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The impact of resistance-based training programs on throwing performance and throwing-related injuries in baseball players: A systematic review

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ABSTRACT

The aim of this systematic review is to assess the effects of structured resistance training programs on the throwing performance and injury risk of baseball players, irrespective of their age or sex. The literature search was carried out on 18/10/2023, utilizing databases that include PubMed, Scopus, and the Web of Science. Our inclusion criteria encompassed research involving baseball players of all ages and sex who had undergone resistance-based training interventions. For comparison, we considered active control groups, irrespective of their exposure to additional training programs. The outcomes under investigation were related to throwing performance (i.e., throwing velocity and accuracy) and injuries associated with throwing. In our review, we exclusively included studies with a two- or multi-arm design. We evaluated the risk of bias using the PEDro scale. Out of the initial pool of 509 studies, we carefully examined 27 full-text articles and ultimately selected and analyzed 16 studies for inclusion in our review. Out of the 12 studies that compared and presented the inferential statistics for the post-training effects of the experimental versus control groups, it was observed that 8 of these studies demonstrated a significantly more favorable impact of the experimental group on enhancing throwing velocity when compared to the control group. Out of the three studies that compared the experimental and control groups in terms of throwing accuracy, only one study showed a significant improvement in the experimental group compared to the control group after the intervention. In conclusion, this systematic review indicates that resistance-based training interventions appear to be effective in enhancing throwing velocity. However, the evidence regarding the efficacy of these interventions in improving throwing accuracy is less robust. It is worth noting that while some experimental conditions may lead to an increase in injury rates, there is limited data available on this aspect, with only a few studies reporting on this variable.

1. Introduction

Baseball, as a sport, is renowned for its emphasis on precision and the inherent physical demands it imposes on athletes [1]. Derived from earlier bat-and-ball games like cricket and rounders, baseball has evolved into a sport of considerable athletic significance [2]. The primary physical demands in baseball revolve around the act of throwing, a fundamental component of the game's dynamics [3]. Throwing motions are central, notably for pitchers, outfielders, and infielders, and play a pivotal role in shaping the game's outcome

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[4]. The speed, accuracy, and consistency of throws, whether from the pitcher's mound or within the infield, profoundly influence both defensive and offensive strategies [5]. The mastery of these key movements is instrumental in determining competitive success, underscoring the sport's fusion of skill, strategy, and athleticism [6].

In light of the paramount importance of throwing in baseball, it is imperative to delve into the biomechanical intricacies underpinning this critical aspect of the game [6]. Throwing, whether in the form of a pitcher's wind-up or a quick infield release, hinges on a complex interplay of physical forces, muscular coordination, and joint mechanics [7]. The transfer of kinetic energy from the lower body to the upper extremities, the precise synchronization of muscle groups, and the rotational mechanics of the shoulder and elbow joints are all vital elements in achieving optimal throwing velocity and accuracy [8]. Physical fitness, therefore, assumes a pivotal role in facilitating peak performance, as it directly affects an athlete's capacity to harness these biomechanical features [9]. The dynamic balance between strength, flexibility, and endurance is crucial in preserving the integrity of the throwing motion throughout the demanding duration of a baseball game, making it abundantly clear that physical fitness is an indispensable cornerstone for success in this sport [10].

Given the pivotal role of physical fitness and strength in optimizing throwing performance in baseball, it is imperative to consider tailored training interventions [3,11]. Among these, resistance-based training emerges as a potent avenue for enhancing the biomechanical and muscular attributes critical to effective throwing [12]. The implementation of resistance exercises, such as weightlifting, resistance bands, and medicine ball drills, offers athletes the opportunity to target and strengthen the muscle groups central to the throwing motion [11]. This targeted training cultivates the power, speed, and endurance necessary for generating forceful throws and maintaining consistency throughout the course of a game [13,14]. Moreover, resistance-based training provides a means to mitigate injury risk by reinforcing the stability and durability of joints involved in the complex throwing process [15]. As such, the integration of resistance-based training into a comprehensive athletic regimen represents an invaluable strategy for augmenting throwing performance in the sport of baseball [15].

Throwing performance encompasses a combination of velocity and accuracy. However, when implementing resistance training, the primary goal is to prepare the body to increase speed in the ball [15]. While accuracy can be improved through technical training, the main objective of resistance training is to enhance one aspect of performance, namely the ball's velocity. The impact of resistance training on accuracy remains unclear due to limited research in this area [16].

The sport of baseball, with its emphasis on high-velocity throwing, is not without inherent risks, notably the pervasive concern of overuse injuries [17]. Overuse injuries in baseball are largely attributable to repetitive throwing motions and can manifest through kinematic mechanisms such as excessive shoulder abduction, lateral torque, and valgus stress on the elbow joint [18]. Epidemiological data substantiates the prevalence of such injuries, with a significant number of players experiencing shoulder and elbow issues during their careers [19]. In this context, resistance-based training assumes a pivotal role as a preventative measure [20]. By fortifying the muscle groups responsible for these intricate movements, resistance training can enhance the structural integrity of the shoulder and elbow joints, thus serving as a safeguard against overuse-related injuries [18]. As a result, incorporating resistance-based training into an athlete's regimen is not only conducive to improved throwing performance but also a proactive strategy in mitigating the occurrence of these injurious kinematic mechanisms in the world of baseball [18].

The paramount significance of resistance training and the attainment of optimal strength levels in injury prevention during throwing movements, particularly concerning the elbow and shoulder, cannot be overstated [21]. Research findings have consistently underlined the correlation between muscular strength and injury risk mitigation [22]. Adequate strength levels in the shoulder and elbow musculature contribute to the stability and resilience of these vulnerable joints [23]. Specifically, well-developed rotator cuff and scapular stabilizers in the shoulder, coupled with a robust forearm and wrist musculature, play a pivotal role in absorbing the substantial forces encountered during the throwing motion, thereby reducing the incidence of injury [24]. The strengthening of these areas, facilitated through resistance training, is demonstrated to diminish the risk of conditions such as rotator cuff tears and ulnar collateral ligament injuries [25]. Consequently, an athlete's capacity to maintain optimal strength levels is not only conducive to improved performance but also represents a cornerstone of injury prevention, safeguarding the elbow and shoulder against the rigors of the sport [26].

Building upon the foundational principles delineated in the earlier discourse, the undertaking of a systematic review aimed at analyzing the effects of structured resistance training programs on the throwing performance and injury risk of baseball players, irrespective of age or sex, holds significant pertinence within the realm of sports science and injury prevention. Acknowledging the pivotal role of resistance training in both reducing the risk of injuries and enhancing performance, this systematic review aims to consolidate the existing body of literature. It seeks to provide a comprehensive evaluation of the connection between resistance training and its effects on both throwing performance and injury prevention in baseball. This analysis encompasses baseball players of any age or gender and includes studies with randomized and non-randomized two or multi-arm study designs. Such an endeavor is not only timely but indispensable, given the paucity of consolidated results on this subject. The findings of this systematic review are poised to inform both coaches and athletes on the efficacy of structured resistance training programs, thus promoting evidence-based strategies to optimize performance and safeguard against the perils of injury, thereby augmenting the scientific understanding and practical application of resistance training in the context of baseball.

2. Methods

2.1. The registration

This review adhered to the PRISMA 2020 guidelines. The protocol governing our review underwent meticulous registration on the Open Science Framework (OSF) platform, where it acquired a distinctive DOI identifier: 10.17605/OSF.IO/Q5J4H, protocol ID: osf.io/q5j4h.

2.2. Eligibility criteria

For the systematic review undertaken, we incorporated all original articles that had been published in peer-reviewed journals, inclusive of those with an "ahead-of-print" status. The deliberate omission of language restrictions aimed to ensure a broad consideration of articles.

In establishing eligibility criteria, our approach aligned with the PICOS framework, and a comprehensive breakdown of this information is available in Table 1. To encapsulate a wide range, our criteria centered on studies involving baseball players of any age, competitive level, or sex. The requisite condition for inclusion was that these studies featured resistance training interventions as the primary focus, with comparisons against active control groups—comprising those exclusively engaged in in-field training or any other specific training intervention.

Our primary focus in terms of outcomes centered on measures related to throwing performance, specifically velocity and accuracy, as well as throwing-related injuries, particularly those affecting the elbow and shoulder. A discerning emphasis was placed on direct assessments, with the deliberate exclusion of surrogate outcomes. The primary thrust of our investigation honed in on studies employing two- or multi-arm randomized controlled trial designs.

The assessment of article relevance was conducted using the PICOS approach, detailed in Table 1. This approach allowed a comprehensive examination of the content, enabling the establishment of distinct criteria for both inclusion and exclusion. Instances requiring a more thorough evaluation prompted a meticulous analysis of the full texts to ascertain their eligibility for inclusion in the review.

2.3. Information sources

To unearth pertinent studies, we executed an exhaustive search spanning diverse databases: (i) PubMed, (ii) Scopus, (iii) SPORTDiscus, and (iv) Web of Science, all on the specific date of October 18, 2023. To fortify the all-encompassing nature of our strategy and mitigate the risk of overlooking relevant materials, we additionally conducted manual searches within the reference lists of the studies assimilated into our review.

2.4. Search strategy

Employing Boolean operators AND/OR, we systematically conducted the search, deliberately refraining from imposing filters or constraints on the date of publication or language. This intentional strategy was chosen to maximize the chances of identifying relevant studies. The intricate details of our systematic search strategy can be found in Table 2, presented below for meticulous reference.

Table 1
Eligibility criteria based on PICOS.

	Inclusion criteria	Exclusion criteria
Population	Inclusive in the analysis are baseball players of any age or sex, with no limitations imposed on a specific competitive level.	Para-athletes, injured or ill at the time of the study. Exclusively focused on baseball without considering other sports.
Intervention/ exposure	Supplementary to the regular in-field training sessions of the players, resistance training programs, irrespective of their type or training objectives, will be considered. A minimum duration of two weeks of training is established as a standard to promote chronic adaptations.	Excluded from consideration are alternative training modalities beyond resistance training, such as aerobic-based training, flexibility exercises, speed training, and other variations. Furthermore, combined forms of training, such as resistance training paired with high-intensity interval training, will also be excluded.
Comparator	Active controls denote participants exclusively involved in in-field training without exposure to other specific training programs. Conversely, active controls may also encompass participants exposed to training programs other than resistance training.	Mixed training programs, such as combinations of resistance training and high-intensity interval training, will not be considered.
Outcomes	Throwing performance measures, including throwing velocity and accuracy, as well as the occurrence of throwing-related injuries, such as shoulder or elbow injuries, will be assessed.	Surrogate variables, such as physical fitness status indicators that may be linked to injury risk or incidence (e.g., range of motion) or associated with throwing performance (e.g., muscular power).
Study design	The review is set to encompass two-arm controlled studies, irrespective of randomization status, along with quasi-experimental controlled studies.	Observational studies.

Table 2
Full search strategy for each database.

Database	Specificities of the databases	Search Strategy	Number of articles
PubMed	Search for title and abstract also includes keywords	(((baseball*[Title/Abstract]) AND (throw*[Title/Abstract])) AND (training*[Title/Abstract] OR program*[Title/Abstract])) AND (resistance*[Title/Abstract] OR strength*[Title/Abstract] OR neuromuscular*[Title/Abstract] OR power*[Title/Abstract] OR "Weight-Lifting"[Title/Abstract] OR "Weight-Bearing"[Title/Abstract] OR "eccentric"[Title/Abstract] OR "elastic band*"[Title/Abstract])	110
Scopus	Search for title and abstract also includes keywords	(TITLE-ABS-KEY (baseball*) AND TITLE-ABS-KEY (throw*) AND TITLE-ABS-KEY (training* OR program*) AND TITLE-ABS-KEY (resistance* OR strength* OR neuromuscular* OR power* OR "Weight-Lifting" OR "Weight-Bearing" OR "eccentric" OR "elastic band"))	202
Web of Science	Search for title and abstract also includes keywords and its designated "topic"	baseball* (Topic) and throw* (Topic) and training* OR program* (Topic) and resistance* OR strength* OR neuromuscular* OR power* OR "Weight-Lifting" OR "Weight-Bearing" OR "eccentric" OR "elastic band" (Topic)	197

2.5. *Selection process*

The screening phase involved meticulous scrutiny carried out by two assigned authors, specifically HZ and QJ. They independently examined the retrieved records, including titles and abstracts, and proceeded to individually assess the complete texts of the chosen records. When discrepancies in evaluations arose, a collaborative reevaluation ensued, with the objective of achieving consensus. Should consensus prove elusive, the final decision-making responsibility rested with a third author, AL. To streamline record management, we employed the EndNote X9.3.3 software, developed by Clarivate Analytics in Philadelphia, Pennsylvania, USA.

2.6. *Data collection process*

Data collection was autonomously carried out by the authors HZ and QJ. In instances of discord during this phase, AL took on the role of a mediator to reconcile any disparities. To facilitate and maintain organizational coherence throughout this procedure, we instituted a specialized Microsoft® Excel datasheet. This datasheet systematically encompassed all relevant data and crucial information, ensuring a methodical and effective approach to data management.

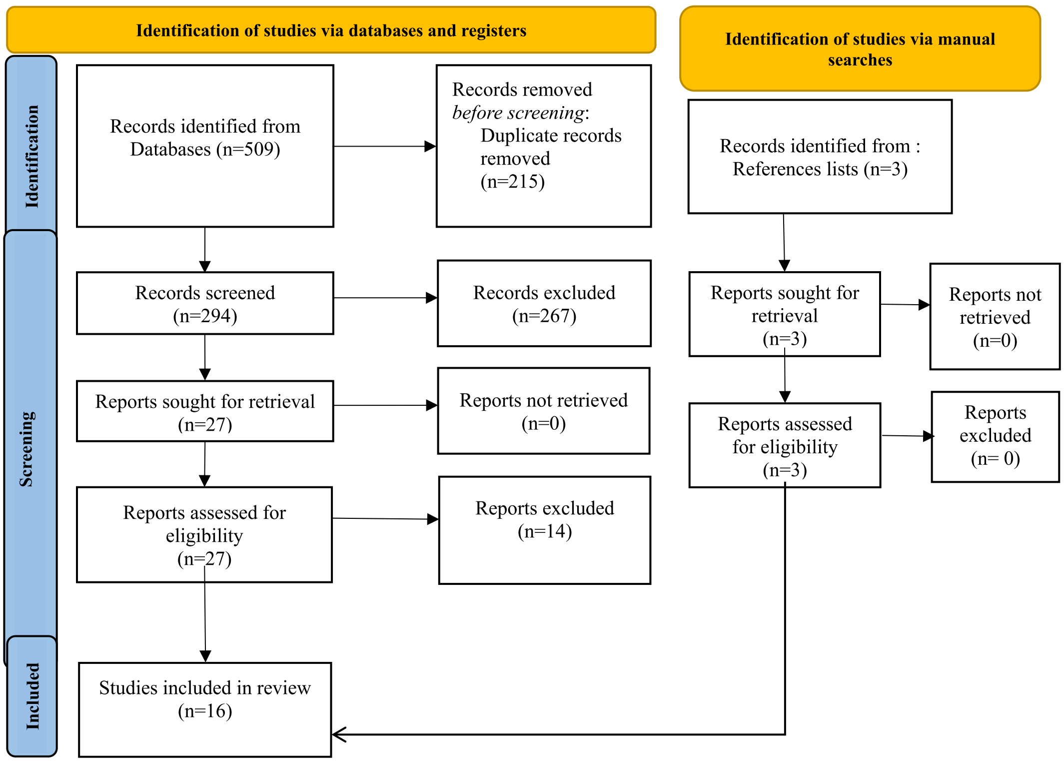

Fig. 1. PRISMA flow diagram.

2.7. Data items

Data gathering pertaining to participants and contextual aspects was conducted with meticulous consideration. This encompassed a spectrum of variables, including but not limited to the publication date, primary research objectives, sample size, country of origin, age distribution, sex composition, clinical details, and the competitive level of the subjects [27].

Regarding intervention-related particulars, we systematically recorded information related to the timing of the competitive season, program duration, training frequency, adherence to the training regimen, and various elements of the training dosage. This included details on duration, repetitions, rest intervals, intensity, frequency, and training density.

Furthermore, we meticulously documented specifics about the comparators, encompassing details about active control groups, as well as information about the type of exercises, exercise intensity, and volume.

In the collection of outcome measures, our primary emphasis was directed towards throwing performance and injuries associated with throwing. Concerning throwing performance, variables such as throwing speed and accuracy were taken into account. For injuries related to throwing, our focus extended to injury ratios and occurrences in the shoulder and elbow regions.

2.8. Study risk of bias assessment

To assess the potential bias in the studies included in our analysis, we employed the Physiotherapy Evidence Database (PEDro) scale. This scale, previously validated and demonstrated as reliable [28,29] appraises eleven distinct criteria, with the cumulative score assigned to each article derived from ten of these criteria. The scores on this scale range from 0, indicating the lowest quality, to 10, representing the highest quality. Typically, predefined score thresholds are employed to classify articles into qualitative categories: 'poor' (<4 points), 'fair' (4–5 points), 'good' (6–8 points), and 'excellent' (9–10 points).

In the evaluation process, two authors independently assessed and rated the articles using the PEDro scale. Subsequently, these two authors (HZ and QJ) compared their individual scores, engaging in thorough discussions to address any discrepancies on an item-by-item basis. In cases where consensus proved elusive, a third author (AL) was brought into the consultation, providing their score and ultimately rendering the conclusive decision on the rating.

3. Results

3.1. Study identification and selection

Following an initial exploration, a pool of 509 titles surfaced, as depicted in Fig. 1. A meticulous curation process ensued, employing both automated algorithms and manual interventions, resulting in the removal of 215 duplicate entries. This refinement yielded a collection of 294 distinct titles, subjected to a careful evaluation for relevance based on both titles and abstracts. Subsequent to this scrutiny, 267 studies were deemed irrelevant and consequently excluded.

An in-depth examination of the full texts of the remaining 27 studies was then undertaken. Following this comprehensive review,

Table 3
Physiotherapy Evidence Database (PEDro) scale ratings.

Study	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	Score
Brose et al. [30]	0	0	0	1	0	0	0	1	1	1	0	4
Carter et al. [36]	1	1	0	0	0	0	0	1	1	1	1	5
DeRenne et al. [31]	0	1	0	1	0	0	0	1	1	1	1	6
DeRenne et al. [34]	0	1	0	1	0	0	0	1	1	1	1	6
Escamilla et al. [38]	1	1	0	1	0	0	0	1	1	1	1	6
Escamilla et al. [35]	1	1	0	0	0	0	0	1	1	1	1	5
Kurland et al. [39]	0	0	0	1	0	0	0	1	1	1	0	4
Lachowetz et al. [53]	0	1	0	0	0	0	0	1	1	1	1	5
Logan et al. [54]	0	0	0	1	0	0	0	1	1	1	1	5
Lust et al. [16]	1	1	0	1	0	0	0	1	1	1	1	6
McEvoy et al. [37]	0	0	0	1	0	0	0	1	1	1	1	5
Newton et al. [40]	0	1	0	0	0	0	0	1	1	1	1	5
Potteiger et al. [55]	0	1	0	1	0	0	0	1	1	1	1	6
Reinold et al. [32]	1	1	1	1	0	0	1	1	1	1	1	8
Wooden et al. [56]	1	1	0	0	0	0	0	1	1	1	1	5
Yang et al. [33]	0	0	0	0	0	0	0	1	1	1	1	4

C1: eligibility criteria were specified; C2: subjects were randomly allocated to groups; C3: allocation was concealed; C4: the groups were similar at baseline regarding the most important prognostic indicators; C5: there was blinding of all subjects; C6: there was blinding of all therapists who administered the therapy; C7: there was blinding of all assessors who measured at least one key outcome; C8: measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups; C9: all subjects for whom outcome measures were available received the treatment or control condition as allocated, or, where this was not the case, data for at least one key outcome were analyzed according to "intention to treat"; C10: the results of between-group statistical comparisons are reported for at least one key outcome; C11: the study provides both point measures and measures of variability for at least one key outcome. Score: The score is derived by summing the scores from C2 to C11, as recommended by the PEDro scale.

Table 4
Characteristics of the included studies.

Study	Competitive level	N	Age (years old)	Sex	Experimental groups (n)	Control groups (n)	Randomization	Study duration (w)	Outcomes extracted	Instruments/tests for measuring the outcomes
Brose et al. [30]	Trained	21	18–19	Men	2 groups (n = ND)	1 group (n = ND)	No	6	Throwing velocity; Throwing accuracy	Throwing at maximal velocity for a target at 35 ft. Accuracy was determined by measuring the distance from the center of the target to the place the ball hit.
Carter et al. [36]	Trained	24	19.7 ± 1.3	ND	1 group (n = 13)	1 group (n = 11)	Yes	8	Throwing velocity	The throwing velocity of each participant was measured using a calibrated JUGS MPH Cordless Radar Gun. The evaluation of maximum throwing velocity was conducted over a distance of 18.44 m (60 feet 6 inches).
DeRenne et al. [31]	Trained	30	16–18	ND	2 groups (n = 20)	1 group (n = 10)	Yes	10	Throwing velocity	The measurement of throwing velocity utilized an electromagnetic radiation radar. The test involved ten baseball pitches, each using a 5-ounce baseball.
DeRenne et al. [34]	Trained	225	16.6 ± 0.6 and 19.6 ± 0.5	Men	2 groups (n = 150)	1 group (n = 75)	Yes	10	Throwing velocity	The measurement of throwing velocity utilized an electromagnetic radiation radar. The test involved fifteen baseball pitches, each using a 5-ounce baseball.
Escamilla et al. [38]	Trained	34	12.5 ± 1.5	ND	1 group (n = 17)	1 group (n = 17)	Yes	4	Throwing velocity	The measurement of throwing velocity was conducted using a calibrated Jugs Tribar Sport radar gun (Jugs Pitching Machine Company, Tualatin, OR, USA). Each participant performed overhand throws from a flat surface with maximum effort, targeting a point positioned at approximately chest level and 13.7 m away.
Escamilla et al. [35]	Trained	58	14–17	ND	3 groups (n = 43)	1 group (n = 15)	Yes	6	Throwing velocity	The throwing velocity was measured using a precision-calibrated Jugs Tribar Sport radar gun, manufactured by Jugs Pitching Machine Company in Tualatin, Oregon, USA. Each participant commenced their throws from a starting line positioned 22.9 m away from a circular target with a diameter of 1.8 m. The center of this target was approximately at chest level, standing at a height of 1.30 m.
Kurland et al. [39]	Trained	20	13–16	Men	1 group (N = 10)	1 group (N = 10)	No	6	Throwing velocity	Not described
Lachowetz et al. [53]	Trained	22	18–22	ND	1 group (N = 12)	1 group (N = 10)	Yes	8	Throwing velocity	The assessment of throwing performance was conducted over a distance of 18.44 m, with velocity being measured using a sports radar gun.
Logan et al. [54]	Trained	39	ND	ND	2 groups (n = 26)	1 group (N = 13)	No	6	Throwing velocity	The players executed a series of 10 throws from a distance of 15 feet, and a velocitimer was employed to measure the throwing velocity.
Lust et al. [16]	Trained	40	20.0 ± 1.5	ND	2 groups (n = 25)	1 group (N = 15)	Yes	6	Throwing accuracy	It was employed the functional throwing-performance index.

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Table 4 (*continued*)

Study	Competitive level	N	Age (years old)	Sex	Experimental groups (n)	Control groups (n)	Randomization	Study duration (w)	Outcomes extracted	Instruments/tests for measuring the outcomes
McEvoy et al. [37]	National level	18	24 ± 4	Men	1 group (N = 9)	1 group (N = 9)	No	10	Throwing velocity	Throwing velocity was assessed over distances of 18.44 m using the ProSpeed Professional radar gun model from Decatur Electronics to measure the velocity.
Newton et al. [40]	Trained	24	16–23	Men	2 groups (n = 16)	1 group (N = 8)	Yes	8	Throwing velocity	Throwing velocity was assessed over distances of 18.44 m using the ProSpeed Professional radar gun model from Decatur Electronics to measure the velocity.
Potteiger et al. [55]	Trained	21	19.6 ± 1.3	Men	1 group (n = ND)	1 group (n = ND)	Yes	10	Throwing velocity	Throwing velocity was assessed using radar gun technique (RA-GUN G1, Decatur electronics).
Reinold et al. [32]	Trained	38	15.3 ± 1.2	ND	1 group (n = 19)	1 group (n = 19)	Yes	6	Throwing velocity; Injury rate	They delivered 10 fastballs with a standard 5-ounce regulation baseball from a typical pitching mound. The velocity of each pitch was recorded using a radar gun (Stalker Radar). Injury rate was measured after the training program.
Wooden et al. [56]	Trained	27	15.5 ± 1.0	ND	2 groups (n = ND)	1 group (n = ND)	Yes	5	Throwing velocity	Throws executed at a distance of 60 feet were assessed using a calibrated radar gun, specifically the Magnum X Ban radar gun.
Yang et al. [33]	Trained	38	15.3 ± 1.2	ND	1 group (n = 19)	1 group (n = 19)	No	6	Throwing velocity; throwing accuracy	The measurement of throwing velocity entailed employing ten fastballs, each thrown with a standard 5-ounce regulation baseball, from a conventional pitching mound. The radar gun was utilized for the precise determination of the throwing speed.

ND: not described.

Table 5
Characteristics of the experimental programs and the control groups.

Study	Training frequency (n/w)	Total of training sessions (n)	Experimental groups (description of the training process)	Control groups (description)
Brose et al. [30]	3	18	(Group 1) Wall Pulley: the overload training phase incorporated the use of a wall pulley device. This device was adapted by replacing the handle with a baseball. The overload tension applied amounted to 10 pounds, as precisely gauged by a calibrated spring scale. (Group 2) Weighted baseballs: the overload training regimen involved throwing baseballs that were weighted to 10 ounces (20 maximal throws). Given that the standard weight range for a baseball falls between 5.0 and 5.25 ounces, this adjustment effectively imposed nearly a twofold increase in load.	The control group was strictly prohibited from incorporating overload balls into their training regimen.
Carter et al. [36]	2	16	Plyometric training: In the experimental group, participants engaged in additional training exercises, with each exercise consisting of 3 sets and a variable number of repetitions ranging from 10 to 20, progressing gradually over the weeks. The exercises included: Latex tubing external rotation; Latex tubing 90/90 external rotation; Overhead soccer throw using a 6-lb medicine ball; 90/90 external rotation side-throw using a 2-lb medicine ball; Deceleration baseball throw using a 2–lb medicine ball; Baseball throw using a 2-lb medicine ball.	During the offseason, participants engaged in strength and conditioning activities, which encompassed regular cardiovascular conditioning and comprehensive overall strength training routines. These routines included isotonic exercises designed to strengthen the rotator cuff, and this regimen was consistent for both the control and experimental groups.
DeRenne et al. [31]	3	30	(Group 1) Overweight Balls: Players were introduced to baseballs weighing between 5 and 6 ounces. They completed a 50-pitch session. (Group 2) Underweight Balls: Players were introduced to baseballs weighing between 4 and 5 ounces. They completed a 50-pitch session.	Players consistently used 5-ounce baseballs and completed a 50-pitch session.
DeRenne et al. [34]	3	30	(Group 1) Combined Training: Participants in this group pitched using a combination of heavy, light, and standard balls, which weighed between 4 and 6 ounces. The total number of pitches per session ranged from 54 to 78. (Group 2) Blocked Training: In this group, participants initially trained with heavy and standard balls for the first five weeks, and in the subsequent five weeks, they trained with light and standard balls, all within the weight range of 4–6 ounces. The total number of pitches per session also varied from 54 to 78.	The control group consistently used 5-ounce balls for their throws, with the total number of pitches per session varying between 54 and 78.
Escamilla et al. [38]	3	12	Elastic tubing and distance-based interval throwing: The program involved the utilization of elastic tubing, specifically the “MVP Band” from A Change of Pace, Inc. in Davis, CA, USA. This component comprised 17 upper extremity resistance exercises intended to enhance muscular strength, power, and endurance. It is noteworthy that the MVP Band differs from the typical elastic tubing devices in that it is secured around the wrist rather than utilizing a handle held in the hands. Each of the 17 resistance exercises (e.g., focused on shoulder, and elbow) was executed for a single set, encompassing 20 to 25 repetitions. Furthermore, the subsequent 30-min segment entailed a distance-based interval throwing long-toss program.	The control group did not undergo any supplementary training program.
Escamilla et al. [35]	3	18	(Group 1) Throwers: Perform 8–12 repetitions for 36 sets. This program typically includes executing each repetition at a deliberate and controlled pace (at approximately 45–60°/s). It incorporates both concentric and eccentric muscle actions. (Group 2) Keiser Pneumatic: Aim for 8–12 repetitions over 32 sets. The resistance remains consistent throughout the entire range of motion and is unaffected by exercise speed. This program employs explosive training techniques, emphasizing baseball-specific functional training that engages the lower	The control group did not undergo any supplementary training program.

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Table 5 (*continued*)

Study	Training frequency (n/w)	Total of training sessions (n)	Experimental groups (description of the training process)	Control groups (description)
			extremities, trunk, and upper extremities sequentially. (Group 3) Plyometric: Execute 6–10 repetitions across 32 different exercises. All exercises involve the stretch-shortening cycle, characterized by a rapid eccentric muscle action (prestretch), followed by a countermovement consisting of a rapid concentric muscle action to generate peak force as swiftly as possible. Medicine ball exercises engage the entire body, progressing from the lower extremities to the trunk and then to the upper extremities. These movements predominantly occur in transverse and diagonal planes, chosen for their relevance to throwing and similar baseball-related actions.	
Kurland et al. [39]	3	18	Circuit training: The training regimen comprised two circuits, each consisting of 10 stations. Each station involved a 20-s exercise period followed by a 40-s rest interval. These exercises were isokinetic in nature and included movements such as upright row, knee flexion/extension, elbow flexion/extension, hip flexion/extension, squats, and various others.	The control group did not undergo any supplementary training program.
Lachowetz et al. [53]	4	32	Strength training: Upper body strength training involved a total of 11 exercises, including movements such as shoulder rotation, shoulder abduction and adduction, shoulder extension, lateral row, and flat bench press. The weekly routine consisted of four training days, with six exercises performed on Monday and Thursday, and five exercises on Tuesday and Friday. Typically, each exercise was performed for three sets, with the last set supplemented by an additional 5 assisted repetitions after the initial 11 repetitions.	The control group did not undergo any supplementary training program.
Logan et al. [54]	5	30	(Group 1) Isotonic Resistance Training: In this group, players underwent isotonic resistance training using the Exer-genie device, which was designed to pull a baseball attached to an engine. Participants carried out 30 overhand throws daily. (Group 2) Throwing Training: This group engaged in 30 overhand throws using a standard baseball.	The control group was strictly prohibited from incorporating throwing or performing resistance training
Lust et al. [16]	3	18	(Group 1) Open Kinetic Chain/Closed Kinetic Chain Exercises: Open kinetic chain exercises encompassed both concentric and eccentric contractions and included four specific exercises in this study: Sitting scaption with the arm positioned at a 30° angle of horizontal abduction and internal rotation; Prone-lying horizontal abduction with the arm externally rotated; Prone-lying single-arm rowing; Supine-lying barbell bench press. Closed kinetic chain exercises featured in this group comprised the following: BAPS-board exercises; Step-ups; Balance exercises on an exercise ball. Plyometric exercises consisted of the following movements: 2-handed chest pass; 2-handed overhead soccer throw; 2-handed side throw; 1-handed baseball throw. (Group 2) Open Kinetic Chain/Closed Kinetic Chain/Core Stability: participants engaged in both open and closed kinetic chain exercises, similar to those described for Group 1. Additionally, a core stability program was introduced, featuring a progression of exercises: Dead bug exercises; Partial sit-ups; Bridging exercises; Prone exercises; Quadruped exercises; Wall slides; Ball exercises. The duration for all exercises within the core-strengthening program commenced at 30 s and progressed to intervals ranging from 1 min to 45 s	The control group was not required to attend any of the exercise training sessions.
McEvoy et al. [37]	3 every two weeks	15	Dynamic ballistic resistance training: In this training regimen, the group utilized the Plyometric Power System, a specialized device designed for dynamic	They exclusively took part in standard baseball training.

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Table 5 (*continued*)

Study	Training frequency (n/w)	Total of training sessions (n)	Experimental groups (description of the training process)	Control groups (description)
			weight training with adjustable loads. Players completed three sets of 6–8 maximal effort repetitions in exercises such as the bench throw and jump squat.	
Newton et al. [40]	2	16	(Group 1) Medicine Ball Group: The exercises within this group included the explosive two-hand chest press and two-hand overhead throw, utilizing a 3 kg medicine ball. These exercises incorporated a countermovement. Participants completed 3 sets of 8 repetitions and progressed to four repetitions after completing the fourth week of training. (Group 2) Weight Training: In this regimen, participants engaged in the barbell chest press and barbell pullover exercises. During the initial four weeks, they completed 3 sets of 8–10 repetitions at maximum effort for each exercise. Afterward, the protocol transitioned to 6 to 8 maximum-repetition sets.	This group did not partake in any form of resistance training and solely followed the standard baseball training program identical to the experimental groups.
Potteiger et al. [55]	4	40	Weight and Sprint Training: This comprehensive hour-long workout combined strength and sprint training. It included 3 sets of 8–12 repetitions for each of the 8 exercises, such as bench press, military press, squat, lat pulldown, leg extension, leg curl, tricep extension, and bicep curl. The sprint portion of the workout involved a series of sprints, which comprised: A 10-s sprint at 50% of maximal effort; three 10-s sprints at 100% of maximum effort; one final 20-s sprint at 100% of maximum effort.	Dance Training: This dance training session lasted for 40 min and included a combination of aerobic dance routines and calisthenic activities, guided by a certified training instructor.
Reinold et al. [32]	3	18	Weighted Ball Training Program: In this program, throwing exercises were conducted from each position during every training session, using a set of five differently weighted balls (ranging from 2 to 32 ounces). The training positions included knee, rocker, and run and gun stances. Typically, two to three repetitions were performed per position per session, with the weekly total number of throws varying between 15 and 35.	The control group was strictly prohibited from incorporating underload or overload balls into their offseason training program for throwing.
Wooden et al. [56]	3	15	(Group 1) Individualized Dynamic Variable Resistance Mode: Participants engaged in exercises utilizing 100% of the variable resistance offered by the motor performance curve. Participants performed 6–7 sets of 10 maximal repetitions. (Group 2) Isokinetic Mode: In this mode, participants performed exercises at a constant velocity of 500°/s.	Not described.
Yang et al. [33]	3	18	Weighted Ball Training Program: In the weighted ball training program, three distinct throw positions were utilized (knee, rocker, run and gun), incorporating a range of five weighted balls (ranging from 2 to 32 ounces). The weekly volume of throws exhibited variability, spanning from 15 to 35 throws per week.	The control group was strictly prohibited from incorporating underload or overload balls into their offseason training regimen.

ND: not described.

13 studies were pinpointed as meeting the eligibility criteria. Beyond the database perusal, an extensive manual search probed the references cited within the selected articles, uncovering three additional studies meeting the inclusion criteria. Consequently, our systematic review embraced a total of 16 articles. For a nuanced breakdown of the full-text screening and the rationale for exclusions, kindly refer to Supplementary Material 1.

3.2. Assessment of the risk of bias

Within the scope of this systematic review, scrutiny has been directed towards a compilation of sixteen studies (refer to Table 3). Among these, ten studies exhibited a quality score ranging between 4 and 5 points, signifying a moderate level of quality. In contrast, the remaining six studies garnered a quality rating spanning 6 to 8 points, indicating a notably higher level of quality. Notably, a prevalent deficiency identified across all included articles pertained to the omission of reported details regarding blinding procedures for both subjects and individuals responsible for investigation and evaluation.

Table 6
Results of individual studies on throwing velocity.

Study	Group	Baseline	Post-intervention (mph)	Differences	Within group comparison*	Between group comparison*
Brose et al. [30]	EG (Pulley)	not described	not described	−.001, 132,01	Significantly improved	Not significant
Brose et al. [30]	EG (Weighted balls)	not described	not described	−.000,729,54	Significantly improved	Not significant
Brose et al. [30]	CG	not described	not described	−.000,303,96	Not significant	Not significant
Carter et al. [36]	EG (Plyometric training)	83.19 ± 3.06 mph	85.14 ± 4.53 mph	+1.95	Significantly improved	Significantly better than CG
Carter et al. [36]	CG	78.97 ± 3.06 mph	79.18 ± 4.54 mph	+0.21	Not significant	Significantly worse than EG
DeRenne et al. [31]	EG (Overweight Balls)	70.58 ± 4.03 mph	74.33 ± 5.24 mph	+3.75	Not described	Significantly better than CG
DeRenne et al. [31]	EG (Underweight Balls)	70.78 ± 4.87 mph	75.50 ± 4.07 mph	+4.72	Not described	Significantly better than CG
DeRenne et al. [31]	CG	69.63 ± 3.57 mph	70.47 ± 3.57 mph	+0.88	Not described	Significantly worse than EGs
DeRenne et al. [34]	EG (Combined training)	HS: 73.02 ± 0.57 mph UP: 76.95 ± 0.25 mph	HS: 77.09 ± 1.95 mph UP: 80.26 ± 1.16 mph	HS: 4.07 UP: 3.31	Significantly improved	Significantly better than CG
DeRenne et al. [34]	EG (Blocked Training)	HS: 74.09 ± 0.69 mph UP: 76.46 ± 0.43 mph	HS: 78.16 ± 1.88 mph UP: 79.34 ± 0.98 mph	HS: 4.07 UP: 2.88	Significantly improved	Significantly better than CG
DeRenne et al. [34]	CG	HS: 71.52 ± 0.75 mph UP: 76.1 ± 0.49 mph	HS: 71.96 ± 1.75 mph UP: 76.28 ± 1.29 mph	HS: 0.44 UP: 0.18	Not significant	Significantly worse than EGs
Escamilla et al. [38]	EG (Elastic tubing and distance-based interval throwing)	25.1 ± 2.8 m/s	26.1 ± 2.8 m/s	+1.0	Significantly improved	Not described
Escamilla et al. [38]	CG	24.2 ± 3.6 m/s	24.0 ± 3.9 m/s	−0.2	Not significant	Not described
Escamilla et al. [35]	EG (Throwing training)	32.0 ± 1.9 m/s	32.6 ± 1.5 m/s	+0.6	Significantly improved	Not described
Escamilla et al. [35]	EG (Keiser Pneumatic)	32.4 ± 2.5 m/s	32.8 ± 2.4 m/s	+0.4	Significantly improved	Not described
Escamilla et al. [35]	EG (Plyometric)	33.0 ± 2.3 m/s	33.7 ± 2.3 m/s	+0.7	Significantly improved	Not described
Escamilla et al. [35]	CG	32.6 ± 3.1 m/s	32.5 ± 2.5 m/s	−0.1	Not significant	Not described
Kurland et al. [39]	EG (Circuit training)	not described	not described	not described	Not significant	Not described
Kurland et al. [39]	CG	not described	not described	not described	Not significant	Not described
Lachowetz et al. [53]	EG (Strength training)	69.08 ± 3.07 mph	70.77 ± 2.36 mph	+1.69	Not described	Significantly better than CG
Lachowetz et al. [53]	CG	70.36 ± 4.17 mph	69.31 ± 3.52 mph	−1.05	Not described	Significantly worse than EGs
Logan et al. [54]	EG (Isotonic resistance training)	75.90 mph	84.00 mph	+8.1	Significantly improved	Significantly better than throwing training group and CG
Logan et al. [54]	EG (Throwing training)	75.90 mph	78.84 mph	+2.9	Not significant	Significantly worse than isotonic resistance training group but not different from CG
Logan et al. [54]	CG	75.16 mph	75.31 mph	+0.2	Not significant	Significantly worse than isotonic resistance training group but not different from throwing group
McEvoy et al. [37]	EG (Dynamic ballistic training)	33.7 ± 1.4 m/s	34.3 ± 1.2 m/s	+0.6	Significantly improved	Not significant
McEvoy et al. [37]	CG	34.7 ± 1.2 m/s	34.5 ± 1.2 m/s	−0.2	Not significant	Not significant
Newton et al. [40]	EG (Medicine ball)	31.0 ± 1.9 m/s	31.5 ± 1.5 m/s	+1.6	Not significant	Not significant
Newton et al. [40]	EG (Weight training)	31.7 ± 2.5 m/s	33.0 ± 2.2 m/s	+4.1	Significantly improved	Not significant

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Table 6 (*continued*)

Study	Group	Baseline	Post-intervention (mph)	Differences	Within group comparison*	Between group comparison*
Newton et al. [40]	CG	32.5 ± 1.6 m/s	32.3 ± 2.3 m/s	−0.7	Not significant	Not significant
Potteiger et al. [55]	EG (Weight and sprint training)	74.8 ± 5.0 mph	77.1 ± 3.8 mph	+2.3	Significantly improved	Not significant
Potteiger et al. [55]	CG	73.7 ± 4.3 mph	73.0 ± 5.0 mph	−0.7	Not significant	Not significant
Reinold et al. [32]	EG (Weighted balls)	29.9 ± 1.5 m/s	30.9 ± 1.5 m/s	+1.0	Significantly improved	Significantly better than CG
Reinold et al. [32]	CG	30.9 ± 1.3 m/s	31.2 ± 1.3 m/s	+0.3	Not significant	Significantly worse than EG
Wooden et al. [56]	EG (Individualized Dynamic Variable Resistance Mode)	Not described	Not described	+2.1	Not described	Significantly better than isokinetic group and CG
Wooden et al. [56]	EG (Isokinetic Mode)	Not described	Not described	+0.9	Not described	Significantly worse than resisted mode but not different from CG
Wooden et al. [56]	CG	Not described	Not described	−0.3	Not described	Significantly worse than resisted mode but not different from isokinetic group
Yang et al. [33]	EG (Weighted Ball Training Program)	107.81 ± 6.66 kph	111.18 ± 6.74 kph	+3.20	Significantly improved	Significantly better than CG
Yang et al. [33]	CG	107.75 ± 8.51 kph	108.54 ± 8.18 kph	+0.77	Not significant	Significantly worse than EG

HS: high-school; UP: university pitchers; * To achieve a p-value <0.05, as indicated by the tests conducted in the individual studies.

Table 7
Results of individual studies on throwing accuracy.

Study	Group	Outcome	Baseline	Post-intervention	Differences	Within group comparison*	Between group comparison*
Brose et al. [30]	EG (Pulley)	Accuracy on the target (cm)	not described	not described	−2.9786	Not significant	Not significant
Brose et al. [30]	EG (Weighted balls)	Accuracy on the target (cm)	not described	not described	+0.0900	Not significant	Not significant
Brose et al. [30]	CG	Accuracy on the target (cm)	not described	not described	−2.1086	Not significant	Not significant
Lust et al. [16]	EG (Open Kinetic Chain/ Closed Kinetic Chain Exercises)	Functional throwing-performance index	0.53 ± 0.14	0.63 ± 0.14	+0.10	Not significant	Significantly better than CG
Lust et al. [16]	EG (Open Kinetic Chain/ Closed Kinetic Chain/Core Stability)	Functional throwing-performance index	0.50 ± 0.11	0.61 ± 0.12	+0.11	Not significant	Significantly better than CG
Lust et al. [16]	CG	Functional throwing-performance index	0.51 ± 0.13	0.49 ± 0.08	−0.02	Not significant	Significantly worse than EGs
Yang et al. [33]	EG (Weighted Ball Training Program)	Accuracy on the target (cm)	39.83 ± 6.12	40.37 ± 6.01	−1.74	Not significant	Not significant
Yang et al. [33]	CG	Accuracy on the target (cm)	35.39 ± 5.64	35.85 ± 5.68	−1.41	Not significant	Not significant

CG: control group; EG: experimental group; * To achieve a p-value <0.05, as indicated by the tests conducted in the individual studies.

3.3. Studies characteristics

Table 4 offers a comprehensive summary of the fundamental characteristics characterizing the studies encompassed within this review. Predominantly, these investigations were conducted within the realms of trained or developmental competitive levels (n = 15). The majority of the studies involved an exclusively male participant base (n = 6), with the sex of participants left unspecified in the remaining studies (n = 10). It is pertinent to note that 12 studies adhered to established randomization procedures, whereas 4 studies lacked explicit documentation of their randomization process for assigning players to groups.

Within the aggregate of 679 participants incorporated across the 16 studies, 379 participants were designated to experimental groups, while control groups comprised 231 participants. Additionally, three studies did not furnish information regarding the number

Table 8
Results of individual studies on injury incidence.

Study	Group	Injury information
Reinold et al. [32]	EG (Weighted balls)	In the training group, four elbow injuries were recorded, affecting 24% of the participants, ultimately requiring medical attention. These injuries encompassed two instances of olecranon stress fractures, one occurrence of a partial UCL injury, and another UCL injury that warranted surgical reconstruction. Notably, two of these injuries manifested during the course of the training program, as previously discussed, while the remaining two occurred in the subsequent baseball season.
Reinold et al. [32]	CG	There were no injuries in the control group.

CG: control group; EG: experimental group.

of participants in each group.

Moreover, the temporal span of the majority of studies extended to 6 weeks (n = 7). The evaluation of throwing performance predominantly focused on metrics such as throwing velocity (n = 15), throwing accuracy (n = 3), and injury rate (n = 2).

Table 5 offers a comprehensive insight into the training programs utilized for both the experimental and control groups considered within this present systematic review. Among the experimental groups, five studies incorporated weighted baseball training programs as a component of their training regimen [30–34]. Additionally, plyometric and ballistic training was implemented in four of the studies [16,35–37]. Furthermore, various alternative training methods, such as using elastic tubing [38], wall pulley [30], circuit training [39], or medicine ball exercises [40] were also observed in the research.

3.4. Results of individual studies

The outcomes related to throwing velocity from individual studies are presented in Table 6. Among the 12 studies that conducted comparisons and presented inferential statistics for the post-training effects of experimental versus control groups, it was noted that 8 studies revealed a significantly more favorable impact of the experimental group on enhancing throwing velocity in comparison to the control group. Regarding within-group analysis, which compares pre-training to post-training performance, among the 12 studies providing inferential statistics, 11 studies indicated a significant improvement in throwing velocity within the experimental group.

Table 7 displays the outcomes of individual studies related to throwing accuracy as the outcome measure. Out of the three studies that compared the experimental and control groups in terms of throwing accuracy, only one study [16] showed a significant improvement in the experimental group compared to the control group after the intervention. Interestingly, all three studies indicated that none of the experimental groups demonstrated within-group improvements following the interventions.

Table 8 provides the findings from individual studies concerning the outcome of injury rate. In the sole study [32] that reported results related to injury rates during the training intervention, it was found that the experimental group (which had undergone a weighted ball training program) experienced four injuries, accounting for 24% of the participants, with two of these injuries occurring during the training sessions themselves.

4. Discussion

Among the various resistance training methods examined in the individual studies included in this systematic review, which encompassed weighted baseball throwing techniques (n = 5), upper limb plyometric and ballistic training (n = 5) or weight training (n = 3) a consistent trend emerged. Experimental groups, exposed to these methods, generally exhibited improvements in throwing velocity when compared to control groups, which typically received standard baseball training for throwing. However, fewer studies delved into the impact of resistance-based training on throwing accuracy. Those that did investigate this aspect failed to show significant benefits.

Moreover, considering the potential implications of resistance-based training, it would be reasonable to expect reports on the occurrence of injuries during the training process. However, it is important to note that such data was not consistently recorded and reported, with one notable exception. In one article [32], which explored the injury rate in weighted ball throwing methods, it was revealed that 24% of players in experimental groups suffered injuries, in contrast to zero injuries in the control group.

Despite these findings, and with regard to the majority of the included studies, there was a moderate level of methodological quality. This was primarily attributed to shortcomings related to the randomization processes or the absence of blinding procedures for participants, trainers, and assessors.

Resistance-based training offers several potential benefits for baseball pitchers seeking to enhance their throwing performance. Firstly, this form of training can help improve muscle strength, particularly in the shoulder and arm muscles, which are critical for generating velocity and accuracy in throws [41]. By increasing muscle mass and power, pitchers may experience greater force production during their pitching motion [42]. Additionally, resistance training may play a crucial role in enhancing stability in shoulder rotation for baseball pitchers [43]. By specifically targeting the muscles surrounding the shoulder joint, such as the rotator cuff and scapular stabilizers, resistance exercises help reinforce and balance the musculature that controls shoulder rotation during the pitching motion [36]. Thus, properly designed resistance-based programs can address muscular imbalances and improve overall functional strength, leading to improved pitching mechanics [44]. Consequently, this type of training may contribute to increased throwing speed, accuracy, and overall performance, making it an integral component of many pitchers' training regimens.

Weighted baseball programs have gained popularity in the realm of scientific research and baseball training, with the aim of enhancing throwing performance in baseball pitchers. These programs commonly incorporate the use of baseballs with added weight or those that are lighter than standard baseballs. The rationale behind this approach is to induce an overload effect, thereby challenging the muscles engaged in the pitching motion. Among the included studies in this systematic review delving into weighted baseball training [30–34], it was observed that four promoted significant within-group improvements [31–34], although one revealed no significant differences from control groups in post-intervention stages [30]. These training regimens typically incorporated weighted balls ranging from 4 to 6 ounces (the standard baseball weighs between 5 and 5.25 ounces) and spanned a duration of 6–10 weeks. The total number of training sessions varied, with a minimum of 18 sessions and a maximum of 30 sessions.

One possible explanation for the effectiveness of weighted baseballs lies in their potential to induce neural adaptations. They compel the neuromuscular system to recruit motor units more efficiently, thereby enhancing the synchronization and coordination of muscle firing [45]. This, in turn, can lead to improved motor control and enhanced neuromuscular efficiency during the pitching motion, ultimately resulting in more precise and powerful throws. Additionally, these neural adaptations may enhance the timing and sequencing of the pitching motion, a critical factor in generating maximum speed and accuracy [46].

It is important to note that the use of weighted baseballs remains a subject of ongoing debate within the scientific and coaching communities [47]. While injuries were not consistently reported, concerns have been raised regarding the adaptations in internal and external shoulder torque and elbow torque, which raises safety concerns for players [48,49]. Additionally, in the unique study [32] that reported injury rates during weighted baseball training, 24% of participants suffered injuries during the sessions or after. These injuries included 2 olecranon stress fractures, 1 partial Ulnar Collateral Ligament injury, and 1 Ulnar Collateral Ligament injury for which surgical reconstruction was recommended. The latter participant chose to retire from baseball rather than undergo surgery. It is worth noting that two injuries occurred during the training sessions [32]. Therefore, the use of weighted baseball programs should be approached with caution, ideally under the guidance of knowledgeable coaches and with careful monitoring to balance the potential benefits with injury prevention strategies. The decision to incorporate weighted baseballs into a training regimen should be individualized and take into account the specific needs and goals of the pitcher.

Another approach to resistance-based training aimed at enhancing throwing velocity involves plyometric training and ballistic training [16,35–37] and the use of medicine balls [40] with pre-stretching activities to activate the stretch-shortening cycle. Upper plyometric training includes explosive exercises that focus on the upper body, such as clapping push-ups and medicine ball throws, designed to improve power, speed, and coordination in the arms, shoulders, and chest. Both plyometric and ballistic training methods may have the potential to stimulate fast-twitch muscle fiber recruitment [50] and optimize the timing and coordination of the pitching sequence, thereby translating into increased throwing velocity. Among the individual studies included in our systematic review, significant within-group improvements were found in three studies [35–37]. In comparison to controls, two studies revealed significant benefits [36,38] of these training methods, while two did not [37,40]. Additionally, Lust et al. [16] demonstrated that both Open Kinetic Chain/Closed Kinetic Chain Exercises and Open Kinetic Chain/Closed Kinetic Chain/Core Stability programs, which included plyometric training, led to significantly better throwing accuracy than the control group, despite the absence of significant within-group improvements.

Interestingly, also other training methods as using pulley (involves using a system of ropes and pulleys to perform resistance exercises that target the muscles) or weighted baseballs training did not contributed significantly for improving the throwing accuracy of the players [30,33]. Pulley training and weighted baseball training primarily focus on enhancing throwing velocity and strength, with limited impact on throwing accuracy. The scientific rationale behind this limitation may lies in the specific adaptations these methods induce in the musculature and mechanics involved in the pitching motion. While they can contribute to increased muscle activation, crucial for velocity, they may not directly translate to the fine motor control required for pinpoint accuracy. Throwing accurately necessitates precise coordination of various muscle groups and the ability to control the release point and ball spin, aspects not primarily addressed by these training methods [51]. Furthermore, alterations in mechanics and timing due to the additional weight can sometimes hinder accuracy [52].

Regarding the study limitations, it's important to note that the current systematic review includes individual studies that have several drawbacks. These drawbacks include the lack of consistent employment of randomization processes and the absence of reporting allocation concealment. Additionally, neither the experimenters nor the assessors were blinded to the process, which can introduce bias. Future research should aim to address these limitations and ensure a more robust study design.

Furthermore, future research in this area should focus on identifying the optimal training dosage required for individual improvements in throwing performance. Additionally, there is potential to combine different training methods to enhance both throwing velocity and accuracy simultaneously.

Lastly, it is imperative for future studies to include injury reports, as this would help in assessing the impact of training programs on injury risk. This information is vital for making informed decisions about the risk-benefit profile of employing specific training methods.

As practical applications, resistance training may play a pivotal role in enhancing throwing performance among baseball players, impacting various aspects of their game. For instance, strength and power gained from resistance training can significantly improve a player's ability to generate greater velocity during throws. This increased throwing speed can directly impact the player's effectiveness in both pitching and fielding. However, it is important to note that when incorporating resistance training into a player's regimen, caution must be exercised to avoid injuries. Special attention should be given to avoiding excessive loads or improper techniques, especially in the context of weighted baseball throwing, as the risk of injury increases. Balancing the advantages of resistance training with injury prevention measures is essential in optimizing a baseball player's performance and longevity in the sport.

5. Conclusions

The current systematic review has unveiled a consistent trend in various resistance-based training methods, including the use of weighted baseballs, plyometric training, and weight training. These methods have demonstrated a notable and consistent enhancement in throwing velocity when compared to control groups exposed to traditional baseball training. However, the research concerning the impact on throwing accuracy is notably scarce, and the few available reports indicate no significant within-group improvements, along with inconsistent differences in performance between the experimental and control groups. Furthermore, the solitary study that reported on injury rates within training programs disclosed a surprisingly elevated incidence of injuries in the experimental group employing weighted balls. While it is essential to recognize that generalization may be limited, this finding underscores the importance of including injury rates as a critical supplementary outcome when assessing the effects of training programs.

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CRediT authorship contribution statement

HongBo Zhang: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Qiang Jiang:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Ang Li:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

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