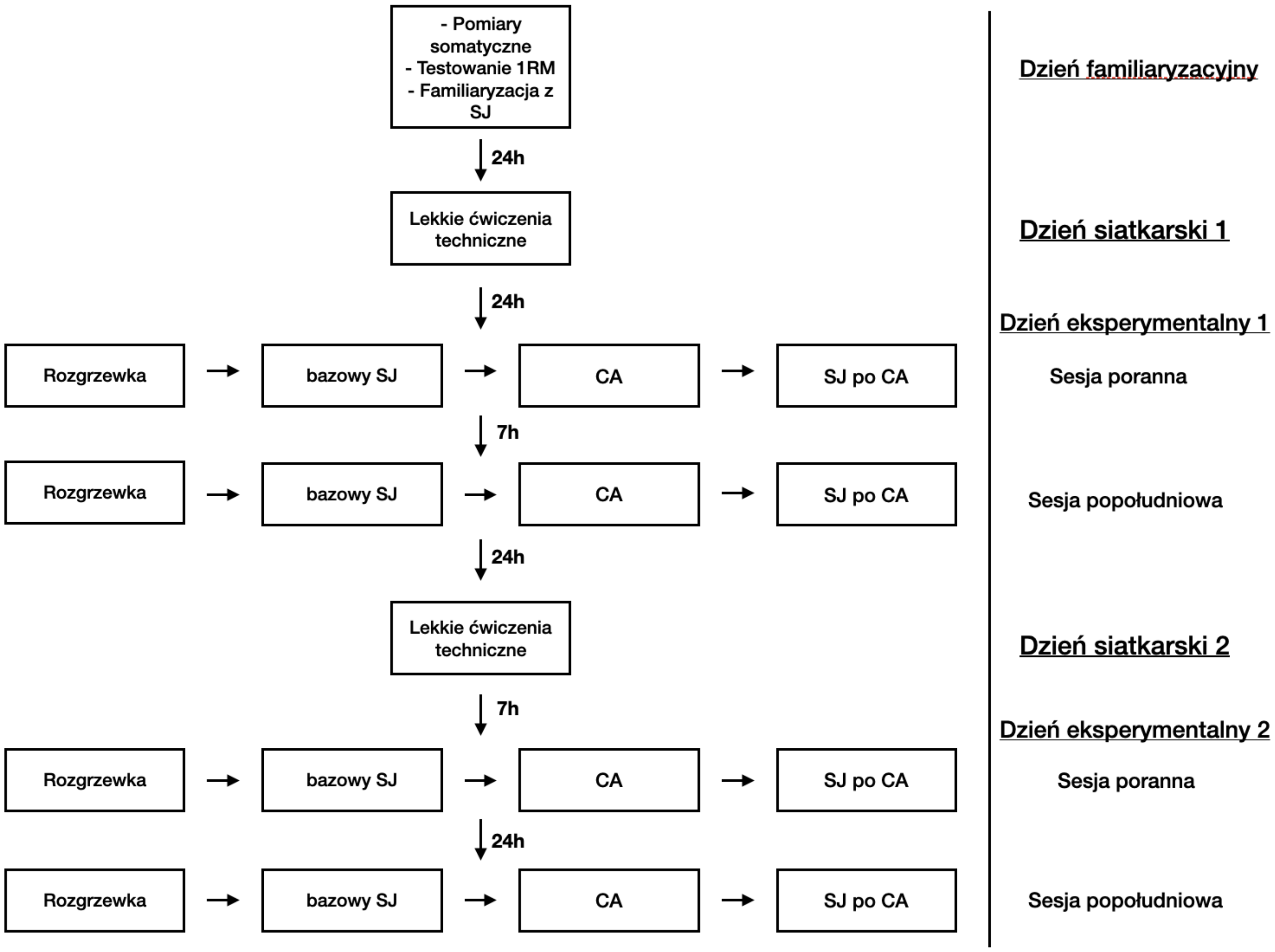
4.4 Publikacja nr 4

Masel, S. & Maciejczyk, M. No effects of post-activation performance enhancement in elite male volleyball players under complex training. Sci. Rep. ***14*** *(2024).*

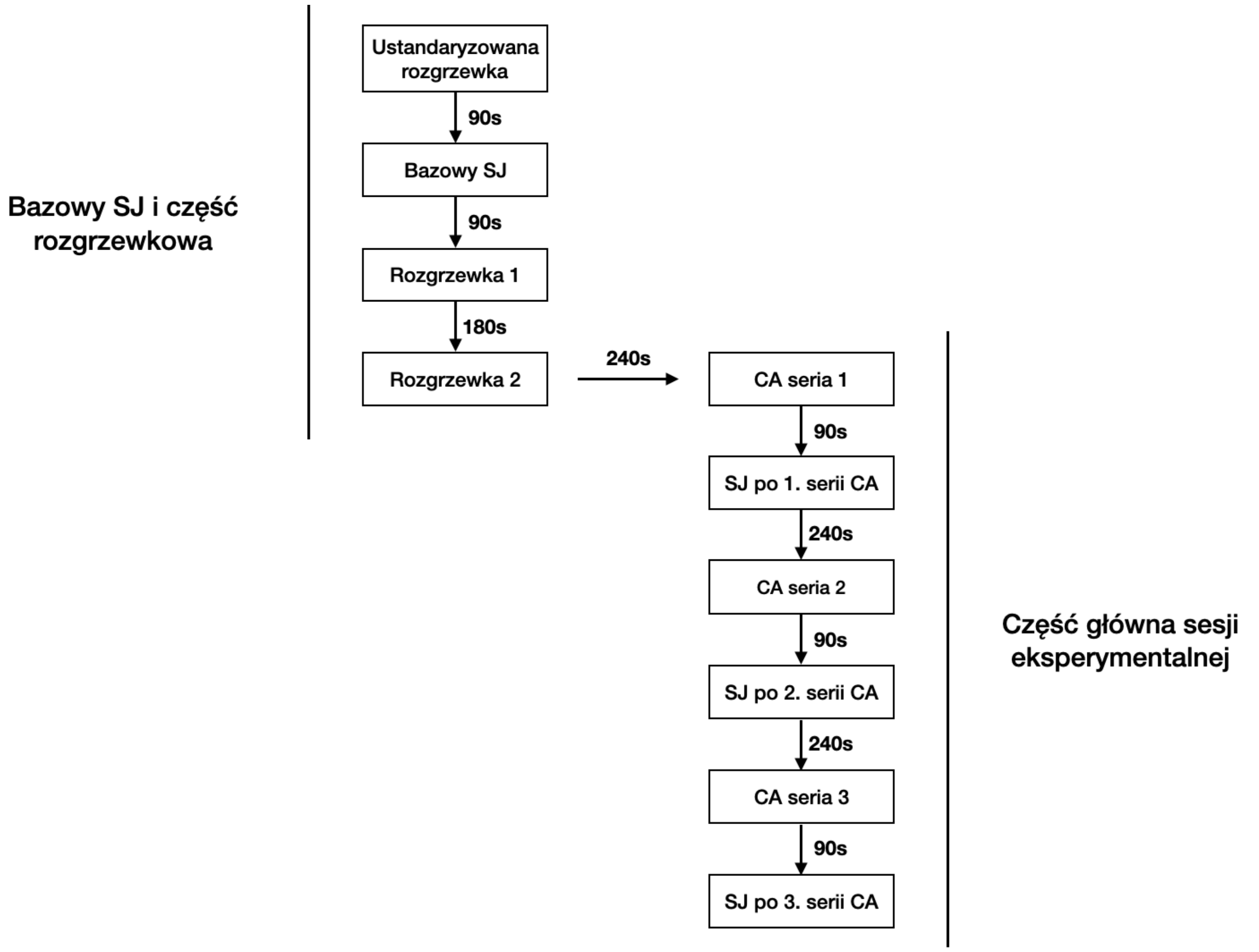
Zebrane dane i doświadczenia z wcześniejszych badań zostały wykorzystane w kolejnym etapie badań. Wybrany najefektywniejszy protokół z poprzednich części badań został ponownie wykorzystany do badań z udziałem siatkarzy. Tym razem postanowiono rozszerzyć część badań o zwielokrotnienie użycia CA - w poprzednich częściach badań została zastosowana tylko 1 seria CA, w tej części 3 serie (tak jak w przykładowym treningu kompleksowym (CT)). Prowadząc badania nad PAPE i obserwując bieżące doniesienia naukowe można zaobserwować deficyt badań weryfikacyjnych w kontekście powtarzalności efektu PAPE. PAPE jest zjawiskiem występującym indywidualnie i chcieliśmy sprawdzić, czy występuje ono niezależnie od dnia i pory dnia [61, 62]. Dlatego zdecydowaliśmy się wprowadzić ten sam CA w małych sesjach CT 4 razy (2 rano i 2 po południu) i zbadać jego niezawodność. Głównym celem tej pracy było zweryfikowanie skuteczności wielokrotnego zaimplementowania tego samego protokołu u wyczynowych siatkarzy, a według mojej wiedzy, do tej pory nie było to przedmiotem badań naukowych dotyczących PAPE. Postawiono hipotezę, że protokół PAPE w ramach CT, będzie miał powtarzalny pozytywny wpływ na wysokość skoku wertykalnego u wyczynowych siatkarzy. Spodziewano się również indywidualnej reakcji na CA, a wprowadzenie indywidualnej analizy było kolejnym celem tego badania.

W badaniu uczestniczyło 12 wyczynowych siatkarzy (wiek 10,2±2,3 lata; wysokość ciała: 193,4±7,6; masa ciała: 84,1±8,1 kg) o wysokim poziomie siły relatywnej (2,07±0,22 kg/kg masy ciała). Badania trwały trzy dni, a badani wzięli udział w pięciu sesjach: jednej familiaryzacyjnej i czterech eksperymentalnych. Dwie z sesji eksperymentalnych odbywały się tego samego dnia (rano i po popołudniu) z około 7-godzinną przerwą i po 48h został przeprowadzony analogiczny protokół badawczy. W dniach wolnych od sesji eksperymentalnych siatkarze uczestniczyli w popołudniowym treningu siatkarskim, którego intensywność była niska i zawierała głównie podstawowe ćwiczenia techniczne, bez elementów o wysokiej intensywności, wymagające skoków tj. atak, blok, zagrywka (Ryc. 4).



Ryc. 4. Plan badań (1RM – jedno powtórzenie maksymalne; CA – conditioning activity; SJ – squat jump)

Badani zostali podzieleni na 4 grupy po 3 osoby, aby uniknąć ewentualnych utrudnień w przeprowadzaniu sesji eksperymentalnych. W różne dni eksperymentalne badani zaczynali dane sesje o tej samej godzinie i przebiegały one w takiej samej kolejności. W odróżnieniu do pierwszych części badań, w tej części badań ten sam protokół był zastosowany trzykrotnie, a między seriami wprowadzono 240s przerwy wypoczynkowej (Ryc. 5).



Ryc. 5. Plan sesji eksperymentalnej (SJ – squat jump; CA – conditioning activity).

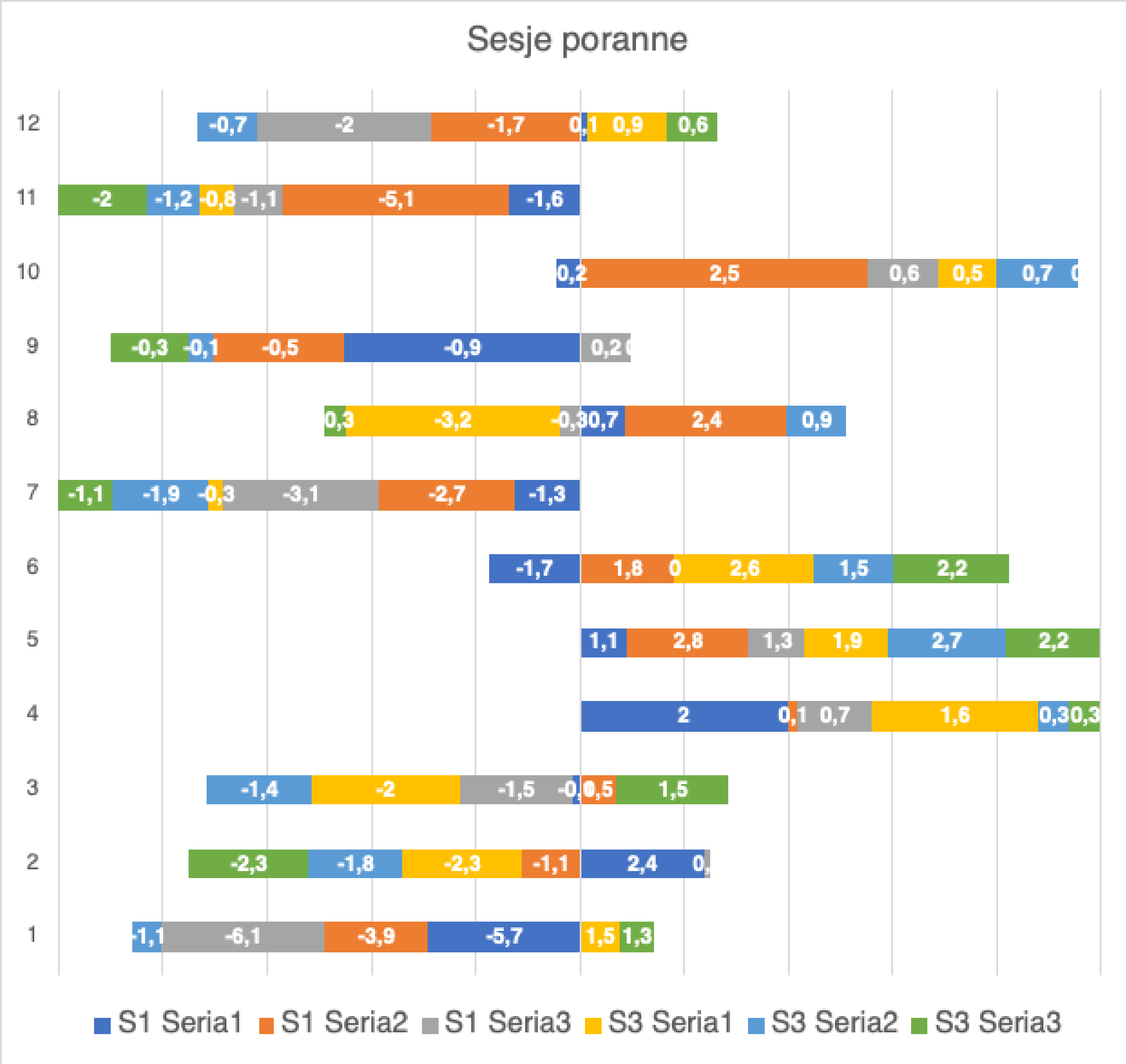
Rozkład danych został sprawdzony przy użyciu testu Shapiro-Wilka, a jednorodność wariancji testem Levena. Do określenia istotności różnic użyto ANOVA z powtarzanymi pomiarami (rożnice uznawano za istotne, gdy $p < 0,05$), a wielkość efektu została oceniona przy użyciu d Cohena. Ocena powtarzalności zjawiska PAPE została przeprowadzona przy użyciu współczynnika korelacji międzyklasowej (ICC, Intraclass Correlation Coefficient), zgodnie z obowiązującymi wytycznymi [63, 64]. Powtarzalność zjawiska PAPE została zweryfikowana na 3 sposoby: 1) porównanie sesji popołudniowych/porannych między dniami; 2) porównanie sesji popołudniowych/porannych tego samego dnia; 3) porównanie efektów między seriami podczas tej samej sesji.

Każda z sesji eksperymentalnych wskazała na brak istotności statystycznej dla zmian w wysokości skoku pomiędzy bazowym SJ a SJ po zastosowaniu CA. W przypadku 5 z 8 pomiarów wysokości wyskoku, ICC wskazuje na dobrą powtarzalność (powtarzalność popołudniowa międzydniowa, poranna i popołudniowa wewnątrzdniowa dla sesji 1 i 2, wewnątrzdniowa między seriami dla sesji 1, 2, 3); 2 z 8 na umiarkowaną (powtarzalność poranna międzydniowa, powtarzalność wewnątrzdniowa między seriami dla sesji 4) i 1 z 8 na słabą (poranna i popołudniowa wewnątrzdniowa dla sesji 3 i 4) (Tabela 2). Zaobserwowano również indywidualną odpowiedź na zastosowane CA (Ryc. 6 i 7). Z racji na brak danych dotyczących powtarzalności tego samego protokołu w badaniach PAPE, podjęto decyzję o wprowadzeniu arbitralnej klasyfikacji efektów badań: 1) ≤4 pozytywnych zmian wysokości skoku (do 33%) - powtarzalna odpowiedź negatywna (reliable non-responder); 2) 5-8 pozytywnych zmian wysokości skoku (41.7 - 66.7%) - rezultaty mieszane (cannot classify clearly); 3) ≥ 9 pozytywnych zmian wysokości skoku (75-100%) - powtarzalna odpowiedź pozytywna (reliable responder). Protokół PAPE okazał się nieskuteczny w poprawie wysokości wyskoku przy różnych okazjach, jednakże wyniki badań wskazują na relatywnie dobrą powtarzalność zjawiska PAPE w treningu kompleksowym siatkarzy i zdaje się być wskazane by implementować tego rodzaju trening u osób, które pozytywnie odpowiadają na CA (reliable responder). Jednakże, nie jest wskazane stosowanie tego rodzaju treningu dwukrotnie tego samego dnia ze względu na przeciwstawne wyniki powtarzalności wewnątrz dniowej (dobra 0,88 i niska 0,48).

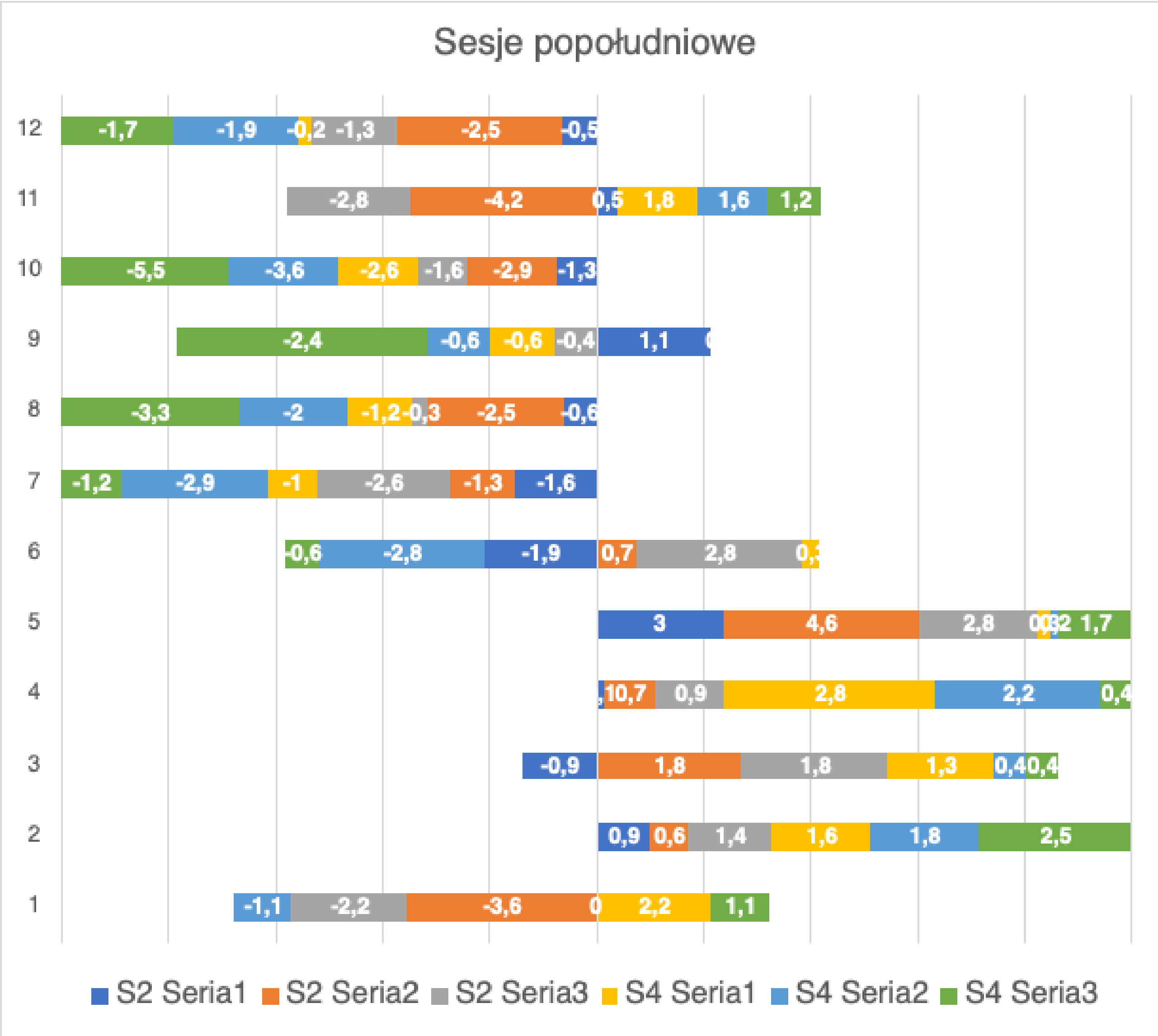
Tabela 2. Powtarzalność pomiarów

Powtarzalność	Sesja	ICC
Poranna międzydniowa	1 i 3	0.67
Popołudniowa międzydniowa	2 i 4	0.8
Poranna i popołudniowa wewnątrzdniowa	1 i 2	0.88
Poranna i popołudniowa wewnątrzdniowa	3 i 4	0.48
Wewnątrzdniowa między seriami	1	0.87
	2	0.82
	3	0.83
	4	0.58

ICC - Intraclass correlation coefficient



Ryc. 6. Indywidualne zmiany wysokości skoku podczas sesji porannych.



Ryc. 7. Indywidualne zmiany wysokości skoku podczas sesji popołudniowych.

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No effects of post-activation performance enhancement in elite male volleyball players under complex training

Sebastian Masel✉ & Marcin Maciejczyk

The aim of this study was to establish reliability of post-activation performance enhancement in three manners: (1) interday morning and afternoon reliability; (2) intraday morning and afternoon reliability; (3) intraday set-to-set reliability. Twelve elite male volleyball players experienced in resistance training performed four identical experimental sessions—two in the morning and two in the afternoon. During each session participants performed a mini complex training session—three sets of a conditioning activity (CA) (3 repetitions of a trap bar deadlift at 80% 1RM with 15% of accommodating resistance) and 90 s after a CA performed squat jump (SJ) with 4 min intra-set rest interval. The ANOVA with repeated measures was used to assess significance of the effect of a CA and ICC to assess reliability of measurements. The PAPE protocol was found to be ineffective to subsequently enhance JH on various occasions. Also, the results of this study suggest that the practitioners may effectively implement appropriately organized complex training as both intraday set-to-set (0.87 and 0.82 for morning sessions; 0.83 and 0.58 for afternoon sessions) and interday morning (0.67) and afternoon (0.8) reliabilities seem to be acceptable. However, introducing two CT sessions within one day is highly questionable as at the moment intraday morning and afternoon reliability is vague (0.88 and 0.48).

Keywords PAPE, Power, Measurements, Accommodating resistance, Strength training, Trap bar deadlift

Post-activation performance enhancement (PAPE) is a physiological phenomenon that is observed by an increased power output in an explosive exercise such as sprinting or jumping after applying a specific conditioning activity (CA). Potential increases in muscle temperature, muscle and muscle fiber water content and muscle activation have been associated with PAPE effect[1]. Efficacy of PAPE is dependent on introducing an appropriate combination of volume[2,3] and intensity[3,4] of a CA and a proper rest interval before implementing an explosive exercise. Different authors of meta-analyses suggest different rest intervals to have the biggest effect: 5–7 min[5], 6–10 min[6] or 3–7 min[7] considering specifically vertical jump performance. PAPE response was found to be highly individual[8] and self-selected rest intervals can also be effective to acutely enhance performance[9]. Thus, PAPE protocols should be designed appropriately to a given athlete to optimize the training process. Apart from CA attributes, inter-individual differences[10] and a relative strength level of an individual are also important factors[5,11] to determine an efficient training protocol.

Current PAPE research indicates that various PAPE protocols may be implemented and acutely enhance subsequent post-CA performance. The authors introduced and found beneficial effects of various application methods such as isometric CA[12,13], traditional resistance[3,14], accommodating resistance[15,16] or flywheel devices[17]. The approach to evaluate PAPE responses may differ between the protocols—the post-CA explosive exercise may be introduced after a single set of a CA[18], after multiple sets of the same CA[19] or between each set of the same CA[20]. In order to implement different PAPE protocols with different CAs authors tend to introduce separate experimental sessions[3,18]. After receiving a positive or a negative outcome of the protocol, it is a common practice to omit repeating the same protocol, the researchers simply move to another PAPE protocol and examine the effects of another CA. So far, various jumping tests' reliability have been examined i.e. countermovement jump (CMJ) and squat jump (SJ)[21] or drop jump (DJ)[22]. However, no authors put the same interest in PAPE—no study provided results about the reliability of PAPE phenomenon. Using reliable jumping tests to assess post-CA performance is a standard procedure[15,23], but assessing their effectiveness on various occasions within the same

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individuals has not been studied so far. As PAPE response is individual[8], there could be a possibility that the same individual could react differently to the same type of CA. Therefore, one could suggest that repeating the same PAPE protocol may provide different results, especially considering an individual response to a stimulus.

The PAPE phenomenon can be implemented in various manners such as warm-up, testing and monitoring or priming and rewarm-up during the competition[24]. It is also frequently introduced within training methods and is described as a contrast or complex training[25]. These two methods have their differences, but the practitioners tend to use both terms interchangeably, whereas in fact what they introduce to their athletes is complex training (CT)[25]. CT is defined as a training method that involves PAPE—high-load weight training exercise is implemented as a CA and after intra complex recovery interval (ICRI) is alternated with a plyometric or power exercise, set for set[26]. Response to a complex training, similarly to PAPE, was found to be highly individualized and players competing in sports in which jumping actions are crucial for performance may benefit the most to this type of training[26]. Other authors also suggest that CT can be an effective training method to improve vertical jump performance[27,28]. It may be particularly important in relation to professional volleyball as jump demands are high[29] and increases in jump height may support subsequent effectiveness in offensive actions[30]. Also, volleyball players tend to jump higher than basketball or handball players on high[31] and college level[32]. Despite the fact that the majority of PAPE research focuses on acute effects of PAPE protocols on various power adaptations[18,20,33], it cannot be seen in relation to CT. The CT research tends to consider long-term effects of repeatable PAPE incidents on vertical jump or sprinting. The authors put their interest in performance improvements after training interventions lasting ≥ 4 weeks, but they do not consider the acute PAPE effects of CT sessions[25–28]. Marshall et al. analyzed training responses from various CT protocols, but the main focus of these studies was to introduce various PAPE protocols with different CAs[34]. However, they did not analyze acute PAPE responses of multiple CT sessions with the same type of CA. Thus, since no research has focused on the acute PAPE effects of multiple CT sessions with the same CA, it is uncertain if the PAPE effect actually occurs repeatedly within these sessions or it could occur only after training interventions lasting ≥ 4 weeks. It could undermine the reasonableness of introducing CT to the athletes if it cannot be performed regularly for ≥ 4 weeks.

Despite extensive literature regarding PAPE, the current research does not provide interventions regarding the same PAPE protocol with the same CA during separate experimental sessions. Evaluating reliability of the same PAPE protocol within the same sample and in the same conditions may be crucial for further implementation of PAPE phenomenon in athletes' training programs. It could occur that an experimental protocol which did not enhance subsequent explosive performance may provide different results if it had been retested. Introducing retesting of the same protocol could give a better understanding of PAPE and broaden the application possibilities for the practitioners. PAPE is an individually occuring phenomenon and we wanted to test if it occurs independently from the day and time of the day. Thus, we decided to introduce the same CA under small CT sessions 4 times (2 in the morning and 2 in the afternoon) and examine its reliability. It was hypothesized that the PAPE protocol under CT would have a repeatable enhancement effect on vertical jump performance in elite volleyball players. We also expected an individual response to a CA and introducing an individual analysis was another aim of this study.

Material and methods
Study design
This study took three days (familiarization day and two experimental days) and participants took part in five sessions: one familiarization and four experimental sessions (S1, S2, S3 and S4). The familiarization session was performed in the morning (from 10 a.m. to 12 a.m.) and two of the subsequent experimental sessions were performed in the morning (S1 and S3; from 9:30 a.m. to 12:00 a.m.) and two in the afternoon (S2 and S4; from 5:00 p.m. to 7:30 p.m.). Experimental sessions were small CT sessions and were performed in two experimental days and each experimental session took approximately 35 min. The morning and afternoon experimental sessions were performed with approximately 7 h break between the sessions. Apart from experimental days, players participated in their volleyball afternoon training sessions. As this study took place at the beginning of the preparatory cycle, the intensity of volleyball sessions was low, they consisted mainly of basic technique drills and did not involve high intensity activities such as spiking or service. First day of the study was a familiarization session which started with somatic measurements and therefore, a one-rep maximum determination in a trap bar deadlift (1RM) and familiarization with a SJ test were performed. After the familiarization session, the participants were split into four groups of three participants to perform experimental sessions in the same order and avoid potential interruptions during the experimental protocols. In the main part of the study the participants performed four experimental sessions that included a standardized warm-up, baseline SJ, CA (trap bar deadlift with accommodating resistance) and post-CA SJ measurements. A conditioning activity used in the study was 3 repetitions of a trap bar deadlift at 80% 1RM where 65% of 1RM was provided by free weight and approximately 15% of 1RM was accommodating resistance. A conditioning activity was implemented three times during each experimental session—90 s after each CA the participants performed post-CA SJ (Fig. 1.).

Inclusion criteria, required to participate in the study included: (a) professional level of competition (Divisions under Polish Volleyball League (PLS—Polska Liga Siatkówki); (b) valid medical examination to participate in competition; (c) lack of injuries or other health contraindications in the last 6 months. The participants were instructed to maintain their usual dietary and sleep habits throughout the study. They took part in the study voluntarily after being informed about the study protocol and potential risks and benefits of the study and provided informed signed consent. The Bioethics Committee accepted the study protocol (Regional Medical Chamber in Kraków, Poland; opinion no: 1/KBL/OIL/2022) and the study was performed in accordance with the ethical standards of the declaration of Helsinki 2013.

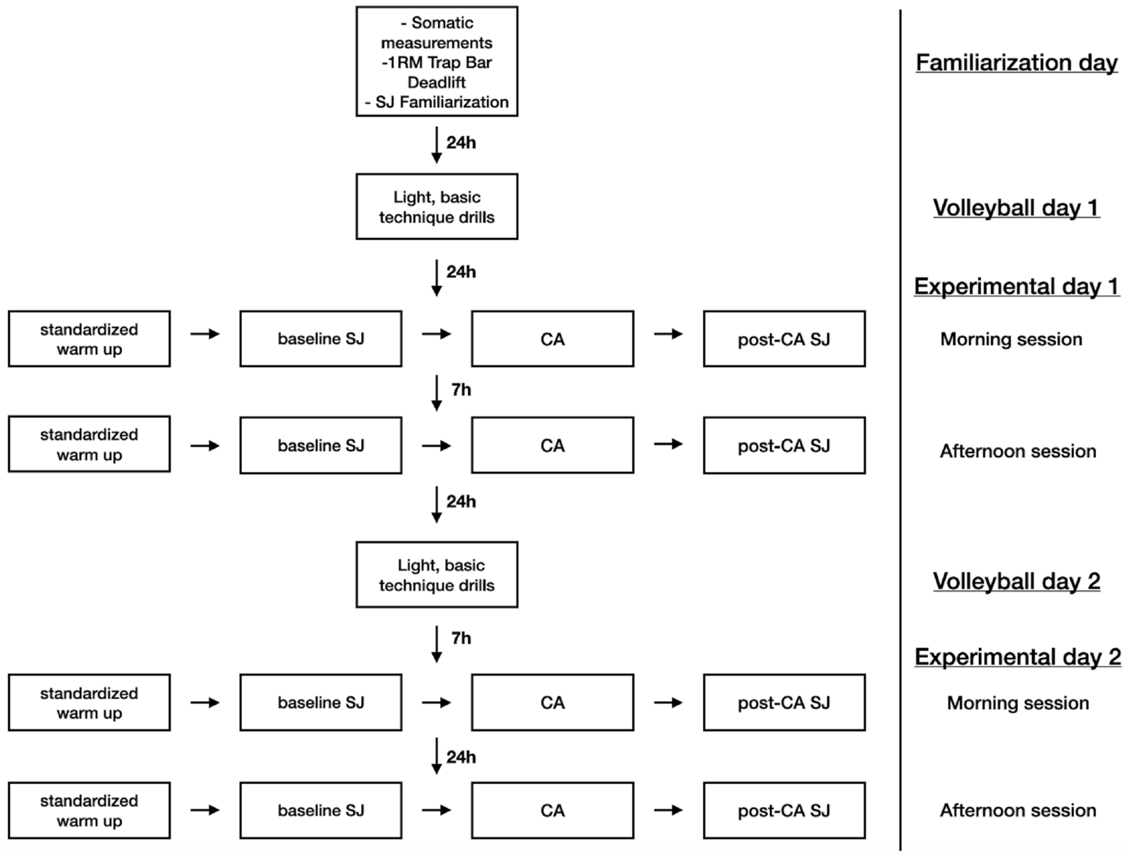

Figure 1. Study Design. 1RM—one repetition maximum; SJ—squat jump; CA—conditioning activity.

Participants
Twelve elite male volleyball players (age: 22 ± 2 years; volleyball training experience: 10.2 ± 2.3 years, body height: 193.4 ± 7.6, body mass: 84.1 ± 8.1 kg) experienced in resistance training (7 ± 1.6 years) participated in the study. They practice volleyball daily and compete in the second highest volleyball division in Poland (Tauron 1. League). Volleyball players participating in the study included players competing in every volleyball position: 4 outside hitters, 3 middle blockers, 2 setters, 2 liberos and 1 opposite hitter.

Warm-up
Each day started with a standardized warm-up that took approximately 15 min and consisted of three parts: (1) aerobic warm-up (2) full-body mobility; (3) dynamic warm-up. To increase body temperature, a standardized warm-up began with 5 min of jogging on a mechanical treadmill at a velocity of 7–8 km/h. Afterwards, full-body mobility was introduced—exercises were performed in 3 positions: quadruped: (a) extending/flexing spine, (b) internal/external rotation in the hips; half-kneeling: (a) adductor mobility, (b) hip mobility in 3 positions, (c) thoracic rotations; plank: (a) isolated downward-upward movement of the scapulas, (b) pushings hips up with straight legs ("downward dog") and returning to plank position. Last part of the standardized warm-up was a dynamic warm-up that consisted of a set of 10 repetitions each of dynamic stretching exercises: (a) knee to chest with calf raise, (b) heel to buttocks with calf raise. It was followed by (a) 2 sets of pogo jumps (mini jumps using only ankle joints) for 10 s, (b) 5 squat jumps.

Familiarization session
The familiarization session was conducted in the same manner as previously described[18,35]. It consisted of three parts—somatic measurements, 1RM determination in a trap bar deadlift and familiarization with the SJ test. During somatic measurements 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, bio-electrical impedance analysis). 1 RM determination was performed after a standardized warm-up and it resulted in the mean relative of 2.07 ± 0.22 kg/body mass. Last part of the session was familiarization with the SJ test and participants executed the SJ test several (3 to 5) times.

Experimental sessions
Each experimental session was conducted in the same manner and began with the standardized warm-up and 90 s after the standardized-warm up the participants performed baseline SJ. 90 s after baseline SJ they performed a first warm-up set that consisted of 3 repetitions at 50% of 1RM. 180 s after the first warm-up set the

participants performed a second warm-up set that consisted of 3 repetitions at 70% of 1RM. Then, 240 s after the second warm-up set the participants performed a first set of CA of the study—3 repetitions of a trap bar deadlift at 80% of 1RM with approximately 15% of 1RM of elastic bands. 90 s after this set they performed their first post-CA SJ. This cycle of alternating a CA with SJ was repeated two times until the participants performed a CA and post-CA SJ three times in a set for set manner (Fig. 2). In all of the SJ measurements the participants performed two repetitions of SJ and the one with a higher jump height (JH) value was used in further statistical analysis. Additionally, during experimental sessions a velocity monitoring device (VmaxPro/enodePro, Germany) was introduced to increase training motivation and encourage the athletes to put maximum effort during the concentric portion of the lift. VmaxPro was proved to be a reliable and sensitive device for resistance training monitoring and prescription[36]. The athletes were instructed to perform each repetition with a maximal velocity in the concentric phase of the lift and controlled eccentric phase (approximately 2 s of lowering the bar). Due to manufacturer's instructions on how a trap bar deadlift should be performed to obtain correct measurement data, each repetition was performed dead-stop (full stop at the bottom of the lift) without bouncing the bar off the floor between the repetitions.

Squat jump measurements

Squat jump measurements were conducted analogously to the previous study by Masel and Maciejczyk[35]. Instructions for the participants included a fast downward movement until they reached approximately 90° of knee flexion, followed by an isometric hold of 2 s and a maximal jump from an isometric position. Isometric hold at the bottom of the squat was counted by the supervisor of the study to optimize a proper execution of the test. OptoJump (Italy) device was used for the measurements—an optical measurement system[37].

Band tension measurements

Before the start of the study, band tension was determined with a qualified biomechanist to optimize subsequent measurements during experimental sessions. Adjustments of elastic bands were executed based on previous studies by Wallace et al. and Popp Marin et al.[38,39]. Band tension was determined at different lengths using separately a force plate and a load cell (both produced by a polish manufacturer). Four types of elastic bands (Domyos, Germany) of different thickness were introduced during adjustment and afterwards used throughout the study. Elastic bands were brand new to avoid any potential modifications of band tension.

Statistical analysis

All data regarding baseline to post-CA changes is presented as mean and standard deviation (SD). Shapiro–Wilk test was used to check the distribution of variables. Anova with repeated measures was implemented to assess the significance of the CA on jumping performance. Levene's test was used to check the homogeneity of variance within the groups. The differences were considered statistically significant for $p < 0.05$. If ANOVA did

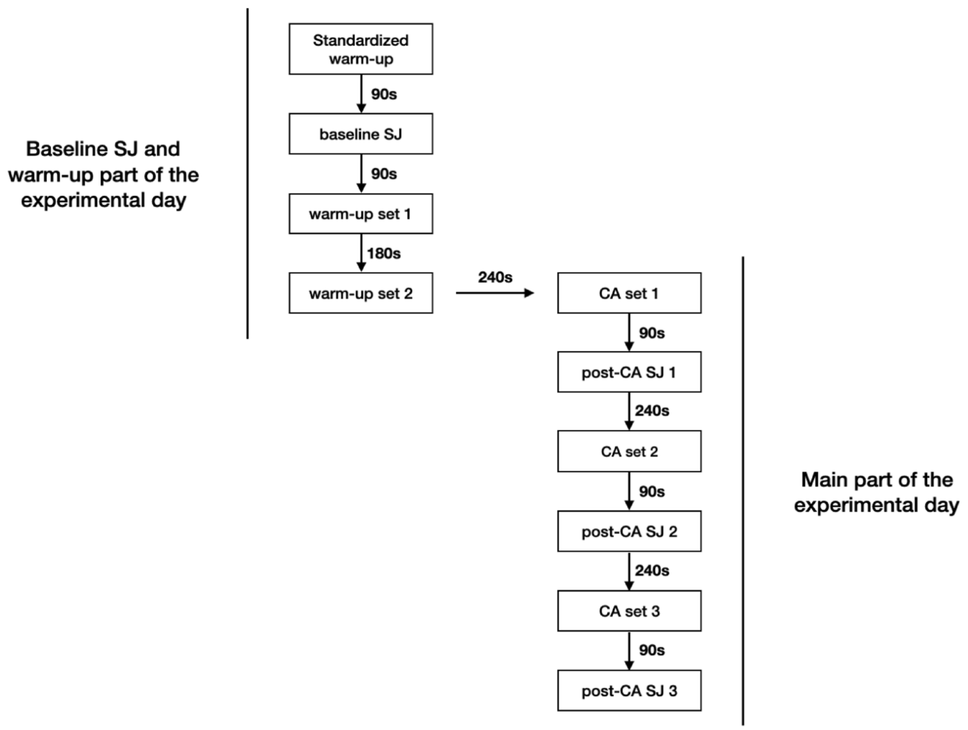

Figure 2. Experimental session flow.

not reveal any significant interaction, a post-hoc analysis was not conducted. The effect size (Cohen's d) was calculated and interpreted as small (0.20), medium (0.50), or large (0.80)[40]. To assess the reliability of PAPE the Intraclass Correlation Coefficient (ICC) was introduced in accordance with guidelines of its use[41,42]. The reliability of the measurements was based on an absolute-agreement, 2-way mixed effects model and interpreted as poor (ICC < 0.5), moderate (0.5–0.75), good (0.75–0.9) and excellent (ICC > 0.9). The reliability was assessed in three manners: 1) interday morning and afternoon reliability; 2) intraday morning and afternoon reliability; 3) intraday set-to-set reliability. The STATISTICA 13.1 PL (StatSoft, Inc., Tulsa, OK, United States) and PQ Stat 1.86 (PQStat Software, Poland) were implemented for statistical calculations.

Results

Group analysis

Analyzing the data, no PAPE effect was found in any of the four experimental sessions. Baseline to post-CA changes in JH in SJ were statistically insignificant (Table 1). Baseline JH is constant for different sets within the same experimental session and post-CA performance after different sets is compared with baseline JH for a given session. Also, a consistent small effect size for JH changes was observed (Table 1). ANOVA with repeated measures did not indicate a statistically significant effect for session ($F = 0.8$; $p = 0.5$; $\eta^2 = 0.05$), set ($F = 1.78$; $p = 0.15$; $\eta^2 = 0.04$) or interaction between these two factors ($F = 0.69$; $p = 0.72$; $\eta^2 = 0.04$).

Reliability measurements

Table 2 displays the reliability of the measurements in three manner assessment. Interday morning (S1 and S3) reliability was moderate (ICC = 0.67) and afternoon (S2 and S4) was good (0.8). Intraday morning and afternoon reliability was good for S1 and S2 (0.88) and poor for S3 and S4 (0.48). Intraday set-to set reliability was good in morning sessions (S1—0.87 and S3—0.82), whereas in afternoon sessions it was good in S2 (0.83) and moderate in S4 (0.58) (Table 2).

Individual analysis

Individual analysis of the players demonstrates high inter and intraindividual variability of post-CA effects. Despite no statistically significant group effects, some players repeatedly improved their post-CA improvements, whereas the others have mixed or generally negative results (Tables 3 and 4, Figs. 3 and 4).

Session	Set	Baseline JH (cm)(95% CI)	post-CA JH (cm)(95% CI)	Cohen's d
S1	1	45.1 ± 3.0 (43.2 – 47)	44.7 ± 2.9 (42.9 – 46.5)	0.14
	2	45.1 ± 3.0 (43.2 – 47)	44.7 ± 3.5 (42.5 – 46.9)	0.12
	3	45.1 ± 3.0 (43.2 – 47)	44.2 ± 3.0 (42.3 – 46.1)	0.3
S2	1	46.0 ± 2.0 (44.7 – 47.3)	45.9 ± 2.9 (44.1 – 47.7)	0.04
	2	46.0 ± 2.0 (44.7 – 47.3)	45.3 ± 3.6 (43 – 47.6)	0.24
	3	46.0 ± 2.0 (44.7 – 47.3)	45.9 ± 3.0 (44 – 47.8)	0.04
S3	1	44.6 ± 2.6 (43 – 46.2)	44.6 ± 2.7 (42.9 – 46.3)	0
	2	44.6 ± 2.6 (43 – 46.2)	44.4 ± 2.9 (42.6 – 46.2)	0.07
	3	44.6 ± 2.6 (43 – 46.2)	44.8 ± 2.7 (43.1 – 46.5)	0.08
S4	1	46.4 ± 2.8 (44.6 – 48.2)	46.7 ± 3.3 (44.6 – 48.8)	0.10
	2	46.4 ± 2.8 (44.6 – 48.2)	45.6 ± 3.5 (43.4 – 47.8)	0.25
	3	46.4 ± 2.8 (44.6 – 48.2)	45.7 ± 3.9 (43.3 – 48.1)	0.21

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

Reliability	Sessions	ICC
Interday morning	1 and 3	0.67
Interday afternoon	2 and 4	0.8
Intraday morning and afternoon	1 and 2	0.88
Intraday morning and afternoon	3 and 4	0.48
Intraday set-to-set	1	0.87
	2	0.82
	3	0.83
	4	0.58

Table 2. Reliability of the measurements. ICC, intraclass correlation coefficient.

No	Session 1							Session 3						
	Baseline (cm)	Set 1 (cm)	Change in %	Set 2 (cm)	Change in %	Set 3 (cm)	Change in %	Baseline (cm)	Set 1 (cm)	Change in %	Set 2 (cm)	Change in %	Set 3 (cm)	Change in %
12	41.7	41.8	0.2%	40	-4.1%	39.7	-4.8%	39.8	40.7	2.3%	39.1	-1.8%	40.4	1.5%
11	44.4	42.8	-3.6%	39.3	-11.5%	43.3	-2.5%	45.8	45	-1.7%	44.6	-2.6%	43.8	-4.4%
10	42.4	42.2	-0.5%	44.9	5.9%	43	1.4%	43	43.5	1.2%	43.7	1.6%	43	0.0%
9	48.8	47.9	-1.8%	48.3	-1.0%	49	0.4%	48	48	0.0%	47.9	-0.2%	47.7	-0.6%
8	43.1	43.8	1.6%	45.5	.,6%	42.8	-0.7%	44.6	41.4	-7.2%	45.5	2.0%	44.3	-0.7%
7	43.5	42.2	-3.0%	40.8	- .,2%	40.4	-7.1%	42.1	41.8	-0.7%	40.2	-4.5%	41	-2.6%
6	42.2	40.5	-4.0%	44	4.3%	42.2	0.0%	41.5	44.1	6.3%	43	3.6%	43.7	5.3%
5	48.8	49.9	2.3%	51.6	5.7%	50.1	2.7%	47.7	49.6	4.0%	50.4	5.7%	49.9	4.6%
4	42.1	44.1	4.8%	42.2	0.2%	42.8	1.7%	42.7	44.3	3.7%	43	0.7%	43	0.7%
3	47.1	47	-0.2%	47.6	1.1%	45.6	-3.2%	45.4	43.4	-4.4%	44	-3.1%	46.9	3.3%
2	46.4	48.8	5.2%	45.3	-2.4%	46.5	0.2%	47.9	45.6	-4.8%	46.1	-3.8%	45.6	-4.8%
1	50.7	45	-11.2%	46,8	-7.7%	44.6	-12.0%	46.4	47.9	3.2%	45.3	-2.4%	47.7	2.8%
x	45.1	44.7	-0.9%	44.7	-0.8%	44.2	-2.0%	44.6	44.6	0.2%	44.4	-0.4%	44.8	0.4%
SD	3.0	2.9	4.2%	3.5	5.5%	3.0	4.1%	2.6	2.7	3.9%	2.9	3.0%	2.7	3.1%

Table 3. Individual analysis of JH changes during morning sessions.

No	Session 2							Session 4						
	Baseline (cm)	Set 1 (cm)	Change in %	Set 2 (cm)	Change in %	Set 3 (cm)	Change in %	Baseline (cm)	Set 1 (cm)	Change in %	Set 2 (cm)	Change in %	Set 3 (cm)	Change in %
12	43.5	43	-1.1%	41	-6.1%	42.2	-3.1%	41	40.8	-0.5%	39.1	-4.9%	39.3	-4.3%
11	46.2	46.7	1.1%	42	-10.0%	43.4	-6.5%	45.5	47.3	3.8%	47.1	3.4%	46.7	2.6%
10	45	43.7	-2.9%	42.1	-6.9%	43.4	-3.7%	46.7	44.1	-5.9%	43.1	-8.4%	41.2	-13.3%
9	47.1	48.2	2.3%	47.1	0.0%	46.7	-0.9%	48	47.4	-1.3%	47.4	-1.3%	45.6	-5.3%
8	45.5	44.9	-1.3%	43	-5.8%	45.2	-0.7%	47.3	46.1	-2.6%	45.3	-4.4%	44	-7.5%
7	45	43.4	-3.6%	43.7	-3.0%	42.4	-6.1%	43	42	-2.4%	40.1	-7.2%	41.8	-2.9%
6	43	41.1	-4.4%	43.7	1.6%	45.8	6.1%	46.1	46.4	0.6%	43.3	-6.5%	45.5	-1.3%
5	48	51	6.3%	52.6	8.7%	50.8	5.5%	49.9	50.2	0.6%	50.1	0.4%	51.6	3.3%
4	43.4	43.5	0.2%	44.1	1.6%	44.3	2.0%	43.1	45.9	6.1%	45.3	4.9%	43.5	0.9%
3	49.7	48.8	-1.8%	51.5	3.5%	51.5	3.5%	49.7	51	2.5%	50.1	0.8%	50.1	0.8%
2	47.3	48.2	1.9%	47.9	1.3%	48.7	2.9%	45.5	47.1	3.4%	47.3	3.8%	48	5.2%
1	48	48	0.0%	44.4	-8.1%	45.8	-4.8%	50.4	52.6	4.2%	49.3	-2.2%	51.5	2.1%
x	46.0	45.9	-0.3%	45.3	-1.9%	45.9	-0.5%	46.4	46.7	0.7%	45.6	-1.8%	45.7	-1.6%
SD	2.0	2.9	2.8%	3.6	5.4%	3.0	4.2%	2.8	3.3	3.3%	3.5	4.3%	3.9	5.1%

Table 4. Individual analysis of JH changes during afternoon sessions.

Discussion

The most important finding of this study is that the reliability of PAPE phenomenon under mini CT sessions in elite volleyball players may be considered relatively good. Our study proved that the similar effect can occur independently from day and time of the day. We did not observe the phenomenon occuring in the first session and it also did not occur during subsequent sessions. 5 out of 8 ICC measurements showed good reliability, 2 out of 8 moderate reliability and only 1 out of 8 poor reliability. PAPE effects seem to be more reliable during morning sessions as 3 out of 4 ICC measurements indicated good reliability and 1 out of 4 moderate reliability whereas during afternoon sessions 2 of 4 showed good reliability, 1 out of 4 moderate reliability and 1 out of 4 poor reliability (Table 2) Additionally, the measurements of SJ were similar at the baseline and after introducing a CA for multiple sets during the sessions performed at the same time of the day (Table 1).

To our knowledge, this is the first study that examined the reliability of PAPE effects under CT. This type of training, using PAPE phenomenon, is often introduced to the athletes to develop lower body force, velocity, power and jump height[34]. Freitas et al. suggested that this type of training can be especially beneficial for players competing in sports in which jumping actions are crucial for performance[26]. Also, high vertical JH may allow to maximize the efficacy of volleyball offensive actions[30]. In comparison with basketball or handball, the volleyball players tend to jump higher[31,32] and basketball or handball also involve a lot of running and changes of direction that is not observed in volleyball. Introducing this type of training to the volleyball players may be absolutely relevant as the majority of their technical elements (spiking, blocking, service, setter's setting) is based on jumping.

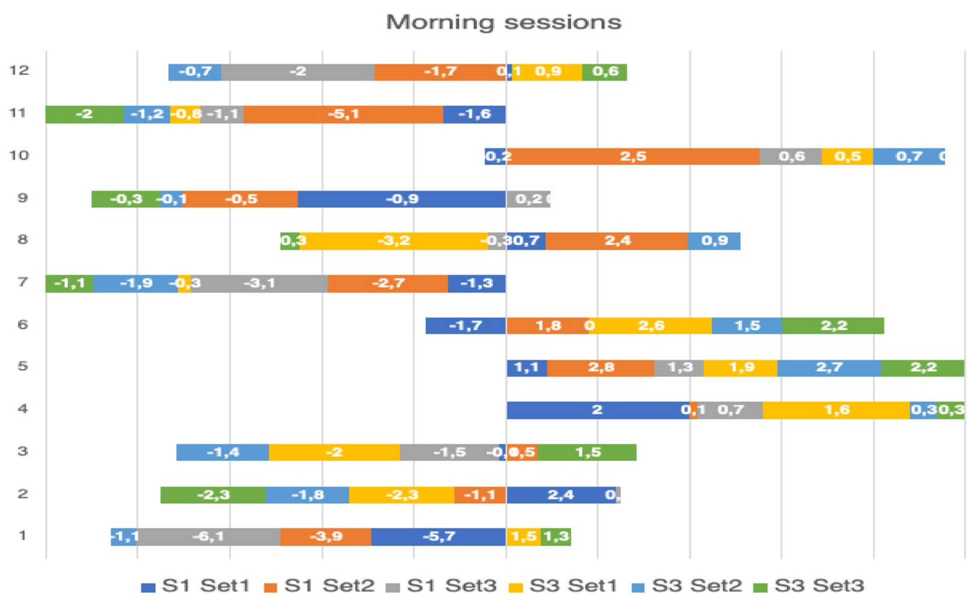

Figure 3. Individual set to set changes in JH (in cm) during morning sessions.

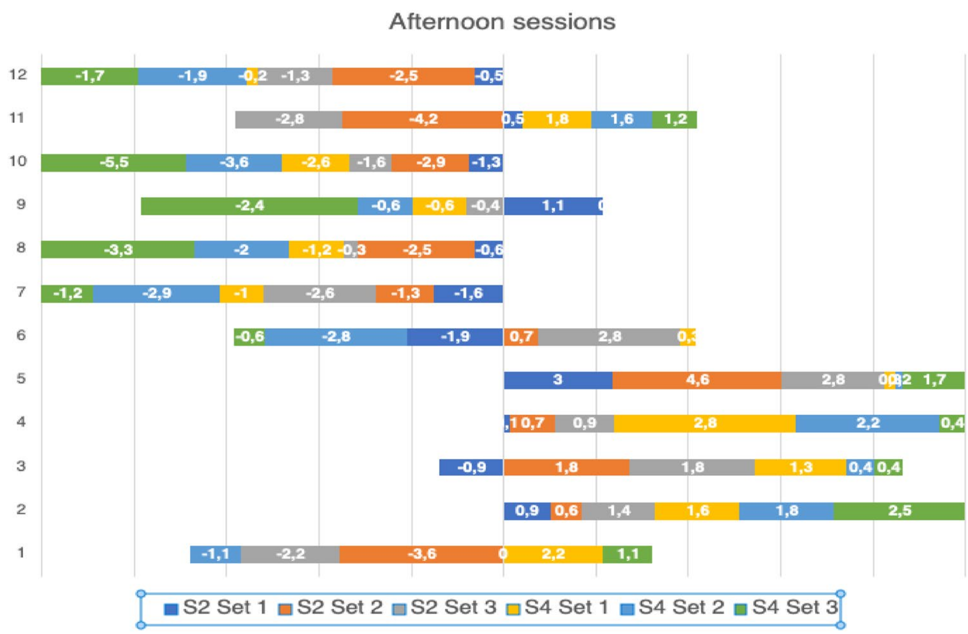

Figure 4. Individual set to set change in JH (in cm) during afternoon sessions.

Thus, in this study we proposed the following procedure: introducing the same PAPE protocol 4 times (2 sessions in the morning, 2 in the afternoon) under small CT sessions. We decided to implement a CA to elite volleyball athletes that we already used previously[18,23,35] and had an individual response and a potentiating effect on strong individuals[18,35]. Apart from examining the reliability of PAPE, introducing sessions at different times of the day provides additional benefit as this area of PAPE research has not been studied extensively so far[43,44]. Additionally, our study provided an important insight into PAPE research regarding elite male volleyball players as so far, the majority of evidence has focused on elite female volleyball players[45–47].We decided to investigate this matter in elite volleyball players with high relative strength level (relative 1RM in a trap bar deadlift 2.07 ± 0.22 kg/body mass) as it was suggested that the athletes with relative strength level of > 1.5 kg/body mass[5] or > 2 kg/body mass[11] should be a target group for this kind of measurements. Examining the reliability of CT in such population may be valuable as its results can be directly applicated into sports training.

The results of our study indicate an overall good reliability of PAPE effects under CT in elite volleyball players. Interday reliability of morning (0.67) and afternoon (0.8) sessions suggests that there is a high likelihood that the same training protocol introduced within the same population on different training days could generate similar training effects. Intraday reliability between morning and afternoon sessions on the same day of 0.88 for S1 and S2 and 0.48 for S3 and S4 is ambiguous and does not really provide a meaningful insight. A discrepancy between two days is very high and these kinds of results suggest that on one day while introducing CT twice, we can expect the same training effects and on a different day we could obtain a totally different outcome. Third reliability measurements concerned set-to-set reliability to check if PAPE effects may be reliable within the same training session when multiple sets of CA and an explosive exercise are introduced. ICC results of 0.87 and 0.83 for morning sessions and 0.82 and 0.58 for afternoon sessions indicate that we can expect a similar training effect within the same training session. Therefore, there is a high likelihood that if an individual experiences a potentiating effect after the first set of a CA, the effect may be sustained after completing subsequent sets of a CA. That is an important conclusion for the practitioners as they usually tend to program multiset training plans of a given exercise to their athletes. If the effect was not reliable over multiple sets, it would decrease the efficacy and utility of this type of training.

Introducing ICC to assess the reliability of the measurements was our primary goal for this study but monitoring pre to post-CA changes in JH and its significance could be another method to check the reliability of PAPE effect. In this manner, the results are consistent—100% of the sets performed in this study indicated no statistical significance in JH changes, the protocol was consistently ineffective for the group. It shows that a training protocol introduced to the volleyball players was ineffective (considering results for the group) and should not be subsequently transferred to their training program. One could speculate if ICC reliability measurements are valuable as no PAPE effects were found within the group after any set in four experimental sessions. However, despite not having significant pre to post-CA changes in JH, the results of this study still provide important conclusions about reliability of the phenomenon. After this kind of investigation, a decision-making process for the coach becomes less complicated as he can reject this training protocol for the training group as there is a high likelihood that the same training protocol will not provide different results. This allows to program the training process more efficiently as the coach can quickly adjust a training program and not implement inefficient training protocol to the group continuously. It is especially important in a group setting where proper time management is particularly important as the coaches usually have limited time for the session.

Despite not seeing a potentiating effect for the group, it is worth introducing an individual analysis of the players as both PAPE effect and response to a CT are individual[8,26]. So far, no guidelines have been proposed on how to classify PAPE responders and non-responders. As the reliability of PAPE has not been studied yet, we propose an arbitral classification to assess an individual reliability to a training protocol. In this study, we obtained 12 pre to post-CA changes in JH and we suggest a following classification: (1) ≤ 4 positive changes (up to 33% of sets) in post-CA JH—a reliable non-responder; (2) 5–8 positive changes (41.7–66.7% of sets) in post-CA JH—ambiguous results, cannot classify clearly; (3) ≥ 9 positive changes in post-CA JH (75–100% of sets)—a reliable responder. Taking into consideration the above mentioned classification, it can be seen that 7 out of 12 players would be classified as reliable non-responders, 2 out of 12 reliable responders and 3 out of 12 cannot be clearly classified. An interesting fact is that 1 participant (n7) did not improve his post-CA SJ after any of 12 sets and 2 participants (n4 and n5) improved their post-CA SJ after all of 12 sets (Figs. 3 and 4). Despite the classification being arbitrary, we would recommend the coaches to test post-CA performance in their athletes and then decide if the CA is appropriate for a given individual. Therefore, after testing the athlete multiple times and having post-CA improvements in performance on ≥ 75% occasions, the training protocol is probably efficient and can be used to increase athlete's performance. On the contrary, if the athlete cannot achieve this percentage using a given training protocol, he should probably be introduced to a different protocol (if he had had ambiguous results) or even a different training method (if he had been a reliable non-responder).

An individual analysis provided an insight regarding their individual response to a CA stimulus but it can be also analyzed in relation to their playing position. It is an important concern as the authors found a large variability in jump demands between professional volleyball players on different positions during training sessions and matches[29,48].The setters generally have the highest number of the jumps but their jumps are relatively low in relation to their maximal jump height (approximately 56%). Also, their weekly training load is the highest as the specificity of their position involves a high number of jumps[29]. Middle blockers also have a high number of the jumps as apart from technical elements such as block, spiking and service, their actions also involve simulation of the spike[48] and their relative jump height is higher than the setters (approximately 64%). Opposites, in comparison with the middle blockers, are generally introduced to a similar jumping load during the matches[29,48] but their number of the jumps during the week is lower and their relative jump height is the highest of all positions (approximately 73%). The outside hitters' jumping load seems to be the smallest as their number of the jumps during the matches and weekly sessions is the lowest of all positions[29,48]. Our results provided a different PAPE response based on players' position. One of the setters (n1), liberos and outside hitters (n12-n7) were found to be reliable non-responders, two of the middle blockers (n5, n4) were found to be reliable responders, and the results of the second setter (n2), the third middle blocker (n6) and the opposite (n3) were ambiguous and cannot be clearly classified. Therefore, apart from the general individual response to an applied CA, an individual response based on players' position can also be observed. Based on this analysis, the middle blockers seem to be the most appropriate to apply this type of intervention as their efficacy is the highest of all positions.

Our study provides practical applications for the coaches regarding PAPE phenomenon under CT that was examined to be reliable, especially during the same training session. Also, we proposed a classification that can be applied in the same manner or slightly modified by a coach and simplify the decision making process about training methods for the athlete. Training intervention was introduced to professional athletes so the results of the study can be easily transferred to athletes' training programs. However, we would like to see our results reexamined in the group that positively responds to an introduced CA. Also, despite examining elite volleyball athletes we suggest applying results of this study with caution as this is the first study that examined the reliability of PAPE response. We recommend to test the athlete's response to a given CA several times and then adjust the training process as a response can vary drastically between the athletes within the same sport. We cannot assume with certainty that further investigation will confirm our results as the PAPE research is broad and the athlete's response to a given CA can be unpredictable. Thus, in future research the investigators should focus on repeating the same training protocols with various application methods (i.e. isometric, flywheel, accommodating resistance) and check its reliability instead of introducing new training protocols and only changing rest intervals or volume and intensity of a CA.

Limitations of the study

Despite its strengths, the study also has a few limitations. Firstly, the study involved only twelve players so in the future studies the number of participants could be increased. However, it was necessary to include in the study only players performing the same training (from the same team) to avoid the effect of the variety of training performed. Also, we tested the reliability of only one protocol, investigators could consider introducing a few training protocols and testing its reliability. Regarding results of our study, one could question introducing the same protocol with the same CA and testing its reliability when its initial effects did not provide PAPE effect. Thus, in future research, investigators could consider testing reliability of these procotols that had a potentiating effect in the group.

Additionally, we would recommend implementing force plates for the extended measurements of the jumps. That would allow to not only assess JH but also kinetic characteristics of the jump i.e. depth and velocity of the jump that affect subsequent JH[49,50]. It would be particularly valuable if the investigators decided to introduce countermovement jump as a baseline and post-CA explosive exercise, that has no isometric pause at the bottom as SJ. Then, it could be assessed if an athlete repeatedly increases his post-CA performance due to a PAPE effect or possibly due to changing execution of the jump.

Conclusions

This study provides a novel understanding of the PAPE phenomenon under CT in elite male volleyball players. The PAPE protocol was found to be ineffective to subsequently enhance JH on various occasions. Results of this study also suggest that the practitioners may effectively implement appropriately organized CT as both intraday set-to-set and interday morning and afternoon reliabilities seem to be acceptable. However, they should seek other CAs as the one used in this study was not appropriate to induce PAPE response. Implementing CT at both times of the day may be beneficial with a small advantage of afternoon sessions. Introducing two CT sessions within one day is highly questionable as at the moment intraday morning and afternoon reliability is vague.

Data availability

The datasets analyzed during the study are available from the corresponding author (SM) on reasonable request.

Received: 23 March 2024; Accepted: 11 June 2024
Published online: 14 June 2024

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Author contributions

SM collected data and wrote the original draft; MM edited and revised the manuscript; SM and MM designed the research, analyzed and interpreted data.. Both authors approved the final paper version.

Funding

The APC was financed within the program of the Minister of Science in Poland under the name 'Regional Excellence Initiative' in years 2024–2027 (project number: RID/SP/0027/2024/01) in the amount of PLN 4,053,904.00.

Competing interests

The authors declare no competing interests.

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5. Wnioski

1. Zastosowany protokół badawczy (90-sekundowa przerwa przed SJ i 3 powtórzenia martwego ciągu ze sztangą trapezową z intensywnością 80% 1RM, gdzie 15% 1RM stanowiło dopasowujące obciążenie jako CA) był nieefektywny do wywołania efektu PAPE u wyczynowych siatkarzy (publikacje nr. 1 i 4) i zarazem okazał się być efektywny do wywołania efektu PAPE u aktywnych fizycznie mężczyzn (publikacja nr. 2).
2. Jako ćwiczenie dynamiczne powinno implementować się ćwiczenie o takim samym charakterze pracy mięśniowej jak CA (publikacja nr. 1).
3. W protokole wykorzystującym obciążenie dopasowujące do wywołania efektu PAPE wydłużenie przerwy wypoczynkowej pomiędzy ćwiczeniem indukującym PAPE a wysiłkiem testowym do więcej niż 90 sekund nie pozwala na wystąpienie zjawiska PAPE u aktywnych fizycznie mężczyzn (publikacja nr. 2).
4. Badania wskazują, że wykorzystanie obciążenia dopasowującego może być skuteczniejsze do wywołania efektu PAPE w porównaniu do tradycyjnego obciążenia przy użyciu relatywnie krótkiej przerwy wypoczynkowej (90s) u aktywnych fizycznie mężczyzn (publikacja nr. 3).
5. Postactivation Performance Enhancement jest zjawiskiem indywidulanie występującym - zaobserwowano indywidualną odpowiedź na zastosowane CA u wyczynowych siatkarzy i aktywnych fizycznie mężczyzn (publikacje nr. 1, 2, 3, 4).
6. Występowanie zjawiska PAPE w treningu kompleksowym u wyczynowych siatkarzy charakteryzuje się dobrą powtarzalnością (publikacja nr. 4) u zawodników, którzy pozytywnie odpowiadają na ćwiczenie ukierunkowane na wywołanie efektu PAPE (publikacja nr. 4).

6. Zastosowanie aplikacyjne

1. Zastosowanie martwego ciągu ze sztangą trapezową i dopasowującego obciążenia może być skuteczne do indywidualnego wywołania zjawiska PAPE u osób z wysokim poziomem relatywnej siły mięśniowej w ćwiczeniach kończyn dolnych (minimum 1,5 kg/kg masy ciała) (publikacje nr. 1, 2, 3, 4).
2. Zastosowanie dopasowującego obciążenia jako część obciążenia CA może być zasadne, gdy chcemy skrócić czas między CA a ćwiczeniem dynamicznym (publikacje nr. 1, 2, 3, 4).
3. Osoby niebędące wyczynowymi sportowcami, a mające wysoki poziom relatywnej siły mięśniowej w kończynach dolnych, również mogą wykorzystywać efekty PAPE w treningu przygotowaniu fizycznego (publikacje nr. 2 i 3).
4. Implementacja treningu kompleksowego u sportowców powinna być poprzedzona sprawdzeniem czy dane protokół CA jest dla nich efektywny do wywołania PAPE (publikacja nr. 4).
5. Stosowanie treningu kompleksowego u sportowców może charakteryzować się dużymi różnicami interpersonalnymi w wywołaniu PAPE u sportowców trenujących tą samą dyscyplinę sportową (publikacja nr. 4).

7. Streszczenie

Zjawisko Post-Activation Performance Enhancement (PAPE) polega na zwiększeniu mocy mięśniowej w ćwiczeniu o charakterze dynamicznym (np. bieg, skok rzut) po wykonaniu ćwiczenia z wysoką intensywnością (np. wyrażonej jako %1RM), najczęściej o charakterze siłowym. Powodzenie danego protokołu zależne jest od wielu czynników, a najlepsze efekty PAPE osiągają sportowcy z wysokim poziomem relatywnej siły mięśniowej. Z uwagi na różnice interpersonalne i indywidualną odpowiedź, należy dobrać odpowiednią objętość, intensywność i przerwę wypoczynkową ćwiczenia aktywacyjnego (CA), aby zmaksymalizować prawdopodobieństwo wystąpienia zwiększonej mocy mięśniowej w ćwiczeniu dynamicznym.

Badania zostały przeprowadzone na wyczynowych siatkarzach (publikacje nr. 1 i 4) i osobach aktywnych fizycznie (publikacje nr. 2 i 3). Celem publikacji nr. 1 pracy było zbadanie efektywności opracowanego protokołu indukującego PAPE na wysokość wyskoku podczas dwóch rodzajów skoków tj. CMJ i SJ, a wyniki wskazują na silniejszy efekt w przypadku SJ. Celem publikacji nr. 2 było zbadanie efektywności protokołu PAPE z różnymi przerwami wypoczynkowymi na wysokość wyskoku w SJ i protokół z 90-sekundową przerwą wypoczynkową okazał się najskuteczniejszy. Celem publikacji nr. 3 było porównanie skuteczności tego samego protokołu badawczego z wykorzystaniem tylko tradycyjnego obciążenia (TR) lub części obciążenia dobranego jako obciążenie dopasowujące (AR) i wyniki wskazują na pozytywny efekt dla AR i brak efektu dla TR. Celem publikacji nr. 4 było zweryfikowanie skuteczności wielokrotnego zaimplementowania tego samego protokołu u wyczynowych siatkarzy i stwierdza się dobrą powtarzalność zjawiska PAPE w treningu kompleksowym siatkarzy.

Protokół badawczy użyty w publikacji nr. 1, 2 i 4 był nieefektywny do wywołania efektu PAPE u wyczynowych siatkarzy (publikacje nr. 1 i 4) i zarazem okazał się być efektywny do wywołania efektu PAPE u aktywnych fizycznie mężczyzn (publikacja nr. 2). W przypadku użycia AR, wydłużenie przerwy wypoczynkowej do więcej niż 90 sekund nie pozwoliło na wystąpienie zjawiska PAPE u aktywnych fizycznie mężczyzn (publikacja nr. 2). Użycie relatywnie krótkiej przerwy wypoczynkowej (90s) przy użyciu tradycyjnego obciążenia nie pozwoliło na zaobserwowanie zjawiska PAPE u aktywnych fizycznie mężczyzn (publikacja nr. 3). PAPE jest zjawiskiem indywidulanie występującym - zaobserwowano indywidualną odpowiedź na zastosowane CA u wyczynowych siatkarzy i aktywnych fizycznie mężczyzn (publikacje nr. 1, 2, 3, 4). Dowiedziono też, że zastosowanie zjawiska PAPE w treningu kompleksowym u wyczynowych siatkarzy charakteryzuje się dobrą powtarzalność u zawodników, którzy pozytywnie odpowiadają na ćwiczenie ukierunkowane na wywołanie efektu PAPE (publikacja nr. 4).

8. Abstract

Post-Activation Performance Enhancement (PAPE) phenomenon relies on increasing muscle power in dynamic exercise (i.e.g sprinting, jumping, throwing) after performing a high intensity exercise (i.e. expressed as %1RM), usually of a strength nature. Efficacy of a given protocol depends on many factors and the highest PAPE effects can be observed in the athletes with relative strength level. Due to large interpersonal variability and individual response to a given stimuli, an appropriate volume, intensity and rest period of a conditioning activity (CA) to maximise possibility of increasing muscle power in a dynamic exercise.

The research was conducted in elite volleyball players (publications 1 and 4) and physically active males (publications 2 and 3). The goal of the first publication was examining the efficacy of a protocol to induce PAPE and increase vertical jump in two jumping tests: CMJ and SJ and the results indicate higher effect for SJ. The goal of the second publication was examining the efficacy of the same PAPE protocol with different rest intervals on vertical jump height in SJ and 90s protocol was found to be the most effective one. The goal of the third publication was comparing the efficacy of the same PAPE protocol while using only traditional resistance (TR) or the addition of accommodating resistance (AR) and the results indicate a positive effect for AR and no effect for TR. The goal of the fourth publication was to verify the efficacy of multiple implementation of the same PAPE protocol to elite volleyball players and a good reliability was found in the volleyball players under complex training.

A study protocol introduced in publications 1, 2 and 4 was ineffective to induce PAPE effect in elite volleyball players (publications 1 and 4) and effective in physically active males (publication 2). In case of introducing AR, prolonging rest interval to more than 90s did not allow to induce PAPE effect in physically active males (publication 2). Introducing relatively short rest period after CA (90s) while using traditional resistance did not allow to observe PAPE phenomenon in physically active males (publication 3). PAPE is an individually existing phenomenon – an individual response to a given CA was observed in elite volleyball players and physically active males (publications 1, 2, 3, 4). Additionally, introducing PAPE phenomenon under complex training in elite volleyball players was found to have a good reliability (publication 4).

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Komisja Bioetyczna
przy Okręgowej Izbie Lekarskiej
w Krakowie

Nr 1/KBL/OIL/2022 z dnia 11 lutego 2022 r.

Na posiedzeniu w dniu 11 lutego 2022 r. Komisja zapoznała się z wnioskiem (dokumentacja w załączeniu) złożonym przez :

Koordynator Badania: mgr Sebastian Masel

Akademia Wychowania Fizycznego, Centralne Laboratorium Naukowo Badawcze, Al. Jana Pawła II 78, 31-571 Kraków

Tytuł badania: **Badanie wpływu dopasowującego się obciążenia na PAP (postactivation Potentation) u wyczynowych siatkarzy.**

Do wniosku dołączono:

1. Protokół badania
2. Streszczenie badania
3. Wzór Informacji dla Pacjenta
4. Wzór Formularza Świadomej Zgody
5. Wzór Formularza o Ochronie Danych Osobowych
6. Polisa Ubezpieczenia OC lekarza nadzorującefo badanie
7. Polisa Ubezpieczeniowa Ośrodka
8. Lista ośrodków biorących udział w badaniu

Komisja wyraża zgodę na przeprowadzenia badania na warunkach przedstawionych we wniosku.

Zgoda Komisji dla Ośrodka jest ważna do dnia ważności Polisy Ubezpieczeniowej
Skład i działanie Komisji zgodne z zasadami Dobrej Praktyki Klinicznej (GCP) oraz wymogami lokalnymi
Lista członków Komisji biorących udział w posiedzeniu stanowi załącznik do niniejszego dokumentu.
Pouczenie: W ciągu 14 dni od otrzymania niniejszej opinii Wnioskodawcy przysługuje prawo odwołania do Komisji Odwoławczej za pośrednictwem Komisji Bioetycznej przy OIL w Krakowie

Kraków, dnia 25.02.2022 r.

Przewodniczący Komisji Bioetycznej
przy OIL w Krakowie

Dr Mariusz Janikowski

Komisja Bioetyczna
przy Okręgowej Izbie Lekarskiej
w Krakowie

Lista obecności członków Komisji Bioetycznej przy Okręgowej Izbie Lekarskiej w Krakowie na posiedzeniu w dniu 11 lutego 2022r.

dr Mariusz Janikowski ....
lekarz– specjalista chorób wewnętrznych,
diagnosta laboratoryjny
Zakład Diagnostyki Katedry Biochemii Klinicznej SU

dr med. Stefan Bednarz ....
dr medycyny – specjalista chorób wewnętrznych
I Klinika Chorób Wewnętrznych i Gerontologii
Szpitala Uniwersyteckiego w Krakowie

mgr Jerzy Bilek ....
mgr farmacji

ks. dr hab. Jerzy Brusiło ....
Uniwersytet Papieski Jana Pawła II
duchowny, etyk

dr Mirosława Noppenberg ....
Przełożona Pielęgniarek
Szpital Specjalistyczny im. J. Dietla w Krakowie

dr med. Jerzy Friediger ....
dr medycyny – specjalista chirurgii ogólnej
Szpital Specjalistyczny im. S. Żeromskiego w Krakowie

dr Irena Gawrońska ....
lekarz– pediatra, neonatolog
SPZOZ im. Śniadeckiego w Nowym Sączu

mgr Zbigniew Grochowski ....
mgr psychologii
Szpital Specjalistyczny im. Dietla w Krakowie

prof. dr hab. med. Zbigniew Kojs ....
specjalista ginekologii i położnictwa
Szpital Specjalistyczny im. L. Rydygiera Krakowie

Lek. dent. Dariusz Kościelniak ....
Specjalista stomatologii ogólnej i ortodoncji
Gabinet ortodontyczno – dentystystyczny
„Pod Kasztanem"

dr Lech Kucharski ....
lekarz - specjalista chorób wewnętrznych
Szpital Specjalistyczny im. S. Żeromskiego w Krakowie

dr med. Janusz Legutko ....
doktor medycyny –specjalista chirurgii ogólnej
I Katedra Chirurgii Ogólnej
i Chirurgii Gastroenterologicznej SU w Krakowie

prof. dr hab. Janusz Raglewski ....
Katedra Prawa Karnego UJ