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Research article

Acute Effects of Complex Conditioning Activities on Athletic Performance and Achilles Tendon Stiffness in Male Basketball Players

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Abstract

The goal of this study was to compare the effects of a bilateral conditioning activity consisting of back squats and drop jumps with a unilateral one consisting of split squats and depth jumps to lateral hop over sequentially performed countermovement jump (CMJ), modified t-agility test (MAT), and Achilles tendon stiffness. Twenty-six basketball players participated in this study and were randomly and equally assigned to one of two different test groups: bilateral (B - CA) or unilateral (U - CA) conditioning activity group. The B - CA group completed 2 sets of 4 repetitions of back squats at 80% of one-repetition maximum (1RM), then 10 drop jumps, while the U - CA group performed 2 sets of 2 repetitions of split squats on each leg at 80%1RM, followed by 5 depth jumps to lateral hop on each leg as conditioning activity (CA) complexes. After a warm-up and 5 min before the CA the baseline Achilles tendon stiffness, CMJ, and MAT time measurement were performed. In the 6th min after the CA, all tests were re-tested in the same order. The two-way repeated measures mixed ANOVAs revealed that both B - CA and U - CA failed to produce significant improvements in CMJ and MAT performance. In addition, a significant increase in Achilles stiffness was demonstrated with both protocols (a main effect of time: p = 0.017; effect size = 0.47; *medium*). This study revealed that combining back squats and drop jumps, as well as split squats and depth jumps to a lateral hop, had no effect on subsequent CMJ and MAT performance in basketball players. Based on these results, it can be assumed that combinations of exercises, even if they have similar movement patterns, may cause excessive fatigue, resulting in no PAPE effect.

Key words: Post-activation performance enhancement, PAPE, change of direction, countermovement jump.

Introduction

The post-activation performance enhancement (PAPE) phenomenon refers to a brief, intense voluntary activity that will increase the performance of a subsequent athletic task (Gołaś et al., 2016; Blazevich and Babault, 2019; Krzysztofik et al., 2020). To achieve this effect, in training practice as well as in scientific research, high-intensity resistance exercises are most often used before an explosive task with a similar movement pattern (Seitz and Haff, 2016). For example, a back squat performed prior to a vertical jumping. Since numerous studies have confirmed the efficacy of PAPE in acute athletic performance improvement (Chen et al., 2017; Tsoukos et al., 2019; Timon et al., 2019; Krzysztofik and Wilk, 2020; Ciocca et al., 2021), it has become widely used in training sessions and as part of a pre-competition warm-up (O'Grady et al., 2021; Finlay et al., 2022). As mentioned above, chosen pairs of PAPE exercises should have similar movement patterns. This has to do with the fact that there is a high probability that the effect of PAPE is mainly local (Seitz and Haff, 2016; Cuenca-Fernández et al., 2017; Wong et al., 2020) and, for example, performing a back squat may improve vertical jump performance, but the effect may not be as significant in broad jump performance. Nevertheless, athletic requirements, both during training and sports competition, involve performing complex motor tasks, often in different directions, such as running with a change of direction.

Considering the similarity principle, it seems reasonable to perform several high-intensity exercises as a conditioning activity. Interestingly, to the best of the authors' knowledge, so far only a single study has evaluated the performance of two exercises as a conditioning activity. Kalinowski et al. (2022) assessed the impact of the use of isometric back squats in combination with drop jumps on the subsequent countermovement jump (CMJ) and a modified t-agility test (MAT). In order to better imitate the movement pattern, these exercises were performed bilaterally and unilaterally with the assumption that the former will improve CMJ and the latter MAT (bilateral half squat and double leg drop jump vs. split squat and single leg drop jump). Indeed, bilateral conditioning activity enhanced CMJ performance but not MAT. However, the unilateral conditioning activity was ineffective in enhancing both CMJ and COD. In fact, running is a cyclic action in which the individual alternates between flight and unilateral ground contact. Therefore, it seems that unilateral exercise may be more effective than bilateral ones in this case. However, during the MAT test half of the distance is covered using the slide-step movement. Therefore, lateral movements or a combination of split squats with lateral movement exercises would be even closer to mimicking the MAT test.

Another factor determining the PAPE effect is the fatigue-potentiation relationship (Seitz and Haff, 2016). The applied conditioning activity causes a certain level of fatigue and potentiation; thus, the objective is to perform the chosen exercise with a load in which potentiation exceeds fatigue. Following such an activation protocol an improvement in athletic performance can be expected. In a

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study by Kalinowski et al. (2022), a significantly higher level of Achilles tendon stiffness was observed after unilateral conditioning activities compared to bilateral ones, which could indicate fatigue. In studies examining changes in muscle or tendon stiffness after fatigue protocols, an increase in stiffness was observed, which was accompanied by a decrease in physical performance (Wang et al., 2016; 2017; Trybulski et al., 2022; Lall et al., 2022). Accordingly, this indicates that the unilateral conditioning activity used in the study by Kalinowski et al. (2022) led to a level of fatigue that exceeded the potentiation, and, as a result, there was no effect on the CMJ and MAT results.

Therefore, the main goal of this study was to compare the effects of a bilateral conditioning activity consisting of back squats and drop jumps with a unilateral one consisting of split squats and depth jumps to lateral hop over sequentially performed CMJ, MAT test, and Achilles tendon stiffness. This was performed to expand the knowledge related to the principle of similarity of exercises and to determine how effective pairs of exercises are in PAPE protocols. We hypothesized that bilateral conditioning activities would improve CMJ but not MAT, while unilateral ones would improve MAT but not CMJ. We also hypothesized that none of the CAs would contribute to changes in Achilles tendon stiffness.

Methods

Participants

Twenty-six basketball players participated in this study and were randomly and equally assigned to one of two different test groups: bilateral (B-CA) (age: 24 ± 6 yrs, body mass: 87 ± 11 kg, body height: 191 ± 8 cm, basketball training experience: 15 ± 5 yrs) or unilateral (U-CA) conditioning activity group (age: 25.5 ± 8.6 yrs, body mass: 89.2 ± 12.7 kg, body height: 197 ± 17 cm, basketball training experience: 12 ± 6.5 yrs). The inclusion criteria were as follows: i) free from neuromuscular and musculoskeletal disorders, ii) no lower-limb surgery for two years prior to the study, iii) have at least four years of experience in basketball training and competition iv) take part in regular basketball and resistance training, and competition for a year prior to the study, v) consider themselves safe to participate in the exercise protocol included in the study design as determined by the self-administered Physical Activity Readi ness Questionnaire (PAR-Q). Participants were instructed to maintain their usual dietary and sleep habits, and not to use any stimulants and alcoholic drinks throughout the study. Moreover, they were asked not to perform any additional resistance exercises 48-h before testing to avoid fatigue. Participants were allowed to withdraw from the experiment at any time and were informed about the benefits and potential risks of the study before providing their written informed consent for participation. Participants were not told of the expected study outcomes. The study protocol was approved by the Bioethics Committee for Scientific Research, at the Academy of Physical Education in Katowice, Poland (3/2021) and performed according to the ethical standards of the Declaration of Helsinki 2013. The sample size was calculated a priori based on a statistical power of 0.8, an effect size of g = 0.29 - 46, and a significance level of 0.05, taking acute changes in stiffness after exercise, and post-activation performance enhancement in jumping performance as a reference variable (Seitz and Haff, 2016; Pereira et al., 2020). A minimum sample size of between 12-26 individuals was obtained (G*Power [version 3.1.9.2], Dusseldorf, Germany).

Experimental sessions

The participants were randomly (using web-based software: randomization.com) assigned to either a B - CA or U - CA conditioning activity complex (Figure 1). The B - CA group completed 2 sets of 4 repetitions of back squats at 80% 1RM, then 10 drop jumps, while the U - CA group performed 2 sets of 2 repetitions of split squats on each leg at 80%1RM, followed by 5 depth jumps to lateral hop on each leg as conditioning activity complexes. A 3-minute rest interval was allowed between sets, while there was no rest within the conditioning activity complex. The high-intensity back squats, split squats, and drop jumps have been previously indicated to be effective in inducing an improvement in physical performance (Andrews et al., 2016; Dello Iacono et al., 2016; Krzysztofik et al., 2021; 2022). After a standardized warm-up, the tests were carried out in the following order: baseline Achilles tendon stiffness, CMJ performance and MAT time, CA, and post-CA re-test in the same order. The measurements ended approximately 5 min before the conditioning activity and the 6th min after the conditioning activity. This rest interval was selected because the greatest PAPE effect was reported typically 5-7 min (Wilson et al., 2013; Seitz and Haff, 2016).

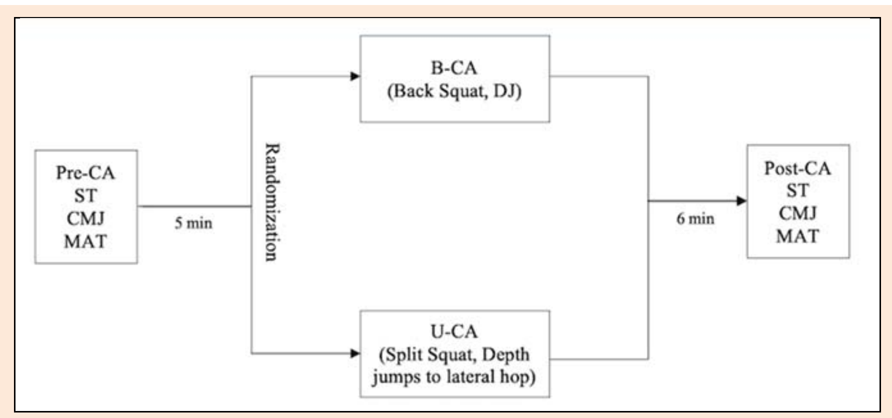

Figure 1. Study design. CA – conditioning activity; CMJ – countermovement jump; B-CA – bilateral conditioning activity; U-CA – unilateral conditioning activity; MAT – modified t-agility test.

Familiarization and one-repetition maximum test session

After a general body warm-up, the same as in the upcoming experimental session, the participants performed two attempts of the CMJ and MAT starting with shuffling on the dominant and non-dominant leg sides. Following that, the 1RM back squat and split squat (both legs at one session) tests were performed in random order as described elsewhere (McCurdy et al., 2004). Afterward, the players performed the specific squat warm-up repetitions at a load of 20, 40, and 60% of their estimated 1RM. The first testing load was set to an estimated 80%1RM and was increased by 2.5 to 10 kg for each subsequent trial. This process was repeated until failure but in no more than 5 attempts.

The familiarization session was conducted at least one week before the main experiment.

Measurement of Achilles tendon stiffness

The MyotonPRO, hand-held myometer (MyotonPRO, Myoton AS, Tallinn, Estonia) was used for the non-invasive assessment of viscoelastic muscle properties of the Achilles tendon through superficial mechanical deformation. The measurement of Achilles tendon stiffness (both limbs) was performed 2cm proximal to the superior aspect of the calcaneus (Bizzini and Mannion, 2003; Taş and Salkın, 2019) in a state of muscle relaxation with participants lying in a prone position with their arms resting beside the body. The probe of the device was positioned perpendicular to the skin, and a preload force of 0.18 N was used continuously while a brief mechanical compression (0.4 N for 15 ms) was applied. An accelerometer records the dampened oscillation that the soft tissue produces in response to mechanical impulses. The Myoton accelerometer was set at 3200 Hz with an average value obtained from three consecutive measurements. The validity and reliability of this device have been previously confirmed (Feng et al., 2018).

Measurement of jumping performance

Jumping assessments were performed on a force plate (Force Decks, Vald Performance, Australia), which has been previously confirmed as valid and reliable (Heishman et al., 2020). Each participant performed two CMJ without arm swing at pre-CA as a baseline and ~6 min. post-CA. The participant started in the standing position with hands placed on the hips for this measurement. Then, they dropped into the countermovement position to a self-selected depth and immediately followed by a maximal effort vertical jump. The participants were instructed to land in the same position as the take-off, in the midsection of the force plate. The participant reset to the starting position after each jump, and the procedure was completed for a total of two jumps. The jump height (calculated from flight time [$9.81 \times \{\text{flight time}\}^2/8$]), peak velocity, contraction time, and reactive strength index modified (as a ratio of jump height and contraction time) were evaluated. The best jump height after post-CA was kept for further analysis.

Measurement of change of direction performance

A MAT-test was used to determine multi-directional running speeds such as forward sprinting, right and left shuffling, and backpedaling. Each participant performed the test twice, starting with shuffling on the dominant and non-dominant leg sides, in random order. The players started with the front foot placed 0.3m behind the starting gate A, then sprinted forward (at their own discretion) to cone B and touched the base of it. Facing forward and without crossing their feet they shuffled to the left or right cone C or D and touched its base, then shuffled to the corresponding cone D or C and touched its base. Following that, they shuffled back to cone B, touched its base, and finally ran backward to the starting gate. Running times were recorded using Swift timing gates (Swift Performance Equipment, QLD, Australia). The height was set at approximately 0.7m off the ground, corresponding to participants' hip height to avoid the timing gates being triggered prematurely by a swinging arm or leg. Times were measured to the nearest 0.01s. The best running time was kept for further analysis.

Statistical analysis

All statistical analyses were performed using SPSS (version 25.0; SPSS, Inc., Chicago, IL, USA) and were shown as means with standard deviations (±SD) with their 95% confidence intervals (CI). Statistical significance was set at $p < 0.05$. The Shapiro–Wilk, Levene, and Mauchly's tests were used to verify the normality, homogeneity, and sphericity of the sample's data variances, respectively. The two-way repeated measures mixed ANOVAs (2 × [B - CA vs. U-CA group] × 2 time-points [pre- vs. post-CA]) were used to investigate the influence of CA on CMJ performance, MAT time, and Achilles tendon stiffness. When a significant main effect or interaction was found, the post-hoc tests with Bonferroni correction were used to analyze the pairwise comparisons. The magnitude of mean differences was expressed with standardized effect sizes. Thresholds for qualitative descriptors of Hedges g were interpreted as ≤0.20 "small", 0.21 - 0.79 "medium", and >0.80 as "large".

Results

The Shapiro-Wilk test did not show a statistically significant violation of data distribution in any of the examined variables. Levene's test showed heterogeneity of variance for RSImod, therefore, the ANOVA was carried out on absolute deviations from the mean of each group.

Countermovement jump performance

There were no statistically significant interactions for jump height ($F=2.122$; $p=0.158$; $\eta^2=0.081$), peak velocity ($F=0.396$; $p=0.535$; $\eta^2=0.016$), contraction time jump ($F=0.736$; $p=0.399$; $\eta^2=0.03$), or RSImod ($F=0.438$; $p=0.514$; $\eta^2=0.018$). Similarly, there were no main effect of condition for jump height ($F=0.259$; $p=0.616$; $\eta^2=0.011$), peak velocity ($F=0.396$; $p=0.535$; $\eta^2=0.016$), contraction time jump ($F=0.685$; $p=0.416$; $\eta^2=0.028$), or RSImod ($F=3.646$; $p=0.068$; $\eta^2=0.132$). Finally, there was no significant main effect of time-point for jump height ($F=0.165$; $p=0.688$; $\eta^2=0.007$), peak velocity ($F=1.424$; $p=0.244$; $\eta^2=0.056$), contraction time jump ($F=2.014$; $p=0.169$; $\eta^2=0.077$) or RSImod ($F=0.027$; $p=0.872$; $\eta^2=0.001$) (Table 1).

Table 1. Comparison of jumping performance pre- and post-conditioning activity.

Group	Pre-CA	Post-CA	ES	Δ%
	Jump Height [cm]			
B-CA	39.3 ± 5.1 (36.5 to 42.1)	39.8 ± 5.1 (37 to 42.7)	0.10	1.3 ± 4.4
U-CA	38.7 ± 4.7 (35.9 to 41.6)	38.4 ± 4.8 (35.6 to 41.3)	-0.06	-0.9 ± 3.6
	Peak Velocity [m/s]			
B-CA	2.87 ± 0.19	2.89 ± 0.16	0.11	1.3 ± 4.1
U-CA	2.84 ± 0.19	2.86 ± 0.18	0.10	0.4 ± 2.1
	Contraction Time [ms]			
B-CA	868 ± 167	821 ± 165	-0.27	-4.9 ± 14.3
U-CA	808 ± 113	796 ± 103	-0.11	-3.5 ± 11.5
	RSImod			
B-CA	0.47 ± 0.12	0.51 ± 0.14	0.30	9.2 ± 16.4
U-CA	0.48 ± 0.06	0.49 ± 0.13	0.13	1.3 ± 12.6

Change of direction performance

There were no statistically significant interactions for COD performance on the dominant side (F=1.337; p=0.259; η^2=0.053) and on the non-dominant side (F=2.024; p=0.168; η^2=0.078). Similarly, there were no main effects of condition on the dominant side (F=0.701; p=0.411; η^2=0.028) and the non-dominant side (F=0.606; p=0.444; η^2=0.025). Finally, there was no significant main effect of time-point on the dominant side (F=1.651; p=0.211; η^2=0.064) and the non-dominant side (F=0.152; p=0.701; η^2=0.006) (Figure 2).

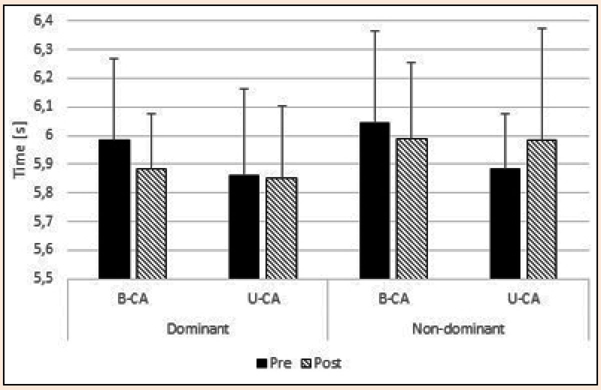

Figure 2. Comparison of Modified t-agility test time stiffness pre- and post-conditioning activity.

Achilles tendon stiffness

There were no statistically significant interactions for the dominant leg (F=0.899; p=0.353; η^2=0.036) and non-dominant leg (F=0.118; p=0.734; η^2=0.005) Achilles tendon stiffness. Similarly, there were no main effects of the condition for the dominant leg (F=1.2; p=0.284; η^2=0.048) and non-dominant leg (F=3.579; p=0.071; η^2=0.130) Achilles tendon stiffness. Moreover, there was no main effect of time-point on the non-dominant leg (F=1.946; p=0.176; η^2=0.075), but a statistically significant main effect of time-point for dominant leg Achilles tendon stiffness (F=6.576; p=0.017; η^2=0.215) was found. The post-hoc comparisons showed a significant increase in Achilles tendon stiffness for the post-CA measure (p=0.017; effect size=0.47) in comparison to the pre-CA (Figure 3).

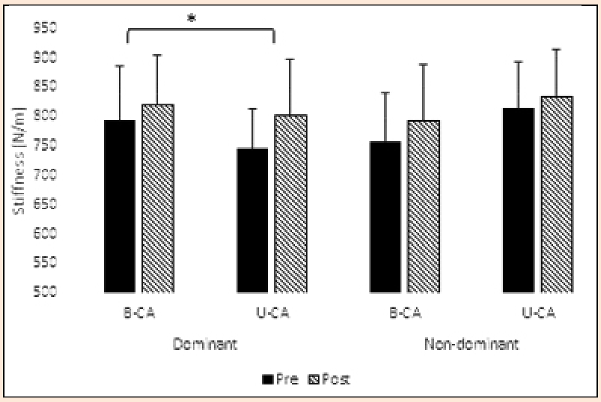

Figure 3. Comparison of Achilles tendon stiffness pre- and post-conditioning activity. * $p < 0.05$.

Discussion

The main goal of this study was to find out if the bilateral and unilateral conditioning activation complex contributes to a significant improvement in CMJ and MAT performance and if there is a significant difference in the magnitude of PAPE responses between these protocols. The findings revealed that both B-CA (back squats and drop jumps), as well as U-CA (split squats and depth jumps to lateral hop) failed to produce significant improvements in CMJ and MAT performance. In addition, an acute significant increase in Achilles stiffness may indicate decrease in sport performance was demonstrated with both protocols.

Several factors have been proposed to modulate PAPE responses (Seitz and Haff, 2016); however, it appears that they are primarily restricted to fatigue and potentiation net balance. Therefore, it seems that the explanation of these results should be sought in the unfavorable relationship between fatigue and potentiation after the applied conditioning activity. It has been repeatedly suggested that the applied conditioning activity induces a certain level of potentiation and fatigue (Seitz and Haff, 2016), when fatigue subsides and potentiation is still maintained at a high level, performance improvement is noted. Thus, it seems that in the current study, the level of potentiation and fatigue was unfavorable with both conditioning activities used. To the best of the authors' knowledge, this is the second study to date that considers the use of combined conditioning activities, and the first one was conducted in males. The study by Kalinowski et al. (2022) revealed that 6s maximal attempts of bilateral back squats followed immediately by 10 repetitions of drop jumps (as a bilateral conditioning activity) significantly enhanced CMJ performance but not MAT time in female volleyball players. Furthermore, 2 sets of 3s maximal trials of unilateral single-leg split squats followed by five repetitions of drop jumps on each leg failed to produce any significant changes in CMJ or MAT performance. However, it must be highlighted that in the MAT test, half the distance is covered with a slide step. Therefore, the unilateral exercises used in the Kalinowski et al. (2022) protocol does not fully reflect the lateral movements in the MAT test. Accordingly, one of the innovative aspects of the present study included the use of a depth jump to a lateral hop, which was supposed to mimic the side step found in the

MAT. We assumed that, in accordance with the motion similarity principle (Gołaś et al., 2016; Dello Iacono et al., 2016), the U-CA would contribute to a greater acute improvement in MAT performance than the B-CA. Nonetheless, the conditioning activity used in this study did not improve either MAT or CMJ. It appears that the level of fatigue exceeded potentiation, and as a result, no improvement in fitness was obtained. Although the volume of conditioning activities in the current study was low, similar to the study by Kalinowski et al. (2022), a significant increase in Achilles stiffness after each conditioning activity was reported. An increase in tendon and muscle stiffness has been previously found after fatiguing protocols and was accompanied by an acute performance decrease (Wang et al., 2016;2017; Trybulski et al., 2022; Lall et al., 2022). Therefore, it appears to confirm that the applied conditioning activity indeed produced a level of fatigue that exceeded potentiation.

Surprisingly, unlike the study by Kalinowski et al. (2022), the current study found no improvement in CMJ performance, MAT time after B-CA, and an increase in Achilles tendon stiffness. It seems that the sex of the participants may be an explanation, as males participated in this study and females in a study by Kalinowski et al. (2022). Despite the fact that a meta-analysis by Wilson et al. (2013) showed that sex does not moderate the magnitude of the PAPE effect, recent studies reported indications that such differences may exist (Wong et al., 2020). On the other hand, taking into account the sex difference in fatigability and recovery from fatiguing tasks and the impact of the potentiation-fatigue relationship on the PAPE effect, it can be assumed that males and females will respond differently to the same conditioning activity. Indeed, males are usually more fatigable than females, and recovery of force is slower for males after dynamic and isometric contractions (Hunter, 2016; Senefeld et al., 2018). Considering the above, it appears that males require a longer recovery time after the conditioning activity than females.

Moreover, in the study by Kalinowski et al. (2022) an isometric-plyometric conditioning activity was used, while in the present study, an isotonic-plyometric conditioning activity was applied. There is extensive evidence that both isometric and dynamic conditioning activities are highly effective in inducing the PAPE effect (Bogdanis et al., 2014; Spieszny et al., 2022; Krzysztofik et al., 2023). Moreover, even direct comparisons as in the Vargas-Molina et al. (2021) study showed similar increases in CMJ height after isometric (2 sets of 4 s at 75%1RM) and isotonic (2 sets of 3 repetitions at 75%1RM) squats. While this study used similar intensity and volume for barbell squats (2 sets of 4 repetitions at 80% 1RM), 10 drop jumps were then performed after each set. In addition, the energy cost of isometric work compared to dynamic is slightly higher (Duchateau and Hainaut, 1984; Cady et al., 1989). Due to this and the fact that males participated in the current study, perhaps the applied conditioning activities were too fatigable.

The results of this study should be considered in light of certain limitations. First of all, it should be emphasized that this study was not conducted in a crossover pattern. Despite the fact that the participants had a similar sports level, taking into account the inter-individual variability in response to the conditioning activity (Chiu et al., 2003) it is not excluded that if the participants performed both protocols, the results of this study may have been different. Furthermore, the testing order of CMJ performance and MAT was not randomized, therefore it is possible that they might have impacted each other. Moreover, evaluations were made only after a single rest interval, so it is possible that the recorded PAPE response could differ after using rest intervals of a different time. In addition, although the conditioning protocols were similar in volume, performing a unilateral one could be more demanding given balance requirements. Finally, we did not measure the ground reaction forces during drop and depth jumps, thus the total volume being the same, perhaps the protocols differed in terms of intensity.

Conclusion

The findings of this study revealed that combining back squats and drop jumps, as well as split squats and depth jumps to a lateral hop, had no effect on subsequent CMJ and MAT performance in basketball players. Based on these results, it can be assumed that combinations of exercises, even if they have similar movement patterns, may cause excessive fatigue, resulting in no PAPE effect. However, due to the lack of significant evidence regarding the effectiveness of conditioning activation complexes in PAPE protocols, we recommend further testing them before complete rejection.

Acknowledgements
The experiments comply with the current laws of the country in which they were performed. The authors have no conflict of interest to declare. The datasets generated and analyzed during the current study are not publicly available, but are available from the corresponding author who was an organizer of the study.

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Key points

- There is limited data regarding the combination of exercises used as a conditioning activity to elicit post-activation performance enhancement.
- Complex conditioning activations consisting of high-intensity resistance and plyometric exercise combinations may be too fatigable to induce a post-activation performance enhancement effect in males.
- An acute significant increase in Achilles stiffness may indicate a decrease in sports performance.

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