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

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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 $60°\cdot s^{-1}$ 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 $60°\cdot s^{-1}$. 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 $60°\cdot s^{-1}$, ii) 12 repetitions at $180°\cdot s^{-1}$, iii) 20 repetitions at $300°\cdot s^{-1}$, iv) 4 repetitions at $180°\cdot s^{-1}$, v) 4 repetitions at $300°\cdot s^{-1}$. 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 $180°\cdot s^{-1}$.

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

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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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