

Weighted-Ball Velocity Enhancement Programs for Baseball Pitchers

A Systematic Review

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Background: Weighted-implementation training utilizing over- or underweight baseballs has increased in popularity at all levels in competitive baseball. However, there is no consensus on the efficacy or safety of these training methods.

Hypothesis: This systematic review was intended to answer the following questions: Does weighted-ball training improve pitching velocity? Does weighted-ball training increase the risk of injury?

Study Design: Systematic review; Level of evidence, 4.

Methods: Searches were conducted with MEDLINE, EMBASE, and the ProQuest Physical Education Index. Articles were included if the study population consisted of adult, adolescent, or youth baseball pitchers training with under- or overweight baseballs, with velocity as a measured outcome. Articles were excluded if they were review articles, examined sports other than baseball, utilized weighted implements other than baseballs, or were not published in peer-reviewed journals. Included articles were at least level 4 evidence. Data extracted for qualitative analysis included training protocol parameters (such as ball weight, number of pitches, duration of training), velocity change, and injuries or complications reported.

Results: A total of 4119 article titles were retrieved, of which 156 were selected for abstract review. After manual removal of duplicates, 128 abstracts were reviewed. Of these, 17 met the inclusion criteria, and the full text was obtained. After full-text review, 7 additional articles were excluded, leaving 10 articles that met inclusion criteria and were included for analysis.

Conclusion: Weighted-implementation training increased pitching velocity in the majority of the included studies. However, the quality of available evidence was determined to be very poor, and there was marked heterogeneity in training protocols, ball weights, and study populations. There was inadequate evidence reported to determine the risk of injury with this type of training.

Keywords: baseball; pitching; weighted ball; velocity enhancement; throwing

Throwing velocity is one of the most prized characteristics of the competitive baseball pitcher. Each additional 1-mph increase in ball velocity decreases the batter's time to react

by about 4 milliseconds (roughly 1%). While this difference may seem modest, the difference between a hit and a strike is often measured in milliseconds. The quest to maximize this aspect of performance has been a focus of baseball players, coaches, and athletic trainers for generations, prompting multitudes of training philosophies, devices, and programs with varying degrees of success. The overhead baseball pitch is a complex motion requiring coordination of the entire body in a kinetic chain to produce explosive forces.⁴² Velocity is the product of a multivariate system in which the athlete's biology, mechanics, and kinematics all play a role. Among youth baseball pitchers, intrinsic features—such as age, height, separation of rotation in the hips and shoulders (during the cocking phase, the pitcher's hips rotate to face to the batter while the shoulders remain tangential), and stride length—were found to have significant influences on maximum pitch velocity.³⁵ Of the modifiable (and trainable) athlete characteristics, strength and power are consistently shown to be important contributors to throwing speed.^{4,6}

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One or more of the authors has declared the following potential conflict of interest or source of funding: C.S.A. has received research support from Arthrex, Major League Baseball, and Stryker; is a consultant for Arthrex; receives royalties from Arthrex and Lead Player; and has stock/stock options in At Peak. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

The Orthopaedic Journal of Sports Medicine, 7(2), 2325967118825469

DOI: 10.1177/2325967118825469

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To build strength and improve power, professional baseball players participate in a range of general and sport-specific training activities, including plyometric and resistance exercises.¹⁰ General strength training has been shown to improve throwing velocity in several sports, including baseball, cricket, water polo, and European handball.^{3,19,24} However, modern trends in training techniques have sought to improve efficiency and focus on sport-specific activities. For example, Hegedus et al²⁰ developed a golf-specific resistance training program, and although it did result in increased driver speed and distance, the degree of improvement did not differ from traditional training methods. Likewise, Escamilla et al^{11,12} conducted a series of studies demonstrating that a baseball-specific resistance training program improves throwing velocity over a 4- or 6-week training period, regardless of the specific program elements.

Weighted-ball throwing programs have generated excitement as a promising type of sport-specific resistance training for baseball pitchers. Weighted implements have been utilized for decades in training regimens for multiple sports with variable success.⁹ Australian rules football players practiced with weighted balls to increase kicking distance but found no improvement over standard balls.² Likewise, training with a heavy rugby ball failed to significantly improve youth rugby players' passing velocity relative to the same training with a regular ball.²² To improve the throwing velocity of cricket bowlers, Petersen et al³² used training with either over- or underweight balls but found no effect on speed. In a follow-up study, Wickington and Linthorne⁴⁴ hypothesized that the lack of positive outcomes was due to insufficient variation of ball weight, and they attempted a similar study with divergent weights, which yielded modest improvements in their small number of participants. Van den Tillaar and Marques⁴⁰ examined the effects of 3 training programs with various weighted balls on the overhead throw-in velocity for soccer players. After 8 weeks, the authors found no difference between training with weighted implements versus standard balls when the total workload of the workout was kept the same. A similar study was repeated with a youth population and showed that increased total workload was more important to enhancing performance than the specific weight of the implements used.⁴¹ The concept of total workload (defined as the mass thrown multiplied by the number of throws) as the critical variable for training effectiveness was reinforced by Marques et al,²⁸ who found that throwing velocity in water polo players increased proportionally with the total workload of their training program, regardless of the individual elements of the program. Similar positive results were found for ice hockey players who trained with a weighted puck, resulting in improved grip endurance in a randomized trial.³⁶

Within the baseball community, the use of over- or underweight baseballs as part of a sport-specific training program has ignited controversy. Proponents of this technique argue that it is a safe and effective method for increasing throwing velocity, while opponents point to a lack of credible evidence proving efficacy and worry about increased risk of injury. What is highly unknown is the training protocol and frequency needed for players to see

a sustained increase in velocity. Multiple authors have sought to examine the safety and effectiveness of weighted-ball training, but results in the literature have been mixed. The objective of this systematic review was therefore to answer the following questions: Does weighted-ball training improve throwing velocity in competitive baseball pitchers? Does weighted-ball training increase the risk of injury?

MECHANISM OF ACTION

While a standard baseball weighs 5 oz, published weighted-implement training programs have used varying combinations of balls, ranging from 4 to 32 oz. While the exact mechanism is not known, several hypotheses have been proposed to explain why these techniques may be effective. Fleisig et al¹⁷ suggested that underweight-ball training allows the pitcher to increase shoulder and elbow angular velocity, thus increasing recruitment and accelerating the firing pattern of fast-twitch muscle fibers throughout the throwing motion. Overweight balls, however, are thought to be more akin to resistance training. Van den Tillaar and Ettema³⁹ attributed the improvement with overweight training to "neurophysiologic adaptations" in response to an increase in the total workload (the total force over time or mass thrown multiplied by velocity), not the speed of the motion. Escamilla et al¹³ proposed that observed increases in pitching velocity after overweight-ball training is attributed to an increase in arm strength, similar to that seen after participation in weight-training programs. Indeed, this group demonstrated that conditioning programs targeted toward strengthening the rotator cuff also improved throwing velocity.^{11,12} Conversely, while Reinold et al³³ also noted an increase in velocity, they found that overweight-ball training either had no effect or, in the case of shoulder external rotation, actually decreased strength relative to a control group training with a standard-weight ball. They hypothesized that the improvement in velocity was due to a significant increase in passive shoulder external rotation, which was not seen in the control group. As the authors indicated, increased external rotation had been previously associated with increased pitching velocity.⁴³

METHODS

We conducted a systematic review of the literature according to the PRISMA (Preferred Reporting Items for Systematic Meta-Analyses) guidelines.²⁹ We determined our study protocol a priori; however, this study was not eligible for PROSPERO registration because it did not pertain to clinical outcomes. No external funding was sought or used for this study. We searched for terms including "weighted ball," "implement," "pitching," "velocity," "overload training," "ballistic resistance," "modified implement training," and combinations thereof. Searches were conducted with MEDLINE, EMBASE, and the ProQuest Physical Education Index. A representative search strategy is shown in the Appendix.

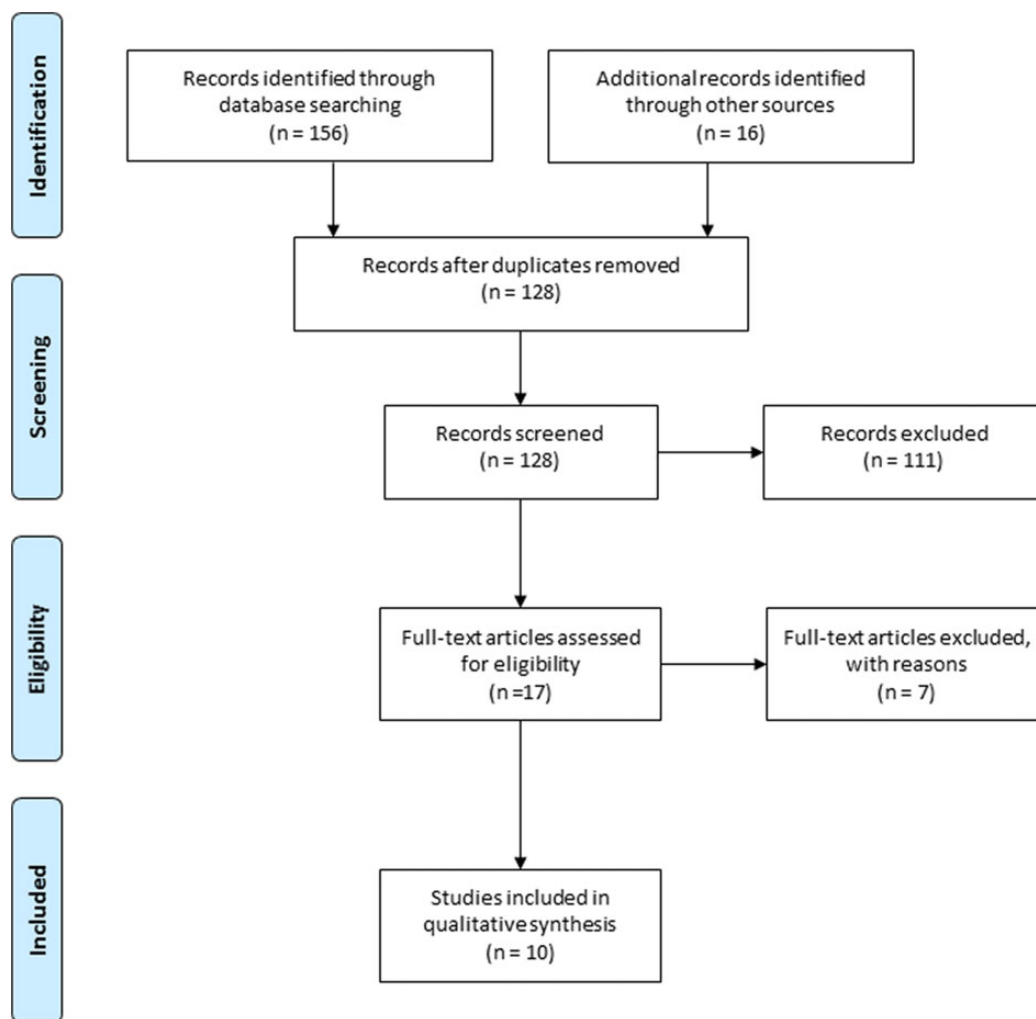


Figure 1. PRISMA (Preferred Reporting Items for Systematic Meta-Analyses) flowchart showing application of inclusion and exclusion criteria to search results.

Articles were included if the study population consisted of adult, adolescent, or youth baseball pitchers training with under- or overweight baseballs, with velocity as a measured outcome. Articles were excluded if they were review articles, were for sports other than baseball, utilized weighted implements other than baseballs, or were not published in peer-reviewed journals. We excluded material published outside of peer-reviewed journals, such as graduate theses, marketing materials, or sponsored research projects. We did not restrict our analysis to any particular level of evidence, since there are no known high-level trials addressing this topic.

A total of 4119 article titles were retrieved, of which 156 were selected for abstract review (Figure 1). After manual removal of duplicates, 128 abstracts were reviewed. Of these, 17 met inclusion criteria, and the full text was obtained. After full-text review, 7 articles were excluded for the following reasons: not containing velocity as a primary endpoint ($n = 4$), not being published in a peer-reviewed journal ($n = 1$), or not specifically utilizing weighted-ball

training ($n = 2$). Ten articles met inclusion criteria and were included in this study (Table 1). Data for extraction included training protocol parameters (duration of training, number of pitches thrown, weight of balls used), pitch velocity before and after training, and injuries reported. Included articles were assessed for quality according to the standards outlined in the Cochrane manual (Table 2).²¹ The quality of the body of literature was assessed with the terminology and guidelines proposed by the Grading of Recommendations Assessment, Development and Evaluation (GRADE) Working Group.¹

RESULTS

Velocity Enhancement

Ten studies were identified that met inclusion criteria for the primary endpoint (Table 1). Logan et al²⁶ examined a weighted-ball training program for pitchers as early as 1966. In their study, 19 college-aged pitchers were divided

TABLE 1
Summary of Included Studies

Study	Year	n	Level	Ball Weight ^a	Training Duration	Velocity Change, mph
Logan ²⁶	1966	19	College	2.5-5.5 lb (pulley)	4 wk	+9.28
Brose ⁵	1967	21	College	10-lb pulley, 10-oz ball	6 wk	No significant difference reported ^b
Straub ³⁷	1968	48	High school	7-17 oz, incremental	6 wk	No significant difference reported ^b
Litwhiler ²⁵	1973	5	College	7-12 oz, incremental	12 wk	+11.2
DeRenne ⁸	1990	30	High school	4-6 oz, incremental	10 wk	Underweight, +4.72; overweight, +3.75
DeRenne ⁷	1994	225	High school and college	4 or 6 oz	10 wk	+5 (approximate) ^c
Szymanski ³⁸	2011	21	High school	7 oz	8 wk	No significant difference reported ^b
Yang ⁴⁶	2013	24	High school	4.4 oz	10 wk	+2.1
Reinold ³³	2018	38	High school	2-32 oz, incremental	6 wk	+2.2
<i>Warm-up with weighted ball</i>						
Straub ³⁷	1968	60	High school	10 and 15 oz	20 pitches	No significant difference reported ^b
Morimoto ³⁰	2003	8	College	4.5 and 5.5 oz	6 or 18 pitches	+3 (approximate) ^c

^aA regulation baseball weighs 5 oz.

^bThe authors did not report quantitative velocity data.

^cApproximate values are used when only graphical presentations of the outcome measure were available in the report.

TABLE 2
Assessment of Potential Bias^a

Study	Bias						GRADE Quality
	Selection	Performance	Detection	Attrition	Reporting		
Logan ²⁶	High	High	Low	Unclear	High	Very low	
Brose ⁵	High	High	Low	Unclear	High	Very low	
Straub ³⁷	Unclear	High	Low	Unclear	High	Very low	
Litwhiler ²⁵	High	High	Low	Low	Unclear	Very low	
DeRenne ⁸	Unclear	High	Low	Low	Unclear	Low	
DeRenne ⁷	Unclear	High	Low	Low	Unclear	Low	
Szymanski ³⁸	Unclear	High	Low	Unclear	High	Very low	
Yang ⁴⁶	High	High	Low	Low	Unclear	Low	
Morimoto ³⁰	Unclear	High	Low	Low	Unclear	Low	
Reinold ³³	Unclear	Unclear	Low	Low	Low	High	

^aEach study was assessed for potential bias according to the guidelines in the Cochrane manual.²¹ An evidence grade was assigned according to the GRADE Working Group guidelines.¹

into 3 training groups: group 1 trained with a ball attached to a variable-weight pulley system, group 2 trained with a regular ball, and group 3 did not train at all. In both training groups, pitchers threw 30 pitches daily, 5 days a week, for a total of 4 weeks. In the resisted group, the initial resistance was set to 2.5 lb and increased 1 lb per week. At the conclusion of the study, group 1 (the resisted group) had a statistically significant increase in velocity of 9.2 mph relative to an improvement of 4.13 mph in the normal-ball group and no improvement in the control group.

Brose and Hanson⁵ evaluated 21 freshman collegiate baseball players from all positions and assigned them to a 6-week training program with a 10-lb pulley-resisted baseball, a 10-oz leaded baseball, or regulation balls. The players trained 3 times a week over 6 weeks and were tested at the conclusion of the training for velocity and accuracy. Although the authors did not report their data, they stated that there was "significant improvement" in

velocity in both overload groups with no change in accuracy. However, this improvement was not statistically significant relative to training with standard baseballs; thus, they concluded that the weighted-ball training was ineffective. Note that this study was profoundly flawed, as it did not include any quantitative analysis or reporting of data.

Straub³⁷ examined the immediate effects of overload warm-up as well as a 6-week overload training program. In the long-term training component of the study, 48 participants were divided into 1 of 4 groups: a control group and 3 overload groups that trained with progressively heavier balls with an emphasis on speed, accuracy, or both. The weighted baseballs were 7 oz during the first week and increased by 2 oz each week to a maximum of 17 oz during the sixth week. Participants trained 3 days per week for 6 weeks and were tested for velocity and accuracy. At the conclusion of the training period, there were no significant

improvements in speed or accuracy in the overload groups relative to the control group (exact velocities were not reported). Of note, the study population was chosen at random from the student body of a public school without regard for baseball experience or skill.

Litwhiler and Hamm²⁵ introduced a progressive weighted-ball training program in 5 collegiate baseball pitchers. The players trained 3 days per week for 12 weeks with weighted balls and regulation balls in each session. The weight of the balls began at 7 oz for the first 2 weeks, 9 oz for the second 2 weeks, and then increased by 1 oz per week for the remainder of the program to a maximum weight of 12 oz. At the conclusion of the 12-week program, velocity and accuracy were tested, and the authors reported a significant gain in pitch velocity of 16.4 ft/s (11.2 mph) as well as a trend toward increased accuracy. However, with their small sample size, the study had significant methodological flaws, including a lack of a control group, an interruption in the training program because of a school break, and no discussion of their statistical methods or data.

Interest in weighted-ball training increased again in the 1990s with a series of studies by DeRenne et al.^{7,8} Their first study prospectively evaluated 30 high school baseball pitchers over the course of a 10-week training program with regulation weight, progressively underweight, or progressively overweight baseballs. Pitchers trained 3 days per week. At each session, they warmed up with a regulation-weight ball and then threw 20 maximum-effort pitches with a regulation-weight ball, followed by 20 pitches with the altered-weight ball and then 10 pitches more with a regulation-weight ball. In the over- and underweight groups, the ball was increased or decreased, respectively, by 0.25 oz every 2 weeks, resulting in a maximum weight of 6 oz or a minimum weight of 4 oz by the end of the training period—a maximum difference of 20%. The authors found that both training groups had a statistically significant increase in velocity relative to the control group (overweight, 3.75 mph; underweight, 4.72 mph).⁸

The same author group followed up their findings with a larger sample, including high school and college-aged pitchers.⁷ They established 3 groups: a mixed training group, which used over- and underweight baseballs during training; a blocked training group, which used overweight balls for 5 weeks and then underweight balls for 5 weeks; and a control group, which used only regulation balls. For this study, the overweight balls weighed 6 oz; the underweight balls, 4 oz; and the standard balls, 5 oz (regulation). Training sessions occurred 3 days per week over 10 weeks. Each training session consisted of warm-up with a regulation ball, followed by altered-weight ball pitches and concluding with regulation-weight pitches with a total of 54 to 78 pitches per session. After a 10-week training period, the authors found significant increases in pitching velocity in the mixed and blocked training groups relative to the control group. The magnitude of the improvement was approximately 5 mph relative to negligible improvement in the control group, although the authors presented only a graphical summary of their results and exact values were not reported. They did not report any injuries. Of note, high

school and college athletes had similar improvements, while the control athletes' velocity did not significantly change over the course of the training.

Szymanski et al.³⁸ evaluated the addition of overweight implement training for 21 high school players as part of a progressive full-body resistance preseason exercise program. Athletes in both groups trained 3 times a week for 8 weeks (in addition to their regular practice sessions 6 days per week). Players in the overweight implement group used a 7-oz ball and a 5-oz ball (regulation) in a 2:1 ratio, while the control group used only the 5-oz ball. The volume increased from 54 to 72 throws per session over the course of the program. The other aspects of the training program were the same in each group. At the conclusion of the 8-week training period, there was no significant difference in throwing velocity between the groups, although a secondary outcome, bat speed, was higher in the overweight training group.

Yang et al.⁴⁶ set out to determine if a lighter baseball would improve the throwing performance and improve the safety of young pitchers. Twenty-four high school pitchers were recruited and divided evenly into a lightweight-ball training group (4.4 oz) and a regulation-ball training group (5 oz). Both groups trained 3 times per week for 10 weeks with pitch totals varying between 42 and 66 per week. After 10 weeks of training, the lightweight-ball group significantly increased its throwing velocity by approximately 2 mph and its maximum arm swing velocity by about 1 m/s. Accuracy and maximum external rotation remained the same in both groups.

Most recently, Reinold et al.³³ conducted a randomized controlled trial evaluating velocity, range of motion, strength, and injury profile of a weighted-ball training program. Thirty-eight healthy high school pitchers between 13 and 18 years old were randomized into a training or control group. Both groups were studied during the off-season and completed a throwing program that excluded pitching from the mound. The program consisted of a 6-week schedule of throws from 3 positions: knee, rocker, and run and gun. From each position, 2 or 3 throws were completed according to a progressive schedule of increasing intensity. The control group utilized a regulation baseball, while the training group used 2-, 4-, 6-, 16-, and 32-oz balls. Pre- and posttraining measurements, including elbow and shoulder strength and range of motion, were collected in triplicate and were found to have strong reliability based on intraclass correlation coefficients. Velocity was measured as the mean of 10 maximum-effort pitches from a mound with a standard baseball after the players' usual warm-up routine. At the completion of the study period, the throwers in the weighted-ball group improved velocity by 2.2 mph relative to 0.67 mph in the control group. External rotation strength in the weighted-ball group increased by only 3.9 N relative to a 12.8-N improvement in the control group. Additionally, the weighted-ball group experienced a 4.7° increase in shoulder external rotation, while the control group decreased by 1.2°. There were no other statistically significant differences in strength or range of motion, and accuracy was not measured.

Weighted Balls for Warm-up

Warm-up with an altered-weight implement has also been evaluated for pitchers. In another arm of the same study, Straub³⁷ looked at the immediate effects of warming up with an overweight ball (10 oz or 15 oz) relative to a standard ball. Participants completed a warm-up period with a standard baseball, followed by 20 warm-up pitches with a standard ball, 10-oz weighted ball, or 15-oz weighted ball and then immediately by maximum-effort pitches with a regulation ball. The authors found no significant improvement in pitch velocity in any group.

Morimoto et al³⁰ evaluated 8 pitchers over an 8-day period, testing a combination of warm-up routines involving either 6 or 18 pitches with a 10% overweight ball, 10% underweight ball, standard ball, or a combination thereof. They found that 6 or 18 warm-up pitches with a 10% underweight ball or 18 pitches with a combination of the over- and underweight balls significantly increased immediate subsequent pitch velocity relative to pitching with a standard or heavyweight ball alone (a difference of about 3 mph). They did not find any statistically significant difference in accuracy between the groups. The authors noted that in spite of the increased velocity, pitchers reported that the regulation ball felt heavier and seemed more difficult to pitch after warm-up with a lightweight ball.

Risk of Injury

The rate of shoulder and elbow injuries among baseball pitchers is high, with nearly 5% to 10% of them sustaining serious injuries requiring surgery or even retirement from baseball within 10 years.¹⁴ Pitchers are more than twice as likely as any other player to be injured.²³ A recent survey indicated that a majority of youth baseball players experienced arm pain while throwing or during the day after throwing, and nearly one-fourth had a previous overuse injury.²⁷ Described risk factors for youth baseball pitchers are largely related to overuse: number of innings pitched per year, pitch counts (per game and per season), multiple teams or overlapping seasons, and pitching while fatigued.^{15,18,45} However, little is known about the effect of weighted-ball training programs on injury rates.

The majority of the aforementioned studies did not comment on injuries or arm pain over the course of the study. Those that did mention injuries had none to report. While injuries were not a primary outcome of these studies, it is interesting to note that no injuries were reported in either the experimental groups or the control groups, which pitched exclusively with regulation baseballs. This could be because of the relatively short observation period of these studies or the relatively small sample sizes relative to the injury prevalence. A search of the literature revealed a single case report of a collegiate softball pitcher who developed an ulnar stress fracture attributed to weighted-ball training.³¹ The authors hypothesized that the increased mass of the ball magnified torsional and valgus loading on the distal ulna, resulting in stress fracture. However, the mechanics of underhand throwing involve pronation of the forearm coupled with flexion of

the wrist and fingers, which may not be comparable with the overhand throwing motion. Proximal ulnar stress fractures have been reported in baseball pitchers before but have never been specifically tied to weighted-implement training.³⁴

Fleisig et al¹⁷ conducted a biomechanical study with lightweight baseballs (4 oz) and found that using the lighter ball decreased the varus torque across the elbow of youth pitchers. This force is responsible for the greatest stress to the ulnar collateral ligament. In their follow-up study with under- and overweight baseballs and high school and collegiate pitchers, the authors found that as ball weight increased, angular velocity of the pelvis, upper trunk, shoulder, and elbow as well as torque across the elbow and shoulder decreased significantly. However, pitching position and mechanics did not change.¹⁶ The authors stated that although the weighted ball had greater mass, the decreased angular velocity and acceleration resulted in lower force and torque being applied across the athlete's elbow and shoulder relative to a standard ball. The authors did not comment on any injuries in their trials, although they hypothesized that the change in kinematics observed with the underweight baseballs may reduce the risk of injury among youth pitchers.¹⁷

The first study to formally address the question of injury with weighted-ball training is the recent randomized trial by Reinold et al.³³ Of the 38 athletes who participated, 4 in the training group did not complete the study: 2 because of elbow injuries sustained during the training program and 2 to non-throwing-related lower extremity injuries. The authors also found that 24% of the training group suffered a significant injury either during the training program or in the following season. Injuries included olecranon stress fractures and ulnar collateral ligament injuries, one of which was referred for surgical repair. In the same period, there were no injuries reported in the control group. The authors noted that athletes in the weighted-implement group increased shoulder external rotation by 4.7° over the course of a 6-week program. The same lead author had previously found similar range of motion changes among professional pitchers, but the changes occurred over an entire 8-month season. The significance of this rapid increase in external rotation is unclear, but Reinold et al³³ suggested that it may represent maladaptive damage to the static stabilizers of the shoulder.

SUMMARY OF THE EVIDENCE

Does Weighted-Ball Training Increase Throwing Velocity?

The included studies are summarized in Table 1. Pitching velocity was reported to improve in 7 of the 10 studies that utilized underweight, overweight, or a combination of baseballs in their training program. In the studies that showed benefit, the magnitude of improvement varied widely, from 2 to >11 mph over the course of the training program. However, the quality of the studies cited varied widely. There was marked variation of training protocols, pitch counts,

athlete level and experience, ball weights, and other variables, making direct comparisons of results difficult. While the majority of the studies we reviewed reported some beneficial effect on pitching velocity, it was difficult to determine what the ideal ball weight, training frequency, or training program parameters are.

All studies included in this review were assessed for bias with the guidelines proposed in the Cochrane manual for systematic reviews,²¹ and all were found to have a high risk of 1 or more types of bias (Table 2). Most studies had a high or unclear risk of selection bias owing to a lack of randomization or, in the cases where some form of randomization was attempted, little to no description of the randomization protocol. Several studies allocated athletes to different treatment groups based on author discretion. Two studies did not use treatment groups at all and can best be considered case series in which all participants underwent the same intervention.^{25,30} Most of the included studies had a high risk of performance bias, as the athletes, the observers, or both were not blinded. The only study to attempt blinding the participants was the case series by Morimoto et al.³⁰ However, in their study, the observers and authors were aware of the treatment condition throughout the testing. While it may be argued that blinding may be impossible, as the athletes could perceive the difference in ball weight, this is not necessarily true, given the relatively small variations in weight in most studies. Furthermore, the observers should be blinded to the treatment condition, especially when tasked with operating a radar gun or timing device to obtain the primary outcome measure. The risk of detection bias was judged to be relatively low across the body of literature because even though there was no blinding of the outcome assessment, the measurement was not likely to be influenced by this. The majority of the studies had complete follow-up and thus were at low risk for attrition bias; however, a few of the reports lacked enough detailed information to make a complete assessment. Finally, there was a high risk of reporting bias in several studies, as the primary outcome variable, velocity, was incompletely reported. For example, several reports included only a test statistic with no mention of mean or standard deviation for velocity change.^{5,26,37,38} Overall, given the significant methodological limitations and high risk of bias, the body of literature as a whole had a quality level of *very poor* per the GRADE Working Group guidelines.¹

Does Weighted-Ball Training Increase Injury Risk?

One of the most glaring unknowns is the dose-response characteristics of weighted-ball training. Overuse injuries are the product of not only the frequency of training but also the intensity. As it is, 25% of pitchers at the professional level have undergone ulnar collateral ligament reconstruction at some point in their careers. It is possible that implementing weighted-ball programs in the off-season could increase the overall risk of injury. The ideal protocol or “safe dose” remains unknown. Another factor to take into consideration is the player’s level of fitness prior to beginning a throwing program. If a player is deconditioned or is not in sufficient physical shape, injury risk may be increased

because of a lack of appropriate function throughout the kinetic chain. Most of the studies included in this review did not comment at all on injuries. Those that did, prior to the recent work by Reinold et al,³³ did not find any injuries to report. It is possible that the duration of prior studies (maximum, 12 weeks) is simply too short to capture the long-term effects of this type of training over the course of a season.

The results reported by Reinold et al³³ are particularly concerning. Not only were 2 of the athletes injured during the training program, but nearly a quarter of those in the weighted-ball program were injured in the subsequent season. One potential explanation for this finding is that the program in this study utilized balls weighing up to 16 and 32 oz, representing up to a 640% increase from a standard ball. These are far heavier than the $\pm 20\%$ (4-6 oz) described in most studies. It is possible that the extreme weight of these balls contributed to additional stress and, ultimately, injuries for the participants. However, given the heterogeneity of the available studies, determining the contribution of ball weight or any other training program parameter is difficult. Additional studies are needed with sufficient follow-up to determine if modified-weight weighted-ball training increases the risk of injury.

CONCLUSION

Professional teams as well as commercial product manufacturers and training facilities have championed weighted-ball training as a proven technique for safely improving pitching performance. Training programs utilizing an under- or over-weight baseball appear to result in increased velocity at the conclusion of the training program. However, the available literature varies widely in terms of the training protocols used, the duration of training, and the weight of the ball. Little is known about the long-term effects of weighted-ball training or its safety. New data are emerging suggesting that there could be a high rate of injury with these training techniques. It is likely there is a “safety envelope” of training program parameters within which positive adaptive changes can be realized and beyond which the risk of injury outweighs the benefit. Unfortunately, the boundaries of such an envelope are currently unknown. Overall, the quality of the available literature is very poor, and a recommendation cannot be made for or against the use of these programs without further carefully considered studies.

This systematic review has several limitations. In addition to the possible sources of bias previously discussed at the individual study level, there is a risk at the systematic review level for incomplete identification and retrieval of relevant literature, especially given that most of the studies on this topic are in journals not included in the major medical indexes. We attempted to minimize this by conducting our search on multiple databases with a variety of search terms and combinations. There is additional risk of reporting bias owing to our necessarily subjective application of inclusion and exclusion criteria. We sought to minimize the risk of this bias by defining explicit criteria a priori and requiring agreement between the primary authors (J.-M.E.C., F.J.A.), with the opinion of the senior author (C.S.A.) resolving any

disagreements. Additional well-designed and controlled studies are needed to further elucidate the effects of this type of training and its risk for injury. Caution should be exercised when embarking on any sport-specific training program, especially for youth athletes.

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APPENDIX

Sample Search Strategy Syntax Used in the MEDLINE Database

1	Baseball/	2148
2	Athletic Performance/	7929
3	1 and 2	158
4	pitching.mp.	826
5	weighted ball.mp.	9
6	overload training.mp.	78
7	ballistic resistance training.mp.	6
8	velocity enhancement.mp.	26
9	weighted implement.mp.	1
10	Resistance Training/	6061
11	1 and 10	17
12	from 3 keep 1-2, 22, 24, 56, 62, 84...	11
13	from 4 keep 19, 125-126, 174, 266, 272, 282...	33
14	from 6 keep 77-78	2
15	from 11 keep 5, 8-9, 13	4