

Effects of Different Conditioning Activities on the Sprint Performance of Elite Sprinters: A Systematic Review With Meta-Analysis

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Purpose: Postactivation performance enhancement (PAPE), which refers to the phenomena associated with the attainment of enhanced performance in sport-specific tasks after a conditioning activity, is an important objective of warming-up practices in many sports. This is even more relevant for sprinters, as potential increases in sprinting speed will directly influence their competitive results. This systematic review with meta-analysis evaluated the effects of different PAPE protocols (ie, using plyometrics, strength-power exercises, and resisted/assisted sprints) on the sprinting performance (ie, sprint time or sprint speed) of competitive sprinters. **Methods:** Initially, 1205 records published until last December 18 were identified, using the following databases: PubMed/MEDLINE, Scopus, and Clarivate Web of Science. After removing duplicates and screening titles and abstracts, 14 high-quality studies met the inclusion criteria for the meta-analysis. **Results:** Overall, there were no significant changes in sprint performance after implementing various types of conditioning activities (standardized mean difference [SMD] = 0.16 [95% CI, -0.02 to 0.33]; $Z = 1.78$; $P = .08$; $I^2 = 0\%$). In addition, when comparing prechanges and postchanges between experimental, control, and other conditions, no significant differences were found in sprint speed or time across all studies (SMD = 0.09 [95% CI, -0.10 to 0.28]; $Z = 0.92$; $P = .36$; $I = 0\%$). **Conclusions:** Results revealed that different types of conditioning activities may not be capable of acutely enhancing the sprint speed of competitive sprinters. This aligns with previous observations indicating that sprinting is a highly stable physical capacity, a phenomenon that is even more consistent among elite sprinters. Coaches and sport scientists should collaborate to develop more efficient PAPE protocols for these highly specialized athletes, with special attention to study design and individualization, while considering their effects on acceleration versus top speed.

Keywords: athletic performance, athletes, track and field, sprint velocity, speed, potentiation

The effective development of sprinting speed is a key objective in many sports, making this topic one of the most widely investigated and discussed in sport science in recent years.¹⁻³ Indeed, in numerous sports, decisive situations (eg, scoring a goal in soccer or a try in rugby) are typically preceded by maximal sprints executed over a range of paths and distances.⁴⁻⁶ Despite the variations in patterns and trajectories within different sport contexts, there is a common understanding that linear sprinting performance strongly correlates with the performance obtained in other speed-related tasks, such as rapid directional changes and curvilinear sprints.⁵⁻⁷ Therefore, examination of the training schemes and methods commonly employed by sprint coaches—professionals who work with the world's fastest athletes—is of great interest for sport science research to further develop current practices.⁸ In this regard, a series of recent survey studies have been conducted with the aim of describing and critically analyzing the training practices adopted by elite sprint coaches.⁸⁻¹⁰ Additionally,

it has been shown that sprint speed is a highly stable physical capacity, exhibiting minimal variations during the competitive season (ie, $\pm 1.4\%$ in 100-m sprint time over the annual training season)¹¹ and even throughout the professional careers of elite sprinters (ie, $\leq 0.2\%$ during the 5 y preceding peak performance in the 100-m race time).¹² Hence, identifying effective strategies aiming to increase sprinting abilities (eg, acceleration and top-speed), and thereby producing a significant improvement in the competitive performance of sprinters, is of paramount importance for coaches and practitioners not only in track-and-field disciplines but also in a number of other sports.


Postactivation performance enhancement (PAPE) refers to any enhancement in performance in voluntary exercises or movements (eg, sprint or jump trials) after specific conditioning activities (CAs) such as traditional resistance or ballistic exercises.^{13,14} For this reason, PAPE is usually regarded as an important objective of regular warm-up protocols in a wide variety of sports.^{13,15,16} In sprinting disciplines, coaches usually aim to implement effective CAs to increase the acceleration capacity and the maximal sprinting speed of their athletes. For instance, Bomfim-Lima et al¹⁷ demonstrated that highly trained sprinters experienced significant decreases (ie, $\sim 2.5\%$) in their 50-m sprint times, 10 and 15 minutes after completing 2 sets of 5, 75-cm drop jumps. Subsequently, Yoshimoto et al¹⁸ found similar results after using 3 sets of 10

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consecutive “mini-hurdle drills” with collegiate sprinters (ie, on average, sprinters exhibited a decrease of -1.6% in the 60-m sprint time). On the other hand, several investigations conducted with competitive sprinters at various competitive levels (ie, regional, national, and international)^{19–21} did not find any significant improvement in sprint performance across a range of distances (from 5 to 40 m) following the utilization of different types of exercises and motor tasks as CAs (eg, isometric contractions, resisted sprints, and reactive hops). Therefore, even for these highly specialized athletes with a clear performance indicator (ie, sprinting time or sprinting speed), there is still no consensus on which strategy to use or whether there is in fact a strategy capable of acutely enhancing their sprint performance.

Thus, the aim of the current systematic review with meta-analysis was to summarize and evaluate the effectiveness of different PAPE protocols in increasing the sprint speed of competitive sprinters. Drawing upon the theoretical and empirical arguments mentioned above, we believe that this review can serve as a valuable and useful guide for coaches and practitioners in multiple sports and as a foundation for future research into acceleration- and speed-related training practices.

Methods

Study Design

The purpose of this systematic review with meta-analysis was to summarize and assess the effectiveness of various PAPE protocols in enhancing the sprint performance of competitive sprinters. All procedures used to perform and conduct the study were in accordance with the Preferred Reported Items for Systematic Reviews and Meta-Analyses guidelines.²² The criteria used for literature search and data sources, study eligibility and selection, data extraction and analysis, and the assessment of risk of bias and study quality are listed and adequately detailed in the following topics.

Literature Search and Data Sources

The literature search was carried out using the following online databases: PubMed/MEDLINE, Scopus, and Clarivate Web of Science. It included studies published until December 18, 2023. Keywords were defined based on previous studies and aligned with the study objectives. The following keywords were used in combination with the Boolean operators “AND” and “OR,” using the PICO method (ie, participants, intervention, comparator, and outcomes) as part of the search strategy: (athletes OR sprinters OR “track and field” OR “track & field”) AND (“post-activation performance enhancement” OR “post-activation potentiation” OR PAPE OR PAP OR “acute effects” OR potentiation) AND (sprint OR sprinting OR speed OR performance). Lastly, the reference lists from relevant articles were examined to identify other potentially eligible studies.

Eligibility Criteria

Randomized peer-reviewed studies published in English, Spanish, or Portuguese were considered for inclusion, with no age or sex restrictions. Studies were included based on the following criteria: (1) subjects were submitted to an acute CA; (2) the sample was exclusively composed of competitive sprinters, competing at both national and/or international level; and (3) linear sprint performance (ie, sprinting speed or sprinting time) was defined as the outcome variable. Regarding the exclusion

criteria, studies were not considered for analysis if (1) no other comparison group or control condition was tested or implemented; (2) chronic effects were assessed; (3) the full text was not available; and (4) ergogenic aids (eg, preconditioning ischemic, caffeine, sodium bicarbonate, and transcranial direct current stimulation) were utilized.

Study Selection

The initial search was conducted by 2 researchers (Pereira and Moura). After removing duplicates, titles and abstracts were screened, and studies that did not meet the eligibility criteria were excluded. Subsequently, the full texts of the remaining articles were analyzed. Then, in a blind and independent manner, 2 reviewers (Pereira and Moura) selected the studies for inclusion, following the eligibility criteria. In cases where no agreement was reached, a third researcher (Loturco) was consulted.

Data Extraction and Analysis

Mean, SD, and sample size data were extracted from the included manuscripts by 2 authors (Pereira and Moura). When needed, contact was made with the authors to obtain the data. If there was no response from the authors, the study was excluded from the analysis. Any disagreements during the process of data extraction and analysis were resolved by consensus among 4 authors (Pereira, Moura, Loturco, and Boullosa).

The meta-analysis was conducted using Review Manager software (RevMan 5.4.1; Cochrane Collaboration). A random-effects meta-analysis was performed to estimate the summary effect of the different types of CAs on linear sprint performance. Effects between interventions or control conditions, as well as the differences between premeasurements and postmeasurements are expressed as standardized mean differences (SMD) with their respective 95% confidence interval (CI). SMDs were used because sprint performance was assessed across a range of distances. The thresholds used to qualitatively interpret SMD were <0.2 (trivial), ≥ 0.2 (small), ≥ 0.5 (moderate), and ≥ 0.8 (large).²³

Heterogeneity among studies was assessed using I^2 statistics. I values range between 0% and 100% and are considered low, modest, or high for $<25\%$, 25% (50%), and $>50\%$, respectively. High heterogeneity indicates substantial variability among studies in terms of outcomes and methodological aspects, resulting in varying weights of evidence. While it is not a requirement for conducting a meta-analysis, it is always preferable to have lower levels of heterogeneity among the included studies. Heterogeneity may be assumed when the P value of the I test is $<.05$; statistical significance was set at $P < .05$.^{24,25}

Risk of Bias and Quality of the Studies

Methodological quality and the risk of bias were independently assessed by 2 authors (Pereira and Moura) using the “Cochrane risk of bias tool” (RoB 2.0).²⁶ Any disagreements were resolved through a third-party evaluation (Loturco), as recommended by the Cochrane Collaboration Guidelines.²⁷ The methodological quality of the included studies was assessed using the Physiotherapy Evidence Database scale.²⁸ Quality assessments were categorized as follows: ≤ 3 for poor quality, 4 to 5 for moderate quality, and 6 to 10 for high quality. Two authors (Pereira and Moura) independently conducted the assessments, with any disagreements being resolved through a third-party evaluation (Loturco).

Results

Study Selection

A total of 1205 records were initially identified through database searching, and no additional studies were found from other sources. After screening titles and abstracts, 779 out of the 819 studies that remained following duplicate removal were excluded. As a result, 40 studies were evaluated for eligibility, and based on the inclusion and exclusion criteria (see Figure 1), 14 studies were finally included in the meta-analysis.^{17–21,29–37} Overall, the risk of bias among the analyzed studies was considered “low,” with 13 demonstrating a “low risk of bias” and 1 presenting “some concerns” (see Figure 2). The quality of the studies, as assessed by the Physiotherapy Evidence Database scale, was high, with a mean score of 6.9 (0.3) out of 10 points (see Table 1).

Characteristics of the Interventions

The methodological characteristics of the included studies are presented in Table 2. In total, 197 sprinters were assessed, comprising 125 male and 72 female athletes. The CAs included assisted sprints, resisted sprints, dynamic squats, weighted jump squats, and plyometric exercises, such as drop jumps, reactive hops, bounding, and continuous unloaded vertical jumps. The interval between the CAs and the sprint tests varied from 10 to 20 seconds to 15 minutes. Sprint distances tested ranged from 5 m (split time between 25 and 30 m) to 60 m.

Main Effects

Figure 3 displays the forest plot illustrating the comparisons between premeasures and postmeasures of linear sprint performance among the various studies. No significant changes in sprint performance were observed after implementing the different types of CAs (SMD = 0.16 [95% CI, -0.02 to 0.33]; $Z = 1.78$; $P = .08$; $I^2 = 0\%$). When comparing prechanges and postchanges between experimental and control conditions (ie, standard warm-up) or other interventions (see Figure 4), no significant differences were detected in sprint performance, considering all the studies included in this meta-analysis (SMD = 0.09; [95% CI, -0.10 to 0.28]; $Z = 0.92$; $P = .36$; $I^2 = 0\%$).

Discussion

This systematic review with meta-analysis was conducted to evaluate the effectiveness of different PAPE protocols in improving the sprint performance of competitive sprinters. After revisiting the literature and analyzing the results of 14 high-quality studies on this topic, it was concluded that, in general, the various forms of CAs were unable to reduce sprint times or increase the sprint speed of these athletes. Despite the acute effects typically expected and assessed in PAPE interventions, this finding agrees with previous observations, indicating that the competitive performance of sprinters tends to exhibit minimal variations across annual seasons or even throughout their professional careers.^{11,12,38}

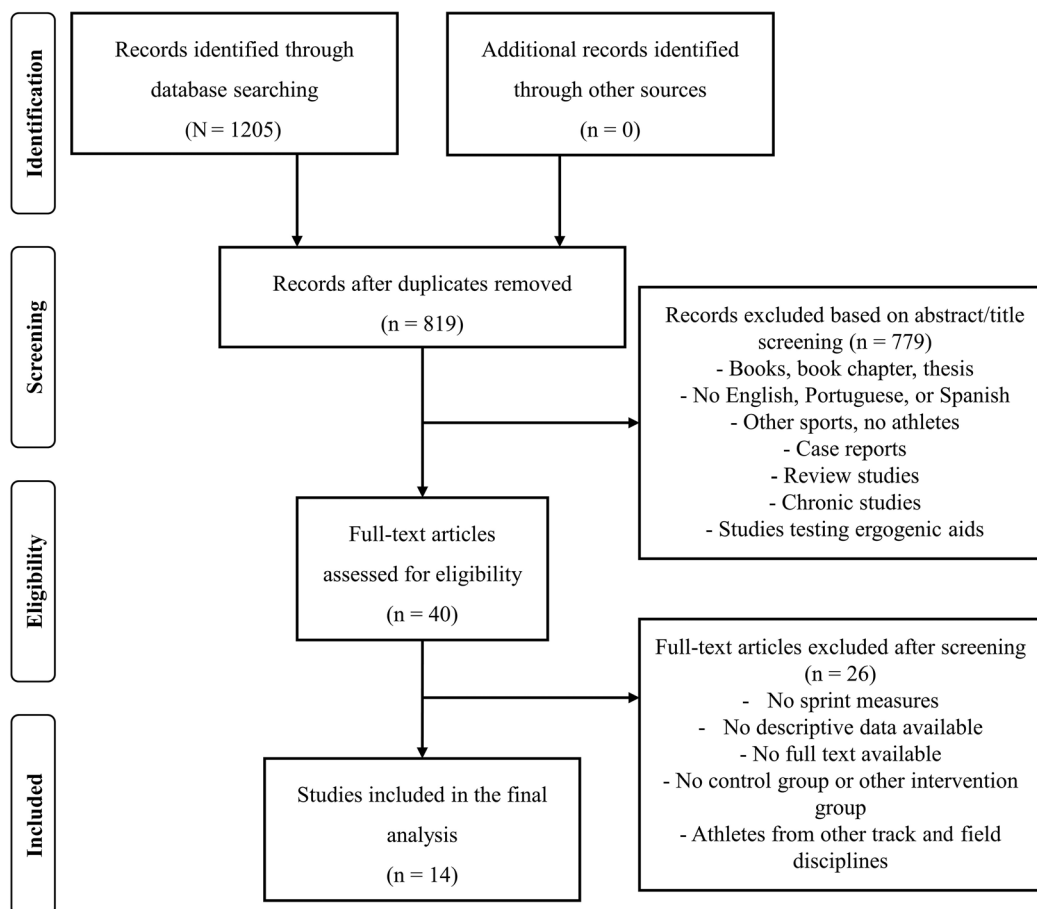


Figure 1 — Flowchart of study selection.

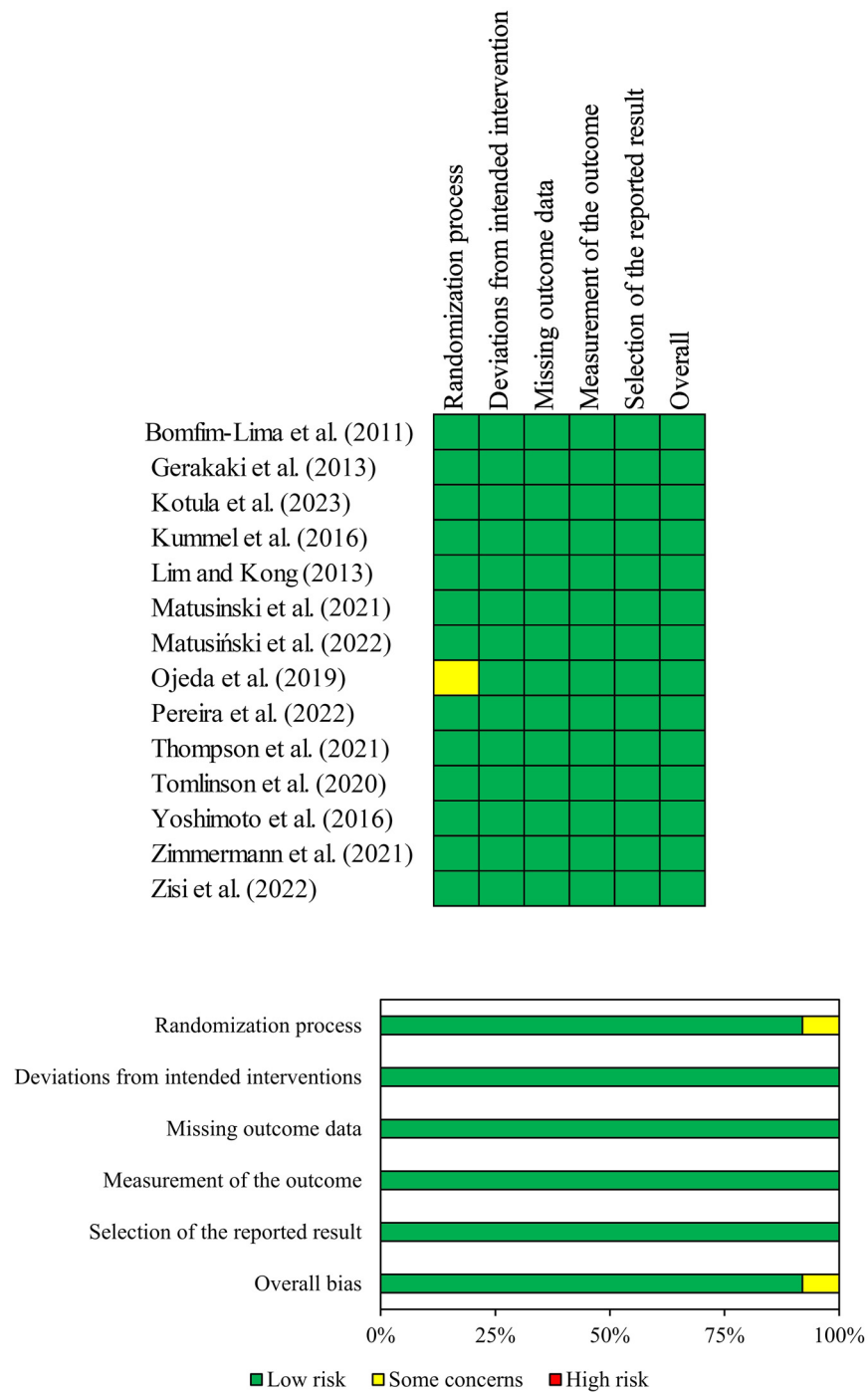


Figure 2 — Risk-of-bias assessment for the studies included in the meta-analysis.

In fact, under a realistic scenario, it would be highly surprising to find any strategy capable of significantly and acutely increasing the sprint speed of competitive sprinters. As a comparison, a recent study¹² has showed that elite sprinters experienced annual increases of $\leq 0.2\%$ from their early to mid-20s. Furthermore, in the 5 years preceding their peak performance, the top-100 sprinters worldwide (data extracted from the statistical section of “World Athletics” from 2002 to 2016) exhibited performance improvements of $< 2\%$ compared to their personal bests.¹² Indeed, substantial variations in sprint times during a given training period (2–3 y) or even during the competitive season are not usually expected in

professional sprinters. In this regard, another recent study showed that male and female 100-m sprinters (personal bests between 10.07 and 10.61 s, and 11.03 and 11.61 s, respectively), who trained with different coaches, presented an average variation in sprint times of only $\pm 1.4\%$ over the course of 14 consecutive months.¹¹ It is worth noting that the > 100 sprinters considered in both of these studies followed a wide variety of training programs under the guidance of multiple coaches with distinct expertise and backgrounds, and this factor does not appear to have a significant influence on training outcomes.³⁸ Hence, it seems highly improbable that an acute training strategy, regardless of its

Table 1 Physiotherapy Evidence Database Scale Scores for the Studies Included in the Meta-Analysis

Study	Physiotherapy Evidence Database scale items											Total score
	1	2	3	4	5	6	7	8	9	10	11	
Bomfim-Lima et al ¹⁷	1	1	1	1	—	—	—	1	1	1	1	7 (high)
Gerakaki et al ²⁹	1	1	1	1	—	—	—	1	1	1	1	7 (high)
Kotuła et al ³⁵	1	1	1	1	—	—	—	1	1	1	1	7 (high)
Kummel et al ¹⁹	1	1	1	1	—	—	—	1	1	1	1	7 (high)
Lim and Kong ²⁰	1	1	1	1	—	—	—	1	1	1	1	7 (high)
Matusinski et al ³¹	1	1	1	1	—	—	—	1	1	1	1	7 (high)
Matusiński et al ³⁰	1	1	1	1	—	—	—	1	1	1	1	7 (high)
Ojeda et al ³²	1	—	1	1	—	—	—	1	1	1	1	6 (high)
Pereira et al ³³	1	1	1	1	—	—	—	1	1	1	1	7 (high)
Thompson et al ²¹	1	1	1	1	—	—	—	1	1	1	1	7 (high)
Tomlinson et al ³⁴	1	1	1	1	—	—	—	1	1	1	1	7 (high)
Yoshimoto et al ¹⁸	1	1	1	1	—	—	—	1	1	1	1	7 (high)
Zimmermann et al ³⁶	1	1	1	1	—	—	—	1	1	1	1	7 (high)
Zisi et al ³⁷	1	1	1	1	—	—	—	1	1	1	1	7 (high)

arrangement or nature (ie, volume, intensity, sequence, and type of exercises used as CAs), would be able to produce a substantial improvement in the sprint performance of competitive sprinters. However, this does not mean that PAPE methods cannot be used as effective ways to warm up sprinters and prepare them for more intense sprint-specific training sessions or even for complementary training practices where enhancements in other physical capabilities are relevant (eg, to induce acute increases in leg power and jumping ability before plyometric activities).^{13,39,40}

Two out of the 14 studies considered in this review exhibited promising (yet distinct) results in sprint performance. In the first of them, Matusiński et al³⁰ compared the effects of assisted versus resisted sprints on the 10- and 50-m sprint times of male and female national and international sprinters (ie, sprinters with vast experience in international competitions). Although both sexes presented significant decreases in sprint times, the extent of these decreases was considerably greater for male athletes (ie, -6.2% and -2.5% vs -2.6% and -0.8% in 10-m and 50-m sprint times, for male and female sprinters, respectively). According to the authors, the differences in PAPE responses between sexes may be explained by the greater strength capacity of male sprinters, who may be more susceptible to potentiation effects.¹³ Previous research reinforces this suggestion, indicating that these contrasting results between sexes are likely related to differences in muscle composition, specifically to muscle fiber percentage,^{40–42} with males tending to display elevated levels of myosin phosphorylation (ie, one of the potential PAPE mechanisms) after CAs, due to their higher percentage of type II fibers (compared to female athletes).^{42–44} Another indication that this positive effect was possibly associated with corresponding changes in muscle contractile properties is the fact that, for both male and female athletes, the mean increases in sprint speed were greater over the acceleration sprinting phase (ie, 10 m; increases equal to $\sim 4.5\%$ vs $\sim 1.7\%$, for 10-m and 50-m sprints, respectively). Indeed, it is well established that the initial acceleration phase of sprinting relies heavily on the ability to apply force (and maximize net horizontal impulse) over a relatively extended period of time.^{45,46} This ability, in turn, appears to greatly benefit from the increases in maximal strength resulting from the acute improvements in muscle contractile properties and maximal voluntary contractions, typically observed after postactivation

potentiation protocols.^{47–50} The similarity between the exercise used as CA (ie, resisted sprinting with 10% of body mass) and the potentiated activity⁵¹ (ie, acceleration phase of sprint running) in the study by Matusiński et al³⁰ may also be a relevant factor to consider and examine in future research involving competitive sprinters. However, to date, it is worth noting that the current evidence does not support the necessity of using biomechanically (ie, kinetic and kinematic aspects) similar exercises in PAPE protocols.¹⁴ Finally, the second study¹⁷ utilized 2 sets of drop jumps at 75 cm as a form of CA for regional sprinters, reporting greater improvements in sprint time over longer sprint distances compared to shorter distances (ie, -2.4% in 50-m vs -1.4% in 10-m sprint times). A notable difference in this study was the use of a plyometric activity as a form of CA, as opposed to the resisted sprint drills used in the other study. When prescribed as CA, it could be speculated that plyometric exercises may induce acute increases in motor-neuron excitability, motor-unit recruitment pattern, and the activation of synergist muscles. Masamoto et al⁵² suggested that the responses associated with this “explosive-type loading” could enhance the excitability of the fast-twitch units which, in theory, might facilitate the function of the neuromuscular system, thus enhancing top-speed qualities. Nonetheless, these are speculations based on Masamoto’s inferences and should be confirmed by future research on the neuromuscular mechanisms responsible for improving (or not) the speed-power performance of competitive sprinters after plyometric activities.

Despite these few exceptions, the results of the current meta-analysis are quite clear: The PAPE protocols currently developed cannot significantly enhance the sprint performance of competitive sprinters. Nevertheless, as mentioned earlier, this does not imply that this training strategy is ineffective and should therefore be disregarded by sprint coaches. A more in-depth analysis of the studies included in this review suggests that significant improvements in jumping ability and peak power may be observed in sprinters as a result of various types of CAs,^{17,19,31} an inference that can be supported by previous meta-analyses on this specific topic.^{39,40,53} It is important to emphasize that these reviews were not exclusively conducted with competitive sprinters, and the results showed that the extent of the acute effects on leg power and jump performance depends on a series of factors, such as the exercise type

Table 2 Characteristics of the Studies Included in the Meta-Analysis

Study	N	Competitive level; experience; 100-m PB	Gender	CA exercise	Volume and load	Rest interval	Sprint measure	Distance, m
Bomfim-Lima et al ¹⁷	10	National level; 6 y	Male	Drop jumps (75 cm)	2×5	15 min	Infrared timing system	50
Gerakaki et al ²⁹	15	3–4 y; 11.04 (0.4) s	Male	Semisquat and lunge of each leg	2 s concentric—2 s eccentric 3 s concentric—2 s eccentric with 50 Hz vibration	6 min	Photocells	60
Kotula et al ³⁵	10	International level; 5.6 (0.2) y	Female	Assisted sprints Resisted sprints Combined	4×40 m (+105% V _{max}) 4×40 m (10% BM) 2×40 m of each	7 min	Photocells	50
Kummel et al ¹⁹	5	International level	2 females 3 males	Reactive hops	10 maximum hops	10–20 s	Opto-electronic system	30
Lim and Kong ²⁰	12	Well trained; 10.93 (0.29) s	Male	Dynamic squat	3 rep (90% IRM)	4 min	Speedlight timing system	30
Matusinski et al ³¹	10	International level; >2 y	Female	Resisted sprints	1×(5% BM) 1×(10% BM) 1×(15% BM)	5 min	Photocells	20
Matusinski et al ³⁰	6	International and national level; >6 y	Female	Assisted sprints	3×40 m	8 min	Photocells	50
	5		Male	Assisted sprints	3×40 m (10% BM)			
	6		Female	Resisted sprints	3×30 m (10% BM)			
	5		Male	Resisted sprints	3×30 m (10% BM)			
Ojeda et al ³²	10	—	Female	Squat	5×(22% IRM) 4×(60% IRM)	1 min	Photocells	30
Pereira et al ³³	12	International level; >6 y; 10.10–11.17 s	Male	Drop jumps (60 cm)	2×5 (hard or sand surfaces)	15 min	Photocells	60
Thompson et al ²¹	10	—	9 females 11 males	Resisted sprints	3×20 m (~45% BM)	3–10 min	1080 sprint device	20
	10			Unresisted sprints	3×20-m			
Tomlinson et al ³⁴	22	College athletes; >1 y	10 females 12 males	Weighted jump squats	2×8 (13% BM)	5 min	Timing gates	30
Yoshimoto et al ¹⁸	10	>4 y; 11.46 (0.57) s	Male	Linear sprint Alternate leg bounding	2×60 m 3×60 m	10 min	High-speed camera	60
				Mini-hurdle sprint (22 cm height)	10×10 hurdles			
Zimmermann et al ³⁶	12	National level; 3 y; 10.38–11.92 s	2 females 10 males	Continuous vertical jumps	3×5	2 min	Photocells	30
Zisi et al ³⁷	12	>3 y	7 females 5 males	Resisted sprints	2×20 m (individualized load)	8 min	Video analysis	Split 25–30

Abbreviations: BM, body mass; CA, conditioning activity; IRM, 1-repetition maximum; V_{max}, maximum velocity.

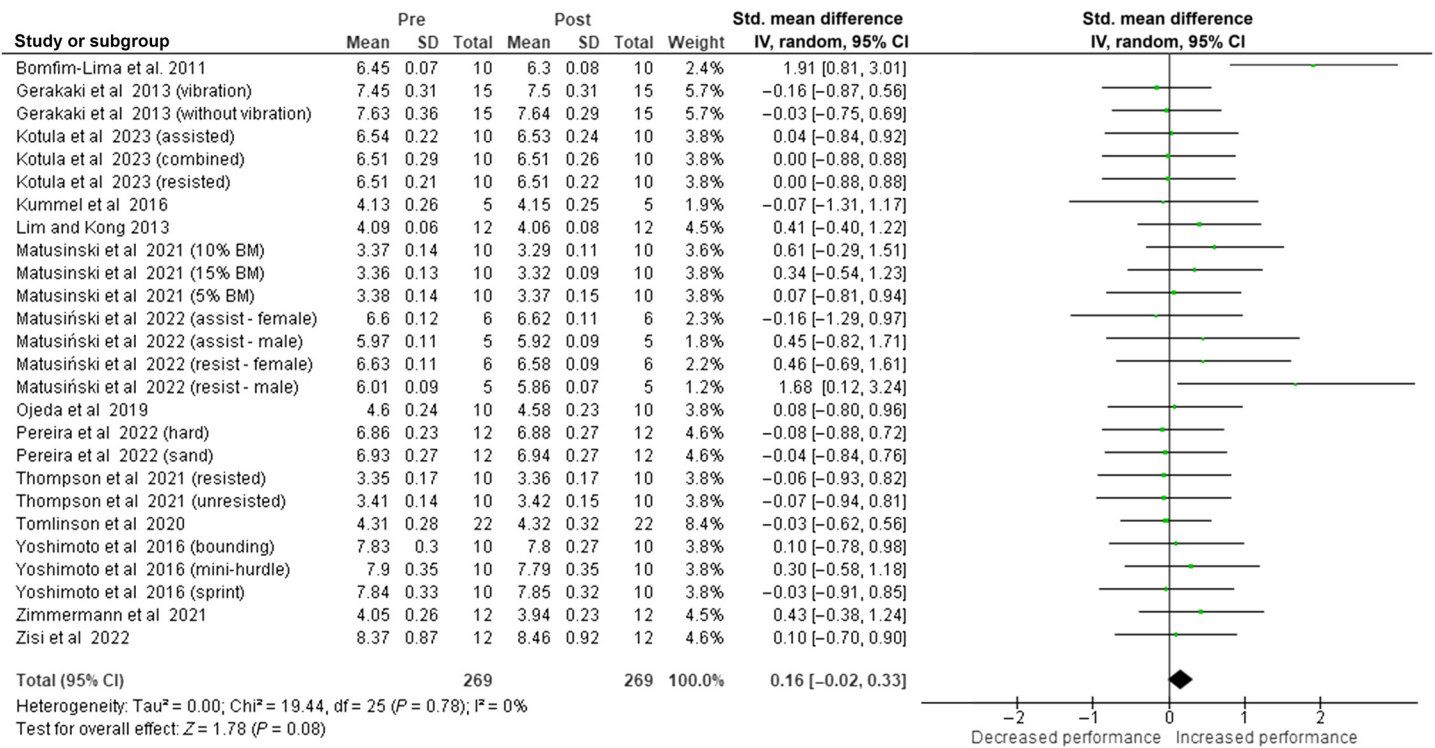


Figure 3 — Forest plot comparing premeasures and postmeasures of linear sprint performance across the 14 studies included in this review.

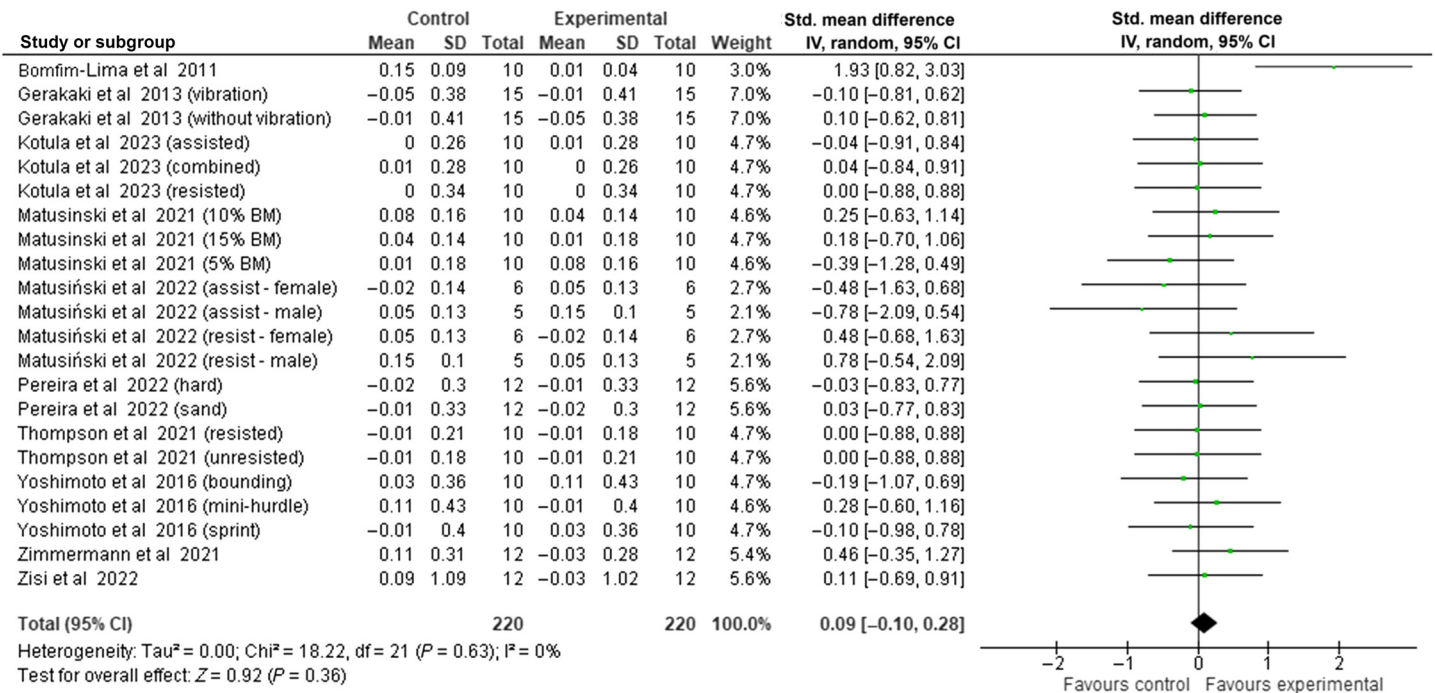


Figure 4 — Forest plot comparing prechanges and postchanges among experimental, control, and other conditions across the 14 studies included in this review.

(ie, ballistic or heavy-weight exercises), athlete’s strength level, recovery periods following the CA, loading intensity (ie, light, moderate, or high), and the number of sets and repetitions (ie, single vs multiple sets).^{39,40,53} Therefore, despite these consistent

and positive indications, a specific systematic review with meta-analysis on the effects of CAs on the power and jump performance of competitive sprinters is still needed. Lastly, it is also important to consider the fact that potentiation effects tend to be superior in

stronger individuals and athletic-trained populations, which may significantly benefit a group composed of competitive sprinters.

The current meta-analysis showed that it may not be possible to acutely increase the sprint speed or decrease the sprint time of competitive sprinters through the use of different and multiple types of CAs. Along with the abovementioned data, this finding confirms that sprinting speed is a highly stable and consistent physical capacity, with very little room for improvement, especially in competitive sprinters. In fact, a simple observation of the progression of the 100 m world record over time,⁵⁴ starting from the breaking of the 10-second barrier by Jim Hines at the 1968 Olympic Games with an official time of 9.95 seconds, reinforces this argument. During this 55-year period, the fastest time achieved by a sprinter was only ~3.7% faster than the time established by Hines. This translates into a modest annual improvement of ~0.07% in the 100-m race time (based on the fastest time achieved over this period). It is worth noting that this improvement was greatly influenced by the extraordinary achievement of Usain Bolt in 2009, when he set the astonishing record of 9.58 seconds. This contrasts with the ~9% improvement observed in the evolution of the world record for the marathon during this period (ie, comparing the world record of 2 h, 12 min, and 12 s established by Derek Clayton in 1967⁵⁵ with the current record of 2 h and 35 s set by Kelvin Kiptum in October 2023). Undoubtedly, for mathematical reasons, competitions with longer durations also provide greater scope for the evolution of athletic performance (which limits even more the evolution of elite sprint performance). Based on these numbers and being realistic, it would not be easy to find a strategy capable of substantially inducing acute (or even chronic) increases in the sprint performance of competitive sprinters.

This review is limited by the impossibility of comparing the effects of different types of CAs (eg, resisted sprints vs plyometrics, ballistics vs nonballistic exercises) on the sprint performance of sprinters. This limitation is due to the scarcity of high-quality studies on this topic. Furthermore, the majority of these relevant studies utilized very different PAPE protocols in their experimental designs, thus precluding any comparison in this regard. Nevertheless, this study sheds light on a crucial issue: The actual performance of elite sprinters may not be enhanced with the utilization of pre-CAs (ie, PAPE protocols), at least in the current form in which they are implemented. Coaches and sport scientists should collaborate and combine their efforts to develop more efficient PAPE protocols for enhancing acceleration and top-speed qualities in these highly specialized athletes. Therefore, future studies should evaluate the specific acute physiological and performance effects of each CA while considering the acceleration and maximum speed phases separately.⁵⁶ Meanwhile, the absence of significant changes at a very specific population of athletes does not negate the possibility of positive changes at an individual level. For this reason, future studies should consider athletes' training background, including the level of familiarization and adaptation to the CAs selected, while presenting the individual responses to the evaluated protocols. Finally, most studies evaluate both the control and experimental warm-up protocols within the same session, which would likely introduce some interference between the protocols. Future studies should include appropriate study designs, following the recommendations by MacIntosh et al⁵⁷ and Boullosa et al,¹⁴ to better isolate the specific effects of each CA on different sprinting abilities. Authors are also encouraged to investigate whether different rest intervals (eg, <2 min vs 4–6 min vs 8–10 min) between CAs and the verification test can impact the results, as acute fatigue could be a significant factor in this context.⁵⁸ In this regard, it should be noted that we included studies

with a wide range of recovery times between the CAs and the verification (performance) tests, which may impact the current results.

Practical Applications

Warming-up routines are essential to prepare athletes to cope well with the ever-increasing physical and technical demands of training and competition, and PAPE is considered one of the key objectives of these regular practices.^{13,15} In this context, CAs are commonly used by coaches and practitioners to induce PAPE in athletes engaged in a variety of sport disciplines. Currently, it is not possible to identify a superior warming-up protocol or CA for enhancing the competitive performance of these athletes. Sprint coaches should be aware of this, while also ensuring that effective warming-up strategies are always implemented to adequately prepare their athletes for the subsequent task. For this purpose, warm-up protocols should be designed to increase body temperature, the main factor for performance enhancements, while minimizing the acute fatigue with the implementation of low-volume protocols, using CAs and loads for which the athletes are fully familiarized and adapted. Although the current evidence is limited, the biomechanical similarity between the CA and the sport-specific task to be potentiated is another aspect to take into account when searching for more efficient PAPE schemes, especially when dealing with elite athletes.⁵¹ In this sense, it would be advisable to use different exercises depending on the sprinting phase to be enhanced/potentiated (ie, acceleration vs top-speed).

Conclusions

Postactivation performance-enhancement (PAPE) strategies do not effectively enhance the sprint performance of competitive sprinters over shorter (eg, 20 m) or longer (eg, 60 m) distances. Sprint coaches and sport scientists should collaborate to develop new and more consistent PAPE protocols. This could be particularly beneficial for elite sprinters, as they often exhibit minimal variations in their competitive times throughout their professional careers.

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