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Review

Acute and Chronic Effects of Muscle Strength Training on Physical Fitness in Boxers: A Scoping Review

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Featured Application: It is possible to improve punches' impact force both chronically and acutely. Before fights or sparring sessions, maximal isometric exercises can be integrated with punching techniques (e.g., three repetitions of 3 s), resistance band exercises with punching techniques (e.g., two sets of 5 reps), medicine ball throws with 10% of 5RM bench press (e.g., three sets of 8 reps), SJ with 30% of 1RM (e.g., four sets of 8 reps) and traditional exercises such as bench press and back squat with 80% of 1RM (e.g., three sets of 5 reps) with an improvement window in punches' impact force between 6 and 15 min after the exercises.

Abstract: The aim of this scoping review was to compile the current evidence and provide a summary of the acute and chronic effects of muscle strength training on the physical fitness of amateur boxers and provide recommendations to optimize their physical performance. This scoping review was developed using guidance from the Joanna Briggs Institute and PRISMA-ScR. The search was conducted in the Scopus, PubMed and Web of Science databases between December 2023 and June 2024. In total, 50 full-text articles were assessed to determine eligibility, while 15 studies met the inclusion criteria and were subjected to detailed analysis and assessment of their methodological quality. Our findings indicate that muscular strength training interventions can improve punching performance in amateur boxers acutely and chronically, in addition to improving their physical fitness and generating increases in the capacity to generate maximum force and improvements in RFD and the power production of the upper and lower limbs of boxers. However, this scoping review only included one study in female boxers, so we recommend that future studies contain muscular strength training interventions in females to analyze their adaptations in punching force and physical fitness.

Keywords: boxing; combat sports; muscle strength; post-activation performance enhancement

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1. Introduction

Amateur boxing is characterized as a sport where victory is achieved through "decision" by a greater accumulation of points than the rival or by "stoppage" of the referee by punches that cause a knockout (KO) or technical knockout (TKO) to the rival [1,2]. The main objective during combat is to connect clean punches to the opponent, receiving

the least amount of punches possible [3]. Punches are movements that involve muscular actions at high speeds [4,5], where a transmission of muscle strength is required through the entire kinetic chain of the boxer, starting with the muscle strength applied against the ground of the lower body and subsequently transferring the energy generated through the middle zone to the upper extremities to impact the rival in the head or trunk [6]. There are different types of punches (e.g., jab, cross, hook) which require different biomechanical actions for their application [4,7–9]. For example, a jab or punch with the lead hand has the shortest execution time of all the punches, probably due to the smaller displacement of the arm and the smaller contribution of other segments in its execution [9,10]. In this sense, Finlay [10] with elite senior amateur boxers found the jab presented the lowest absolute maximum force of the punches (1645 ± 537 N, 20.6 ± 4.8 N.kg^{-1}), possibly given the lower generation of reaction forces against the ground and the lesser contribution of the trunk in the execution of the punch [9]. In contrast, the hook with the rear hand has reported absolute maximum force values of 2624 ± 581 N, 33.1 ± 4.3 N.kg^{-1}; this is because it comprises a considerable peak of the ground reaction force (GRF) of the front leg (where the force is transferred from the back leg to the front leg), and it also has a greater trunk rotation that includes a stretch-shortening cycle component whereby a pre-stretch of the trunk is performed before propelling the upper limbs at high speeds towards the opponent [9,11–13], therefore generating greater kinetic energy and transfer through the kinetic chain of movement.

While technique plays an important role in a boxer's punching ability, current evidence has reported that the force production of the neuromuscular system can also limit the impact force of punches (i.e., rate of force development, RFD) [6,14,15]. In addition, Lenestsky et al. [16] have defined the ability to produce and maintain high levels of muscular strength during combat as a key factor in achieving success in boxing. Particularly, maintaining the strength of punches during combat can decrease the opponent's ability to fight, affecting their performance due to the damage received, increasing the chances of a victory by KO or TKO [17]. Additionally, more experienced athletes have been shown to produce greater impact forces [7,10,12] which would evidently result in greater damage to the opponent during combat. Therefore, improving the punch force increases amateur boxers' probability of victory, being considered a key performance indicator when kept in balance with the various physical and physiological requirements [1]. There are various longitudinal study designs that have focused on improving physical performance in combat sports, obtaining significant improvements in maximum isometric strength, maximum dynamic strength and the muscular power of the upper and lower body, as well as improvements in the different types of specific actions [18–22]. Cid Calfucura et al. [23] reported improvements in the physical performance of combat sports athletes through interventions lasting six to twenty weeks in karate [24–28], eight to sixteen weeks in judo [29–35], four to sixteen weeks in boxing [18–21,36], twelve weeks in fencing [37] and four to eight weeks in wrestling [38,39], with a frequency of 2 to 6 weekly sessions of 20 to 165 min, using resistance training exercises within a wide spectrum of loads (20% to 90% one-repetition maximum, 1RM), exercises with eccentric overload (flywheel inertial), specific exercises with elastic bands and multidirectional plyometric exercises.

However, in recent years, interest in improving performance with acute muscle strength activities prior to competition has increased considerably [40–42]. The most used method to improve neuromuscular performance before competition is the pre-competition warm-up [43]. Potentiation activities, typically performed after the general warm-up and activation phases, are responsible for raising warm-up intensity to competition levels and inducing the post-activation performance enhancement phenomenon (PAPE) [43,44]. The PAPE phenomenon can be described as an acute increase in neuromuscular performance for up to ~15 min through prior muscular activity in responding athletes [45,46]. Additionally, various warm-up activities have been reported to enhance performance prior to sports activities, including free weight exercises, plyometrics, ballistic exercises, variable resistance, resisted sprints, and isometric exercises [45,47–49]. In combat sports, specifically

in judo, boxing, karate, taekwondo and kickboxing, a recent systematic review reported acute improvements in muscular power using isometric strength protocols, maximum strength, contrasts of maximum strength with plyometrics, plyometrics, clusters and the use of elastic bands with a load intensity between 65% and 110% of the repetition maximum, with acute improvements reported in time rest of 30 s to 10 min [49]. Therefore, its inclusion has been suggested as a strategy to enhance the competitive performance of boxers [43]. Since victory by KO and/or points is a frequent goal during combat, boxers can benefit from different strategies, training methods and warm-ups to maximize their strength–power capabilities. However, the literature regarding boxing has only focused on reporting the role of punch impact force in amateur and professional boxers, indicating the differences in muscle strength levels according to the competitive level and establishing general recommendations to optimize sports performance. To our knowledge, there is no research examining the acute and chronic effects of muscle strength training on the physical fitness of amateur boxers. This would benefit coaches and technical staff as a current evidence-based guide to implement in their training programs to improve boxing-specific actions (e.g., punch impact force).

Scoping reviews have been demonstrated to be a relevant approach for evaluating the literature that has not been comprehensively reviewed or that shows heterogeneous evidence that is not amenable to a more systematic approach (e.g., systematic review) [50]. In this sense, Bell et al. [51] mention that scoping reviews provide the possibility of drawing broad narratives within a spectrum of limited literature, allowing for the analysis of recent evidence where the precise lines of questioning are undetermined [52,53]. Additionally, these reviews help to establish conceptual boundaries and identify gaps for future research [52].

The available literature on the effects of muscle strength training in amateur boxers is diverse in terms of the different training methodologies and variables analyzed. Furthermore, the studies are characterized by not using a control group within their analyses and not fully detailing the frequency and duration of the training sessions, which reduces the methodological quality of the interventions. Based on the above, after an in-depth research analysis, a scoping review was chosen instead of a systematic review. For this, a population, concept, context (PCC) framework [50] was used to develop the study question: "What is known about the acute and chronic effects of muscle strength training on the physical fitness of amateur boxers?". Therefore, this scoping review aimed to compile the current evidence and provide a summary of the acute and chronic effects of muscle strength training on the physical fitness of amateur boxers and provide recommendations to optimize their physical performance.

2. Methods

2.1. Study Design

This scoping review was developed following the guidance from the Joanna Briggs Institute [54] and PRISMA-ScR [55]. The methodological framework proposed by Arksey and O'Malley was used [52]. The protocol was registered with Open Science Framework on 16 July 2024 (https://osf.io/ydbk7 (accessed on 23 August 2024)).

2.2. Eligibility Criteria

To be included in this review, the articles met the following conditions: (i) a study population of athlete boxers, regardless of sex; (ii) articles published until June 2024; (iii) original articles with no language or publication date restriction; (iv) acute or chronic interventions (intervention); (v) at least one muscle strength (outcome) assessment, pre- and post-intervention; (vi) a pre-experimental, quasi-experimental or experimental study design with pre- and post-assessments. The exclusion criteria were (i) studies with participants outside the age range of 12 to 35 years (junior to elite boxers); (ii) studies such as letters to the editor, translations, notes and book reviews; (iii) cross-sectional, retrospective, prospective studies; and (iv) case studies (i.e., studies using only one athlete).

2.3. Information and Database Search Process

The search was conducted in the Scopus, PubMed and Web of Science (core collection) databases between December 2023 and June 2024. Medical subject headings (MeSH) from the National Library of Medicine of the United States of America and related free language terms were used with muscle strength and boxing. The following search string was used: ("muscle strength" OR "strength" OR "resistance training" OR "explosive strength" OR "power" OR "neuromuscular" OR "acute" OR "short-term" OR "contrast" OR "complex" OR "post activation potentiation" OR "PAP" OR "post-activation performance enhancement" OR "PAPE" OR "warm-up" OR "pre-competition" OR "jump" OR "punch force" OR "punch impact") AND ("boxing" OR "boxers"). The included articles and study eligibility criteria were sent to two experts to help to identify additional relevant studies. Experts had to meet two criteria: (i) hold a PhD in sports science, and (ii) have published on combat sports in different population groups and/or in sports science journals with an impact factor according to Journal Citation Reports®. Finally, a search of the databases was performed on 30 June 2024 to retrieve relevant errata or retractions related to the included studies.

2.4. Selection of Studies and Data Collection

Studies were exported to the Mendeley reference manager (version v1.19.8, New York, NY, USA). Two authors (I.C.C., T.H.V.) independently performed a search, eliminating duplicate articles. Titles and abstracts were then reviewed and full texts of potentially eligible studies were analyzed, reporting reasons for the exclusion of articles that did not meet the selection criteria. No discrepancies were found during this process.

2.5. Assessment of Methodological Quality

To assess the methodological quality of the studies TESTEX scale designed for exercise-based intervention studies was used [56]. TESTEX has a 15-point evaluation scale (5 points for study quality and 10 points for reporting). This process was carried out independently by two authors (I.C.C., J.H.M.), and a third author (P.V.B.) acted as a referee for borderline cases. It should be noted that this procedure was not necessary during the review.

2.6. Data Synthesis

Data regarding the following were obtained and analyzed: (i) author and year of publication; (ii) country of origin; (iii) study design; (iv) number of boxers in the intervention and control groups; (v) mean age of the sample; (vi) activities carried out in the experimental and control groups; (vii) training volume; (viii) training intensity; (ix) variables analyzed; (x) assessment instruments; and (xi) main results.

2.7. Risk of Bias

The risk of bias in individual studies was assessed using the Cochrane risk of bias (RoB 2) [57]. Two authors (I.C.C., J.H.M.) independently completed the RoB analysis, which was reviewed by a third author (T.H.V.). In the original articles, if inconsistencies arose, the procedure was to analyze them until a consensus was reached. However, this was not necessary.

2.8. Certainty of Evidence

Studies were assessed using the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) scale [58] and classified as high, moderate, low or very low certainty of evidence. Two authors (I.C.C., J.H.M.) independently assessed the studies and any discrepancies were resolved by consensus with a third author (T.H.V.).

3. Results

3.1. Study Selection

The search process is detailed in Figure 1. In the study identification phase, a total of 5960 records were found. Duplicate articles were eliminated and studies were filtered by title, abstract and keywords, resulting in 3955 references. A total of 3905 articles were eliminated for not meeting the inclusion criteria. In total, 50 full-text studies were analyzed, of which 25 were excluded for not being a muscle strength training intervention, 9 studies for not being boxing interventions and 1 study for not detailing the training program [18–22,59–66].

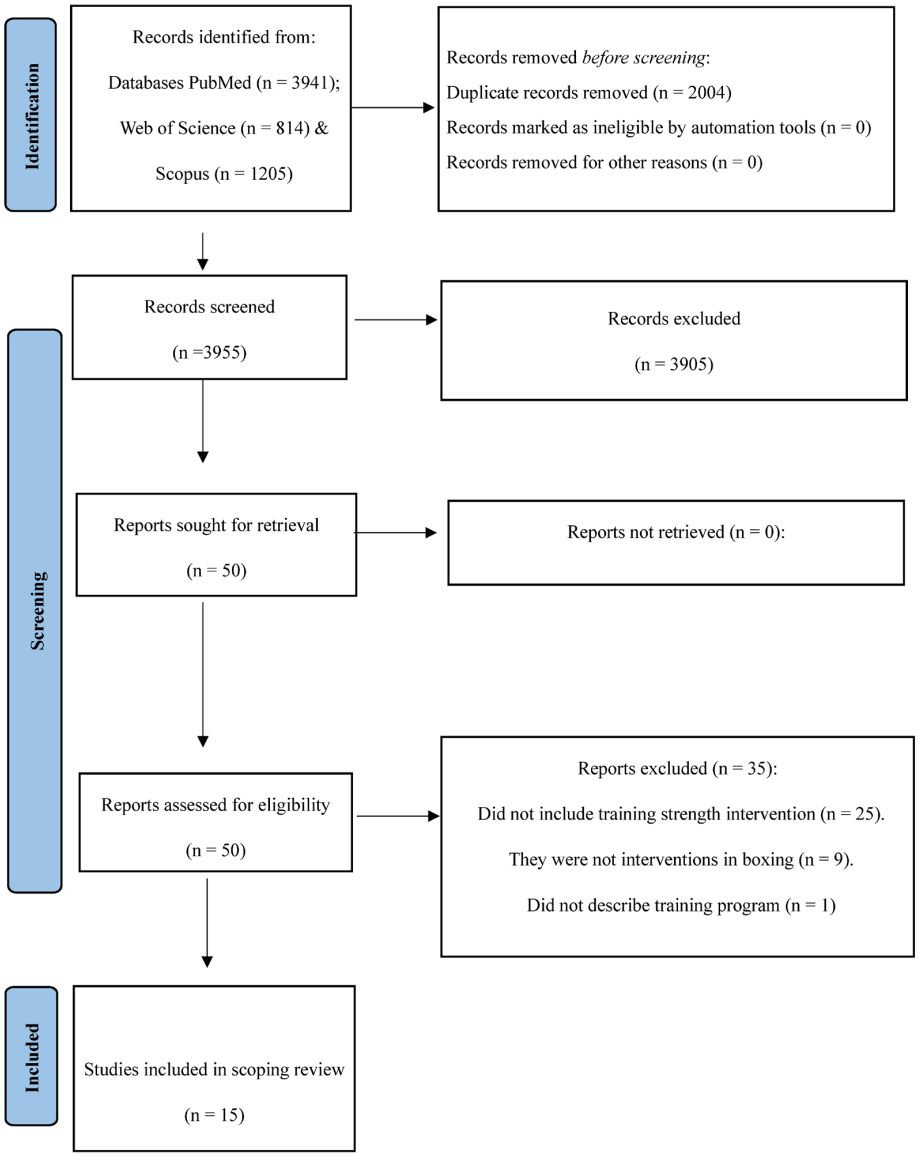


Figure 1. Flowchart of the review process #. Legends: # Based on the PRISMA-P guidelines [67].

3.2. Methodological Quality

The 15 selected articles were subjected to the TESTEX scale (Table 1). All studies achieved a score equal to or above 48% on the scale, that is, 4/15 [20,62], 5/15 [68], 6/15 [19,36] and 7/15 [18,21,63–65], highlighting the studies with 8/15 [22,59,66], 11/15 [60] and 12/15 [61], who obtained 60% or more of the scale score, presenting a moderate to high quality; no study was excluded from the scoping review.

Table 1. Study quality assessment according to the TESTEX scale.

Study	Eligibility Criteria Specified	Randomly Allocated Participants	Allocation Concealed	Groups Similar at Baseline	Assessors Blinded	Outcome Measures Assessed >85% of Participants *	Intention to Treat Analysis	Reporting of Between-Group Statistical Comparisons	Point Measures and Measures of Variability Reported **	Activity Monitoring in Control Group	Relative Exercise Intensity Reviewed	Exercise Volume and Energy Expended	Overall TESTEX #
Čepulenas et al. [20]	No	No	No	No	No	Yes (1)	No	Yes (1)	No	No	Yes	Yes	4/15
Nasser et al. [62]	No	No	No	No	No	Yes (1)	No	Yes (1)	No	No	Yes	Yes	4/15
Soyler et al. [68]	No	No	No	No	No	Yes (1)	No	Yes (2)	No	No	Yes	Yes	5/15
Bruzas et al. [36]	Yes	No	No	Yes	No	Yes (1)	No	Yes (2)	No	No	No	Yes	6/15
Kim et al. [19]	Yes	No	No	No	No	Yes (1)	No	Yes (2)	No	No	Yes	Yes	6/15
Bu [21]	Yes	No	No	Yes	No	Yes (1)	No	Yes (2)	No	No	Yes	Yes	7/15
Loturco et al. [18]	Yes	No	No	Yes	No	Yes (1)	No	Yes (2)	Yes	No	No	Yes	7/15
Yi et al. [64]	Yes	No	No	Yes	No	Yes (1)	No	Yes (2)	Yes	No	No	Yes	7/15
Yi et al. [65]	Yes	No	No	Yes	No	Yes (1)	No	Yes (2)	Yes	No	No	Yes	7/15
Loturco et al. [63]	Yes	No	No	No	No	Yes (1)	No	Yes (2)	Yes	No	Yes	Yes	7/15
Pereira et al. [22]	Yes	No	No	Yes	No	Yes (1)	No	Yes (2)	Yes	No	Yes	Yes	8/15
Finlay et al. [59]	Yes	Yes	No	Yes	No	Yes (1)	No	Yes (2)	Yes	No	No	Yes	8/15
Finlay et al. [66]	Yes	Yes	No	Yes	No	Yes (1)	No	Yes (2)	Yes	No	No	Yes	8/15
Chottidao et al. [60]	Yes	Yes	Yes	Yes	No	Yes (2)	No	Yes (2)	Yes	No	Yes	Yes	11/15
Liu et al. [61]	Yes	Yes	Yes	Yes	No	Yes (2)	No	Yes (2)	Yes	Yes	Yes	Yes	12/15

* Three points are possible: one point if adherence > 85%, one point if adverse events are reported, and one point if exercise attendance is reported. ** Two points are possible: one point if the primary outcome is reported and one point if all other outcomes are reported. # Total out of 15 points. TESTEX: Tool for assessing study quality and reporting in exercise [56].

3.3. Risk of Bias Results

The risk of bias was a high risk for all 15 studies analyzed [18–22,59–66]. In the randomization process, 13 studies showed a high risk [18–22,36,59,62–66,68] and 2 studies showed some concerns [60,61]. While in deviations from the planned interventions, 13 studies showed a low risk [18–20,22,36,60–66,68], 1 study showed some concerns [59] and 1 study showed a high risk [21]. In missing outcome data, all 15 studies showed a low risk [18–22,59–66]. In outcome measurement, all 15 studies showed a high risk [18–22,36,59–66,68], while in the selection of the reported results the 15 studies showed some concerns [18–22,59–66]. Figures 2 and 3 present the analysis of the risk of bias.

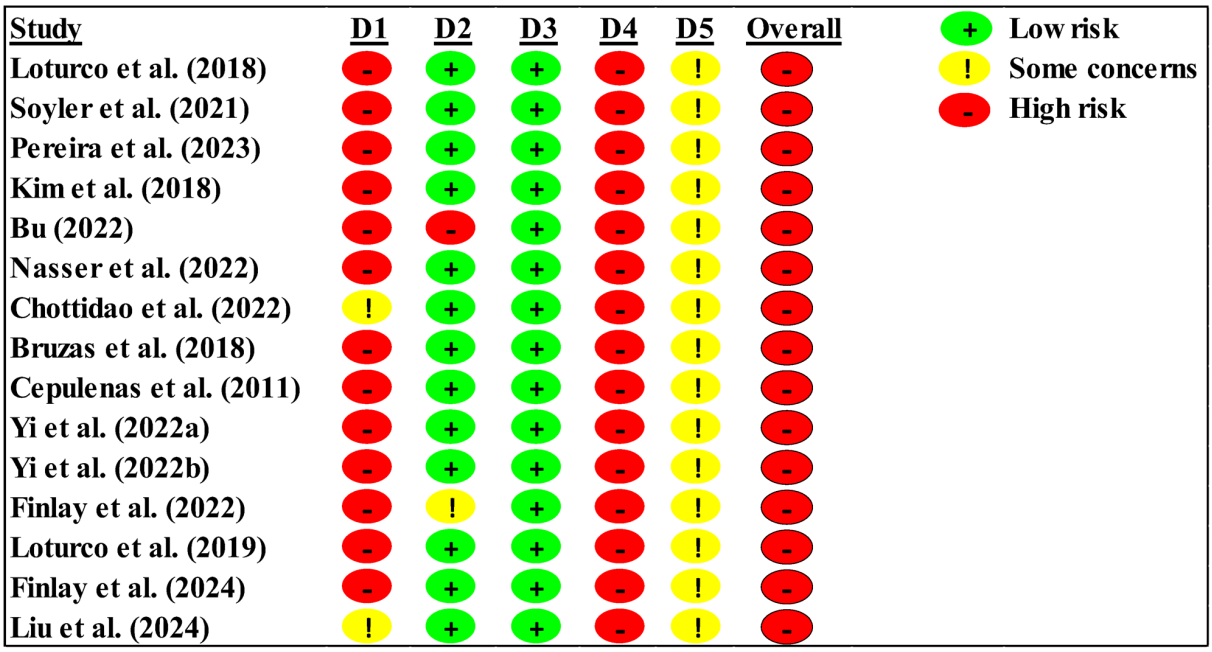


Figure 2. Risk of bias within studies [18–22,36,59–66,68]. Legend: D1: randomization process; D2: deviations from the intended interventions; D3: missing outcome data; D4: measurement of the outcome; D5: selection of the reported result.

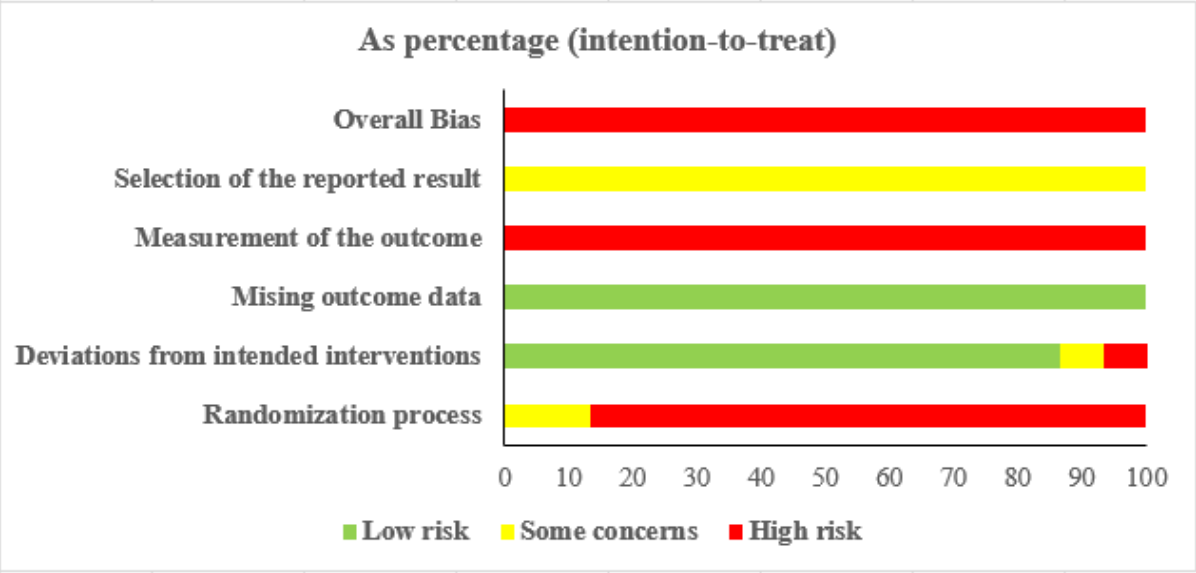


Figure 3. Risk of bias summary: review authors' judgments about each risk of bias item for each included study.

3.4. Certainty of Evidence Results

The certainty of evidence did not allow definitive recommendations to be made in favor of muscle strength training as an intervention to improve punch force and physical fitness in boxers because it was low to very low (Table 2).

3.5. Studies' Characteristics

The variables analyzed in the 15 selected studies are mentioned in Table 3. Three studies were carried out in Brazil [18,22,63], four in China [21,61,64,65], two in Lithuania [20,36], two in the United Kingdom [59,66], one in Korea [19], one in Iraq [62], one in Taiwan [60], and one in Turkey [68]. Two studies were randomized controlled trials [68,69], two studies were quasi-experimental designs [21,22], while eleven studies were pre-experimental designs [18–20,36,60–66].

3.6. Sample Characteristics

Twelve studies had 8 to 15 participants [18–20,22,36,59,62–66,68], while only three studies had 20 to 30 participants [21,60,61]. The total sample was made up of 205 boxers, of which 181 were males and 24 females, with a mean age of 20.5 years. Only two articles had a sample with under-age boxers. Specifically, the sample of Chottidao et al. [60] consisted of junior boxers with an average age of 15 years, while the study of Liu et al. [61] used a sample of adolescent and young adult boxers with ages ranging from 16 to 18 years. Regarding the competitive level of the participants, four studies reported that their participants were elite amateur boxers belonging to national teams with experience in Olympic Games and international tournaments [18,22,63,68], five studies reported that their participants were amateur boxers experienced elite boxers at the national level [19,20,59,62,66], four studies indicated that their participants were college amateur boxers and high school students [60,61,64,65] and two studies only reported that their participants were amateur boxers [21,36].

3.7. Dosing and Conducted Interventions

Two studies were randomized-controlled trials [68,69], two studies were quasi-experimental designs [21,22], while eleven studies were pre-experimental designs [18–20,36,60–66]. Regarding the interventions, two studies carried out a muscle strength training program based on the optimal power load (OPL) [18,63], two studies carried out plyometric training of the upper and lower limbs [36,60], four studies prescribed muscle strength training with traditional, ballistic and plyometric exercises [20–22,61], one study conducted specific muscle strength training for boxers based on core exercises, traditional strength exercises, derived from weightlifting, jumping and throwing with medicine balls [19], one study executed circuit muscle strength training with full-body exercises [68], one study executed a battle rope training program [62] and finally four studies performed an acute intervention through ballistic and non-ballistic exercises [59,64–66]. Regarding the supervision of the interventions, nine studies reported that they had physical activity professionals and boxing trainers in charge of the training sessions [18,22,59–61,63–66], while six studies did not report on the supervision of their interventions [19–21,36,62,68]. The duration of the investigations was diverse, ranging from 1 to 4 weeks [20,36,59,63–66,68], 7 to 12 weeks [18,21,60–62] and 16 to 30 weeks [19,22]. The training frequency for the interventions ranged between one and five weekly sessions. Five studies reported that the duration of their training sessions was 10 to 120 min [19,22,60,62,68], while ten studies did not report the duration of their training sessions [18,20,21,36,59,61,63–66].

Table 2. GRADE assessment for the certainty of evidence.

Outcome	Study Design	Risk of Bias in Individuals Studies	Risk of Publication Bias	Inconsistency	Indirectness	Imprecision	Certainty of Evidence	Recommendation
CMJ	1 RCT and 1 NRCT and 36 participants	[1] High	[2] Not Rated	[3] Moderate	[5] Low	[6] High	[7] Low	The certainty of evidence did not allow definitive recommendations to be made in favor of ST as an intervention to improve CMJ, SJ, straight punches force, hook punch force and straight punches speed performance
SJ	1 NRCT and 12 participants	[1] High	[2] Not Rated	[3] Moderate	[5] Low	[6] High	[7] Low	
Straight punches force	7 NRCT and 75 participants	[1] High	[2] Not Rated	[4] High	[5] Low	[6] High	[8] Very low	
Hook punches force	2 NRCT and 21 participants	[1] High	[2] Not Rated	[3] Moderate	[5] Low	[6] High	[7] Low	
Straight punches speed	1 RCT and 2 NRCT and 34 participants	[1] High	[2] Not rated	[3] Moderate	[5] Low	[6] High	[7] Low	

[1] All studies showed a high risk. [2] Not assessed due to the small and moderate number of studies. [3] Moderate statistical heterogeneity (assessed through I 2) and/or moderate clinical or methodological heterogeneity (interventions and study designs) due to the small number of studies. [4] High statistical heterogeneity (assessed through I^2) and/or high clinical or methodological heterogeneity (interventions and study designs) due to the high number of studies. [5] Our study performed measurements directly, so no surrogate results were used. The population (of boxers) was clearly defined and corresponded to our objectives. [6] Very large 95% confidence intervals. [7] Low, high (risk of bias in individual studies), not rated (risk of publication bias), moderate (inconsistency), low (indirectness) and high (imprecision). [8] Very low, high (risk of bias in individual studies), not rated (risk of publication bias), high (inconsistency), low (indirectness) and high (imprecision). CMJ: countermovement jump. RCT: randomized controlled trial. NRCT: non-randomized controlled trial. ST: strength training. SJ: squat jump.

Table 3. Studies report on the effects of chronic and acute muscle strength training on the physical condition of boxers.

Study	Country	Study Design	Groups	Mean Age (Year)	Type of Intervention and Control Group	Training Volume			Training Intensity	Main Outcomes
			(*n*)			Weeks	Frequency (Weekly)	Time per Session (min)		
Pereira et al. [22]	Brazil	QUA	OG: 6 NOG: 6	OG: 22.3 ± 1.4 NOG: 22.8 ± 2.9	OG: SPT and COND NOG: SPT and COND	30	5	40–60	30–75% 1RM	No significant changes for CMJ height and BP-power in either group
Kim et al. [19]	Korea	PRE	EG: 15	23.4 ± 2.2	EG: PCT, ETT, MBE and BST	16	3	90	PCT: 50–70% 1RM ETT: elastic tubes (green, blue and black) MBE: 3, 4 and 5 kg	↑ Punch power FS and FH ↑ BP and SQ strength ↑ BW relative TS in EXT and FLEX at 30°/s. ↑ TS (Nm) in EXT and FLEX at 30°/s. ↑ IP (w) of right and left arm in EXT at 180°/s.

Table 3. *Cont.*

Study	Country	Study Design	Groups (*n*)	Mean Age (Year)	Type of Intervention and Control Group	Training Volume			Training Intensity	Main Outcomes
						Weeks	Frequency (Weekly)	Time per Session (min)		
Bu [21]	Chine	QUA	EG: 10 CG: 10	EG: 22 ± 1.5 CG: 21.8 ± 1.3	EG: RT and SST CG: Only RT	12	3	NR	RT: 5–25 kg SST: BM—2.5 kg	↑ Sitting flat pushing solid ball ↑ Punch speed ↑ Punch power
Nasser et al. [62]	Iraq	PRE	EG: 10	24.4 ± 3.4	EG: Battle rope exercises	8	3	10–20	50–100 A.U	↑ Number of punches singles, doubles and multiples
Chottidao et al. [60]	Taiwan	RCT	PLY: 12 JR: 12	EG: 15.5 ± 1.6 CG: 15.6 ± 1.6	EG1: PLY EG2: JR	8	3	30	72 to 106 foot contacts for both groups	PLY and JR: ↑ PRFD in CMJ, ↑ Reaction time of punch ↑ PGRF in rear leg in jab punch ↑ Velocity in jab punch
Loturco et al. [18]	Brazil	PRE	EG: 12	28.1 ± 3.9	EG: BP and JS with OPL	7	1 to 3	NR	OPL	↑ MP, MPP and PP in BP ↑ MP, MPP and PP in JS
Liu et al. [61]	China	RCT	UNI: 10 BI: 10 UNI + BI: 10	16–18	UNI upper and lower limb exercises BI upper and lower limb exercises UNI + BI upper and lower limb exercises	8	3	NR	50–80% 1RM 80–85% 1RM 50–85% 1RM	UNI, BI and UNI + BI: ↑ PP, AP, PV and AV in 30%, 50% and 80% 1RM in bench press and squat
Bruzas et al. [36]	Lithuania	PRE	EG: 8	22.3 ± 2.5	PLY	4	3	NR	15% BM and external weights of 1–1.5 kg	↑ Rear-hand low punch force ↑ Summative force in 3 s and 8 s ↑ Power production in 3 s and 8 s
Čepulenas et al. [20]	Lithuania	PRE	EG: 10	22.5 ± 3.3	RT, PLY and WS	4	NR	NR	20–90 1RM%	↑ BHP in straight punch, side punch and body punch ↑ FHP in straight punch (jab), side punch (hook to the body) and body punch (straight to the body)
Soyler et al. [68]	Turkey	PRE	EG: 12	22 ± 2.1	EG: HRT in salt cave	2	3	120	NR	↑ SJ and 15 s jump ↑ Punch speed ↑ Reaction time ↑ Balance parameter ↑ VO_{2max}

Table 3. *Cont.*

Study	Country	Study Design	Groups (*n*)	Mean Age (Year)	Type of Intervention and Control Group	Training Volume			Training Intensity	Main Outcomes
						Weeks	Frequency (Weekly)	Time per Session (min)		
Loturco et al. [63]	Brazil	PRE	EG: 8	23.6 ± 2.2	OPL	1	3	NR	OPL	↑ Peak power in JS and HS ↑ Punch impact force
Yi et al. [64]	Chine	PRE	EG: 10	19.5 ± 3.1	BE and HRE	1	1	NR	30% 1RM 80% 1RM	↑ Punch force and punch speed of a rear-hand straight punch at 9 min for PAPE
Yi et al. [65]	Chine	PRE	EG: 14	19.2 ± 1.5	MBP and BP	1	2	NR	10% of BP-5RM and 85% of BP-1RM	↑ Peak force and RFD of the lead-hand punch at 6–15 min for PAPE ↑ Time peak force and RFD of the rear-hand punch at 6–15 min for PAPE
Finlay et al. [59]	United Kingdom	PRE	EG: 10	19.7 ± 1.2	ISO and ER	1	2	NR	MVC	EG: ↑ Punch force and RFD between 7 and 9 min for ISO and ER
Finlay et al. [66]	United Kingdom	PRE	EG: 10	19.8 ± 1.3	ISO and ER	1	2	NR	MVC	↑ Punch force for ISO and ER (individual variability)

RCT: randomized controlled trial. QUA: quasi-experimental. PRE: pre-experimental. OG: Olympic group. NOG: non-Olympic group. NR: not reported. SPT: strength power training. COND: conditioning. CMJ: countermovement jump. BP-power: bench-press power. PCT: power circuit training. ETT: elastic tubing training. MBE: medicine balls exercises. BST: boxing-specific training. TS: trunk strength. FS: facial straight. FH: facial hook. EXT: extension. FLEX: flexion. IP: isokinetic power. RP: relative power. BW: body weight. EG: experimental group. CG: control group. RT: resistance training. SST: speed strength training. BM: body mass. A.U: arbitrary units. RC: randomized controlled trial. PLY: plyometric. JR: jump rope. PRFD: peak rate force development. PGRF: peak ground reaction force. BP: bench press. JS: jump squat. OPL: optimal power load. MP: medium power. MPP: mean propulsive power. PP: peak power. 1RM: one-repetition maximum. BI: bilateral. UNI: unilateral. PP: peak power. AP: average power. PV: peak velocity. AV: average velocity. WS: weighted strikes. BHP: back hand power. FHP: front hand power. HRT: high-intensity resistance training. SJ: squat jump. 15 s: 15 seconds. HS: half-squat. BE: ballistic exercise. HRE: heavy-resistance exercise. PAPE: post-activation performance enhancement. MBT: medicine ball throwing. RFD: rate force development. ISO: isometric. ER: elastic-resistance. MVC: maximum voluntary contraction.

Regarding the intensity of the interventions, Pereira et al. [22] implemented traditional muscle strength and power exercises with 30% to 75% 1RM. Čepulenas et al. [20] based their training program on three stages with different intensities of muscle strength and speed: (i) general strength with 80% to 90% of 1RM, (ii) strength–speed with 60% to 80% (muscle strength) and 20% to 40% (speed) and (iii) speed–strength with 20% to 40% (muscle strength) and 60% to 80% (speed). Kim et al. [19] used traditional muscle strength exercises with 50% to 70% of 1RM, elastic bands of different resistances and 3 kg to 5 kg medicine balls. Liu et al. [61] executed a training program through bilateral and unilateral upper and lower limb exercises with 50% to 85% of 1RM. Yi et al. [64,65] in two studies asked subjects to perform exercises with 30% and 80% of 1RM; and with 10% of five repetition maximums in the bench press and 85% of 1RM in the bench press, respectively. On the other hand, Loturco et al. [18,63] used the OPL for the athletes' training program. Bruzas et al. [36] implemented exercises with 15% of body mass and external weights of 1 to 1.5 kg. Similarly, Bu et al. [21] performed exercises with intensities from 5 kg to 25 kg, in addition to their own body mass. Nasser et al. [62] based their training intensity on arbitrary units (AU), being 50–100 arbitrary units. Chottidao et al. [60] used an intensity based on 72 to 106 floor contacts in rope jumping. Finlay et al. [59,66] used a three-second maximal isometric contraction in the straight punch position, in addition to a straight punch exercise using a resistance band. Finally, only one study did not report the intensity of their training [68].

3.8. Variables Analyzed and Data Collection

The selected studies analyzed various variables to evaluate the effects of the interventions. Twelve articles assessed punching performance [19–21,36,59,60,62–66,68], specifically two studies evaluated punching force through a device (Kiktest-100, Moscow, Russia) consisting of a standard punching bag with a dynamometer and sensor inside [20,36]. Four articles evaluated the impact force of striking through a vertically mounted force platform [59,63–66]. Loturco et al. [63] used a force platform (AccuPower; AMTI, Graz, Austria) mounted on a wall that sampled at a frequency of 2000 Hz. Yi et al. [65] mounted a force platform (Kistler, Winterthur, Switzerland, model 9287B) on a steel frame recording data with a sampling rate of 1000 Hz. Finlay et al. [59,66] used a force platform (Bertec, Columbus, OH, USA) mounted on a custom-made steel apparatus recording data with a sampling rate of 2000 Hz. On the other hand, Kim et al. [19] and Bu [21] measured punch speed and power using a stroboscope (107–104 Hz), three axial acceleration sensors (model 4630, Measurements Specialties, Hampton, VA, USA) and a Sony HDR-CX630E 4K digital camera. Soyler et al. [68] used the "Tendo Power and Speed Analyzer" device (Lexington, USA) to detect the punching speed of boxers. Chottidao et al. [60] calculated the punching speed with 29 reflective markers fixed on body reference points (Helen Hayes model) and 10 high-speed infrared cameras with a frequency of 250 Hz (Motion Analysis System, Rohnert Park, CA, USA), and they additionally attached a triaxial accelerometer (Model SS34L, BIOPAC System, CA, USA) with a sampling rate of 3000 Hz to the target manikin. Yi et al. [64] used a professional boxing transducer (Strike Tec Boxing Sensors, Strike Tec, Dallas, TX, USA; version 1.4.4) with a mobile application to measure the punch force and punch speed calculated from the acceleration. Finally, Nasser et al. [62] determined the number of punches and average punches per round, through combat videos that were presented to three international judges from the international flagship (2Star).

Regarding muscle strength assessments, Kim et al. [19] assessed upper and lower limb maximal strength using a multifunction dynamometer (ACE-2000, Ariel Dynamics Inc., Coto de Caza, CA, USA). In addition, they assessed trunk strength using an isokinetic dynamometer (Humac Norm, Stoughton, MA, USA). One study [68] measured handgrip strength using a Takei Kiki Kogya hand dynamometer (Takei Scientific Instruments Co., Ltd., Tokyo, Japan). Loturco et al. [18,63], Pereira et al. [22] and Liu et al. [61] measured muscle power through a T Force linear position transducer (Dynamic Measurement System; Ergotech Consulting S.L., Murcia, Spain) and GymAware Powertool (Kinetic Performance Technologies, Canberra, Australia). Five studies assessed neuromus-

cular performance using vertical jump [22,59,65,66,68]. Soyler et al. [68] measured vertical jump with the Squat Bounce Test using the Opto Jump Next® device (Microgate, Bolzano, Italy). Chottidao et al. [60] assessed the countermovement jump using two force platforms (AMTI, Inc., Newton, MA, USA) with a sampling rate of 1000 Hz. Pereira et al. [22] measured the SJ and CMJ using a contact platform (Elite Jump®, S2 Sports, São Paulo, Brazil). Finlay et al. [59,66] assessed CMJ using a photocell system (Optojump, Microgate, Bolzano, Italy). Conversely, Bu [21] assessed speed strength by throwing a solid ball and the 15 s fast push-up test, and they also designed an athletic fitness index for boxers composed of sprint tests, vertical and horizontal jumps, hand grip strength, medicine ball throw, abdominal crunches and tapping tests of 5 s and 30 s. Finally, they measured the level of movement capacity through deep squats, front and back lunges, straight-knee leg raises, shoulder joint flexibility, push-ups and rotational stability. Soyler et al. [68] measured the balance of boxers using the Balance System testing device developed by Performan Z. In addition, they measured the athletes' reaction time using a test device developed by "Performan Z" that includes eight light switches that measure the motor reaction of the upper limbs and the visual reaction through cognitive difficulties generated by the device.

3.9. Main Outcomes in the Physical Fitness of Boxers

Regarding the assessment of punches' performance (Table 3), Cepulenas et al. [20] obtained increases in the muscle strength of the straight punch and the low punch with the rear hand ($p < 0.05$) and increases in the side punches and low punches with the front hand ($p < 0.05$). Furthermore, the mean power of straight punches hitting the boxing bag also increased significantly ($p < 0.05$). Bruzas et al. [36] found increases in low rear-hand punch force ($p < 0.05$); however, they did not specifically report the values of the punch force. Additionally, they observed increases in summative strength and power production in 3 s and 8 s ($p < 0.05$) and summative strength ($p < 0.05$) and power production ($p < 0.05$) in the 8 × 8 s series and after training. Kim et al. [19] found increases in the strength of straight punches and hook punches measured through G units ($p < 0.05$). Loturco et al. [63] through OPL training found significant increases in the impact forces of the straight punch ($p < 0.05$). Soyler et al. [68] and Bu [21] observed an increase in the speed of the straight punch ($p < 0.05$). In addition, Bu [21] also reported an increase in the power of the straight punch ($p < 0.05$). Similarly, Chottidao et al. [60] found a significant improvement for jab speed ($p < 0.05$). Moreover, Yi et al. [64] found significant increases for the peak force ($p < 0.05$) and speed of the straight punch ($p < 0.05$) at 9 min of the ballistic exercise (BE) and heavy resistance exercise (HRE) protocol, with no differences between them. In another study, Yi et al. [65] observed increases in peak force ($p < 0.05$) and RFD ($p < 0.05$) for the lead-hand punch. In addition, they found improvements in the time to peak force ($p < 0.05$) and RFD ($p < 0.05$) for the rear-hand punch. The peak force and RFD of the leading hand, as well as the time to peak force and RFD of the trailing hand, improved significantly between 6 and 15 min ($p < 0.05$), compared to baseline data. Finlay et al. [59] identified improvements in the peak force for the straight punch ($p < 0.05$), increasing significantly from baseline to 5 min ($p < 0.05$), 7 min ($p < 0.05$) and 9 min after ($p < 0.05$) and from 3 min later to 7 min ($p < 0.05$) and 9 min later ($p < 0.05$). They also found improvements in the average force of the straight punch ($p < 0.05$), increasing significantly from the beginning to 11 min later ($p < 0.05$) and from 3 min later to 7 min later ($p < 0.05$). Likewise, improvements were observed in the time to peak RFD ($p < 0.05$) and mean RFD ($p < 0.05$). In the same study, improvements were identified in the peak force for the hook punch with the lead hand ($p < 0.05$); in addition, the mean force also increased significantly from the beginning to 7 min later ($p < 0.05$) and 9 min later ($p < 0.05$) and from 3 min later to 9 min later ($p < 0.05$). The hook punch with the lead hand also obtained improvements for the time to peak RFD ($p < 0.05$), as well as improvements in the mean RFD time ($p < 0.05$). The hook punch with the rear hand presented significant increases in peak strength ($p < 0.05$) with an increase from the beginning to 7 min ($p < 0.05$) and 9 min later ($p < 0.05$). The mean muscle strength of the hook punch with the rear hand also increased ($p < 0.05$) with the mean

strength increasing from baseline to 9 min ($p < 0.05$). Finally, an increase was also reported for the time to peak RFD ($p < 0.05$) and for the mean time of RFD ($p < 0.05$). In a continuation of previous studies, Finlay et al. [66] reported increases in the peak force and mean force of the straight punch ($p < 0.05$) from baseline to the start of the first round ($p < 0.05$) and at the beginning of the second round ($p < 0.05$). Also, they found improvements for the hook punch with the lead hand in peak force and mean force ($p < 0.05$) from baseline to the start of the first round ($p < 0.05$). Similarly, they reported a significant main effect over time ($p < 0.05$) for the back-hand hook punch at peak force. Finally, Nasser et al. [62] found an increase in the number of single, double and compound punches ($p < 0.05$) after battle rope training.

Regarding the findings on the physical fitness of boxers (Table 3), Kim et al. [19] found significant improvements ($p < 0.05$) in the maximal muscle strength in the 1RM of the bench press exercises and 1RM of the squat. They also reported increases in trunk flexion strength at 30°/s ($p < 0.05$), trunk extension strength at 30°/s ($p < 0.05$), the relative strength of the trunk in flexion at 30°/s established by means of body mass ($p < 0.05$) and the relative strength of the trunk in extension at 30°/s ($p < 0.05$), in addition to increases in the isokinetic power of the right arm in extension at 180°/s ($p < 0.05$), the isokinetic power of the left arm in extension a 180°/s ($p < 0.05$), the relative power of the right arm in extension at 180°/s ($p < 0.05$) and the relative power of the left arm in extension at 180°/s ($p < 0.05$). Similarly, Loturco et al. [18] used magnitude-based inferences to compare changes in pre- and post-training tests and reported increases in power output for the bench press (+8%) and JS (+7%) after the program of OPL training. In a second study, Loturco et al. [63] also used inferences based on magnitudes and reported increases in power output for JS (+12%) and half-squat (+14%). Liu et al. [61] reported significant improvements ($p < 0.05$) in peak power, average power, peak velocity and mean velocity in the unilateral, bilateral and unilateral more bilateral groups in the bench press and squat exercises with loads of 30%, 50% and 80% of 1RM. In addition, the comparison between groups reported that unilateral and unilateral more bilateral training led to significantly higher power output values ($p < 0.05$) in bench press and squat exercises at 30% of 1RM compared to the bilateral training group. On the other hand, Soyler et al. [68] found significant improvements ($p < 0.05$) between the values of SJ, active jump, 15 s jump, number of jumps in 15 s and visual reaction time of the boxers. Furthermore, a significant difference ($p < 0.05$) was observed between the VO_2 max values of the boxers during the Yo-Yo test. Finally, they also found an increase between the values of left balance ($p < 0.05$), right balance ($p < 0.05$) and double center balance ($p < 0.05$) of the boxers. Chottidao et al. [60] found significant improvements ($p < 0.05$) in the peak RFD of the CMJ for PLY and JR, the jab reaction time for PLY ($p < 0.05$) and RJ ($p < 0.05$) and the GRF peak of the rear leg during the jab for PLY ($p < 0.05$) and RJ ($p < 0.05$). Bu [21] observed significant improvements ($p < 0.05$) in the test of pushing a solid ball sitting in a horizontal position. Finally, Pereira et al. [22] detected no significant changes ($p > 0.05$) throughout the study for CMJ height and bench press power in either group.

Adverse Effects

Another relevant aspect corresponds to the adverse effects and dropouts in the acute and chronic muscle strength interventions performed in boxers. None of the studies reported any type of injury and dropout during the interventions in boxers.

4. Discussion

This scoping review aimed to identify the acute and chronic effects of interventions with muscular strength training on the physical fitness of boxers. After reviewing 5960 records, 15 studies met the inclusion criteria mean a score of 48% (moderately low quality) of the established score for methodological quality. In addition, the certainty of evidence was rated as very low. However, the individual results of the studies analyzed in our scoping review indicate that acute and chronic muscular strength interventions applied to boxers are beneficial to improve punches' strength and for the general physical fitness of

boxers, generating increases in the capacity to generate maximum force and improvements in RFD and the power production of the upper and lower limbs.

4.1. Punches' Performance

Regarding the effects on punches' performance, improvements in the strength of a straight punch with the rear hand [19,20,59,63–66] and improvements in the speed of a straight punch with the rear hand were reported [21,64,68]. Also, increases in lead-hand punch force [20,65] and lead-hand punch speed [60] were observed. The studies analyzed also reported improvements in the strength of low punches [20] and curved punches [19,20,59,66] with both hands. In addition, there was an increase in the volume of single, double and compound punches [62]. During combat, punches are characterized by occurring at high speed, originating from the lower extremities, where a transmission of force from the ground to the upper extremities is required to impact the rival [6] (Figure 4). The interventions analyzed that reported an improvement in punches performance in the present scoping review have as a common pattern the use of multi-joint upper and lower limb exercises in a wide spectrum of intensities and types of muscle contraction, which is in line with the recommendations of Beattie and Ruddock [6], who have suggested that boxers develop the maximum strength capabilities of their legs through high intensities (>80% 1RM) using traditional multi-joint exercises (e.g., squat, bench press, deadlift). Additionally, it has been recommended that boxers maximize their RFD and power production through submaximal loads and medium-to-high velocity lower body movements (e.g., jump squats, box jumps, medicine ball throws, hex-bar jumps) and upper limb movements (e.g., bench press throws, ballistic push-ups, landmine throws) [18], given that the current literature suggests that the neuromuscular performance of the lower and upper limbs is largely associated with the impact force of the punch in elite boxers [6,14]. Additionally, elite boxers who punch with higher impact forces have been shown to have significantly higher levels of explosive strength in the lower body compared to boxers who punch with lower impact forces [6].

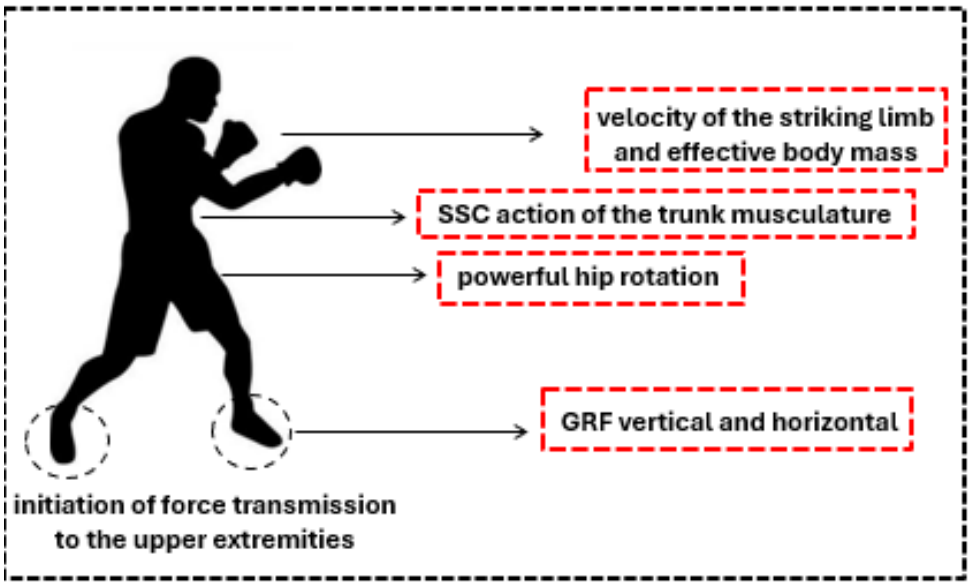


Figure 4. Contributors to punches' performance. SSC: stretch-shortening cycle. GRF: ground reaction force.

4.2. Acute Effects

Seven articles in the present scoping review demonstrated improved punches' performance through chronic training interventions [18–21,60,62,68]; however, four articles demonstrated improved punches' performance acutely through a single training session [59,64–66]. Specifically, Yi et al. [64] in a single session using two potentiation exercises

(medicine ball throw with 10% of 5RM in bench press and bench press with 85% of 1RM) found improvements in the maximum strength and RFD of the front hand, as well as in the time to maximum force and the RFD of the rear hand between 6 and 15 min after performing the potentiation exercises, with no differences in the recovery time for improving the strength of the punch between both exercises. Likewise, in a second study by Yi et al. [65], in a single training session through a ballistic exercise (squat with jump 30% of 1RM) and a heavy load exercise (squat with 80% 1RM) they reported significant improvements in the strength and speed of the punch with the rear hand at 9 min post-intervention compared to baseline, with no clear differences between the ballistic exercise and the heavy load exercise. Finally, Finlay et al. [59] in a single training session using a resistance band exercise imitating the punch gesture (jab and straight) and an exercise with a maximum isometric contraction with the punch gesture (jab and straight) reported significant improvements in the impact force of the punch and in the RFD, highlighting a better response in the maximum isometric contraction exercise, although both exercises reached their maximum point of improvement between 7 and 9 min post-execution. In a second study by Finlay et al. [66] with the same sample and exercises performed (resistance band with punch gesture and maximum isometric contraction exercise with punch gesture), they reported improvements in punch force, but to a lesser extent than the previous study [59], possibly because the inclusion of the exercises was carried out in addition to simulated combat, measuring the impact force of the punch at the beginning of the simulated combat, at the beginning of each round, and at the end of the simulated combat.

The improvements in punches' performance in the single training session articles are supported by the phenomenon of PAPE, described as an acute increase in neuromuscular performance for up to ~15 min, through prior muscular activity [45,46]. This term was introduced by Cuenca-Fernández et al. [70], where PAPE refers only to performance improvements in voluntary exercises, while the concept of post-activation potentiation (PAP) refers to strength increases during contraction verification tests. PAPE is one of the main objectives in warm-up protocols [71], being associated with physiological benefits derived from the increase in body temperature, as well as improvements in neuromuscular and cardiometabolic responses [71–73]. Based on Vandenboom et al. [74], it is theorized that the main mechanism related to potentiation is the phosphorylation of the regulatory myosin light chain, a muscle memory mechanism that increases sensitivity to Ca2+, thus favoring transient increases in maximum force and in the RFD. Yi et al. [64,65] in their respective studies used ballistic exercises and high-load non-ballistic exercises (80% to 85% of 1RM) for the upper and lower body, reporting improvements in the strength and speed of the punch with the rear hand and the front hand, between 6 and 15 min for upper body exercises and 9 min later for lower body exercises. In this regard, the literature suggests that ballistic exercises can generate greater activation of type II muscle fibers, as well as greater power, due to high levels of acceleration throughout the full range of motion [64,75,76], unlike non-ballistic exercises that are characterized by having a deceleration phase that can affect the speed of movement and consequently power production [75]. Conversely, ballistic exercises can generate less fatigue than exercises with high loads [45]. For this reason, BE could be more effective than HRE to induce PAPE; however, in both studies [59,63], both exercise modalities similarly improved exercise punch performance, with no differences in recovery time between both modalities. Similar to the findings of Terzis et al. [77] and Dolan et al. [78] who reported that performance in a throwing test can be increased after performing five consecutive drop jumps or three repetitions of a hang clean and jerk at 80% of 1RM. This supports the idea that BE can generate PAPE to a similar degree as HRE. The potentiation generated by both training modalities may be due to a high recruitment of motor units that comprise type IIX muscle fibers during the exercises performed [64,75]. In addition, the nature of ballistic exercises allows the generation of neuromuscular activity in a few milliseconds, resulting in greater power production [75,79]. Therefore, the findings on the improvement of punch force and speed in the studies by Yi et al. [64,65] could be illustrated by the described mechanisms.

At this point, both BE and HRE can be considered as part of the warm-up session to improve punches' performance during competition or specific sparring sessions. However, it is important to consider that this requires an optimal recovery time, which needs to be individualized for each athlete [46,71]. Finally, the findings of Finlay et al. [59], who reported improvements in the impact strength of straight punches and hook punches with both hands, suggest that a punch-specific isometric exercise may be a more useful activity to perform during warm-up than a specific striking exercise with a resistance band to acutely improve striking performance in amateur boxers. Although both exercises managed to acutely improve punches' performance, the specific isometric exercise was slightly superior. In this regard, the execution of a maximum voluntary contraction at specific joint angles in a ballistic manner has been shown to potentially improve variables such as RFD and speed in long-term training research [80,81]. According to Finlay et al. [59], increases in punch force and RFD after specific isometric exercise may be due to increased neuronal activity; however, this was not evaluated in the study. Moreover, there is a possibility that specific isometric exercise through maximum voluntary contraction improves the "effective mass" during punches. In this sense, McGill et al. [82] reported a double peak of muscle activation during striking techniques, due to the activation, relaxation and reactivation of the muscle groups involved, beginning with an electromyography (EMG) peak (indicating muscle activation) when the movement was initiated, then a drop in EMG throughout the movement and a final EMG peak, moments before impact, where a "hardening" of the body occurs at the moment of impact, thus creating effective mass and reduction in the loss of energy during the impact of the punch. In this sense, an increase in muscle co-contraction around a joint can cause a reduction in the deformation observed during impact, allowing for a greater total effective mass at the impact of the punch [81]. Furthermore, the more segments the athlete involves in the kinetic chain of the movement, the greater the potential to improve effective mass [82]. However, previous studies [6,83] have encouraged the use of isometric contractions to improve this "stiffness" in the final range of the punch in boxers. Although this may be related to long-term adaptations, the striking-specific isometric exercise may have had an acute effect on the body's ability to stiffen upon impact, thus producing greater stiffness and forces in subsequent strikes. Specific isometric exercise could also have improved the impact force of the punch to a greater extent, due to its greater biomechanical specificity and with perhaps less fatigue compared to dynamic exercise with resistance bands, which could have resulted in a more favorable stimulus towards PAPE [71]. Regarding the improvements through specific exercise with a resistance band in the impact force of the punch, these could be explained by the effect of the resistance bands that generate a greater production and application of force during the entire range of motion, while also according to the authors the punch technique was not altered [59]. However, this study [59] did not control the intensity of the resistance bands, which makes interpretation of its findings difficult. For example, Jakubiak and Saunders [84] reported that they used resistance bands at intensities of 78, 108 and 157 newton (N) per 100% elongation, in addition to controlling the training session through the perceived exertion scale (RPE 6–20), determining the type of resistance band and its pre-stretch with an RPE score close to 12, establishing it as the initial resistance to overcome during training, and resulting in a significant improvement in kicking speed by 7% [84].

With everything mentioned thus far, it is important to highlight the recent study by Finlay et al. [66], who through the same intervention and sample [59], but measuring the impact force of the punch before, during and after a simulated combat, also reported improvements in the impact force of the punch, although smaller than in their first study [59]. It should be noted that the recovery period after cessation of the potentiating exercise and the striking test before Round 1 of the simulated combat was individualized based on the results of the previous study [59], so that the optimal punch performance was observed between 2 and 13 min after each condition. Analysis of the results suggested a high variability between each subject in relation to the PAPE response. At the individual boxer level, specific isometric exercise was superior in improving neuromuscular performance and punching

in six boxers. In contrast, only one boxer improved his punching performance further by performing the resistance band exercise, and only three boxers showed similar levels of performance improvement after both power exercises. As mentioned above, this highlights the large interindividual variability in the PAPE response and confirms the need for coaches to identify the optimal potentiation exercises and recovery period for their boxers, as major changes in performance could be missed by group analyses [66]. The optimal recovery time described in the above studies is within the range proposed by previous reviews of PAPE in various sports [45,46]. It is clear that in the first minutes after a strengthening exercise there may be few changes or even detriments in performance [45], perhaps due to the presence of fatigue. However, based on the evidence, all of this is highly individualized. Moreover, strength level is also a modulating factor of the PAPE response [46], given that differences in relative strength levels could explain the lower benefit for improving performance in non-responding subjects [46]. In other words, stronger athletes are able to achieve higher levels of PAPE [71,85], compared to their weaker counterparts. It has been suggested that a higher level of strength may make an individual more resistant to fatigue after a conditioning activity, responding better than weaker athletes [46]. It is important that future research investigates the differences between methods that appear to induce a better PAPE response in the impact force of punches, for example, isometric exercises with punching technique compared to BE and HRE. This could help coaches to incorporate the most effective PAPE method for amateur boxers.

4.3. Chronic Effects

Another relevant finding of the present scoping review is related to the chronic effects of muscle strength training on the physical fitness of boxers [18,19,21,22,60,61,63,68]. Kim et al. [19] reported improvements in the maximum 1RM strength in the bench press and squat exercises, in addition to increases in trunk flexion and extension strength at 30°/s and increases in isokinetic power of the left arm and upper arm right in extension at 180°/s through a 16-week specific training for boxers that included multi-joint upper and lower limb strength exercises with free weights, core exercises, plyometric exercises (jumps and throwing medicine balls) and a boxing-specific interval training. The above demonstrates the improvements in physical fitness that can be generated through varied muscle strength training specific to boxers in addition to boxing interval training. In this sense, it has been suggested that a concurrent training modality not only improves sprint capacity and endurance, but also improves the anaerobic threshold level. Therefore, the specific boxing training in this study provided positive results, improving the specific fitness of boxers [86]. Also, training combining free weights and elastic bands has been reported to improve upper body power levels in seven weeks [87], similar to the findings of Kim et al. [19]. Conversely, muscle strength training with free weights in combination with plyometric exercises has shown positive effects in other combat sports. Redondo et al. [37] found increases upper and lower limb maximal strength, as well as increases in SJ and CMJ height and a reduction in the time of the specific lunge action in fencers, supporting the findings of the present study [19]. Loturco et al. [18] reported increases in power production for the half-squat exercise and for the bench press exercise after a training program with the OPL in elite amateur boxers. In a similar study, Loturco et al. [63] during a week with three training sessions through OPL observed improvements of 8% in the impact force of the punch, executing three exercises (bench press, half-squat and SJ loaded). This provides valuable information for coaches to regularly include exercises such as half-squats and SJ loaded, as increases in lower extremity power can be directly transferred to the impact force of the punch, making it a useful and effective training strategy in very short training periods, which can be an advantage in some competitive settings, such as pre-combat phases, when athletes commonly present significant decreases in power and striking performance due to reduced body weight [88]. It has been shown that the power produced by combat athletes in the bench press and SJ loaded exercises is closely related to the impact and acceleration of the punch [15]. This is relevant, given that the power of the legs has a fundamental

role in the performance of the punch [15,16]; specifically, the transmission of force at high speeds from the lower to the upper extremities has proven to be essential to generate greater impact forces [15,16,89,90].

Continuing with the findings reported in the physical fitness of boxers, Bu [21] observed improvements in upper body explosive strength in female boxers through the test of pushing a solid ball sitting in a horizontal position after traditional muscle strength training of 12 weeks with multi-joint upper and lower limb exercises and strength training focused on speed with upper body exercises. These findings are relevant, since they show that female boxers, like male boxers, can benefit from using a muscle strength training program to improve their physical performance in boxing. In this sense, as mentioned in the previous section, an increase in the speed and power of straight punches was also reported in female boxers. The improvements reported in the speed of the upper extremities in Bu [21] lead to greater speed in the execution of straight punches, which may be essential to reduce the reaction time of the opponent and prevent him from reacting in time to effectively block or dodge the punches. During combat, straight punches are the most direct and effective, being important for controlling the pace and tactics of combat, so the ability to generate force quickly in response to an observed or anticipated stimulus during competition is essential for a greater effectiveness of connected punches [1,21,91].

Continuing with the studies, Liu et al. [61] found increases in muscle strength for bench press and squat exercises with 30% of 1RM, 50% of 1RM and 80% of 1RM, specifically in maximum power, average power, peak velocity and mean velocity after a 8-week muscle strength training with unilateral and bilateral exercises in adolescent boxers. In this regard, there is limited evidence on the comparison of the effects of unilateral and bilateral training on strength adaptations. McCurdy et al. [92] reported that strength–power adaptations were similar after 8 weeks of unilateral or bilateral muscle strength training in addition to plyometric exercises in untrained subjects. Speirs et al. [93] reported that 5 weeks of training with the rear foot elevated split squat or traditional back squat produced similar gains in unilateral and bilateral strength gains, sprint speed (10 and 40 m) and change of direction speed (Pro Agility) in academy rugby players. In combat sports, Soñen et al. [25] reported improvements in the explosive strength of the lower body of karate fighters, through the CMJ, single-leg CMJ, horizontal jumps and single-leg horizontal jumps after 6 weeks of unilateral and bilateral plyometric training, having shown two-leg training as a more effective method for reducing CMJ asymmetry; however, both methodologies improved the explosive strength of the lower body. Considering that the striking action in boxing is extremely dynamic, considerable levels of muscular power are required in both the upper and lower extremities to optimize punching performance [1]. As such, the localized effects of bench press training in the study by Liu et al. [61] can be quickly translated into specialized techniques such as straight punches and jabs, effectively improving the speed and power of boxing athletes' punches, although this was not evaluated in the study. However, López et al. [94] reported a positive correlation ($p < 0.05$) between the maximum velocity of the bench press at submaximal intensity and the maximum velocity of the rear-hand straight punch. As mentioned in the previous sections of this scoping review, the force of the punch originates from the lower extremities of boxers [14,61,89]. Following this idea, research has shown that strength training through squats improves lower extremity strength in boxers by improving the effectiveness of punches [15,89]. Furthermore, the CMJ height of boxers has shown a positive correlation with the total number of punches thrown in official fights and the strength of the rear-hand punch [95]. Now, although the effectiveness of bilateral exercises in increasing force transfer during the striking kinetic chain has been established in the studies in this scoping review, studies have suggested that unilateral exercises (e.g., rear-foot elevated split squat elevated) can have a superior transfer to sports performance as a result of the "bilateral deficit", in addition to the correction of muscular imbalances between the dominant and non-dominant extremities [96–98]. It is thought that, given the characteristic of the "divided posture" in the guard position of boxers (i.e., left foot forward in right-handed boxers or right foot forward in left-handed boxers) during

training and competition, unilateral exercises, particularly for the lower body, could have a greater transfer to boxing performance [9]. On this point, unilateral asymmetries of muscle strength between the upper [99,100] and lower extremities [101] have been identified, along with important imbalances of maximum strength between the dominant and non-dominant extremities [102] in boxing athletes. Therefore, it is important to consider the potential benefits of unilateral exercise to correct these muscular imbalances specific to sport [103]. However, trainers should consider that the lower stability of unilateral exercises may limit the safe prescription of heavier loads or poor performance in a state of fatigue, as greater stability in movements leads to a greater ability to express force [104], bilateral exercises may provide better development of an athlete's strength-power characteristics compared to unilateral exercises. This does not mean that unilateral exercises should be excluded when developing strength; on the contrary, they should be implemented during specific phases to complement the primary bilateral lifts, particularly during the general preparation phases [103]. This is supported by the findings of Liu et al. [61] who reported that combined training (unilateral more bilateral) led to significantly higher power values in the bench press and squat exercises at 30% of 1RM compared to the training group that only used bilateral exercises. At this point, it is important to mention the gap in the literature on the effects of unilateral training on the biomechanics of the punches and its comparisons with bilateral training. Future studies should analyze the changes in performance based on interventions resulting from these methods of training, since such knowledge could establish the optimal training modality to improve striking performance, which in turn helps in the development of comprehensive muscle strength and conditioning strategies specific to boxing.

Another article that reported improvements in the physical fitness of boxers was Soyler et al. [68], who found improvements in the explosive strength of the lower body through jump height and the number of jumps, improvements in visual reaction time, balance and the VO_2 max of Olympic boxers through a circuit of high-intensity full body exercises in speleotherapy for 2 weeks. Speleotherapy is the use of karst caves or residual galleries from mining companies for therapeutic purposes used in the Middle East, which have been investigated in terms of their curative (therapeutic) effect, mainly in salt mines [68]. In the literature, there is no study that has examined the performance parameters of Olympic boxers in a salt environment inside a cave, and this type of training is very rare. However, the reported improvements could be specifically due to the gaseous components in the air, the low relative humidity, the increased content of negative ions, the bacterial flora and the absence of air allergens or the slightly increased carbonic acid content, with the effect of a continuous self-cleaning function of the underground environment with air flow [68]. Despite this, more research is needed using this type of training (speleotherapy) to confirm these findings and their possible inclusion in certain phases of the training of Olympic boxers.

In another study analyzed in the present scoping review, Chottidao et al. [60] found increases in the peak RFD of the CMJ, improvements in the peak GRF of the rear leg during the jab and improvements in jab reaction time after an 8-week training period plyometric (through jumping) and jump rope training in junior boxers. It is well documented in the literature that plyometric training is a valid method to improve the explosive strength of the upper and lower body, improving sports performance in different types of sports [25,105–108]. A recent review analyzed the effects of plyometric training in combat sports [109], concluding that it is capable of inducing improvements in maximum strength, jumps, changes of direction and in sport-specific performance, without alterations in body composition, being effective in both males and females, regardless of their previous experience with plyometric training, the specific combat sport practiced or the competitive level. Thus, a minimum effective dose of plyometric training may involve two sessions per week, for four weeks. Although intensity is difficult to prescribe, high-intensity jumping appears safe if the proper technique and progression are considered by professionals in charge of training sessions [109]. The findings in the study by Chottidao et al. [60] are novel, since

the authors hypothesized that the plyometric training program would improve lower extremity sports performance and punch performance to a greater extent than the jump rope training program; however, this was not the case, given that both types of training showed similar improvements in the boxers' performance. A possible explanation is that both types of training were able to reduce the time to complete the stretch-shortening cycles (SSC), improving the eccentric to concentric activation phase of the lower extremities [110,111]. This may have decreased the reaction time and increased the GRF of the rear leg during the jab [112], and consequently generated the increased jab speed in the athletes [60].

The GRF is a kinetic variable essential in punch performance. Liu et al. [113] is one of the few studies that has evaluated this area in relation to the jab. In Liu et al. [113], boxers performed punches at a fixed target while standing with their front and rear legs on separate force platforms. The results indicated that the force produced by the leading leg contributed significantly ($p < 0.01$) to the maximum punch performance. Specifically, it appears that the drive of the lead leg is essential for the performance of the jab [113], while the drive of the back leg is essential for the performance of the straight punch with the rear hand [89,114]. Cheraghi et al. [114] and Lenetsky et al. [16] have highlighted that the impulse developed in both the vertical and horizontal directions from the rear leg towards the front leg (generated through plantar flexion of the ankle joint and extension of the knee joint) is of considerable importance for upper extremity speed, as this "impulse" causes considerable movement in the sagittal plane, improving proximal-to-distal sequencing during the punch. With all of the above, the improvement in punch speed in the study by Chottidao et al. [60], physiologically, may be attributed to an increase in the cross-sectional area of fast-twitch fibers (IIX), increased neuronal activation, changes in intrinsic muscle properties, an increase in myosin–ATP activity and a higher firing frequency of motor units [115], although this was not evaluated in the study. On the other hand, there is a possibility that due to the level of the participants (high school boxers), both training protocols were equally effective in significant improving lower extremity performance. In addition, it was not reported whether the participants had experience with muscle strength training, a relevant aspect since it is well documented that novice athletes in muscle strength training need a low stimulus to generate improvements in their physical performance [103].

At this point, it is important to mention that the age of the participants influences the physical performance of the boxers. For example, Dinu and Louis [13] reported differences in the strength and speed of straight and curved punches between elite and junior amateur boxers. Furthermore, they reported a greater activation of the non-involved muscles during the punches of junior boxers, being less effective than elite boxers. While part of these differences can be explained by the level of experience and technique of the boxers, muscle strength levels are relevant for building punching force and for optimal muscle recruitment during their actions [103]. It is important to consider the maturational state of the athletes, given that in the study by Dinu and Louis [13] it was reported that junior boxers had a lower body mass compared to elite boxers; this could translate into a lower muscle mass which may contribute to differences in force production. Therefore, training programs may have different objectives depending on age and training experience. In adolescent boxers, there is a great opportunity to improve their motor skills and physical performance due to the plasticity of the neuromuscular system in their maturational developmental years [116]. Early inclusion in a strength and power training program can improve neuromuscular fitness and intermuscular coordination [117]. In this regard, adolescent boxers should focus on building a solid technique through traditional strength exercises (e.g., squat, pull-ups, bench press) using bilateral and unilateral variations [116,118]. This can be supplemented with the teaching of weightlifting-derived exercises technique and upper and lower body plyometric exercises at low and moderate intensities [117]. Once low-load and low-volume exercises are mastered, training can progress to generate muscle hypertrophy, which can be beneficial in this growth period for greater long-term muscle strength gains and to decrease the likelihood of boxing-related injuries (e.g., low back pain, rotator cuff disease) [116,119].

It is important to mention that without a solid foundation of movement skills, adolescent boxers will be limited in achieving their full potential as adults and will eventually need to work on their neuromuscular deficiencies as sport specialization increases [116,118].

Finally, Pereira et al. [22] detected no significant changes over a 7-month training period for CMJ height and bench press power in Olympic and non-Olympic amateur boxers. Both groups presented similar results in tests related to power with and without load. However, it seems that at the group level, especially when athletes have a higher level of specialization, muscle power is not able to discriminate between less or more qualified subjects. In this sense, it could be inferred that the classification of boxers for the Olympic Games depends mainly on technical and tactical criteria, skills that cannot be evaluated or classified through the use of batteries of traditional physical fitness tests. Therefore, during the later phases of preparation for international tournaments (e.g., Olympic Games), Pereira et al. [22] recommend coaches focus their attention and training strategies on technical–tactical development. It is important to mention that in this study the boxers were monitored during the competitive phase of the season, when the coaches focused on developing technical and tactical skills, generating a high volume of training in these skills during a typical training week. In this sense, considering that the majority of training sessions during this phase consist of performing high-intensity interval training, continuous running and technical training, the results reported on the maintenance of power levels during this specific period suggest that the training content was appropriately designed and adjusted to avoid any interference of potential adaptations, since it has been reported that high volumes of aerobic training can be detrimental to neuromuscular performance, due to the interference phenomenon induced by concurrent training, which may be even more pronounced in athletes with high power levels [115,120]. Finally, the findings of Pereira et al. [22] demonstrate that at least for national team boxing athletes, when properly planned and prescribed, concurrent training does not negatively impact power-related performance.

4.4. Training Dosage

Regarding the dose used in the articles analyzed, it can be indicated that the acute muscle strength interventions consisted of a single training session [59,64–66], while the chronic interventions ranged from 1 week to 30 weeks [18–22,36,60–63,68]. Only five studies reported the duration of their training sessions, which ranged from 10 to 120 min [19,22,60,62,68], while nine studies did not report the duration of their training sessions [18,20,21,36,59,63,64,66,68]. Regarding the intensity of the interventions, only one study did not report its intensity [68]. It is important that future studies focused on optimizing the physical fitness performance of boxers mention all the characteristics of their training sessions to improve the analysis of interventions and their possible application in the field. Regarding the adherence achieved by participants, all interventions reported an adherence equal to or greater than 85% [18–22,59–66], while no study reported the absence or death of the participants.

4.5. Recommendations

The studies presented various training programs to improve the physical fitness of boxers. Due to the heterogeneity of these studies and the high risk of bias mainly in the reporting of the results, assessments of the main results and the randomization of the studies, it is difficult to establish which training method is better; however, the most appropriate training method could be the one that follows a gradual and systematic process based on the basic principles of training, such as progressive overload, the principle of individualization and the principle of recovery considering the physical and physiological demands of amateur boxing [33,121]. One of the most relevant aspects for planning muscle strength training is the competition date [122]. Amateur boxers usually compete constantly, being able to compete one or more times a month, unlike professional boxers who can compete at least three or four times a year [17]. Based on our findings and the current

literature [6,83], we suggest some recommendations to optimize the physical performance of these athletes (Figure 5).

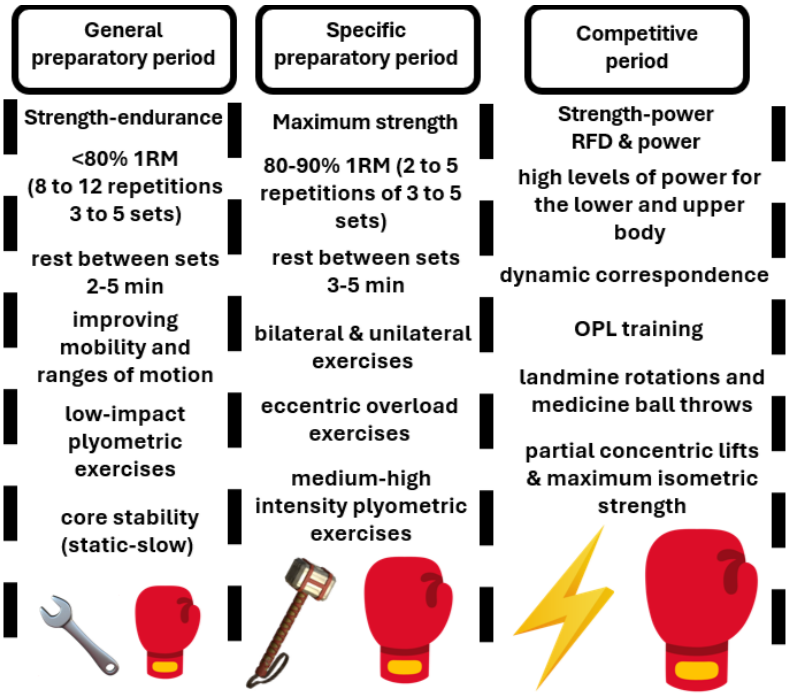


Figure 5. Summary of guidelines according to training period. 1RM: one-repetition maximum. OPL: optimal power load. min: minutes. RFD: rate of force development.

4.5.1. General Preparatory Period

At the beginning of the training cycle or "camp", in line with Beattie et al.'s [6] recommendations, a period of "strength-endurance" can be applied with the aim of adapting the athlete to more intense loads in the later phases, improving mobility and ranges of motion along with the technique of traditional overload exercises (e.g., squat, deadlift, bench press, pull-ups) and exercises derived from weightlifting (e.g., power clean, snatch, split jerk or one-arm variations, such as the kettlebell unilateral snatch). Regarding traditional muscle strength exercises, these can be started with a load of <80% of 1RM (e.g., 8 to 12 repetitions, 3 to 5 sets with a 2 to 5 min rest between sets) to accumulate base strength in the athlete. A linear load progression is an optimal strategy for developing strength in boxers [123]; however, with more experienced athletes it is valid to include an undulating load progression [124]. Due to the different weight categories in boxing, caution must be taken with the prescription of training volume, given that athletes may gain muscle mass and increase their need to execute rapid weight loss procedures to compete in their original weight categories [6]. Evidence has been reported that a morphological increase in the muscle cross-sectional area supports the development of maximal muscle strength and explosive strength [103]. Despite this, the maximum force is not only dictated by this mechanism, but also by neuronal factors such as the recruitment of motor units and the discharge frequency [103,125].

On the other hand, this period can include the performance of multidirectional low-impact plyometric exercises (e.g., pogo jumps, lateral hops) [60,126] and exercises to improve core stability, mainly static–slow (e.g., plank variations frontal and lateral movements with unstable devices such as a Swiss ball or suspension training) with the objective of increasing the recruitment of motor units and the activation sequence of the muscles that play a key role in the force of the punches (e.g., transverse abdominis, quadratus lumborum, external and internal obliques) and in reducing overuse injuries [16,82,123,127,128]. Additionally, this can be worked in conjunction with throwing exercises with medicine

balls that seek to isolate trunk rotation with the purpose of building an optimal throwing pattern that can be transferred to the impact force of the punch in the final phases (e.g., kneeling ball throw in the sagittal and transverse plane) [83,129].

4.5.2. Specific Preparatory Period

In this period, the main objective is neuronal adaptations through maximum muscle strength training [103]. To achieve this goal, the load can be increased to 80% to 90% of 1RM (2 to 5 repetitions of 3 to 5 sets with a 3 to 5 min rest between sets), through exercises that integrate pulling and pushing movement patterns of the upper and lower extremities of the body (e.g., bench press, pull-ups, squat variations, hex bar deadlifts) [6]. Current evidence suggests that the maximal lower body strength is related to punch impact force in elite amateur boxers and that the upper and lower limbs' explosive strength is largely associated with punch impact force in elite amateur boxers [14]. Therefore, it is important that boxers integrate exercises with a predominance of high force and low velocity and low force–high velocity into their different training phases to optimize the performance of their punches [83]. In this sense, maximum force is a fundamental component of explosive force [125]. Research has shown that neuromuscular adaptations to maximal muscle strength training can improve both explosive strength and maximal strength in athletes [103,125].

Based on our findings, the combination of unilateral and bilateral upper and lower body exercises to 30% and 85% of 1RM (five repetitions of three sets with a 3 min rest between sets) were also demonstrated to be an alternative to improve muscle strength and reduce asymmetries in boxers (e.g., single-arm landmine barbell press, Bulgarian split squat) [61]. It is important to consider that unilateral exercises involve a greater training volume due to the division of repetitions in each limb (e.g., 5 repetitions per limb of three series, which adds up to a total of 10 repetitions per series), so its use is recommended only in general preparatory periods and in specific preparatory periods due to the greater accumulation of fatigue they represent in athletes.

In this period, it is also possible to include eccentric overload exercises (e.g., flywheel squat, squat with accentuated eccentric load, bench press with accentuated eccentric load) [108,130,131]. Studies have reported that eccentric training can produce similar or greater adaptations in muscle mechanical function (e.g., muscle strength, rate of force development and muscle stiffness), morphological adaptations (e.g., muscle fibers and tendons cross-sectional area), neuromuscular adaptations (e.g., motor unit recruitment and firing rate) and through performance (e.g., vertical jump, sprint velocity and change of direction) compared to concentric, isometric and traditional training [132–134]. However, as with unilateral exercises, the fatigue generated by this type of training must be considered, given that exercise with eccentric overload is characterized by producing high muscle damage specifically in fast muscle fibers and an increase in muscle mass in athletes [76,132], so its use must be carefully scheduled in general periods or through micro doses in specific periods.

Adding elastic bands or chains to traditional exercises (e.g., bench press, squat, deadlift) is also a viable option in this period. Variable resistance training allows the production of maximum force throughout the range of motion of an exercise [135]; in addition, research has reported a greater improvement in the production of maximum force with the use of variable resistance compared to traditional training [135]. As mentioned in Uthoff et al. [83], the ability to continuously accelerate a load taking into consideration the length–tension relationship of the muscles has a biomechanical similarity to executing a punch; specifically, the upper or lower extremity accelerates from the beginning of the punch and reaches the velocity maximum as close as possible to impact [136]. The literature has reported that variable resistance is beneficial for trained athletes [135,137], so it is not recommended to use this form of training with untrained athletes.

In the specific preparatory period, upper and lower limb plyometric exercises can begin to increase in intensity (e.g., jumps at different box heights, loaded jumps, ballistic

bench press, landmine throw) with the aim of improving the production of force per unit of time and enhance specific boxing actions. Exercises to strengthen the core muscles also involve an increase in difficulty in this phase, so we recommend designing more dynamic exercises with the addition of an external load (e.g., knee up on Swiss ball, pike on Swiss ball, rapid trunk rotations with elastic bands), with the purpose of increasing core strength to optimize the transfer of force and therefore the impact force of the punch in the subsequent phases [9,128].

With all of the above, it is known that athletes have little time to carry out muscle strength training sessions, and the prioritization of other training sessions such as sparring makes it necessary to administer the "minimum effective dose" in the weight room [6,138], reducing the accumulation of fatigue and generating better neuromuscular adaptations for transfer to the impact force of punches. In this regard, we recommend prescribing the loads of multi-joint exercises (e.g., bench press, squat with hex-bar) through training based on the velocity of execution, establishing velocity loss thresholds (e.g., 20% to 30%) which have demonstrated acute and chronic benefits in muscle strength gains [139]. Likewise, the degree of effort perceived by the athlete is reduced, the excess accumulation of fatigue is reduced, and the volume and duration of training sessions is optimally reduced [139]. For this purpose, trainers can use everything from instruments such as linear position transducers to previously validated mobile applications.

4.5.3. Competitive Period

In the competitive period, the principle of specificity (dynamic correspondence) takes on great importance [140], which is why we recommend using exercises similar to competition techniques to improve the sporting performance of boxers. Additionally, exercises that generate high levels of power and high RFD values with an emphasis on speed of execution should be a priority [79]. When boxers are in periods of competition, it may be advisable to use muscle strength training based on OPL with loaded jumps, half-squats and bench presses with the aim of reducing the fatigue levels associated with traditional training [18,63,141]. OPL has demonstrated notable improvements through a week of training with a frequency of three sessions in punch impact force (+7%) in elite amateur boxers [63], as well as improvements in the power levels of the upper and lower limbs during the competition periods with a frequency of three times a week for 7 weeks [18].

Regarding exercise selection, based on the current literature we recommend that boxers perform exercises that generate high levels of lower body power (e.g., jump squats, loaded hex bar jumps, depth jumps, multi-jumps with hurdles) and for the upper body (e.g., bench press throws, ballistic push-ups, landmine throws) with the objective of improving the application of force per unit of time and the impulse generated through the lower extremities during punches [6,83,142]. Because straight punches and curved punches require rapid movement of the entire body in the sagittal, frontal and transverse planes [9], these punches can be replicated through specific exercises (e.g., landmine rotations and medicine ball throws in multiple planes). As mentioned in previous sections, there is evidence that there may be a double "peak" of muscle activation at the end of an effective punch [82]. Therefore, we recommend incorporating specific exercises into training sessions, such as isometric rotations in the final range of a punch. Although there is no consensus on this dose, boxing strength and conditioning coaches usually prescribe three to five sets of 3 s with the maximum isometric force possible, thus seeking to increase the stiffness in the final range of the impact of the punch [83]. Weeks before fights, when the priority of training is sparring and boxers are in an energy deficit due to reducing body mass to achieve the weight class, boxers can perform partial concentric lifts (e.g., 1/4 concentric squats) and/or maximum isometric exercises through squats, deadlifts or bench press, with the purpose of maintaining their maximum muscle strength levels and reducing training fatigue [80].

It is important to mention that to make better decisions in training programming, it is necessary to constantly monitor athletes' performance. For this purpose, the control of the

CMJ has been reported as a valid test to monitor neuromuscular fatigue of the lower body of athletes [22,143]. Coaches can monitor athletes weekly, using force platforms, contact platforms or previously validated mobile applications. Additionally, trainers can monitor boxers' maximal muscle strength through isometric assessments (e.g., IMTP, IBP, ISQ) via force platforms or dynamometers and through submaximal loads by measuring the speed of execution of traditional exercises with the use of a linear position transducer or mobile application [144]. If coaches do not have technology at their disposal, the rating of RPE (CR-10) is validated as a load control of training sessions for athletes [67,145,146].

4.5.4. Sparring Sessions and Fight Day

Finally, acute research from our scoping review demonstrated that during competitions or in specific sparring sessions boxers can integrate maximal isometric exercises with punching techniques (e.g., three repetitions of 3 s), resistance band exercises with punching techniques (e.g., two sets of 5 reps), medicine ball throws with 10% of 5RM bench press (e.g., three sets of 8 reps), SJ with 30% of 1RM (e.g., four sets of 8 reps) and traditional exercises such as bench press and back squat with 80% of 1RM (e.g., three sets of 5 reps) with an improvement window between 6 and 15 min after the strengthening exercise to increase the impact force of the punches [59,64–66]. Both high and light loads were shown to similarly improve the sharp force of the punches, so trainers can select at their discretion which load may be most optimal for their boxers (Figure 6).

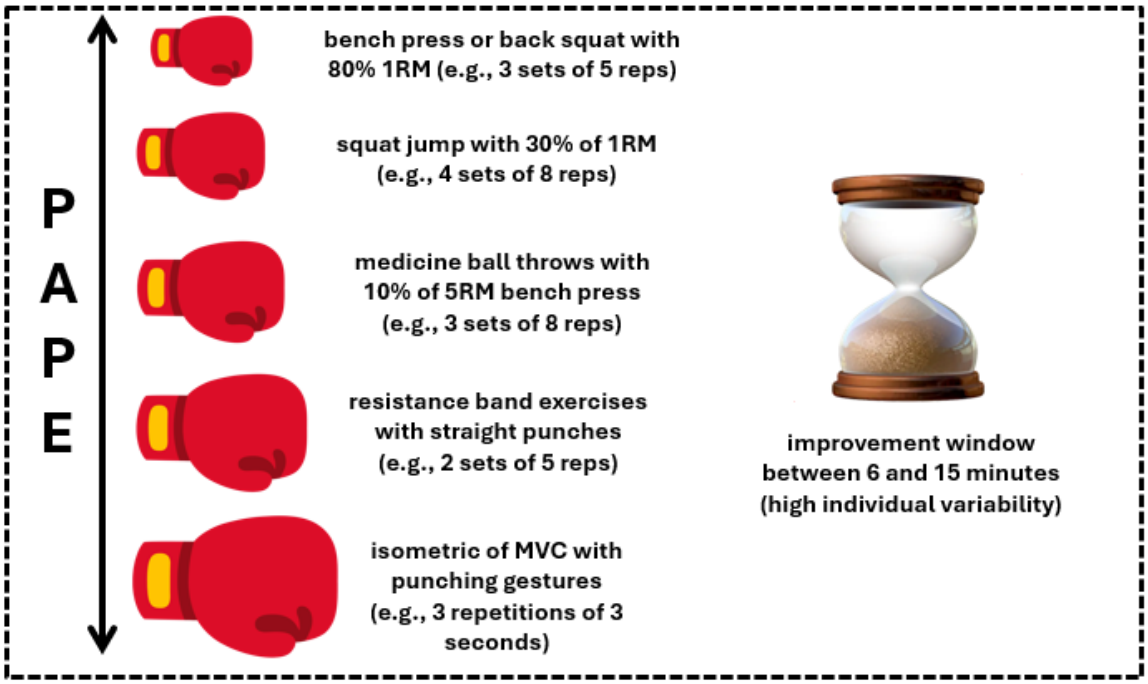


Figure 6. Acute effects of strength interventions on punches' performance. PAPE: post-activation performance enhancement. RM: repetition maximum. MVC: maximum voluntary contraction.

4.6. Limitations and Strengths

The strengths of this scoping review were the following: (i) the inclusion of three generic databases (Scopus, PubMed, Web of Science), increasing precision and reducing possible biases in the results obtained; (ii) the methodological processes followed by the PRISMA ScR, TESTEX, RoB2 and GRADE scales; and (iii) the inclusion of the analysis of the acute effects of muscle strength training in amateur boxers. On the other hand, the main limitations of this review were (i) not having experimental studies that analyzed the effects of muscle strength training in boxers, (ii) the fact that most studies obtained a moderately low rating in TESTEX, (iii) the diversity of instruments and variables observed, such as the different ages of the groups analyzed and (iv) having only one study with female

boxers. It is necessary that future studies carry out research with experimental designs on muscle strength training in boxers, since it helps to improve the quality of the studies, helping readers to understand more clearly how the data were obtained and analyzed, improving the interpretation of the results. Additionally, we encourage researchers to perform interventions in female boxers to improve the understanding of their physical adaptations and optimize sports training processes.

5. Conclusions

Four articles in the present scoping review demonstrated improved punches' performance through interventions acutely. It is important that future research investigates the differences between methods that appear to induce a better PAPE response in the impact force of punches, for example, isometric exercises with a punching technique compared to BE and HRE. This could help coaches to select the most effective PAPE method for warm-ups and sparring sessions of amateur boxers. Seven articles demonstrated improved punches' performance through interventions chronically. Due to the heterogeneity of these studies, it is difficult to establish which training method is better. However, the most appropriate training method could be the one that fits the specific needs of the boxer through a gradual and systematic process based on the basic principles of training, such as progressive overload, the principle of individualization and the principle of recovery considering the physical and physiological demands of amateur boxing. Finally, muscular strength training interventions can improve punching performance in amateur boxers acutely and chronically, in addition to improving their physical fitness and generating increases in the capacity to generate maximum force and improvements in RFD and the power production of the upper and lower limbs of boxers. However, our scoping review only included one study in female boxers, so we recommend that future studies contain muscular strength training interventions in females to analyze their adaptations in punching force and physical fitness.

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