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Review article

Effects of Unilateral Conditioning Activity on Acute Performance Enhancement: A Systematic Review

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Abstract
This review aimed to summarize the reported effects of unilateral conditioning activity (CA) on unilateral performance, bilateral performance, and the contribution of activated body limb to bilateral performance. A systematic search on MEDLINE, SPORTDiscus, Scopus, and Google Scholar was conducted on February 2022. Twenty-three studies met the inclusion criteria. Throwing, jumping, swimming, change of direction, and isokinetic performance were used as outcome measures to assess the impact of unilateral CAs on inducing post-activation performance enhancement. Eleven studies examined the effectiveness of resistance exercises as a CA, seven investigated plyometric exercises, and five used isokinetic muscle actions as CAs. Notably, only three studies directly compared the effects of bilateral and unilateral CA, and no study reported possible changes in the contribution of each limb during bilateral exercises executed following unilateral CA. Split squats were the most often studied CA (7), and it was shown that multiple sets of high-loaded split squats (85% one-repetition maximum) executed as CA, improve vertical jumping and change of direction after 4 to 8 min of recovery. At the same time, multiple sets of alternate leg bounds performed with ~10% body weight or without any external load result in an improvement of sprint performance, 2 and 8 min later, with the effect being greater when loaded jumps are used. The unilateral CAs such as split squats, alternate leg bounds, and drop jumps can be effectively used to acutely improve a wide variety of athletic tasks, including jumping, sprinting, change of direction, and swimming performance.

Key words: Post-activation performance enhancement, post-activation potentiation, athletic performance, resistance training.

Introduction

During the last two decades, the post-activation performance enhancement (PAPE) phenomenon caused great interest among sports professionals and researchers. This interest mainly originated from the possibility of individuals to acutely improve physical performance during a competition, a high-quality training session, or complex training. The PAPE effect is described as an increase in neuromuscular performance after a previous exercise which is called the conditioning activity (CA) (Blazevich and Babault, 2019). In practice, the CA (i.e., back squat) precedes an explosive activity which is biomechanically similar (i.e., vertical jump). However, performance enhancement is also achieved after CAs involve a different movement pattern executed with the same muscles. For instance, a set of bilateral power clean or back squat exercise is executed before the sprint, which involves repeated unilateral take-off actions (Seitz, Trajano and Haff, 2014a). The duration of PAPE lasts up to 16-20 min (Bevan et al., 2010; Wilson et al., 2013; Seitz et al., 2014b) and may be explained by several mechanisms such as changes in muscle temperature and intramuscular fluid accumulation, neural mechanisms, or phosphorylation of the myosin regulatory light chains (Blazevich and Babault, 2019). The selection of an appropriate CA may affect PAPE's timing and magnitude, but there is no information regarding the interaction between unilateral and bilateral PAPE effects so as to reach firm conclusions (Wilson et al., 2013; Seitz and Haff, 2016; Finlay et al., 2022).

The changes in performance due to PAPE depend on the relationship between potentiation and fatigue (Macintosh and Rassier, 2002), while the balance between these components determines subsequent performance. Hence, the potentiation induced by the CA has to exceed the fatigue levels to improve voluntary performance. Most research investigating this phenomenon examined different potentiation complex settings, especially on the type, volume, and intensity of exercise used as a CA. Generally, the greatest PAPE effect was reported typically 5-7 min following low volume CA (1-3 sets) using high-resistance (>85% one-repetition maximum [1RM]) (Wilson et al., 2013; Seitz and Haff, 2016; Krzysztofik et al., 2021). Even though the movement pattern of CA and the subsequent exercise should be similar (Gołaś et al., 2016), most studies aimed to induce PAPE using bilateral CAs, even though the majority of motor tasks in sports are executed unilaterally (Wilson et al., 2013; Seitz and Haff, 2016; Krzysztofik et al., 2021). Recent reviews show that PAPE may be explained by changes occurring locally in the exercising muscles, such as increased temperature and fluid shifts, which modify muscle metabolism and contraction mechanics (Blazevich and Babault, 2019). Therefore, the CAs used as a part of a pre-competition or pre-training warm-up should involve the same muscle groups that will be used in the next task, ideally in a unilateral fashion, which should also mimic the subsequent sports task. On the other hand, some disadvantages of the unilateral exercises include (a) higher balance requirements than bilateral movements (Andrews et al., 2016), a greater level of fatigue, and, as a result, a lower intensity of the CA to limit fatigue. For these

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reasons, the existing recommendations for potentiation complexes may not be optimal when using unilateral CAs.

Furthermore, the non-localized manner of the PAPE effect could be considered an advantage and a method for individualizing and strategic use of potentiation protocols. For instance, as a solution to acutely reduce the inter-limb strength asymmetries by performing CA only for a weaker limb. Besides that, excessive inter-limb asymmetries (>15%) have been associated with increased injury incidence (Grindem et al., 2011), which could impair physical and sports performance (Hoffman et al., 2007). Asymmetries in strength (~10%) would seem to negatively affect performance tasks, including change of directions (COD) (Hoffman et al., 2007), jumping (Bell et al., 2014), and sport-specific skills such as kicking accuracy (Hart et al., 2014). Therefore, striving to minimize it, even in the short term, would be beneficial for preventing injuries and sports performance. In this scenario, the CAs may only be performed on the weaker side of the body to reduce the asymmetry during a subsequent task acutely. However, there might be a possibility to have a crossover effect of unilateral CAs, thereby increasing the performance of the other limb as well (Miller et al., 2020). Therefore, this should be interpreted with caution until it can be verified through an experiment specifically designed to test the cross PAPE effect or influence on inter-limb asymmetry.

Since the effect of unilateral CA is not clear in the current literature, this review aims to summarize the impact of unilateral CAs on performance enhancement. Specifically, to determine whether unilateral CAs can enhance unilateral performance, bilateral performance, and the contribution of activated body limb to bilateral performance. Moreover, this review will attempt to quantify volume, intensity, and rest periods to elicit the greatest PAPE effect by unilateral CA. Considering the above and the importance of explosive power in many sports, a more comprehensive and recent literature review on unilateral PAPE complexes is required.

Methods

Literature search

A literature review was conducted according to the Preferred Reporting Items for Systematic Review and Meta-analyses (PRISMA) guidelines (Figure 1). MEDLINE, SPORTDiscus, Scopus, and Google Scholar databases were searched until February 2022 for all studies investigating unilateral conditioning activity's influence on the PAPE effect. The search was undertaken using the following keyword combinations in the English language: “unilateral” AND “PAP” OR “post-activation potentiation” OR “PAPE” OR “post-activation performance enhancement” OR “conditioning contraction” OR “conditioning activity.” Additionally, the reference lists of the selected articles were scanned using Google Scholar to find additional articles.

Data extraction

The screening and data extraction process was carried out by two independent reviewers (XX and XX) and included: study outcomes, the procedure used to elicit PAPE, sample size, sex, training experience, and strength levels. Any discrepancies between the two reviewers were discussed by all co-authors until a consensus was reached. The methodological quality of studies was evaluated using the Physiotherapy Evidence Database (PEDro) scale. Total PEDro scores are reached based on satisfaction of criterion measures relating to participant allocation, allocation

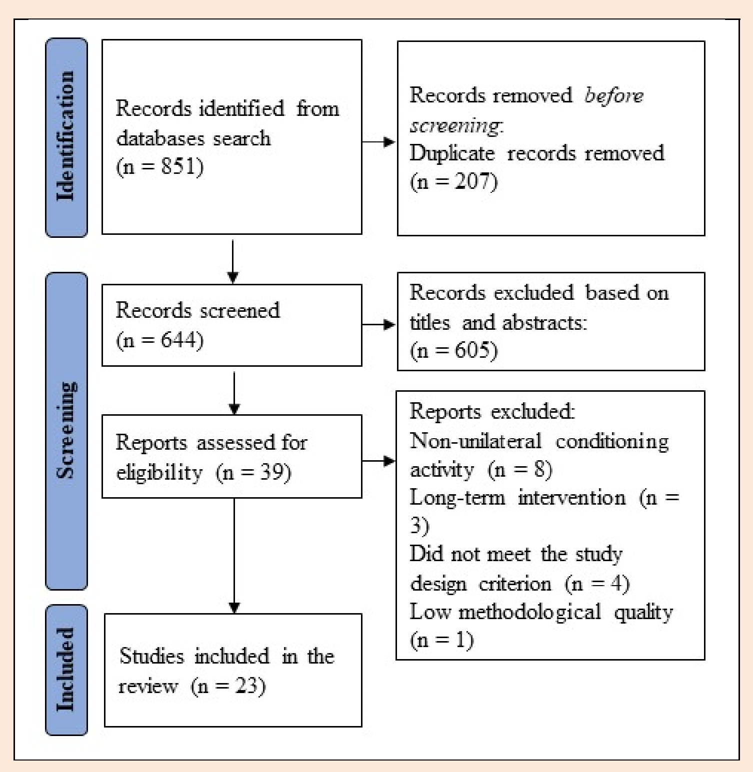

Figure 1. PRISMA flow diagram of the search and study selection process.

concealment, blinding of participants, therapists, and assessors, and the provision of sufficient statistical information. Initially, a total of 11 criterion measures are assessed; however, criterion measures 1 and 6 assess external validity and blinding of therapists who administered the therapy and are not included in the total PEDro score. Therefore, a total score of 9 is attainable (Finlay et al., 2022).

Study identification and selection

Studies investigating the effects of unilateral CAs on the subsequent jump, sprint, and sport-specific tasks were the primary focus of the literature search. The secondary aim was to examine the contralateral effect of unilateral CAs. To warrant inclusion in the current analysis, studies were required to meet the following criteria: (1) used human participants without known chronic disease or injury (<44 years); (2) studies exploring the effects of prior voluntary conditioning activity; (3) randomized controlled trials or pre- and post- study designs; (4) studies in which the conditioning activity was performed using a single limb (e.g. single leg jumping) or in a unilateral manner (i.e., split squat) or a combination of the two; (5) PAPE quantified by monitoring performance in general or sport-specific tests; (6) studies including a standardized warm-up; (7) full-text versions of studies accessed in the English language, in peer-reviewed journals.

Results

The results of the search and the study selection process are depicted in Figure 1. The literature search yielded a total of 851 articles. After the duplicates were removed and a screening of titles and abstracts, 39 full-text studies were scrutinized. Sixteen studies were excluded for the following reasons: (a) use of non-unilateral CA, (b) did not meet the study design criteria, (c) involved long-term intervention, and (d) had low methodological quality (Figure 1). In total, twenty-three studies were included in the analysis (Table 1 and Table 2).

The total number of participants was 493 (361 males and 132 females). Of them, 207 participants were athletes (team sports, track and field, and swimming); 118 were resistance-trained individuals (at least 1-year training experience), and 168 were physically active individuals (i.e., <6 months of resistance training experience). All participants were between 15 and 35 years old.

The number studies investigated different potentiation complexes is presented in Table 3, while the number of studies investigating different unilateral exercises used as CAs is presented in Table 4. Furthermore, Table 5 shows the number of studies that examined different post-conditioning activities. We found no study investigating the effects of pure unilateral CA (i.e. mono-articular unilateral movements) on bilateral post-CA tasks. On the other hand, three studies directly compared the effectiveness of bilateral and unilateral CA (Dello Iacono et al., 2016b; Asencio, 2020; Escobar Hincapié et al., 2021) and three more studies examined the contralateral effects of unilateral CA (Andrews et al., 2016; Wong et al., 2020; Power et al., 2021).

Of all the studies included in the review, sixteen effectively enhanced subsequent performance (Batista et al., 2007; Turner et al., 2015; Cuenca-Fernández et al., 2015, 2019, 2020; Seitz et al., 2015, 2016; Andrews et al., 2016; Dello Iacono et al., 2016a; Bishop et al., 2017; Ferreira-Júnior et al., 2018; Doma et al., 2020; Wong et al., 2020; Ciocca et al., 2021; Brink et al., 2021; Escobar Hincapié et al., 2021). In seven studies, subsequent performance was

Table 1. The methodological quality of included studies via PEDro scale.

	1	2	3	4	5	6	7	8	9	10	11	Total
Andrews et al. (2016)	-	1	0	1	0	-	0	1	1	1	1	6
Asencio et al. (2020)	-	1	0	1	0	-	0	1	1	1	1	6
Batista et al. (2007)	-	1	0	1	0	-	0	1	1	1	1	6
Bishop et al. (2017)	-	1	0	1	0	-	0	1	1	1	1	6
Brink et al. (2021)	-	1	0	1	0	-	0	1	1	1	1	6
Ciocca et al. (2021)	-	1	0	1	0	-	0	1	1	1	1	6
Cuenca-Fernandez et al. (2015)	-	1	0	1	0	-	0	1	1	1	1	6
Cuenca-Fernandez et al. (2019)	-	1	0	1	0	-	0	1	1	1	1	6
Cuenca-Fernandez et al. (2020)	-	1	0	1	0	-	0	1	1	1	1	6
de Arruda et al. (2020)	-	1	0	1	0	-	0	1	1	1	1	6
Dello Iacono et al. (2016a)	-	1	0	1	0	-	0	1	1	1	1	6
Dello Iacono et al. (2016b)	-	1	0	1	0	-	0	1	1	1	1	6
Doma et al. (2020)	-	1	0	1	0	-	0	1	1	1	1	6
Escobar Hincapie et al. (2021)	-	1	0	1	0	-	0	1	1	1	1	6
Ferreira-Junior et al. (2018)	-	1	0	1	0	-	0	1	1	1	1	6
Lockie et al. (2017)	-	1	0	1	0	-	0	1	1	1	1	6
Martinez-Garcia et al. (2021)	-	1	0	1	0	-	0	1	1	1	1	6
Orjalo et al. (2020)	-	1	0	1	0	-	0	1	1	1	1	6
Power et al. (2021)	-	1	0	1	0	-	0	1	1	1	1	6
Seitz et al. (2015)	-	1	0	1	0	-	0	1	1	1	1	6
Seitz et al. 2016)	-	0	0	0	1	-	0	1	1	0	1	4
Turner et al. (2015)	-	1	0	1	0	-	0	1	1	1	1	6
Wong et al. (2020)	-	1	0	1	0	-	0	1	1	1	1	6

1 = criterion was satisfied, 0 = criterion was not satisfied. Each satisfied criterion measure, excluding item 1 and 6, contributes 1 point to the total PEDro score (1–9). Criteria: (1) eligibility criteria were specified ([a]not applicable); (2) random allocation; (3) concealed allocation; (4) groups similar at baseline; (5) blinding of participants; (6) blinding of therapists who administered the therapy ([a]not applicable); (7) blinding of assessors; (8) less than 15% drop-outs; (9) intention to treat; (10) between-group statistical analysis; (11) point measures and variability data.

enhanced after split squat (Cuenca-Fernández et al., 2015, 2019, 2020; Andrews et al., 2016; Bishop et al., 2017; Doma et al., 2020; Escobar Hincapié et al., 2021), in four studies after alternate leg bounds (Turner et al., 2015; Ferreira-Júnior et al., 2018; Ciocca et al., 2021; Brink et al., 2021) and maximum isokinetic contractions (Batista et al., 2007; Seitz et al., 2015, 2016; Wong et al., 2020), and in one after drop jump (Dello Iacono et al., 2016a).

Regarding the rest interval between the CA and the performance test, most studies showed improvements after 4-8 min of recovery (Batista et al., 2007; Cuenca-Fernández et al., 2015, 2019, 2020; Seitz et al., 2015; Andrews et al., 2016; Dello Iacono et al., 2016a; Bishop et al., 2017; Ferreira-Júnior et al., 2018; Doma et al., 2020; Escobar Hincapié et al., 2021). In four studies, improvements were seen after a shorter rest interval, i.e. less than 4 min (Andrews et al., 2016; Wong et al., 2020; Ciocca et al., 2021; Brink et al., 2021), while in three studies, improvements were evident after at least 8 min of recovery (Batista et al., 2007; Andrews et al., 2016; Doma et al., 2020).

Regarding the load used in the CA, a moderate intensity, ranging from bodyweight to light external loads, resulted in performance enhancement in seven studies (Turner et al., 2015; Dello Iacono et al., 2016a; Bishop et al., 2017; Ferreira-Júnior et al., 2018; Doma et al., 2020; Ciocca et al., 2021; Brink et al., 2021). In contrast, maximum muscle actions were effective in five studies (Batista et al., 2007; Seitz et al., 2015, 2016; Cuenca-Fernández et al., 2020; Wong et al., 2020), while four studies showed performance improvements after high intensity CAs (Cuenca-Fernández et al., 2015, 2019; Andrews et al., 2016; Escobar Hincapié et al., 2021). Multiset CAs augmented performance in eight studies (Andrews et al., 2016; Dello Iacono et al., 2016a; Bishop et al., 2017; Ferreira-Júnior et al., 2018; Doma et al., 2020; Ciocca et al., 2021; Brink et al., 2021; Escobar Hincapié et al., 2021), while in seven studies, a single set CA was adequate (Batista et al., 2007; Cuenca-Fernández et al., 2015, 2019, 2020; Seitz et al., 2015, 2016; Wong et al., 2020).

Discussion

This review summarizes the knowledge regarding the effectiveness of unilateral CA's in eliciting a PAPE effect. Throwing, jumping, swimming, COD, and isokinetic performance were used as outcome measures to assess the impact of unilateral CAs on inducing PAPE. Twenty-three studies were included in this review, and most (20 out of 23) examined lower-limb performance. Furthermore, eleven studies examined the effectiveness of resistance exercises as a CA, seven studies investigated plyometric exercises, and five studies used isokinetic muscle actions as CAs. Notably, only three studies directly compared the effects of bilateral and unilateral CA (Dello Iacono et al., 2016b; Asencio, 2020; Escobar Hincapié et al., 2021), and no study reported possible changes in the contribution of each limb during bilateral exercises executed following unilateral CA. Data from studies included in this review suggest that several CAs can be used to improve athletic performance acutely. In the majority of the studies showed that the PAPE effect was evident 4 to 8 min after multiset (2-3 sets), bodyweight to moderate load CA. Furthermore, unilateral CAs can increase performance not only of the limb involved but also bilateral performance of the lower limbs (COD, agility runs, jumps) or the upper limbs (swimming).

Lower body effect

The mostly frequently used unilaterally based exercise as CA was split squat with high-load (~85% 1RM) or repetitions performed on an isoinertial device with maximum effort. For instance, a series of studies by Cuenca-Fernandez et al. (2015, 2019, 2020) showed that split squats performed either against a high-load or on an isoinertial device were effective CAs to elicit improvements in subsequent (6-8 min later) performance of the swimming start and the first 15 m, but not for the total 50 m swimming time. This result is consistent with the findings of the study conducted by de Arruda et al. (2020), who showed no differences in 50 m swimming time compared to the control condition after using a split squat with a load of 85% 1RM, possibly due to the relatively long duration of effort. The authors speculated that such an effect might be due to upper body fatigue manifested as a lower stroke rate, especially between 35-50 m after the CA compared with the control condition (Cuenca-Fernández et al., 2020). This may suggest that although the PAPE effect is viewed as being primarily local, it appears that the CAs may also affect muscles that are not involved in the CA. The possible local and non-local effects of CAs are discussed in detail later.

High-load split squats have also been used to acutely improve vertical jumps performance (Andrews et al., 2016; Bishop et al., 2017; Doma et al., 2020; Escobar Hincapié et al., 2021). Andrews et al., (2016) showed an increase in unilateral countermovement jump performance after 3 sets of split squats performed as follows: 5 repetitions at 50% 1RM, 2 repetitions at 70% 1RM, and 1 repetition at 90% 1RM, with jump performance measured 1, 5 and 10 min after the CA. This performance improvement was observed only when the same leg was used in the CA and during the countermovement jump. On the other hand, no significant improvements were shown in the drop jump. The authors explained that the high balance requirements during the performance of the single leg drop jump limited the potentiation effect. In contrast to that study, Escobar Hincapié et al. (2021) showed a significant decrease in jump height 5 min after bilateral squats and split squats against a load that allowed attaining a mean propulsive velocity of 0.59 m/s (approximately equivalent to 87% 1RM). Nevertheless, the authors noted an improvement in COD assessed by the T-agility test, with a similar effect after the split squat than the bilateral squat (effect size = 1.3 vs. 0.99, respectively). Both the above studies involved similar groups of participants, consisting of males and females with experience in resistance training; hence the different results may be due to the CA protocols used and the type of activity that followed. It is possible that the CA applied by Escobar Hincapié et al. (2021), i.e., 3 sets of 3 repetitions of split squat at ~87%1RM compared to those used by Andrews et al. (2016) (sets with increasing intensity 50/70/90% 1RM and 5/2/1/ repetitions, respectively) induced a higher level of fatigue, which exceeded the potentiation effect.

Table 2. **Basic description of studies reporting unilateral post-activation performance enhancement effect included in the analysis.**

Reference	Participants: Male/female (n): age (years), weight (kg), Height (m)	Participants: Population, Resistance Training Experience, Strength level	Conditioning Activity: Exercise	Conditioning Activity: Volume and Load	Intra-complex rest intervals	Potentiated Exercise	Main Outcomes	PEDro Score
Andrews et al. (2016)	8 males: 21.3 ± 1.8, 80.4 ± 11.8, 1.77 ± 0.05 6 females: 21.2 ± 0.4, 63.8 ± 3.1, 1.68 ± 0.08	university athletes, > 2, years, NR	Split squat front dominant limb; Split squat supporting limb; non-dominant limb	Every CA: 5 repetitions at 50%1RM, 2 repetitions at 70%1RM, 1 repetition at 90%1RM	1-, 5-, 10 min.	Unilateral CMJ with arm swing and DJ akimbo	↑ CMJ height of the exercised limb. ↓ CMJ height contralateral limb at all time points	6
Asencio et al. (2020)	14 males: 23.8 ± 3.7, 81.8 ± 8.9, 1.82 ± 0.02	Amateur handball players, NR, 1.08 ± 0.19 relative bench press	1) Bench Press 2) Isoinertial Throw Conical Pulley	1) 3 repetitions at 90%1RM 2) 6 repetitions at 0.16 $kg{\cdot}m^2$	4 min	Handball throws	↓throwing velocity	6
Batista et al. (2007)	10 males: 25.1 ± 2.6, 79.8 ± 6.4, 1.81 ± 0.08	active men no strength training, NR	Unilateral isokinetic knee extensions	10 maximal repetitions at $60°{\cdot}s^{-1}$ with 30s rest between each	4, 6, 8, 10, 12 min	Unilateral isokinetic knee extensions	↑ peak torque	6
Bishop et al. (2017)	12 males: 22.3 ± 1.4, 92.4 ± 9.6, 1.84 ± 0.05	semiprofessional rugby players, > 3 years, NR	Body-weight split squat Weighted split squat	2 sets 10 repetition per leg body-weighted or 30kg vest loaded	5 min	Unilateral and bilateral CMJ and broad jumps	↑bilateral jump, insignificant ↑ unilateral jumps	6
Brink et al. (2021)	69 males: 24 ± 5, 69.2 ± 9.8, 1.74 ± 0.06	professional soccer players (half squat strength: 1.85 ± 0.19 kg/kg body mass)	1) Sprint (n=23) 2)Alternate-leg bounds (n=23) 3) Walking (n=23)	1) 2 all-out 20m sprints 2) 3 sets of 10 repetitions (5 per leg) with 10% body weight vest 3) 90 second of walking	2- and 6 min post-CA	20m sprint velocity	↑10- and 20m sprint velocity at 2 min post-CA	6
Ciocca et al. (2021)	18 males: 22 ± 2, NR	university soccer players, multi-year soccer experience, NR	1) Alternate-leg bounds 2) Control condition	1) 3 sets of 10 repetitions (5 per leg) 2) ~75 seconds of walking	15s, 2-, 4-, 8-, 12-, 16 min	Deceleration after 0-10m sprint	Improved deceleration performance at 2 min post-CA	6
Cuenca-Fernandez et al. (2015)	10 males and 4 females, between 17-23 yrs, 69 ± 11.4, 1.76 ± 0.09	trained swimmers, at least 5 years in national competitions, 3RM split squat (77.1 ± 23.4)	1) Split squat on Smith Machine 2) Simulated block swimming start performance on flywheel device	1) 3 repetitions at 85%1RM 2) 4 repetitions at maximal voluntary contraction	8min	Swimming Start Performance	Both protocols ↑swimming start performance	6

CA – conditioning activity; CMJ – countermovement jump; COD – change of direction; DJ – drop jump; NR – not reported;

Table 2. Continue.

Reference	Participants: Male/female (n): age (years), weight (kg), Height (m)	Participants: Population, Resistance Training Experience, Strength level	Conditioning Activity: Exercise	Conditioning Activity: Volume and Load	Intra-complex rest intervals	Potentiated Exercise	Main Outcomes	PEDro Score
Cuenca-Fernandez et al. (2019)	17 males, 18.42 ± 1.39, 73.65 ± 8.99, 1.81 ± 0.02	competitive male swimmers, at least 5 years of participation in regional- and national-level competition, 1RM arm stroke 38.82 ± 5.29 and 1RM split squat 93.35 ± 12.51 kg	1) Split squat and arm strokes on adapted Smith machine 2) Split squat and arm strokes on flywheel device 3) Control condition: same warm-up as in other conditions (swim warm-up followed by dynamic stretching)	1) 3 repetitions at 85%1RM 2) 4 repetitions at maximal voluntary contraction	6min	50m swimming performance	Both protocols ↑ swimming performance at first 15m but not whole 50m swim	6
Cuenca-Fernandez et al. (2020)	11 males: 18.95 ± 1.63, 76.61 ± 9.12, 1.81 ± 0.03 and 2 females: 19.02 ± 0.78, 59.43 ± 8.23, 1.62 ± 0.05	competitive swimmers, at least 5 years of participation in national-level competition, NR	1) Control condition: same warm-up as in other conditions (swim warm-up followed by dynamic stretching) 2) Simulated block swimming start performance on flywheel device	1) moderate intensity 400m front crawl, and two starts from the wall 2) Five repetitions at maximal voluntary contraction	6 min	Swimming Start Performance	PAP protocol was better than control condition but not when compared with PEAK (best outcomes obtained from each subject across standard trial) improved swimming start performance	6
de Arruda et al. (2020)	13 males: 19.46 ± 3.45, 72.02 ± 7.61, 177.85 ± 5.4	male swimmers, > 3 years of swimming experience, NR	1) 30 min warm-up in water, followed by 10 min interval and 50-m freestyle maximum attempt 2) 15min warm-up in water, followed by split squats 3) 15min warm-up in water, followed by 3 reps pull-ups 5 box jumps with 10% body weight vest 4) Combination 2 and 3	2) 3 repetitions at 85%1RM 3) 3 repetitions of pull-ups and 5 repetitions of box jumps with 10% body weight vest 4) Combination of 2 and 3	Individual interval 4-, 8-, or 12min	50m freestyle swimming performance	No differences in comparison to the control condition	6

CA – conditioning activity; CMJ – countermovement jump; COD – change of direction; DJ – drop jump; NR – not reported

Table 2. **Continue.**

Reference	Participants		Conditioning Activity		Intra-complex rest intervals	Potentiated Exercise	Main Outcomes	PEDro Score
	Male/female (n): age (years), weight (kg), Height (m)	Population, Resistance Training Experience, Strength level	Exercise	Volume and Load				
Dello Iacono et al. (2016a)	18 males, 19.6 ± 0.5, 83.8 ± 8.4, 182.5 ± 6.4	elite handball players, 6 years of high-level handball practice and 4 years of specific jumping and sprinting training, NR	1) Vertical alternate single leg-drop jumps 2) Horizontal alternate single leg-drop jumps	1 and 2) 3 sets of 10 repetitions (5 per leg)	8 min	CMJ and 25m (2x 12.5m) 180° COD	Both protocols ↑ jumps and COD performance, with different and specific adaptations - greater improvements in jump after vertical DJ, while horizontal DJ enhanced sprint performance.	6
Dello Iacono et al. (2016b)	26 males, 15.4 ± 0.3, 61.4 ± 7.6, 169.5 ± 6.4	12 handball, 14 basketball players, members of young elite teams, NR	1) Bilateral drop jump 2) Alternate-one-leg drop jumps 3) Control condition	1) 3 sets of 10 repetitions 2) 3 sets of 5 repetitions 3) 8 min of walking at 5km/h	15s, 4-, 8-, 12-, 16-, 24-, 30min post-CA	CMJ and 20m sprint	↓ explosive performance at each time-point in both groups	6
Doma et al. (2020)	18 males, 22.9. ± 5, 79.4 ± 9.9, 1.8 ± 0.06	anaerobically trained, at least of 6 months in anaerobic training, NR	1) Split squats 2) Split squats combined with blood flow restriction	3 sets of 8 repetitions	3-, 6-, 9-, 12-, 15min post-CA	DJ 30cm	Split squats with blood flow restriction ↑ DJ performance within 6-15 min.	6
Escobar Hincapie et al. (2021)	12 males and 5 females, 25 ± 1.6, 70 ± 9.8, 171 ± 7.5	Healthy individuals, 7.6 ± 2.3 years in strength and power training, NR	1) Split squat 2) Bilateral squat	3 sets of 3 repetitions at 0.59m/s	5min	CMJ and T-agility test	Decrease in jump height and improvements in T-agility test with greater improvements for the unilateral protocol	6
Ferreira-Junior et al. (2018)	11 males, 16.3 ± 1.2, 68.3 ± 10.6, 179 ± 8	high school track and field male athletes, at least one year of experience with regional and national track and field, competitions, NR	1) Control 2) Alternate leg bounds 3) Free sprint 4) Resisted sprint	1) No conditioning activity 2) 3 sets of 10 repetitions 10% body mass 3) two 20m sprint 4) two 20m sprint controlled by partner at first 10m	7 min	100m sprint (30-, 50-, 70-m)	All protocols ↑ 70-100m performance, while resisted sprint ↑ also 30-50m.	6

CA – conditioning activity; CMJ – countermovement jump; COD – change of direction; DJ – drop jump; NR – not reported;

Table 2. **Continue.**

Reference	Participants		Conditioning Activity		Intra-complex rest intervals	Potentiated Exercise	Main Outcomes	PEDro Score
	Male/female (n): age (years), weight (kg), Height (m)	Population, Resistance Training Experience, Strength level	Exercise	Volume and Load				
Lockie et al. (2017)	6 males, 23.83 ± 1.17, 79.3 ± 10.36, 1.77 ± 0.06 and 3 females, 23 ± 2.65, 56.4 ± 5.44, 1.61 ± 0.06	Strength trained, at least one year, 5RM 0.61 ± 0.15 relative lunge	1) Walking Lunges 2) Control	1) 5 repetitions of walking lunges on each leg with 85% 1RM 2) 4 min recovery in a seated position	15s, 2-, 4-, 8-, 12-, 16min post-CA	20-m sprint, with 0-5 and 0-10m	No significant potentiation of 0-5 m, 0-10 m, or 0-20 m sprint performance	6
Martinez-Garcia et al. (2021)	14 females, 21.2 ± 2.7, 70.3 ± 9.5, 167.6 ± 6.5	females handball players, at least 8 years of experience in handball, NR	1) Standing unilateral (dominant) bench press 2) maximum isometric contraction (90-degree elbow flexion)	5 repetitions at an initial velocity of 0.6m/s and a final velocity of 0.9m/s Single set of 5s	Immediately, 1-, 2-, 10 min post-CA	Throwing velocity during overhead throws	No significant potentiation after both CAs	6
Orjalo et al. (2020)	20 males, 24.1 ± 2.71, 79.08 ± 12.15, 1.77 ± 0.1 and 20 females, 23.35 ± 2.08, 67.71 ± 9.74, 1.65 ± 0.06	Recreationally active, at least one year experience in resistance training, NR	1) Alternate-leg bounds 2) Loaded alternate-leg bounds 3) Control condition	1) 3 sets of 10 repetitions (5 per leg) 2) 3 sets of 10 repetitions (5 per leg) with a 10% body mass vest 3) 4 min of seating	15s, 4-, 8-, 12-, 16min post-CA	505 COD test	No improvements in comparison to the control condition	6
Power et al. (2021)	16 males, 22.9 ± 2.03, 82.8 ± 9.43, 1.81 ± 0.06 and 16 females, 23.1 ± 2.8, 66.4 ± 11.09, 1.67 ± 0.07	Athletically (an athlete on a varsity or provincial sports team) Recreationally (regularly participating in physical activity for recreational purposes), NR	Knee extensions: 1) dominant limb conditioned and tested 2) non-dominant limb conditioned and tested 3) dominant limb conditioned and non-dominant limb tested 4) non-dominant limb conditioned and non-dominant limb tested	4 repetitions of 5 s knee extensions MVIC with one-minute of rest after the first and third repetition, and 3 min after the second repetition.	1 and 10-min post-CA	Knee extension: peak force, force produced in the first 100ms, EMG of vastus lateralis and biceps femoris Unilateral drop jump	No PAPE effect, decrease in force produced in the first 100ms at 1st and 10th min post-CA,	6
Seitz et al. (2015)	17 males, 25.4 ± 3.9, 84.3 ± 10.5, 1.82 ± 0.04	resistance-trained men, > 6 months in lower body resistance training, NR	Isokinetic knee extensions	1) 4 reps at 60°/s 2) 4 reps at 180°/s 3) 4 reps at 300°/s 4) 12 reps at 180°/s 5) 20 reps at 300°/s	1, 4 ,7, 10, 13 min post-CA	Isokinetic knee extensions at 180°·s^{-1}	↑ knee extensor torque in 4th and 7th min post-CA after: 4 reps 60°/s; 12 reps at 180°/s; and 20 reps at 300°/s	6

CA – conditioning activity; CMJ – countermovement jump; COD – change of direction; DJ – drop jump; NR – not reported

Table 2. Continue.

Reference	Participants		Conditioning Activity		Intra-complex rest intervals	Potentiated Exercise	Main Outcomes	PEDro Score
	Male/female (n): age (years), weight (kg), Height (m)	Population, Resistance Training Experience, Strength level	Exercise	Volume and Load				
Seitz et al. (2016)	13 males, 24.1 ± 3, 86.1 ± 10.1, 1.85 ± 0.11	Resistance-trained, > 1 year in lower body resistance training, NR	Isokinetic knee extensions	4 repetitions at 60°·s^{-1} with 10s rest period between each	1, 4 ,7, 10 min post-CA	Isokinetic knee extensions at 180°·s^{-1}	Significant ↑ in knee extensor torque	4
Turner et al. (2015)	23 males, 22 ± 1, 82.4 ± 8.7, 1.82 ± 0.08	Healthy participants, 5 ± 1 years in plyometric training	1) Lateral bounds 2) Lateral bounds with a 10% body mass vest 3) Control condition	1) 3 sets of 10 repetitions (5 per leg) 2) 3 sets of 10 repetitions (5 per leg) with a 10% body mass vest 3) ~75 seconds of walking	15s, 4-, 8-, 12-, 16 min post-CA	20-m sprint performance	Both experimental conditions ↑ sprint performance at 4th and 8th min	6
Wong et al. (2020)	45 males and 62 females 22 ± 2, 74 ± 18.3, 169.8 ± 9.6	untrained (27 males and 48 females) and trained (18 males and 14 females)	1) Same arm as subsequently exercised 2) Opposite arm as subsequently exercised 3) Control condition	1 and 2) 6 seconds of maximal isometric elbow flexion contraction 3) 8 min rest	3 min	Isokinetic strength	↑ isokinetic strength on the ipsilateral arm. Greater improvements in resistance trained.	6

CA – conditioning activity; CMJ – countermovement jump; COD – change of direction; DJ – drop jump; NR – not reported

However, the improved performance during the T-agility test may imply that sprinting and COD may be less affected by fatigue (Seitz and Haff, 2016). Moreover, unilateral CAs may provide a more task-specific stimulus for running than jumping. Interestingly, a study by Lockie et al. (2017) assessed the effects of 5 repetitions of walking lunges on each leg using a load of 85% 1RM, on subsequent 20 m sprint performance (divided into 0-5 m and 0-10 m sections), in a group of strength-trained participants. The authors did not show any significant improvements in any of the analyzed running sections evaluated repeatedly from 15 s after the CA until 16 min later (at 2 min intervals). However, when the best individual time after CA was considered, there was a 1.98% improvement in the 0-5 m interval, indicating that the PAPE response was greatest during the acceleration phase. This finding may partially explain the improvements shown in the study of Escobar Hincapié et al. (2021), as the T-agility test requires multiple changes in running direction over short distances of 5 m and 10 m, thus multiple accelerations and decelerations. Moreover, a study by Lockie et al. (2017) is another one that highlights the high inter-individual variability in the PAPE responses requiring the personalized recovery time approach (Turki et al., 2011; Krzysztofik et al., 2022)

The effect of a low-resistance split squat has been investigated in two studies (Bishop et al., 2017; Doma et al., 2020). However, in contrast to the previously mentioned studies, the CA in these two studies was performed on both the dominant and the non-dominant leg. Bishop and colleagues (2017) showed a significant improvement in bilateral countermovement jump, and broad jump performed 5 min after two sets of 10 repetitions of split squats performed either with body weight or using an additional weight of 30 kg in semiprofessional rugby players. However, the effect was greater in the condition when loaded spit squats were used as CA compared to body weight split squats. When unilateral countermovement jump and broad jump were examined, a statistically insignificant improvement was noted for both the dominant and non-dominant legs. The study of Doma et al. (2020) showed no effect of 3 sets of 8 split squats with bodyweight on both legs on subsequent DJ performance, measured between 3 and 15 min after the CA (with 3 min intervals). However, there was an improvement when the same CA was performed under blood flow restriction. Thus, both studies suggest that unilateral resistance exercises

Table 3. Number of studies investigating potentiation complexes.

Potentiation Complex Setting Conditioning Activity	Potentiation Complex Setting Potentiated Exercise	Number of studies
Pure unilateral	**Pure unilateral**	5 studies (Batista et al., 2007; Seitz et al., 2015, 2016; Wong et al., 2020; Power et al., 2021)
Unilateral fashion	**Unilateral fashion**	16 studies (Asencio, 2020; Turner et al., 2015; Bishop et al., 2017; Cuenca-Fernández et al., 2015, 2019, 2020; Dello Iacono et al., 2016a; 2016b; Lockie et al., 2017; Ferreira-Júnior et al., 2018; Orjalo et al., 2020; de Arruda et al., 2020; Ciocca et al., 2021; Brink et al., 2021; Escobar Hincapié et al., 2021; Martínez-Garciá et al., 2021)
Unilateral fashion	**Bilateral movement**	5 studies (Dello Iacono et al., 2016a; Dello Iacono et al., 2016b; Bishop et al., 2017; Doma et al., 2020; Escobar Hincapié et al., 2021)

Pure unilateral: monoarticular unilateral movements, e.g. one-leg extension; Unilateral fashion: multi-joint unilateral movements, e.g. split squat or sprint

Table 4. Number of studies investigating different conditioning activities.

Conditioning Activity	Number of studies
Split squat	8 studies (Cuenca-Fernández et al., 2015, 2019, 2020; Andrews et al., 2016; Bishop et al., 2017; Doma et al., 2020; de Arruda et al., 2020; Escobar Hincapié et al., 2021)
Walking lunges	1 study (Lockie et al., 2017)
Alternate leg bounds	5 studies (Turner et al., 2015; Ferreira-Júnior et al., 2018; Orjalo et al., 2020; Ciocca et al., 2021; Brink et al., 2021)
Drop jumps	2 studies (Dello Iacono et al., 2016a; b)
Isokinetic leg extension	4 studies (Batista et al., 2007; Seitz et al., 2015, 2016; Power et al., 2021)
Simulated handball throw on conical pulley	1 study (Asencio, 2020)
Single arm dumbbell bench press	1 study (Martínez-Garciá et al., 2021)
Isokinetic elbow flexion	1 study (Wong et al., 2020)

Table 5. Number of studies investigating different post-conditioning exercises (potentiated exercises).

Potentiated Exercise	Number of studies
Jumping performance	5 studies (Andrews et al., 2016; Bishop et al., 2017; Doma et al., 2020; Dello Iacono et al., 2016a; Escobar Hincapié et al., 2021)
Sprint performance	4 studies (Turner et al., 2015; Lockie et al., 2017; Ferreira-Júnior et al., 2018; Brink et al., 2021)
Change of direction performance	4 studies (Dello Iacono et al., 2016a; b; Escobar Hincapié et al., 2021; Orjalo et al., 2020)
Swimming performance	4 studies (Cuenca-Fernández et al., 2015, 2019, 2020; de Arruda et al., 2020)
Isokinetic performance	4 studies (Batista et al., 2007; Seitz et al., 2015, 2016; Power et al., 2021)
Throwing performance	2 studies (Asencio, 2020; Martínez-Garciá et al., 2021)
Running deceleration performance	1 study (Ciocca et al., 2021)

performed without external load are an insufficient stimulus to induce a PAPE effect.

Unilateral leg extension was used as a CA in several studies using isokinetic or isometric muscle actions (Batista et al., 2007; Seitz et al., 2015, 2016; Power et al., 2021). Batista et al. (2007) analyzed the effect of an intermittent set of CA, consisting of 10 unilateral maximum leg extensions at 60°·s^{-1} with 30s rest intervals between repetitions. The authors demonstrated a progressive increase in peak torque during each repetition of CA and a further increase after the last repetition (measured from 4 to 12 min post-CA, at 2 min intervals). Interestingly, that study showed that this effect was reproducible across 5 testing days. Seitz et al. (2016) also demonstrated the effectiveness of a similar procedure on the increase in peak torque during unilateral leg extension. However, in that study, the participants performed 4 repetitions with a 10 s interval in between at 60°·s^{-1}. The effects of different CA contraction speeds were examined in another study by the same research group (Seitz et al., 2015). Five different CA schemes were employed: i) 4 repetitions at 60°·s^{-1}, ii) 12 repetitions at 180°·s^{-1}, iii) 20 repetitions at 300°·s^{-1}, iv) 4 repetitions at 180°·s^{-1}, v) 4 repetitions at 300°·s^{-1}. This setting allowed to compare three different CA contraction speeds (scheme i, ii, iii), having the same total contraction time (6 s), as well as three schemes with different contraction speeds (scheme i, iv, and v), different contraction times, but the same number of muscle actions. Results showed that 6 s of CA effectively evoked PAPE at 7 min after the CA, with the highest improvement observed after 12 repetitions at 180°·s^{-1}.

The total duration of muscle contraction and possibly the type of muscle contraction of the CA (i.e., isokinetic vs. isometric) seems to have a significant effect on subsequent PAPE. In a study by Power et al. (2021), participants performed 2 sets x 2 repetitions of 5 s of maximum voluntary isometric contraction of knee extension with 3 min rest between sets and 1-minute between repetitions. This scheme of CA resulted in performance impairment, manifested as a decrease in force produced in the first 100 ms and increased contact time during single leg drop jump in the 1st and 10th minute after CA. The prevalence of fatigue vs. PAPE may be due to the higher total duration of muscle contraction (20 s vs. 6-15 s in the studies of Batista et al. (2007) and Power et al. (2021)) or due to the blood flow restriction induced by the much longer isometric exercise bouts (4 x 5 s), which may cause fatigue (McNeil et al., 2015).

Regarding the recovery time after the CA, the conclusions of the present review are in accordance with the systematic review with meta-analysis of Seitz and Haff (2016) who found that the maximization of potentiation is between 5-7 min which is similar to the conclusions of the present review. As evidence, the effect size was 0.49 between 5-7 min after the CA and 0.44 after 8 min. This difference was even greater, especially in stronger individuals (ES: 5-7 min: 0.62 vs >8 min.: 0.23). Furthermore, PAPE has been shown to be affected by the level of muscular strength, the training status, the fiber type distribution and the cross-sectional area of type II muscle fibers of the participants' (Tillin and Bishop, 2009; Terzis et al., 2009) and these parameters are the reasons that the rest interval between the CA and the subsequent explosive activity is highly individual (Bogdanis et al., 2014). As a result, Bogdanis et al. (2014) did not find changes after the CA but when taking into account the best increase of performance after the CA irrespective of rest interval then the authors found differences. In that study, most of the participants peak their performance between the 4th and 8th minute of recovery.

In summary, the results of the studies to date show that a loaded unilateral resistance exercise as a CA (from 30% body mass to ~85%1RM), performed with a low volume (1-3 sets), result in improved jumping ability and acceleration performed 4-8 min later. In the case of isokinetic conditions, a single set of fast a maximum voluntary contraction as short as 6 s is sufficient to induce a meaningful PAPE effect, while longer repeated isometric muscle actions may cause fatigue. The results show that the nature of the effect is primarily local and is achieved for both highly trained and physically active individuals with little experience in resistance training.

Upper body effect

To date only three studies examined unilateral CAs to evoke PAPE on the upper-body (Asencio, 2020; Wong et al., 2020; Martínez-Garciá et al., 2021). Asencio et al. (2020) compared the effectiveness of two different CAs, namely bench press (3 repetitions at 90% 1RM) or a series of simulated handball throws performed on an isoinertial device (6 repetitions with total inertia of 0.163 kg·m^2). Both protocols failed to improve subsequent handball throwing velocity performed 4 min later by amateur handball players. In another study, Martinez-Garcia et al. (2021) examined the effects of standing unilateral chest press as the CA (5 repetitions with increasing velocity, initial: 0.6 m/s, and final: 0.9 m/s) and maximum voluntary isometric contraction in the same exercise (5 s duration with the elbow flexed at 90 degrees), on throwing velocity in female handball players. Similar to the study of Asencio et al. (2020), both CAs failed to elicit performance enhancement within the next 10 min. However, this does not necessarily mean that unilateral CA is ineffective in inducing the upper-body PAPE effect. One possible explanation for the failure of the above CAs to yield PAPE may be the low level of experience of the participants in this type and magnitude of CA load in one study (Martínez-Garciá et al., 2021) and the relatively low level of muscle strength of the participants (1.08 kg/body mass) in the other study (Asencio, 2020). In contrast, Wong et al. (2020) demonstrated an augmentation in torque during unilateral isokinetic elbow flexion after 6 s of maximum voluntary isometric contraction used as a CA, possibly due to the low volume of the CA.

Considering the above, the results of the studies carried out so far should be interpreted with caution. Although unilateral CA did not induce PAPE on the upper-body in two of the three available studies, there are strong indications that the effect is similar to that observed on the lower body, if the volume and intensity are adjusted and if stronger and more experienced participants are examined. Further studies are warranted to examine the impact of varying CA protocols on eliciting upper-body PAPE.

Plyometric exercises as a conditioning activity to induce PAPE

A number of studies examined the use of plyometric exercises as CA (Turner et al., 2015; Dello Iacono et al., 2016a; b; Ferreira-Júnior et al., 2018; Orjalo et al., 2020; Ciocca et al., 2021; Brink et al., 2021). Turner et al. (2015) showed that 3 sets of 10 repetitions of alternate leg bounds (5 for each leg) with an additional load corresponding to 10% body mass led to a significant improvement in sprint velocity during 10 m and 20 m sprints performed 4 and 8 min after the CA. The authors also showed that the alternate bounds with body mass only were also effective to induce sprint performance enhancement, but the effect was smaller. A later study by Ferreira-Junior et al. (2018) confirmed the effectiveness of loaded alternate leg bounds, performed by high school track and field athletes, in decreasing sprint split-time between 70 m and to100 m. In contrast, Orjalo et al. (2020) showed that both loaded and unloaded alternate leg bounds as the CA failed to improve COD performance assessed by a 505 test performed within the next 16 min. However, when the authors analyzed the individual optimal rest interval time after the CA, a decrease in performance time, i.e., a performance improvement, with an effect size of 0.40 to 0.45, was noted for both loaded and unloaded bounds. Still, these positive effects on performance did not reach statistical significance. This inconsistency may be due to the differences between the study participants in the above studies. The study by Orjalo et al. (2020) included active recreational participants with less experience (at least > 1-year experience in resistance training) compared with the studies by Turner et al. (2015) (participants with 5 ± 1 years' experience in plyometric training) and Ferreira-Junior et al. (2018) (high school track and field male athletes with significant competition experience). This may also be confirmed by the results of a recent study (Brink et al., 2021), which showed an increase in sprint velocity at 10- and 20 m, 2 min after (but not 6 min after) a CA containing loaded alternate leg bounds in professional football players. Ciocca et al. (2021) demonstrated a positive effect of unloaded alternate leg bounds used as CA on the deceleration ability of college football players. The authors showed a significant decrease in the time needed to decelerate after a 10 m sprint, two min after the CA. It is worth emphasizing that, according to the authors' knowledge, no research has analyzed the influence of alternate leg bounds on jumping performance. In summary, it seems that performance of leg bounds, with (~ 10% body mass) and without external load can effectively improve sprint performance between 2 and 8 min after CA, in trained individuals. However, the PAPE effect appears to be greater when using loaded rather than unloaded bounds.

Drop jump has been used as a CA in two studies (Dello Iacono et al., 2016a; b). In one study (Dello Iacono et al., 2016b), the effectiveness of bilateral and alternating single-leg drop jump (3 sets of 10 repetitions vs. 3 sets of 5 repetitions on each leg, from 25 cm) on subsequent countermovement jump and 20 m sprint performance was assessed in young handball and basketball players. Bilateral and unilateral CAs led to a performance decrease in both conditions, but the decline was greater after the unilateral CA. Although the same volume of CA was used, the results indicate that alternating single-leg drop jump induced greater fatigue than bilateral. It should be considered that the conditioned limb in unilateral drop jump had to overcome almost 2-fold higher ground reaction forces when landing compared with bilateral drop jump (Vansoest et al., 1985; Bobbert et al., 2006). Therefore, even though total volume was matched, the intensity during unilateral drop jump was higher. The other study (Dello Iacono et al., 2016a) compared the effects of horizontal and vertical alternating single-leg drop jumps (3 sets of 5 repetitions on each leg, from 25 cm) on countermovement jump, 10 m sprint performance and COD, assessed by the T-agility test 8 min later. The results indicated a direction-specific effect of CA, i.e., that horizontal drop jumps improved the T-agility performance, while vertical drop jump improved countermovement jump performance. This confirms the importance of adhering to the similarity principle in designing effective PAPE protocols. It seems that simply engaging the same muscle groups in the CAs and subsequent performance exercises is not adequate to maximize PAPE. The available evidence indicates that the CA and subsequent exercise should be characterized by similar biomechanical patterns and involve similar force application vectors.

Another possible explanation for the contrasting results reported in the two studies analyzed above (Dello Iacono et al., 2016a; b), may be the different levels of experience of the participants. In the study of (Dello Iacono et al., 2016a), which showed positive effects, the participants were elite handball players (U-20 national team). In contrast the participants in the study reporting a negative effect of single leg drop jumps (Dello Iacono et al., 2016b) the participants were young handball and basketball players. Thus, there is an indication that training experience and possibly differences in the levels of muscle strength may modulate the PAPE response during unilateral CA. For instance, multiple sets of very high-intensity plyometric CAs may impair the ability of inexperienced and weak subjects to reach the desired level of potentiation by causing excessive fatigue, which may mask any PAPE effects. This would explain why, in a study by Dello Iacono et al. (2016b), alternating-single-leg drop jump as a CA failed to improve countermovement jump and 20m sprint performance in young handball players and basketball players, but in the elite handball players a similar protocol was effective (Dello Iacono et al., 2016a). This has been previously demonstrated in track and field power athletes, where only the individuals with high jumping ability achieved performance improvement after an isometric CA (Tsoukos et al., 2016).

In conclusion, the results indicate that high-intensity plyometric exercises such as the drop jumps and bounds could effectively improve a variety of sports tasks, but the effect seems to be direction-specific. This implies that vertical drop jump should be used to enhance vertical jumping tasks, while horizontal jumps seem better for sprinting. Furthermore, single leg drop jump might require longer rest intervals (8 min) after completion of CA and should be used with highly trained athletes. However, these findings must be interpreted with caution since only two studies have used unilateral drop jumps as CA.

Contralateral effect

Only three studies have examined the crossover effects of a unilateral CA (Andrews et al., 2016; Wong et al., 2020; Power et al., 2021). Andrews et al. (2016) showed an increase in unilateral countermovement jump height after split squats, but only for the leg that executed the CA. In turn, a trivial decrease in performance was found for the contralateral limb. This suggests that the unilateral CA causes an increase in performance but only when the same muscles are involved in the subsequent task, without any effects on the inactive contralateral limb. In the other two recent studies, performance increased (Wong et al., 2020) or decreased (Power et al., 2021) in the involved limb, with no contralateral limb performance changes. Therefore, it may be argued that a unilateral CA has mainly local effects.

Conclusion

Data from studies included in this review suggest that unilateral CAs such as split squats, alternate leg bounds, and drop jumps can be effectively used to acutely improve a wide variety of athletic tasks, including jumping, sprinting, COD, and swimming performance. Split squats were the most often studied CA, and it was shown that multiple sets of high-loaded split squats (85% 1RM) executed as CA, improve vertical jumping and COD after 4 to 8 min of recovery. At the same time, multiple sets of alternate leg bounds performed with ~10% body weight or without any external load, result in an improvement of sprint performance, 2 and 8 min later, with the effect being greater when loaded jumps are used. It has to be mentioned that the effectiveness of CA exercises appears to be force-vector specific, i.e., vertical drop jumps improve vertical jump performance, while horizontal drop jumps enhance sprint and COD performance. The level of strength and power of the participants seems to modulate the effects of single limb CAs on performance. Furthermore, short duration seems to be a key characteristic of effective CAs (4-5 repetitions or around 6 s) during isoinertial or isokinetic exercise. Since most studies examined lower body exercises, more research is needed to examine the effects of unilateral, upper body CAs on single arm performance. The effects of single limb CA on the contralateral limb has not been thoroughly examined. However, the limited evidence shows that the PAPE effect is mainly local. The findings of this review may be used by coaches and practitioners, who may take advantage of the effectiveness of single limb CA during complex training sessions involving resistance exercises, such as split squats, or alternating leg bounds on the field or court. These interventions may also be used as a part of pre-competition warm-ups to enhance subsequent performance without the need for specific equipment.

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Key points

- Coaches and practitioners may take advantage of the effectiveness of a single limb body-weight conditioning activity, such as, i.e., alternating leg bounds as a part of pre-competition warm- ups to enhance subsequent performance without needing specific equipment.
- The effectiveness of conditioning activity exercises appears to be force-vector specific, i.e., vertical drop jumps improve vertical jump performance, while horizontal drop jumps enhance sprint and change of direction performance.
- The effects of single limb conditioning activity on the contralateral limb have not been thoroughly examined. However, the limited evidence shows that the post-activation performance enhancement effect is mainly local.

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