BRIEF REVIEW

Contributing Factors for Increased Bat Swing Velocity

David J. Szymanski,[1] Coop DeRenne,[2] and Frank J. Spaniol[3]

[1]Department of Kinesiology, Louisiana Tech University, Ruston, Louisiana; [2]Department of Kinesiology and Leisure Science, University of Hawaii at Manoa, Honolulu, Hawaii; and [3]Department of Kinesiology, Texas A & M University–Corpus Christi, Corpus Christi, Texas

Abstract

Szymanski, DJ, DeRenne, C, and Spaniol, FJ. Contributing factors for increased bat swing velocity. *J Strength Cond Res* 23(4): 1338–1352, 2009—Bat swing velocity is an important characteristic of successful hitters in baseball and softball. The purpose of this literature review is threefold. First, before describing what components and training methods have been investigated to improve bat swing velocity, it is necessary to discuss the importance of bat swing velocity and batted-ball velocity. The second purpose is to discuss bat weight during on-deck circle warm-up, bat weight during resistance training, resistance training with an overload of force, performance of additional supplemental resistance exercises, the relationship between strength, power, lean body mass, and angular velocity and bat swing velocity, and the relationship between improvements in strength, power, lean body mass, and angular velocity and improvements in bat swing velocity. The third purpose of this review is to recommend some practical applications based on research results.

Key Words baseball, bat speed, resistance training, overweighted training, underweighted training

Introduction

In 1967, Breen (8) performed a cinematographic analysis to determine what mechanical attributes contribute to the movements involved in hitting a baseball effectively. He stated that 1 of the 5 attributes of successful hitting was greater bat velocity; this has been confirmed by DeRenne (15). A successful hitter was defined as a professional hitter who had a batting average greater than 300 (8). Others have defined a successful hitter as one who had a minimum batting average of 275 for more than 220 times at bat and/or superior skills shown through other hitting statistics, such as home runs, total bases, or slugging percentage (38,60). Since Breen's original work (8), the way in which baseball is played has remained virtually unchanged; however, the way in which baseball players train to enhance their performance has changed.

From the 1950s up until the late 1980s, anecdotal knowledge of baseball coaches suggested that baseball players should not lift heavy weights. In fact, players were instructed by coaches not to get muscle bound from lifting heavy weights because it was believed to decrease baseball performance (15). Today, middle school, high school, and collegiate baseball players' performance levels (e.g., bat and throwing velocities) have increased through strength training by applying the principles of overload, progressive resistance training, and specificity of training (14,17–20,22,29,42,51,54,55,58).

Even though baseball and softball players can develop strength through resistance training, the performance attribute that deserves greater attention for these athletes is the improvement of muscle power. Power is the combination of strength and speed. Power equals force applied multiplied by the velocity at which that force is applied. The force-velocity relationship is an important consideration in the production of muscle power. An inverse relationship exists between the amount of force produced and the velocity of application. Because of this relationship, there is a trade-off between force and velocity. Muscle power increases with increases in velocity, but only up to a certain point. Therefore, peak or maximum muscle power is produced by optimum force and optimum velocity (see Figure 1). Figure 1 is based on the force-velocity curve of muscle contraction described by Kreighbaum and Barthels (32).

Although there is a lack of "power" studies conducted on baseball players (29,41), the 2 components of power (strength and velocity) have been studied. Research results have revealed increases in bat swing velocity by applying the principle of specificity of training by using overweighted baseball bats to develop strength (18,23,42) and underweighted bats to enhance bat speed (18,42).

Furthermore, it is suggested that to develop muscle power in baseball players by using traditional resistance training regimens and equipment, high school and collegiate players should train somewhere in the middle of the force-velocity

Address correspondence to David J. Szymanski, dszyman@latech.edu.

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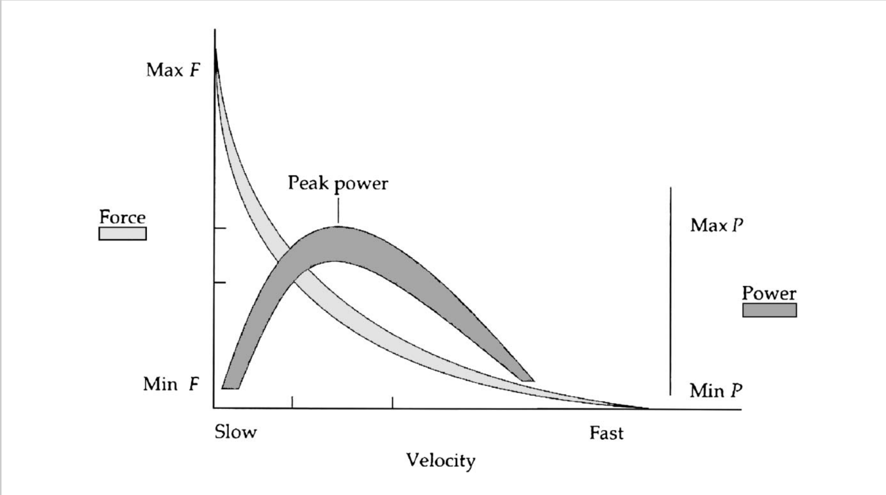

Figure 1. Interrelationship of force, velocity, and power (32). This interrelationship shows that peak power is produced by optimum force and optimum velocity.

curve (49). This means that training should occur with moderate loads (force) at relatively high velocities. However, the optimal resistance training program to develop power is debated. Baechle et al. (3) suggest that single-effort power events, such as swinging a baseball/softball bat, should use 80–90% of 1-repetition maximum (RM), whereas Bompa and Carrera (6) suggest using 50–80% of 1RM.

Baker (4) has stated, and DeRenne et al. have confirmed (22), that resistance training exercises can be classified into 3 categories; general, special, and specific. To develop optimal power, a combination of these 3 resistance training exercises should be implemented. *General* resistance training increases overall strength by using traditional exercises such as squats, bench press, and rows (2,51,54,55). *Special* resistance training is designed to develop power, once strength has been improved, through the use of explosive exercises such as ballistic resistance training like throwing medicine balls, Olympic lifts, and plyometric exercises (2,54). Finally, *specific* resistance training attempts to provide a training stimulus that mimics actual game motions and bioenergetic systems used to perform the activity. For hitting, this can be accomplished by using underweighted and overweighted baseball bats (13,14,18,23,42).

In this review, the different training effects of bat swing velocity studies with their results and shortcomings will be explored. The goals of this review are to discuss the importance of bat swing and batted-ball velocities, to give an overview effect of the different training protocols on bat swing velocity, to describe the relationship between strength, power, lean body mass, and angular velocity and bat swing velocity, to describe the relationship between improvements in strength, power, lean body mass, and angular velocity and improvements in bat swing velocity, and to give some practical applications based on the findings reviewed.

This review does not cover annual periodized resistance training for the baseball/softball player. Interested readers are encouraged to see books by Bompa and Carrera (6) and DeRenne (15).

Literature for this review was compiled by searching the databases MedLine and Sport Discus. The search in these databases was performed on the following words: baseball, bat speed, bat swing velocity, bat velocity, batted-ball velocity, and softball. Together with this search, published articles were collected from references from other relevant articles. Literature on bat swing velocity from baseball and softball is used in this paper because individuals playing or coaching both sports would be interested in this topic.

Forty abstracts, papers, and books related to baseball and softball bat swing and batted-ball velocity were found. Before describing what components and training methods have been investigated to improve bat swing velocity, it is necessary to discuss the importance of bat swing velocity and batted-ball velocity.

Importance Of Bat Swing Velocity

According to investigators (1,8,15,18,28) and coaches (30,37,40), one way in which a baseball (or softball) player can become a successful hitter is to improve his or her bat swing velocity. Three direct benefits of increased bat swing velocity are increased decision time, decreased swing time (assuming swing mechanics have not been changed) (28,37), and increased batted-ball velocity (1,38).

Increased Decision Time

In 1990, Will (62) described how remarkable it is to hit a pitched baseball. If a baseball pitcher throws a 40.2-$m \cdot s^{-1}$ (90 mph) fastball that leaves his or her hand 16.8 m (55 ft) from home plate, it will reach home plate in 0.4167 seconds. A change-up or slow-breaking ball thrown at 35.7 $m \cdot s^{-1}$ (80 mph) will cross home plate in 0.4688 seconds. The difference of 0.052 seconds is crucial to the timing of the hitter. Within this short span of time, hitters must contend with 3 variables. They must identify the type of pitch thrown (i.e., fastball, change-up, breaking ball), the velocity of the pitch, and the location of the pitch. Hitters have to process all of this information and decide whether to swing the bat. The time that the hitter has to evaluate the pitched ball and decide whether to swing is called decision time (28). Decision time lasts between 0.26 and 0.35 seconds for major league hitters

(8). The longer the hitter can wait before swinging, the more likely it is that the hitter will swing at a ball in the strike zone (be more accurate at contact) and arrive on time, which are the 2 most important goals in successful hitting (15). Therefore, the player's ability to wait longer to swing should increase his or her accuracy and timing and should lead to better overall performance (8,60).

Decreased Swing Time

Once a hitter decides to swing, he or she must then physically adjust the swing of the bat to hit the pitched ball. The time needed to do this is called swing time (8,60). Specifically, swing time is the time it takes for the distinct change of the bat's path, known as the slope of the swing, to travel in the opposite direction to ball contact. Swing time is inversely proportional to decision time. The less time it takes to swing the bat, the longer the hitter's decision time, assuming the velocity of the pitched ball stays the same. In general, if a high school baseball pitcher throws a fastball at 35.7 $m \cdot s^{-1}$ (80 mph), which takes about 0.50 seconds to cross home plate, the hitter has a decision time of 0.20 seconds because his or her swing time is about 0.30 seconds (55). Three reasons why young baseball batters have longer swing times is that they typically have less physical strength, have slower bat swing velocity, and do not have swing mechanics that are as good as those of more experienced, mature professional baseball hitters (15). According to Breen (8), major league baseball hitters have swing times of 0.19–0.28 seconds. If a hitter could decrease the swing time, he or she would have a longer decision time, which would allow him or her to be more selective in the batter's box. This would directly affect the hitter's ability to identify the type of pitch thrown, the velocity of the pitch, and the location of the pitch, thus increasing the possibility of being more accurate at bat-ball contact. If a hitter does not swing at balls outside of the strike zone, he or she has a greater chance of getting on base because of a possible walk (4 pitched balls outside the strike zone is a walk), or it simply might allow him or her to select a better pitch to hit. However, it must be stated that even if a hitter does decrease his or her swing time, this does not mean that the hitter's batting average will increase.

Increased Batted-Ball Velocity

The third benefit of increased bat swing velocity is an increase in batted-ball velocity. According to Adair (1), if a hitter could swing a heavier bat at the same velocity as his or her standard game bat, or if a hitter could swing his or her standard game bat faster because of increased bat swing velocity, the ball would either travel farther, be hit harder, or both, because of the larger transfer of momentum imparted into the ball. For example, Adair (1) describes the distance a fastball thrown at 37.9 $m \cdot s^{-1}$ (85 mph) would travel if it were hit at the center of percussion (COP; a sweet spot about 27.25 in from the bat handle) by a 35-in, 32-oz wooden bat at various swing velocities. A wood bat swing velocity of 26.8, 31.2, 35.7, and 40.2 $m \cdot s^{-1}$ (60, 70, 80, and 90 mph) would translate to a ball traveling 99.1, 114.3, 134.1, and 152.4 m (325, 375, 440, and 500 ft), respectively. Interestingly, Adair (1) states that an aluminum bat, which is used in high school and college baseball, would cause the ball to travel an extra 9.1 m (30 ft) farther than wood. This is attributable to increased bat swing velocity (aluminum bats are lighter than wood bats of the same length and can be swung faster) (11,36) and the inherent elastic property (deformation of the bat wall will cause less deformation of the baseball, resulting in less energy loss by the ball and higher batted-ball velocities) of aluminum bats (11).

In summary, if hitters could increase their bat swing velocity, they would decrease their swing time (as long as swing mechanics do not change) and increase their decision time and batted-ball velocity (as long as bat-ball contact is made on the COP of the bat; this subject is discussed later in this article).

Batted-Ball Velocity

As mentioned earlier, 1 of the 3 benefits of improving bat swing velocity is an increase in batted-ball velocity. Batted-ball velocity has been investigated by many researchers. Studies have examined the effects of bat composition and impact location on batted-ball velocity (10,11,25,27,34,36). Researchers (2,7,39,45–47,52,56,57) have identified performance variables that distinguish elite, advanced, and novice baseball and softball players from one another. One performance variable that is pronounced is greater batted-ball velocity.

Five investigations have studied the effects of bat composition on batted-ball velocity (10,11,25,27,36). Each study has reported that batted-ball velocity was greater when using an aluminum bat as opposed to a wood bat. Crisco et al. (11) indicate that because aluminum bats of the same length as wood bats weigh less, they produce greater batted-ball velocities because of the increased bat swing velocity and the inherent elastic property of the bats. Simply stated, it is believed that the barrel walls of aluminum bats have greater deformation than the barrels of wood bats, resulting in less energy loss by the ball and higher batted-ball velocities (11). According to Fleisig et al. (25) and confirmed by Nicholls et al. (36), aluminum bats also have lower moments of inertia, which are more associated with bat swing velocity than bat weight is. The moment of inertia is a measure of how the bat weight is distributed along the bat's length and swing weight: the higher the moment of inertia, the heavier the swing weight. Thus, bats with higher moments of inertia (wood bats) are swung at lower bat velocities.

In a related study, Weyrich et al. (61) have reported that postimpact ball velocity, using static conditions, was increased when using a wood bat. Their results are in opposition with those mentioned above. Weyrich et al. (61) believe that the superior results found in the other 5 studies (10,11,25,27,36) for aluminum bats may have been attributable to the lighter bat weight, which resulted in an increased bat swing velocity and subsequent increased batted-ball velocity. The differences found between Weyrich et al. (61) and the other 5 studies are most likely attributable to the fact that, in their study, all bats were held stationary by a vise (tight tension) or were hung stationary (no tension) by fishing line at the pivot point while the end of the bat rested on a knife edge. In the other 5 investigations, batted-ball velocity was studied in a realistic, dynamic setting (players swinging bats).

Besides examining bat composition, 4 studies have investigated the effect of impact location on the bat to batted-ball velocity (9–11,34). Batted-ball velocity vs. impact location has been shown to have a curvilinear relationship for wood bats, indicating the existence of a region on the barrel of the bat associated with the largest rebound effect, meaning the fastest batted-ball velocity (11). In lay terms, this region is called the sweet spot of the bat. The location of the sweet spot has long been a topic of debate. The sweet spot has typically been defined as the location on the bat that produces the greatest batted-ball velocity (11). Previous research (9,12,59) has predicted that this location corresponds to the COP and/or the node of the lowest vibration. Other research has defined the sweet spot as the location that minimizes the total energy lost to bat vibration and the location that produces the maximum postimpact ball velocity (34,61). For the remainder of this review of literature, the sweet spot of the bat is referred to as the COP. Because the length, mass, and composition of every bat are different, the COP has been located in a region about 10.2–17.8 cm (4–7 in) from the end of a wood or aluminum bat (10,11,34,61). According to Crisco et al. (11), there was not a significant difference in the location and size of the COP between wood and aluminum bats. Performance within the COP seems constant and has been shown to produce the greatest batted-ball and postimpact ball velocities (10,11,34,61). According to Crisco et al. (11), outside of the COP, maximum batted-ball velocity decreased at a rate of about 4.5 $m \cdot s^{-1}$ (10 mph) for every 2.5 cm (1 in).

In contrast to the results mentioned above, Brody (9) has suggested that the maximum power point on the bat–the point at which batted-ball velocity was greatest–was located somewhere between the COP and the batter's hands.

Now that the importance of bat swing velocity and batted-ball velocity have been described, several areas of research will be examined that contribute to our knowledge regarding bat swing velocity. Research has been conducted on the following topics related to bat swing velocity: bat weight while in the on-deck circle, bat weight during resistance implement training, resistance training with an overload of force, performance of additional supplemental resistance exercises, the relationship between strength, power, lean body mass, and angular velocity and bat swing velocity, and the relationship between improvements in strength, power, lean body mass, and angular velocity and improvements in bat swing velocity (see Tables 1–6 for a summary of the different studies in the various categories).

Bat Weight: On-Deck Circle Warm-Up

Five baseball studies have investigated the effects of warming up with various weighted bats in the on-deck circle on bat swing velocity (14,16,21,33,44). Each of these studies used different weighted bats, which are shown in Table 1, before swinging a "standard" (850.5 g, or 30 oz) bat (14,16,21), a "normal" (893.0 g, or 31.5 oz) bat (33), or a "standard" (963.9 g, or 34 oz) bat (44). The overload devices that were used in all of these studies were a 474.9-g (16¾-oz) donut ring, a 793.8-g (28-oz) donut ring, a 907.2-g (32-oz) air-resistance Power Swing, a 113.4-g (4-oz) Power Sleeve, a 963.9-g (34-oz) weighted bat, a 1360.8-g (48-oz) wooden bat, and 6 aluminum lead bats weighing 1190.7, 1275.7, 1360.8, 1445.8, 1564.9, and 1587.6 g (42, 45, 48, 51, 55.2, and 56 oz), respectively. The lighter bats in these studies weighed 272.2, 340.2, 652.0, 708.7, 765.4, and 822.1 g (9.6, 12, 23, 25, 27, and 29 oz), respectively. The results of 4 studies (14,16,21,44), presented in Table 1, reveal that average game bat swing velocity was increased for high school, college, and ex-college baseball players after warming up in the on-deck circle using under- and overloaded bats within ±12% (27–34 oz) of standard game bat weight (30 oz). In addition, DeRenne and colleagues (14,16,21) have concluded that very heavy (donut ring and 1445.8-g, or 51-oz, bat) or very light (652.0 g, or 23 oz) warm-up implements had adverse effects (decreases of 2.2 $m \cdot s^{-1}$, or 5 mph, slower) on standard game bat (850.5 g, or 30 oz) velocity. Montoya et al. (33) have reported that swinging a light (272.2 g, or 9.6 oz) or normal (893.0 g, or 31.5 oz) bat produced the highest bat swing velocities compared with a heavy (1564.9 g, or 55.2 oz) bat in the on-deck circle. Southard and Groomer (44) have reported that after warming up with a weighted bat of 15.6 N (56 oz), standard bat (9.1 N, or 34 oz) moment of inertia significantly increased, and bat swing velocity significantly decreased. It must be stated that the "normal" bat used in Montoya et al.'s (33) study and the "standard" bat used in Southard and Groomer's (44) study were both overloaded bats because they were either 1.5 or 4 oz heavier than the "ordinary standard high school or college" game bat reported by DeRenne and colleagues (14,16,21). Southard and Groomer (44) have concluded that baseball batters should warm up with their respective standard game bats and that using a bat with a larger moment of inertia will reduce bat velocity and change the batter's swing pattern. Montoya et al. (33) also suggest not swinging a heavy bat in the on-deck circle because it produced the slowest bat swing velocities. These results and conclusions partly support the findings of DeRenne et al. (14,16,21), which suggest that players should warm up by swinging bats that are ±12% of their standard game bat weight (30 oz) before game competition.

Warm-up with appropriate-weight implements in high school and collegiate women's softball has not been researched. This may be because women softball players have many warm-up implement options and a wide range of

Table 1. Effect of bat weight swung in the on-deck circle on bat swing velocity.

Reference	Sport	Sex	*n*	Age	Level	Devices and weight	Results
DeRenne (14)	Baseball	Men	23	N/A	College and ex-college	Donut ring (16¾ oz) Power swing (32 oz) Weighted bat (34 oz) Light bat (23, 25, and 27 oz)	Swing bat within ±13% (34–27 oz) of game bat
DeRenne and Branco (16)	Baseball	Men	20	N/A	College	Donut ring (16¾ oz) Power swing (32 oz) Power sleeve (4 oz) Weighted aluminum bat (34, 42, 45, 48, and 51 oz) Underloaded aluminum bat (23, 25, 27, and 29 oz)	25- and 27-oz bats produced greatest bat velocities.
DeRenne et al. (21)	Baseball	Men	60	16–18	High school	Donut ring (28 oz) Power swing (32 oz) Power sleeve (4 oz) Weighted aluminum bat (34, 42, 45, 48, and 51 oz) Underloaded aluminum bat (23, 25, 27, and 29 oz)	Bats within ±13% of game bat produced greatest bat swing velocities. Bats lighter than 27 oz and heavier than 34 oz produced slowest bat swing velocities. Bats weighing 23 and 51 oz and bat with donut ring produced slowest bat swing velocities.
Montoya et al. (33)	Baseball	Men	19	20–28	Recreational	Light bat (9.6 oz) Normal bat (31.5 oz) Heavy bat (55.2 oz)	Light and normal bat produced the fastest bat swing velocity.
Southard and Groomer (44)	Baseball	Men	10	20–25	College	Standard bat (9.1 N) = 33 oz Donut ring (15.6 N) = 56 oz Hollow plastic bat (3.34 N) = 12 oz	Standard bat produced the fastest bat swing velocity. Donut ring produced the slowest bat swing velocity.

Table 2. Effect of training with overweighted and underweighted bats on bat swing velocity.

Reference	Sport	Sex	*n*	Age	Level	Duration (wk)	No. of swings per week	Bat weight (% of regular bat)	Control group	Significant increase (%)
Group A: Overweight training										
DeRenne and Okasaki (23)	Baseball	Men	10	N/A	Ex-college and pro	7	240	32-oz power swing (8%) 34-oz weighted bat (12%)	No	Yes (N/A)
Sergo and Boatwright (42)	Baseball	Men	8	19.4 (1.1)	College	6	300	62 oz (100%)	Yes; same amount of swings with game bat of athlete's choice	Yes (8.0)
Szymanski et al. (53)	Softball	Women	18	19.5 (0.7)	College	4	600	30 oz balanced (13%) 30 oz unbalanced (13%)	No	No
Group B: Overweight and underweight integral training										
DeRenne et al. (18)	Baseball	Men	40	19.5 (0.3)	College	12	600	Batting practice and dry swings 31–34 and 27–29 oz (±12%)	Yes; same amount of swings with 30-oz bat	Yes (6–10)
Sergo and Boatwright (42)	Baseball	Men	8	20.1 (2.1)	College	6	300	62 oz (100%) and fungo	Yes; same amount of swings with game bat of athlete's choice	Yes (8.2)

TABLE 3. Effect of resistance training on bat swing velocity.*

Reference	Sport	No. of participants (sex)	Age	Level	Duration (wk)	Type of resistance training	Sessions per week	Weight	Control group	Significant increase (%)
Group A: Resistance training with increasing weight (pyramid training)										
Schwendel and Thorland (41)	Untrained	15 M 15 W	18–28	College	7	Full-body: 8 exercises; power resistance training (machines)	3	80% 1RM (3× 5, 3, 1 reps)	Yes; no training	Yes; M power (7.9)
Szymanski et al. (51)	Baseball	15 M	15.9 (1.0)	High school	12	Full-body: 7 exercises; stepwise model: 3 × 10, 3 × 8, 3 × 6; 315 dry swings per week with game bat	3	65–85% 1RM	Yes; trained	Yes (4.2)
Szymanski et al. (54)	Baseball	24 M	15.4 (1.2)	High school	12	Full-body: 7 exercises; stepwise model: 3 × 10, 3 × 8, 3 × 6; 300 dry swings per week with game bat	3	65–85% 1RM	Yes; trained	Yes (3.6)
Szymanski et al. (55)	Baseball	20 M	15.3 (1.2)	High school	12	Full-body: 7 exercises; stepwise model: 3 × 10, 3 × 8, 3 × 6	3	65–85% 1RM	Yes; trained	Yes (3.2)
Group B: Resistance training with 3 × 10RM										
Hughes et al. (31)	Baseball	11 M	19.7 (1.3)	College	6	Full-body: 8 exercises	3	3 × 10 using 10 RM	Yes	No
Schwendel and Thorland (41)	Untrained	15 W	18–28	College	7	Full-body: 8 exercises; traditional (machines)	3	3 × 10	Yes; no training	No

M = men; W = women; RM = repetition maximum.

TABLE 4. Effect of training on bat swing velocity for the studies with additional supplemental resistance training exercises.

Reference	Sport	No. of participants (sex)	Age	Level	Duration (wk)	Type of resistance training	Sessions per week	Weight	Control group	Significant increase (%)
Hughes et al. (31)	Baseball	12 men	19.7 (1.3)	College	6	Full body: 8 exercises; 6 grip and forearm exercises	3	3 × 10 using 10RM	Yes	No
Stuempfle et al. (48)	Softball	8 women	20.1 (1.6)	College	8	135 hydro swings per week	3	Water resistance	Yes; no training	No
Szymanski et al. (50)	Untrained	12 men, 20 women	21.8 (2.1)	College	8	Additional weight added to forearms while taking 315 dry swings per week with game bat	3	4 oz every 2 wk or 8 oz every 2 wk	Yes; same amount of swings with 30- or 23-oz bat	Yes (7.8)(6.6)
Szymanski et al. (51)	Baseball	15 men	15.7 (1.0)	High school	12	Full body: 7 exercises; stepwise model: 3 × 10, 3 × 8, 3 × 6; additional weight added to forearms while taking 315 dry swings per week with game bat	3	65–85% 1RM; 4 oz every 2 wk	Yes; trained	Yes (6.0)
Szymanski et al. (54)	Baseball	25 men	15.4 (1.2)	High school	12	Full body: 7 exercises; stepwise model: 3 × 10, 3 × 8, 3 × 6; 300 dry swings per week; 4 rotational medicine ball exercises	3	65–85% 1RM	Yes; trained	Yes (6.4)
Szymanski et al. (55)	Baseball	23 men	15.4 (1.1)	High school	12	Full body: 7 exercises; stepwise model: 3 × 10, 3 × 8, 3 × 6; 7 grip and forearm exercises	3	65–85% 1RM	Yes; trained	Yes (3.5)

RM = repetition maximum.

TABLE 5. Relationship between strength, power, lean body mass, and angular velocity to bat swing velocity.

Reference	Sport	No. of participants (sex)	Age	Level	Performance variable(s)	Significant relationship
Albert et al. (2)	Softball	19 women	9.2 (1.0)	College	Grip strength	No
					Upper-body strength	No
					Lower-body strength	No
					Lower-body power	No
					Lean body mass	No
Basile et al. (5)	Baseball	14 men	N/A	College	Lower-body strength	Yes
					Lean body mass	Yes
Bonnette et al. (7)	Baseball	23 men	20.6 (1.3)	College	Grip strength	Yes
					Rotational power	Yes
					Lean body mass	Yes
Giardina et al. (26)	Softball	18 women	20.3	College	Grip strength	No
Hughes et al. (31)	Baseball	23 men	19.7 (1.3)	College	Grip strength	No
Reed et al. (39)	Baseball	19 men	21.5 (2.0)	College	Grip strength	Yes
		28 women			Lean body mass	Yes
Spaniol (45)	Baseball	425 men	15.1 (1.3)	Adolescent	Grip strength	Yes
					Upper-body power	Yes
					Lower-body power	Yes
Spaniol et al. (46)	Baseball	566 men	15.6 (1.2)	High school	Grip strength	Yes
Spaniol et al. (47)	Baseball	34 men	20.6 (1.3)	College	Grip strength	Yes
					Lower-body power	Yes
					Lean body mass	Yes
Szymanski et al. (52)	Baseball	39 men	19.9 (1.3)	College	Grip strength	Yes
					Upper-body strength	No
					Lower-body strength	No
					Lower-body power	No
					Lean body mass	Yes
Szymanski et al. (56)	Baseball	49 men	15.4 (1.1)	High school	Torso rotational strength	Yes
					Lower- and upper-body strength	Yes
					Torso rotational power	Yes
					Lean body mass	Yes
					Angular hip velocity	Yes
Szymanski et al. (57)	Baseball	30 men	15.4 (1.2)	High school	Grip strength	Yes
					Upper-body strength	Yes
					Lower-body strength	Yes
					Lean body mass	Yes

game bats to select. According to the 2009 National Collegiate Athletic Association (NCAA) softball rules book (35), softball bats cannot be greater than 34 in long or exceed 38 oz in weight. A standard weight to length has not been established by the National Federation of State High School Association and the NCAA. However, the Amateur Softball Association (ASA), the U.S. national governing body for softball, has set a bat performance standard of a maximum batted-ball speed limit of 98 mph (35). Bats that do not meet this bat performance standard are illegal in ASA championship play.

BAT WEIGHT: RESISTANCE IMPLEMENT TRAINING

Four studies, 3 on baseball (18,23,42) and 1 on softball (53), have evaluated the effect of weighted implements used as a form of specific resistance training on bat swing velocity. These 4 weighted implement training studies adhered to the principle of specificity. Each of these studies used different training protocols and durations, which are shown in Table 2. Two of the 4 studies used a "classic" control group that did not perform any training. However, all studies compared at least 2 groups with one another with some form of control (normal training) to treatment (additional training). These studies can be categorized into 2 groups. Group A (23,42,53) used overweighted bats weighing 8–100% more than standard game bat weight. Group B (18,42) used both underweighted bats, which were either a baseball practice fungo bat or bats weighing as light as −12% of the standard game bat, and overweighted bats, which weighed as much as 100% more than standard game bat weight.

TABLE 6. Relationship between improvements in strength, power, lean body mass, and angular velocity to improvement in bat swing velocity.

Reference	Sport	No. of participants (sex)	Age	Level	Performance variable(s)	Significant relationship
Albert et al. (2)	Softball	19 women	19.2 (1.0)	College	Grip strength	No
					Upper-body strength	No
					Lower-body strength	No
					Lower-body power	No
					Lean body mass	No
Reed et al. (39)	Baseball	19 men	21.5 (2.0)	College	Grip strength	No
		28 women			Lean body mass	No
Szymanski et al. (54)	Baseball	49 men	15.4 (1.1)	High school	Torso rotational strength	Yes
					Torso rotational power	Yes
					Angular hip velocity	Yes
Szymanski et al. (55)	Baseball	43 men	15.4 (1.2)	High school	Grip strength	No
Szymanski et al. (57)	Baseball	30 men	15.4 (1.2)	High school	Grip strength	No
					Upper-body strength	No
					Lower-body strength	Yes
					Lean body mass	No

A. Overweight Training. In this category, the results of 2 studies revealed an increase in bat swing velocity after the specific training protocol (23,42). However, in contrast, 1 study (53) did not. Even though the total volume of softball swings (2400) was similar to that in Sergo and Boatwright's study (42), it is probable that the results of the softball study (53) did not demonstrate an increase in bat swing velocity with women collegiate softball players because the training period was only 4 weeks. Typically, 6–8 weeks of training is needed to demonstrate muscular adaptations. DeRenne and Okasaki (23) have reported a significant increase in bat swing velocity among 10 ex-college and professional baseball players after 7 weeks of swinging weighted implements. The overload implements were 1) an unreported, weighted wooden bat of 34 oz, which was 12% greater than the average standard game bat (30 oz) used by the subjects and which was used in subsequent research studies (16,21), and 2) a commercial air-resistance power swing device. Sergo and Boatwright (42) conducted a 6-week weighted implement training study with collegiate baseball players using either a standard game bat (29–31 oz) or an overloaded bat weighing more than 100% standard game bat weight (62 oz). The reported results indicate that both training groups significantly increased bat swing velocity by 8.8 and 8.0%, respectively. Two interesting points need to be discussed. First, the investigators may have assumed and/or not known that their 31-oz test bat, though legal (NCAA standard bat weight range at the time of the study was 29–31 oz), may have been an overloaded bat to some of their respective subjects, because the most popular collegiate game bats used in the 1990s weighed 29–30 oz (18). Second, the investigators have reported that there were no significant differences between groups, yet the control group, which had the greatest bat swing velocity increase (8.8%), trained with the standard bat (bat range of 29–31 oz) of their respective choice. Therefore, the control subjects who trained with a bat weight of 29 or 30 oz actually may have trained with underweighted bats while testing with an overloaded bat of 31 oz.

B. Overweight and Underweight Integral Training. In this category, both studies reported a significant increase in bat swing velocity after training with overweighted and underweighted bats (18,42). In each study, 100 swings per session were taken with the overweighted and underweighted bats. In the study by DeRenne et al. (18), players took 50 additional swings with their standard game bat (30 oz) for a total of 150 swings. There was a 2:1 ratio of overweighted and underweighted bat swings to standard game bat swings. The average bat swing velocity increase reported in these studies ranged from 6–10%. DeRenne et al. (18) used 3 groups: a dry swing, a batting practice, and a control group. The group that took batting practice increased 4% more than the dry swing group. The 10% improvement accomplished by the batting practice group is the most of any bat swing velocity study to date. It was hypothesized that the additional improvement was attributable to actually hitting baseballs with the intent of hitting the baseball hard and/or far. The dry swing group swung their bats through the air without hitting a baseball.

Sergo and Boatwright (42) reported that all 3 groups in their study, including the control group, improved bat swing velocity between 8.0 and 8.8%. However, it must be stated that their control group may have swung under-weighted bats of 29–30 oz as compared with the testing bat of 31 oz. Sergo and Boatwright (42) have concluded that players could swing any bat 100 times a day, 3 times a week, for 6 weeks (1800 total swings) and improve bat swing velocity. This is in contrast to what DeRenne et al. (18) have reported: the control group in their study took 150 swings a day, 4 times a week, for 12 weeks (7200 total swings) with a standard game bat (30 oz) and did not significantly improve bat swing velocity.

In summary, the data presented in Table 2 (groups A and B) indicate that swinging an overweighted or an overweighted and underweighted bat 240–600 times a week for 6–12 weeks produced increases in bat swing velocity. Training studies with overweighted or overweighted and underweighted bats have used various weighted implements but have reported similar findings (18,23,42). In the studies by DeRenne and colleagues (18,23), bat weight was within $\pm 12\%$ of standard game bat weight. These percentages of standard-weight implements are based on DeRenne and colleagues' (16,17,20) under- and overweighted implement training results in baseball hitting and pitching. Sergo and Boatwright (42) have reported that any bat swung 300 times a week for 6 weeks would increase bat swing velocity. However, there is some concern by coaches and researchers that the over-weighted bat (62 oz) used in that study may cause players to alter their swing mechanics (15,18). From a practical standpoint, the batting practice program designed by DeRenne et al. (18) seems to be the most appropriate to use while players are practicing on the field. Other programs, such as the dry swing protocol from DeRenne et al. (18), may be more appropriate to use while at various hitting stations or, possibly, in or outside the weight room during resistance training sessions. An explanation for the results of DeRenne and colleague's bat velocity studies is that baseball hitting is a high-velocity ballistic movement in which velocity is directly related to optimal performance. Although the neurophysiological mechanism for increasing movement velocity is not fully understand at this time, some researchers (24) indicate that peak output of fast-contracting muscle fibers can be 4 times greater than that of slow fibers. Furthermore, it has been suggested that highly specific fast movements could recruit and fire high-threshold motor units (43). In DeRenne et al.'s (18) study, the weighted bats used in precise combinations significantly increased bat swing velocities. This may indicate that a greater exertion of muscle force at high speeds is attributable to a modification of the recruitment pattern of motor units in the central nervous system. It has been suggested that the central nervous system mechanisms that provide for selective activation of the fast motor units in muscle can be specifically trained (18,49).

In an article by Szymanski (49), it has been suggested that collegiate or professional baseball players, who are already strong and powerful because of maturation status or from previous resistance training, may increase their respective bat swing velocities more from training with faster contraction velocities or with greater stretch loads. This type of training may further develop their use of the elastic and neural augmentation that occurs during the stretch-shortening cycle. It was also mentioned that this may not be the case for high school players or novice college-aged individuals who have less strength or skill. These undeveloped athletes and college students may respond to consistent, traditional resistance training (51,54,55) or just swinging a standard game bat, as reported by other researchers (18,42,50).

Resistance Training

Most of the resistance training studies in this review have reported an increase in bat swing velocity after a specific training program. However, as mentioned earlier, some of these studies failed to also conduct the experiment with a "classic" control group (31,51,54,55). Furthermore, the control groups did not always perform additional training to the same degree that the training or treatment group did (31,51,54,55). Four progressive overload resistance training studies, 1 using untrained students (41) and 3 using baseball players (51,54,55), have reported significant improvements in bat swing velocity. In contrast, 2 others (31,41) have revealed no significant improvements (see Table 3). These resistance training studies can be categorized into 2 groups. Group A used progressive overload resistance training (pyramid training) based on an RM as a standard, and group B used a progressive overload resistance training protocol based on 3×10RM. Four of these studies used traditional exercises like the squat for the lower body or bench press for the upper body (31,51,54,55).

A. Progressive Overload Resistance Training (Pyramid Training). In this category, 4 studies–1 using untrained college students (41) and 3 using high school baseball players (51,54,55)–investigated the effects of resistance training on bat swing velocity. All 4 studies have reported significant increases in bat swing velocity ranging from 3.2 to 7.9%. All 4 studies' training protocols used heavier loads (80–85% 1RM) for at least 4 weeks within the 7- to 12-week training periods. Schwendel and Thorland (41) have reported an increase in bat swing velocity for power trained men college students (7.9%) but not for power trained women college students or traditionally trained men or women college students after 7 weeks of training. Power training, as defined by Schwendel and Thorland (41), was based on the cadence for the concentric portion of the lifts. Power training had a concentric time of 2 seconds, whereas the traditional training had a concentric time of 4 seconds. Programs for both types of training were progressive overload protocols conducted with college students. Results from Szymanski and colleagues (51,54,55) are contrary to the results of Schwendel and Thorland (41), who have stated that only power resistance trained men college students increased bat swing velocity. The investigators (41) gave no explanation as to why the women college student power resistance training group did not improve bat swing velocity as the men college student power resistance training group did. Szymanski and colleagues (51,54,55) have reported consistent results in increased bat swing velocity using a similar progressive overload training program for high school baseball players. These results (51,54,55) reveal that for high school baseball players, a significant increase of 3.2–4.2% in bat swing velocity occurred after completing a 12-week progressive overload resistance training program. An explanation for these increases could be related to the size principle for motor unit recruitment. These data (51,54,55) suggest that heavy progressive overload resistance training ($\geq$ 85% 1RM) may elicit strength gains and recruit fast-twitch motor units.

B. Progressive Overload Resistance Training (3 $\times$ 10RM). In this group, 2 progressive overload resistance training studies (31,41) evaluated the effect of traditional weight training exercises on bat swing velocity. Both training studies used 7 or 8 full-body exercises 3 times a week for 3 sets of 10 repetitions. One training study (31) used Division I college baseball players lifting only free weights, whereas the other training study (41) used men and women college students with no prior baseball or softball experience training with weight machines. The results of both training studies have revealed no significant increase in bat swing velocity after 6–7 weeks of training. However, Hughes et al. (31) have reported significant increases in bat swing velocity when combining all subjects into 1 large experimental group.

Resistance Training With Additional Supplemental Exercises

Six training studies have been conducted to determine the effects of progressive overload resistance training using traditional and supplemental exercises on bat swing velocity. The data in Table 4 indicate conflicting results. Three training studies used high school baseball players (51,54,55), 1 training study used college baseball players (31), 1 training study used college softball players (48), and 1 training study used untrained men and women college students (50). In Szymanski and colleagues' 3 training studies (51,54,55), the investigators conducted a similar 12-week stepwise periodized program using 7 full-body progressive overload exercises. In the first of these training studies, the supplemental exercises included 7 additional grip and forearm exercises (55). In the second training study, the supplemental exercises were 4 rotational and 2 whole-body medicine ball exercises (54). In the last training study, the supplemental exercises consisted of players wearing weighted resistance on their forearms while swinging their standard game bats (51). In all 3 training studies, Szymanski and colleagues have reported significant increases in bat swing velocity for high school baseball players. However, in 2 of the studies (51,55), there were no differences between the control and treatment groups. In 1 of these training studies (54), the investigators have reported significantly greater bat swing velocity increases in the group that performed the additional rotational and whole-body medicine ball plyometric exercises compared with the group that completed regular training (weight lifting and swinging bats). Furthermore, in this training study (54), angular hip and shoulder velocities were also measured. The results of that study (54) indicate that the group that trained using rotational and whole-body medicine ball plyometric exercises demonstrated greater angular hip and shoulder velocities than the group that did not perform the medicine ball exercises, which mimicked part or all of the hitting motion.

In addition to the studies mentioned above that have investigated high school baseball players, 3 studies have examined college participants. In the 1 college baseball player training study using supplemental forearm exercises, Hughes et al. (31) have reported no significant improvement in bat swing velocity. In contrast, investigators of a college women softball training study (48), which had players swing bats underwater, have reported a significant decrease in bat swing velocity. Szymanski et al. (50) have reported improvements in bat swing velocity for all 3 groups, with no differences between groups. Statistically, Hughes et al. (31) may not have had enough subjects ($N = 23$) to determine significant improvements. In addition, Stuempfle et al. (48) have reported that softball players were unable to swing the treatment device (30-in, 26-oz Thunderstick) at game speeds, and their bat swing ranges of motion may have been altered because they were submerged in a swimming pool while training. These investigators (48) have concluded that the decrease in bat swing velocity and possible altered bat swing ranges of motion were attributable to the water resistance training protocol. Szymanski et al. (50) have suggested that the resistance was not in an appropriate location to stimulate a training effect and that swinging a standard bat was just as effective as the forearm training device for untrained college students. In conclusion, these data suggest that to have a positive training effect on bat swing velocity increases, the additional resistance training exercises should be skill specific in range of motion and if possible, in rate of motion.

Relationship Between Strength, Power, Lean Body Mass, And Angular Velocity And Bat Swing Velocity

Twelve studies (10 baseball and 2 softball) have examined the relationship between strength (2,5,7,26,31,39,45–47,52,56,57), power (2,7,45,47,52,56), lean body mass (2,5,7,45,47,52,56,57), and angular velocity of the hips and shoulders (56) and bat swing velocity. The data presented in Table 5 indicate specific variables that correlate to those with the greatest bat swing velocity. Giardina et al. (26) evaluated the relationship of grip strength and forearm size to bat swing velocity in college women softball players. The results reveal no significant relationship between bat swing velocity and any forearm size or grip strength measure. The investigators agree with Adair (1) that the torque applied by the hands and wrist during the swing provided little contribution to bat swing velocity. In addition, the investigators suggest that increases in either (or both) hand's grip strength beyond what is accomplished from resistance training will not be of further benefit to increasing bat swing velocity. Furthermore, the investigators state that performing exercises to increase forearm strength will not have a significant effect on bat swing velocity. The data from Albert et al. (2), Hughes et al. (31), and Szymanski et al. (55) support the findings and suggestions of Giardina et al. (26).

In contrast to the 4 studies mentioned above (2,26,31,55), other researchers (7,47,52) suggest that NCAA Division I baseball players with greater grip strength have the greatest bat swing velocity. Researchers also suggest that college baseball players with the greater lower-body strength (5), lower-body power (47), rotational power (7,52), and lean body mass (5,7,47,52) have the greatest bat swing velocity. Research also indicates that upper-and lower-body strength (56,57), grip strength (45,46,57), upper-body and lower-body power (45,46), lean body mass (39,56,57), and angular hip velocity (56) had a significant relationship with bat swing velocity in men high school baseball players and novice college-aged students. These data (5,7,39,45–47,52,56,57) collectively indicate that the individuals with the greatest bat swing velocity are strong, powerful individuals who have lean body mass.

Relationship Between Improvements In Strength, Power, Lean Body Mass, And Angular Velocity And Improvements In Bat Swing Velocity

Four studies (3 baseball and 1 softball) have demonstrated that when correlation tests were conducted to examine the relationship between improvement scores (difference of posttreatment score minus pretreatment score) in various performance variables and improvement scores in bat swing velocity after 8–12 weeks of training, significant relationships for high school baseball players, college softball players, or novice college students were low or had not been demonstrated (2,39,55,57). However, 1 baseball study (54) has shown that improvements in high school baseball players' angular hip velocity, 3RM dominant torso rotational strength, and torso rotational power (medicine ball hitter's throw) related to improvements in bat swing velocity. These data indicate that strong, powerful actions of the components of the kinetic link (hips and torso) contribute significantly to increased bat swing velocity (Table 6). If each of these strength and velocity components are improved, it would be reasonable for greater momentum to be generated from the large base segments (legs and hips) and be transferred through the torso muscles to the smaller adjacent segments (shoulders and arms).

Practical Applications

Bat swing velocity is an important component of successful baseball and softball hitting performance. This review reveals the various resistance training regimens that significantly increase bat swing velocity. Importantly, high school and collegiate coaches may now select a specific warm-up and a specific training protocol (or several in combination) to use during the off- and in-season to increase bat swing velocity. For individuals who are interested in reading information about periodized resistance training for baseball/softball that addresses more than bat swing velocity, see Bompa and Carrera (6) and DeRenne (15). In summary, the investigators recommend the following:

1. It is suggested that to obtain optimal bat swing velocity before stepping into the batter's box, a high school or collegiate baseball player should warm up with a specific, weighted bat that is identical to or very close to the same weight (±12% or 27−34 oz) as his standard game bat (30 oz), and the player should replicate his standard range of motion while swinging a bat at high game velocity.
2. Furthermore, it is suggested that swinging a very light (< 27 oz) or heavy (> 34 oz) baseball bat before hitting may actually have a negative impact on a baseball player's bat swing velocity.
3. The commercial donut ring, which is the most commonly used warm-up device in baseball in the on-deck circle, should be avoided because it produced the slowest bat swing velocities.
4. For untrained individuals or those who are not in bat swing condition, swinging a standard game bat at least 100 times per day, 3 times a week, for 6–8 weeks will increase bat swing velocity.
5. Specific resistance training with underweighted and overweighted bats will increase bat swing velocity in highly experienced high school and college players. The largest improvement in bat swing velocity (10%) was found after taking 150 swings, 4 times a week, for 12 weeks with baseball bats weighing ±12% of standard game bat weight. However, it is advisable that the athlete be well conditioned before starting this type of training.
6. Bat swing velocity can be increased after engaging in resistance training programs that incorporate, as a minimum, training 3 times per week for 6 weeks of general resistance protocols for high school baseball players.
7. To maximize the effect of resistance training programs on bat swing velocity, training experience and age must be taken into account.

8. Additional forearm and grip strength does not contribute to further improvements in bat swing velocity for high school baseball and college softball players.
9. Performing additional rotational medicine ball exercises explosively 2 times a week in a progressive manner that replicates the bat swing motion will improve bat swing velocity for high school baseball players.
10. Performing additional forearm and grip exercises, swinging bats underwater, and wearing overweight forearm devices have not contributed to further increases in bat swing velocity for high school or college baseball/softball players or for college students compared with "normal" baseball/softball training.
11. Players with the greatest bat swing and batted-ball velocities have greater strength, power, and lean body mass.
12. Because the baseball/softball swing is a sequential, rotational kinetic link movement that incorporates the entire body from the legs, trunk, and shoulders to the arms, one should mimic the swing with sport-specific exercises. To do this, one should place additional resistance on the bat itself or throw medicine balls explosively to produce greater increases in bat swing velocity.

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