

[Athletic Training]

Biomechanical Analysis of Weighted-Ball Exercises for Baseball Pitchers

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Background: Weighted-ball throwing programs are commonly used in training baseball pitchers to increase ball velocity. The purpose of this study was to compare kinematics and kinetics among weighted-ball exercises with values from standard pitching (ie, pitching standard 5-oz baseballs from a mound).

Hypothesis: Ball and arm velocities would be greater with lighter balls and joint kinetics would be greater with heavier balls.

Study Design: Controlled laboratory study.

Methods: Twenty-five high school and collegiate baseball pitchers experienced with weighted-ball throwing were tested with an automated motion capture system. Each participant performed 3 trials of 10 different exercises: pitching 4-, 5-, 6-, and 7-oz baseballs from a mound; flat-ground crow hop throws with 4-, 5-, 6-, and 7-oz baseballs; and flat-ground hold exercises with 14- and 32-oz balls. Twenty-six biomechanical parameters were computed for each trial. Data among the 10 exercises were compared with repeated measures analysis of variance and post hoc paired *t* tests against the standard pitching data.

Results: Ball velocity increased as ball mass decreased. There were no differences in arm and trunk velocities between throwing a standard baseball and an underweight baseball (4 oz), while arm and trunk velocities steadily decreased as ball weight increased from 5 to 32 oz. Compared with values pitching from a mound, velocities of the pelvis, shoulder, and ball were increased for flat-ground throws. In general, as ball mass increased arm torques and forces decreased; the exception was elbow flexion torque, which was significantly greater for the flat-ground holds. There were significant differences in body positions when pitching on the mound, flat-ground throws, and holds.

Conclusions: While ball velocity was greatest throwing underweight baseballs, results from the study did not support the rest of the hypothesis. Kinematics and kinetics were similar between underweight and standard baseballs, while overweight balls correlated with decreased arm forces, torques, and velocities. Increased ball velocity and joint velocities were produced with crow hop throws, likely because of running forward while throwing.

Clinical Relevance: As pitching slightly underweight and overweight baseballs produces variations in kinematics without increased arm kinetics, these exercises seem reasonable for training pitchers. As flat-ground throwing produces increased shoulder internal rotation velocity and elbow varus torque, these exercises may be beneficial but may also be stressful and risky. Flat-ground holds with heavy balls should not be viewed as enhancing pitching biomechanics, but rather as hybrid exercises between throwing and resistance training.

Keywords: mound; shoulder; elbow; velocity; torque

Studies from the 1960s to 1990s showed increased velocity of throwing standard baseballs after training with underweight and overweight baseballs.^{3-6,11,24} Studies have also shown no effects of these training exercises on pitch accuracy or on injury risk.^{3,5,6,11} Coaches who support weighted baseball training claim that their programs will lead to increased

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baseball velocity.^{2,7,20} Major League Baseball teams are now evaluating their approach to weighted baseball training, considering whether to implement a program throughout their minor leagues and whether to allow particular players to use programs they started as amateurs.

The premise of these training programs is that throwing lighter balls will build arm speed and throwing heavier balls will build arm strength.^{6,11} Today's training programs include not only pitching from a mound with baseballs within 20% of standard weight (ie, 4- to 6-oz balls) but also pitching lighter and heavier balls as well as throwing and holding exercises from flat ground.^{7,20} Youth baseball players pitching standard (5 oz) and underweight (4 oz) baseballs had increased kinematics and decreased kinetics with the underweight baseballs.¹⁹ The throwing biomechanics of high school and collegiate baseball pitchers and football quarterbacks showed that lower overuse injury rates in football may be due to the decreased peak forces and torques with the heavier football (15 oz).¹¹ In team handball players throwing underweight, standard, and overweight balls, arm velocity decreased as ball mass increased.²⁷ While it is tempting to extrapolate conclusions from these previous studies, they do not demonstrate the kinematics and kinetics of weighted-ball exercises compared with standard baseball pitching. Thus, the purpose of this study was to compare biomechanics among common weighted-ball exercises and with standard pitching for experienced high school and collegiate baseball pitchers. It was hypothesized that arm velocities would be greater with lighter balls and joint kinetics would be greater with heavier balls. It was also hypothesized that biomechanics would not differ pitching on a mound, flat ground, or holds on flat ground.

METHODS

This study was approved by the Institutional Review Board of St Vincent's Health System, Birmingham, Alabama. Prior to the data collection each participant provided written informed consent and completed forms about his medical history and baseball background. High school and collegiate pitchers were recruited for the study. Each participant had experience with a weighted baseball exercise program. Pitchers were excluded from the study if they had an injury to their throwing arm in the previous 12 months. Twenty-five baseball pitchers (18 high school, 7 collegiate) met these criteria and agreed to participate. The pitchers were (mean \pm SD) 18.3 \pm 1.5 years old, 1.85 \pm 0.08 m tall, and had a mass of 85.4 \pm 15.1 kg.

Thirty-eight reflective markers were attached bilaterally at the distal end of the third metatarsal, lateral malleolus, medial malleolus, lateral femoral epicondyle, medial femoral epicondyle, greater trochanter, anterior superior iliac spine, posterior superior iliac spine, lateral superior tip of the acromion, sternal end of clavicle, lateral humeral epicondyle, medial humeral epicondyle, forearm, ulnar styloid, and radial styloid. Additional markers were placed on the dorsal surface of the throwing hand, heel of the front foot, inferior angle of the

throwing-side scapula, and C7 of the spine. Four additional markers were then attached to a baseball hat on the front, top, and bilateral sides of the head.

Each participant concluded his preparation by throwing as many warm-up pitches with a standard baseball as desired. Pitchers then performed 3 trials of 10 different exercises at maximal effort. The order of the 10 exercises was randomized for each participant. The exercises were fastball pitching with commercially available 4-oz (0.11-kg), 5-oz (0.14-kg), 6-oz (0.17-kg), and 7-oz (0.20-kg) baseballs (Markwort Sporting Goods Co) from a portable pitching mound (Athletic Training Equipment Co) to a strike zone located above home plate 18.4 m away. Throwing 4-, 5-, 6-, and 7-oz baseballs from flat ground to a strike zone located above home plate 18.4 m away utilizing a "crow hop"; and "holds" from flat ground with "1-pound" and "2-pound" rubber balls. The 1-pound ball was actually 14 oz (0.40 kg) while the 2-pound ball was truly 32 oz (0.91 kg). Both rubber balls were more compressive than baseballs, with the 14-oz ball approximately the same size as a standard baseball and the 32-oz ball slightly larger. A crow hop is a throwing exercise universally used in baseball, where the player makes a few steps toward the target with his body facing perpendicular to the target. There are a couple of techniques for crow hop (such as back foot striding behind the front foot, or shuffle steps with no crossover) and each participant was allowed to use the style he preferred. For holds, the participant was instructed to go through his full pitching motion on flat ground but without releasing the ball. Sample high-speed videos (Vision Research Inc) of a pitch, flat-ground throw, and flat-ground hold are shown in Supplemental Videos 1-3 (available at <http://journals.sagepub.com/doi/suppl/10.1177/1941738116679816>).

For each trial (except for the holds), ball velocity was measured by a radar gun (Stalker Radar). For all trials, the 3-dimensional motions of the reflective markers were tracked with a 12-camera automated motion capture system, sampling at 240 Hz (Raptor System, Motion Analysis Corp). Twenty-six parameters (16 position, 5 velocity, and 5 kinetic values) were calculated for each trial, based on methods previously described.^{8-10,12-18,21,22,26} Kinetic values were reported as the force or torque applied by the proximal segment onto the distal segment at the joint.

All statistical analyses were performed using JMP 10 (SAS Institute). For each participant, the mean value for each exercise was computed for each biomechanical parameter. Preliminary analysis showed within-subject consistency for each parameter and exercise (with intraclass correlation coefficients ranging from 0.8 to 0.99). Differences among the mean values for the pitching and crow hop throwing exercises were analyzed for each parameter with a 2-way (ball mass, throwing condition) repeated-measures analysis of variance (ANOVA). Data for the hold exercises and standard pitching were compared with 1-way repeated-measures ANOVA. Post hoc paired *t* tests were then performed to compare standard pitching (ie, pitching a 5-oz baseball from the mound) with each other exercise. An alpha level of 0.05 was used for all statistical analyses.

RESULTS

Two-way repeated-measures ANOVA revealed no significant interaction between ball mass and throwing condition for any of the 26 parameters. Thus, differences between ball masses and differences between throwing conditions were analyzed separately.

There were significant differences among exercises for all 5 velocity parameters (Table 1). As ball mass increased, ball velocity decreased. In general, as ball mass increased, angular velocities of the pelvis, upper trunk, shoulder, and elbow decreased; however, although these velocities steadily decreased from 5-oz to 7-oz balls, the angular velocities with the underweight 4-oz balls were not significantly different than with the standard 5-oz balls. Velocities of the ball, pelvis, and shoulder were greater for flat-ground throws than for pitching from the mound. Angular velocities for the pelvis, upper trunk, shoulder, and elbow were significantly lower for the flat-ground holds than during standard pitching.

In general, as ball mass increased, elbow and shoulder joint torques and forces decreased (Table 2). Similar to the results described above for angular velocities, most joint kinetics displayed a steady downward trend from 5 to 32 oz, but were not significantly different between the 4- and 5-oz ball trials. The only kinetic parameter that did not follow this pattern was elbow flexion torque, which was significantly greater for the 14- and 32-oz hold exercises. Compared with pitching from a mound, throwing on flat ground produced greater elbow varus torque and less elbow flexion torque.

Although the participants were instructed to simulate their normal pitching mechanics when performing the flat-ground holds, almost every kinematic value differed from standard pitching (Supplemental Tables, available at <http://journals.sagepub.com/doi/suppl/10.1177/1941738116679816>). There were also a few statistical differences in positions between the 4-oz and 7-oz throws. There were several differences between pitching from a mound and throwing from flat ground, specifically in arm, trunk, and leg positions at the instant of foot contact, and trunk and leg positions at ball release (Supplemental Tables).

DISCUSSION

The presumption that exercises with heavier balls demand greater torques and force about the elbow and shoulder was in general not supported by the current limited study. Based on Newton's second law, the force required to move a ball is equal to the mass of the ball multiplied by its acceleration. Although the heavier balls have more mass, the decreased force and torques imply that these exercises had less arm acceleration.

Differences in elbow and shoulder kinetic values between flat-ground throws with a 5-oz ball and standard pitching were minimal and statistically nonsignificant, similar to a previous report.²⁵ However, in a study of adolescent baseball pitchers (12.7 ± 1.3 years old), elbow varus torque and shoulder internal rotation torque were reduced in flat-ground pitching

than from in pitching from a mound.²³ This discrepancy is likely because the flat-ground throws were crop hop motions in the current study and pitching motions from a rubber in previous studies.²³

Varus torque is critical for elbow strength and safety,¹ while shoulder internal rotation velocity is directly related to ball velocity.²² Crop hop throwing from flat ground and the use of underweight (4-oz) baseballs increase such arm kinetics and kinematics, while small increases in ball mass can drastically reduce the kinetics and kinematics (Figures 1 and 2).

Although there were some statistical differences in body positions when pitching balls of varying mass, the magnitudes of these differences were small (about 1°) and probably of little clinical relevance. Thus, it appears that pitchers can train with their normal mechanics when pitching 4- to 7-oz baseballs from a mound.

Pitching from a mound gives the athlete more time to stride as the front foot landed lower (downhill) from the back foot with a longer stride, as well as more shoulder external rotation and pelvis rotation at the instant of front foot contact. At the instant of ball release, there were small differences (about 1°) in forward trunk tilt between conditions, which may be related to differences in ground slope (a mound is sloped about 4° downhill).^{14,25} Because of the kinematic differences between pitching from the mound and crop hop throws from flat ground, flat-ground exercises may not be appropriate for practicing proper pitching mechanics.

There were 2 previous studies of underweight and overweight throwing biomechanics. Pitching biomechanics with 4- and 5-oz balls in a sample of 34 youth (aged 11.1 ± 0.7 years) baseball pitchers showed the lighter baseball was associated with greater arm velocities and decreased kinetics. So 4-oz baseballs might be advantageous for the development of young pitchers. Simulated penalty throws for 24 elite female handball players throwing underweight (0.29 kg), standard (0.36 kg), and overweight (0.43 kg) balls had similar findings²⁷ (Supplemental Tables). These 3 studies showed ball velocity increasing as ball mass decreased. Compared with throwing standard-mass balls, elbow and shoulder velocities increased with lightweight balls for youth baseball players and decreased with overweight balls for adult baseball player and adult handball players.

In conclusion, pitching baseballs that are slightly underweight or overweight (4-7 oz) produces variations in arm kinetics, variations in angular velocities, and relatively small changes in body positions; therefore, these exercises may be reasonable for training pitchers. As flat-ground throws produce increased shoulder internal rotation velocity and elbow varus torque, these exercises may be beneficial but may also be stressful and risky. Flat-ground holds with 14- to 32-oz balls produce markedly different kinematics and kinetics. Thus, these heavy ball holds should not be used to enhance pitching biomechanics, but rather as hybrid exercise between throwing and resistance training. Heavy-ball holds produce significantly decreased elbow varus torque but increased elbow flexion torque, suggesting that this is a good exercise for safely building biceps strength.

Table 1. Comparison of peak velocity data (mean \pm SD) among throws^a

| Velocity | Pitch From Mound | | | | Throw From Flat Ground | | | | Flat-Ground Hold | |
|--|-----------------------------|----------------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| | 4 oz | 5 oz | 6 oz | 7 oz | 4 oz | 5 oz | 6 oz | 7 oz | 14 oz | 32 oz |
| Pelvis angular, deg/s ^{b,c,d} | 554 \pm 84 | 566 \pm 83 | 546 \pm 74 ^e | 535 \pm 71 ^e | 565 \pm 88 | 572 \pm 82 | 561 \pm 83 | 559 \pm 86 | 424 \pm 66 ^e | 389 \pm 51.9 ^e |
| Upper trunk angular, deg/s ^{b,d} | 1092 \pm 96 | 1101 \pm 89 | 1082 \pm 86 ^e | 1076 \pm 94 ^e | 1100 \pm 107 | 1105 \pm 93 | 1089 \pm 97 | 1070 \pm 98 ^e | 914 \pm 94 ^e | 817 \pm 78 ^e |
| Shoulder internal rotation, deg/s ^{b,c,d} | 6579 \pm 824 | 6594 \pm 743 | 6320 \pm 714 ^e | 6111 \pm 641 ^e | 6756 \pm 893 | 6705 \pm 869 | 6516 \pm 894 | 6260 \pm 785 ^e | 3121 \pm 881 ^e | 2055 \pm 569 ^e |
| Elbow extension, des/s ^{b,d} | 2301 \pm 236 | 2305 \pm 221 | 2237 \pm 227 ^e | 2193 \pm 211 ^e | 2326 \pm 248 | 2317 \pm 240 | 2271 \pm 236 | 2203 \pm 231 ^e | 1275 \pm 364 ^e | 921 \pm 257 ^e |
| Ball, m/s ^b | 35.4 \pm 2.0 ^e | 34.2 \pm 2.0 | 33.1 \pm 2.0 ^e | 31.9 \pm 1.6 ^e | 35.8 \pm 2.0 ^e | 37.7 \pm 2.2 ^e | 33.5 \pm 1.8 ^e | 31.7 \pm 2.0 ^e | — | — |

^aValues for standard pitching are shown in boldface.^bSignificant differences ($P < 0.05$) among ball weights (4-7 oz).^cSignificant differences ($P < 0.05$) between pitches from mound and throws from flat ground.^dSignificant differences ($P < 0.05$) among flat-ground holds and standard pitching.^eSignificantly different ($P < 0.05$) from value for standard pitching.

Table 2. Comparison of joint forces and torques (mean ± SD) among throws^a

| | Pitch From Mound | | | Throw From Flat Ground | | | Flat-Ground Hold | | | |
|--|-------------------------|---------------------|-------------------------|--------------------------|-------------------------|-------------------------|-------------------------|--------------------------|--------------------------|--------------------------|
| | 4 oz | 5 oz | 6 oz | 7 oz | 4 oz | 5 oz | 6 oz | 7 oz | 14 oz | 32 oz |
| Arm cocking | | | | | | | | | | |
| Elbow varus torque, N·m ^{b,c,d} | 89.7 ± 27.0 | 90.2 ± 27.6 | 87.3 ± 26.9 | 78.6 ± 24.5 ^e | 91.7 ± 28.0 | 91.7 ± 27.1 | 90.3 ± 27.8 | 81.6 ± 25.5 ^e | 44.1 ± 13.5 ^e | 38.6 ± 11.7 ^e |
| Shoulder internal rotation torque, N·m ^{b,d} | 91.3 ± 27.6 | 91.4 ± 28.2 | 88.7 ± 27.5 | 80.0 ± 25.1 ^e | 93.1 ± 28.9 | 92.8 ± 27.9 | 91.6 ± 28.7 | 83.2 ± 26.6 ^e | 42.2 ± 11.9 ^e | 37.1 ± 11.0 ^e |
| Shoulder horizontal adduction torque, N·m ^{b,d} | 106.2 ± 30.8 | 106.7 ± 32.1 | 105.0 ± 32.5 | 92.7 ± 29.9 ^e | 104.8 ± 29.7 | 104.2 ± 28.9 | 104.2 ± 28.7 | 92.1 ± 26.7 ^e | 42.2 ± 10.7 ^e | 38.1 ± 12.7 ^e |
| Ball release | | | | | | | | | | |
| Elbow flexion torque, N·m ^{b,c,d} | 36.1 ± 9.9 ^e | 37.7 ± 9.2 | 35.8 ± 8.4 ^e | 34.6 ± 8.3 ^e | 34.9 ± 7.9 ^e | 36.1 ± 7.8 ^e | 35.6 ± 9.5 ^e | 33.1 ± 7.9 ^e | 47.5 ± 12.4 ^e | 51.3 ± 16.2 ^e |
| Shoulder proximal force, N ^{b,d} | 1089 ± 218 | 1078 ± 217 | 1040 ± 207 ^e | 972 ± 202 ^e | 1097 ± 193 | 1084 ± 200 | 1055 ± 197 | 980 ± 177 ^e | 638 ± 167 ^e | 524 ± 154 ^e |

^aValues for standard pitching are shown in boldface.

^bSignificant differences ($P < 0.05$) among ball weights (4-7 oz).

^cSignificant differences ($P < 0.05$) between pitches from mound and throws from flat ground.

^dSignificant differences ($P < 0.05$) among flat-ground holds and standard pitching.

^eSignificantly different ($P < 0.05$) from value for standard pitching.

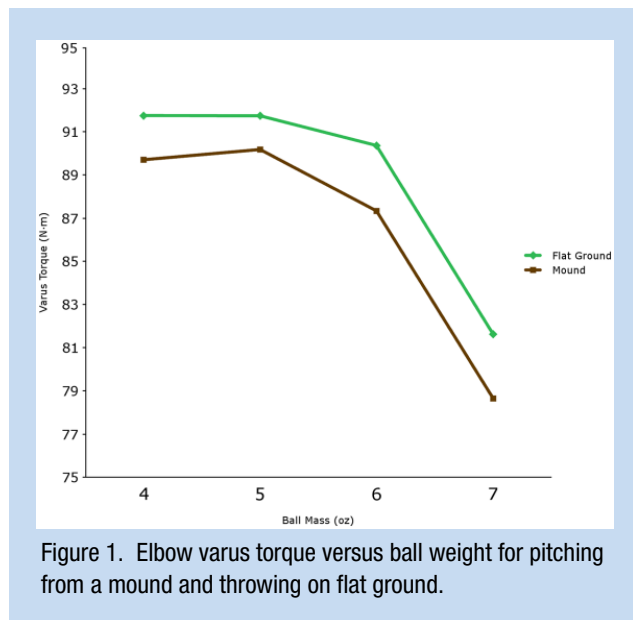


Figure 1. Elbow varus torque versus ball weight for pitching from a mound and throwing on flat ground.

This study has several limitations. The narrow spectrum of participants did not include youth, professional, and position players, limiting its generalizability. Additionally, the study did not include common exercises such as pitching 2- and 3-oz balls and flat-ground pitching. Also, kinematic and kinetic measurements were based on skin markers, which do not precisely mimic bone movement, so there may have been motion artifact.

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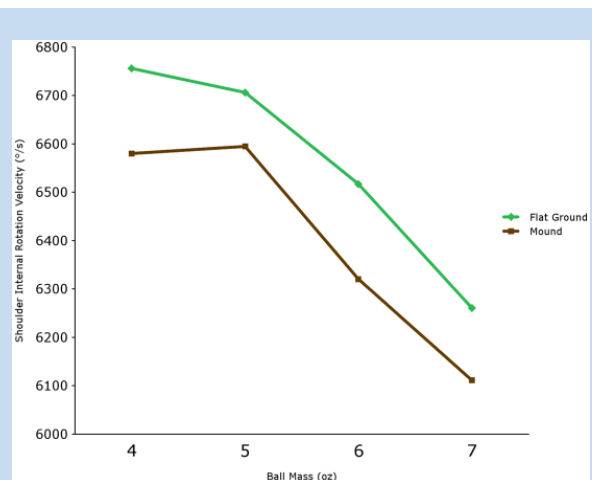


Figure 2. Shoulder internal rotation velocity versus ball weight for pitching from a mound and throwing on flat ground.