



BASIC SCIENCE

Impact of ball weight on medial elbow torque in youth baseball pitchers



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Hypothesis: Our hypothesis was that an increase in ball weight would result in an increase in medial elbow torque during the pitching motion.

Methods: Youth pitchers were recruited for this study and instructed to throw 5 maximum-effort fastballs from ground level using baseballs of 4 different weights: 85 g (3 oz), 113 g (4 oz), 142 g (5 oz), and 170 g (6 oz). The validated Motus sensor was used to assess medial elbow torque, arm speed, arm slot, and shoulder rotation for each pitch. Pitch velocity was measured using a radar gun. Relationships between baseball weight and pitching kinetics and/or kinematics were evaluated using linear mixed-effects analysis. An exit survey was conducted detailing the pitcher's evaluation of the ball weights used.

Results: A total of 19 youth baseball pitchers (average age, 11.8 ± 1.1 years; age range, 9–14 years) completed the study. For every 1-oz (28-g) increase in ball weight, ball velocity decreased 2.0 ± 0.1 mph ($\chi^2 = 52.68$, $P < .001$), medial elbow torque increased 0.92 ± 0.37 newton meters ($\chi^2 = 5.36$, $P = .02$), and arm speed decreased 8.52 ± 3.68 rpm ($\chi^2 = 5.03$, $P = .02$). Shoulder rotation and arm slot were not significantly impacted by ball weight ($P > .05$). Survey results indicated that the 85-g (3-oz) baseball was most favored (8 of 19 pitchers) and believed to result in the highest pitch velocity (15 of 19 pitchers). The 170-g (6-oz) baseball was least favored (17 of 19 pitchers) and believed to result in the slowest pitch velocity (18 of 19 pitchers). No adverse outcomes were reported with the use of any ball weight or the mobile sensor.

Conclusion: Among youth pitchers, an increase in ball weight correlated with greater medial elbow torque, decreased pitch velocity, and decreased arm speed.

Level of evidence: Basic Science Study; Kinesiology

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Keywords: Pitching; ulnar collateral ligament; torque; biomechanics; weighted baseball; weighted ball; overuse injury; youth baseball; throwing program; pitch speed

Institutional review board approval was obtained prior to initiation of this study (Henry Ford Institutional Review Board No. 11756).

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Throwing programs using weighted balls are commonly used while training to increase pitching velocity.^{4,6-10,16,17,19,27} Weighted pitching regimens can include baseballs heavier or lighter than a standard 142-g (5-oz) ball. Throwing with underweight balls is thought to improve arm speed, whereas throwing with overweight balls is thought to increase arm strength.^{4,9,15-17} Recent studies

have shown improvement in pitch velocity following such training programs without compromising pitch biomechanics.^{6,8,9,15,17}

Although weighted-ball programs have shown improved performance potential, their impact on injury risk is still unknown. Prior investigations of training with overweight and underweight balls have reported no additional risk of arm injury.^{4,6,8-10,15-17} These studies have typically focused on skeletally mature athletes such as high school and college throwers.^{1,4,5,7,10,11} The impact of weighted-ball throwing on youth pitchers remains unclear. Youth pitchers have less developed musculature and often non-optimal pitching mechanics, which may predispose them to an increased risk of injury compared with more mature throwers. One biomechanical study focused on the use of underweight baseballs by youth pitchers and indicated that they were safe and possibly useful in preventing overuse injury.¹⁷ However, the impact of the use of overweight baseballs by youth pitchers has not been studied.

The primary purpose of our study was to identify the relationship between ball weight and medial elbow torque in youth baseball pitchers using a validated wearable sensor. Secondary aims included identifying the impact of ball weight on throwing kinematics, such as arm speed, arm slot, and pitch velocity. Our hypothesis was that an increase in ball weight would result in an increase in medial elbow torque during the pitching motion. Understanding the relationship between ball weight and throwing kinematics in youth pitchers may help identify strategies of injury prevention in these athletes.

Methods

Through the request of coaches and throwing trainers, youth baseball players were recruited for this study. Informed consent was obtained from a legal guardian of each player. The inclusion criteria included baseball players aged 9 to 14 years who were actively competing with a team, who pitched in regular-season games for their team, and who had previous experience with weighted-ball programs. The exclusion criteria included players who were not actively participating with a team or who were not competitively pitching for their team. Players were also excluded if they were currently experiencing or had a history of injury in the throwing arm.

Prior to beginning the throwing session, athletes were required to disclose their age, their position, and whether they were currently experiencing arm pain or had any history of injuries. For each pitcher, we recorded the height, weight, and arm dimensions including total arm length, upper arm length, forearm length, elbow circumference, and wrist circumference. With the arm in the neutral position, total arm length was measured as the distance from the lateral aspect of the acromion to the most distal aspect of the fifth digit, upper arm length was measured from the lateral aspect of the acromion to the lateral epicondyle of the humerus, and forearm length was measured from the lateral epicondyle of the humerus to the styloid of the radius. With the elbow in full extension, elbow circumference was measured around the medial

and lateral epicondyles, and wrist circumference was measured around the styloid of the radius and ulna.²⁴ Players' throwing arms were fitted for a Motus Compression Sleeve (Motus Global, Massapequa, NY, USA), and the mobile sensor was aligned 1.5 inches (3.81 cm) distal to the medial epicondyle.

Players were allowed the opportunity to warm up according to their usual pre-game routine prior to pitching. Pitching sessions were conducted with all players throwing from flat ground at a marked strike zone. The strike zone served as a throwing target for the pitchers but was not used for any assessment of pitch accuracy. According to popular baseball leagues and associations, variability in throwing distance recommendations exists across player ages and experience levels.^{1,2,11,12,18} In an effort to ensure player safety, conservative throwing distances were chosen, with players aged 9 to 13 years throwing from a distance of 14 m and players aged 14 years throwing from a distance of 18.4 m. Participants were instructed to throw 5 maximum-effort fastballs with 85-g (3-oz), 113-g (4-oz), 142-g (5-oz), and 170-g (6-oz) baseballs (Driveline Baseball, Kent, WA, USA), totaling 20 pitches. To minimize the effect of fatigue on sequential baseball throws, the sequence of ball weights thrown was randomized. The randomized pitch order was computer generated and followed by all players. Players were not told the order of ball weights being thrown. Rather, players were instructed to throw the baseballs by the color of the ball stitching (85 g [3 oz], light blue; 113 g [4 oz], blue; 142 g [5 oz], red; and 170 g [6 oz], orange). Between pitches, players were timed to rest for 30 to 60 seconds to minimize fatigue and variation in pitching mechanics. To ensure proper positioning, the alignment of the sensor was assessed throughout the pitching session.

The mobile sensor application was used to collect the values of medial elbow torque (the maximum value recorded throughout the throwing motion), arm speed, arm slot (the angle of the forearm in relation to the ground at ball release), and shoulder rotation (the maximum angle of the forearm in relation to the ground during the late-cocking phase of throwing) for all throws. The sensor was previously validated for the collection of medial elbow torque, arm speed, arm slot, and shoulder rotation in a pilot analysis of 35 pitchers.⁵ All 4 measurements were found to have good to excellent correlations compared with the industry gold standard of motion analysis. The mobile sensor is equipped with a 3-axis accelerometer and 3-axis gyroscope, has a sample rate of 1000 Hz, and transmits throwing data wirelessly via Bluetooth (LE) to an iOS compatible device. The sensor weighs 6.9 g with dimensions of 38 mm × 25 mm × 10 mm. A radar gun (Sport II; Stalker Radar, Plano, TX, USA) was used to capture the peak ball velocity of each pitch.

At the conclusion of the throwing session, players completed an exit questionnaire similar to that previously published in an analysis of ball weight and pitching biomechanics in youth pitchers.¹⁷ Players were asked to identify the ball they most preferred, least preferred, threw with the highest velocity, threw with the lowest velocity, threw with the most accuracy, and threw with the least accuracy.

Statistical analysis was conducted by a member of the study team with a PhD in biostatistics. Pitcher demographic characteristics were provided as means, standard deviations, and ranges. Linear mixed-effects analysis of the relationship between ball weight and the 5 pitching parameters (medial elbow torque, arm speed, arm rotation, arm slot, and ball speed) was conducted in the R program (R Foundation for Statistical Computing, Vienna,

Austria) using the lme4 package.³ Ball weight was entered into the model as a fixed effect. Pitcher was used as a random effect because each pitcher was selected from a larger population of pitchers. In addition, each ball weight was nested within each pitcher. This experimental design fit well for mixed-model analysis as there was a random effect, as well as nesting. Visual inspection of residual plots did not indicate any obvious deviations from normality for all models. Plots of the ball weight vs. the pitching parameters and global slopes were generated. Relationships were significant at $P \leq .05$.

Results

Nineteen pitchers were included in the study. Players were on average 11.8 ± 1.1 years of age (range, 9-14 years), with an average height of 158.0 ± 14.2 cm (range, 136-187 cm) and average body mass index of 18.8 ± 2.5 kg/m² (range, 16-24 kg/m²). Of the players, 16 (84%) were right handed and 12 (63%) identified their primary position as pitcher (Table I). No adverse outcomes were reported with the use of any ball weight or the mobile sensor.

Linear mixed-effects analysis showed that ball weight significantly affected medial elbow torque, arm speed, and ball velocity. Medial elbow torque increased 0.92 ± 0.37 newton meters, arm speed decreased 8.52 ± 3.68 rpm, and ball velocity decreased 2.0 ± 0.1 mph per 1-oz increase in ball weight (Figs. 1-3). Arm slot ($\chi^2 = 1.573$, $P = .21$) and shoulder rotation ($\chi^2 = 1.542$, $P = .21$) were not significantly affected by ball weight.

When asked to evaluate the baseballs after the throwing session, most players favored the 85-g (3-oz) ball and believed it to be thrown with the highest velocity. The 170-g (6-oz) baseball was least preferred by players and had the lowest perceived velocity and accuracy. A majority of players endorsed throwing the standard 142-g (5-oz) ball the most accurately (Fig. 4).

Discussion

The results of this study indicate that among youth baseball pitchers, medial elbow torque increased with increasing ball weight. Increased ball weight was also associated with decreased pitch velocity and decreased arm speed. Pitchers generally preferred and had higher perceived throwing velocities with underweight baseballs.

The effects of weighted-ball throwing on medial elbow torque have been evaluated in high school-level and college-level pitchers previously.^{4,6-10,16,17,19,27} In a recent motion capture analysis of 25 experienced, skeletally mature throwers, overweight balls correlated with decreased arm force, torque, and velocity.¹⁶ Pitchers were evaluated while throwing from various positions (flat ground or mound), with various ball weights (4, 5, 6, 7, 14, and 32 oz), and with various techniques (crop throw, hold,

Table I Summary of pitcher demographic variables

| Variable | Data |
|-------------------------------|----------------------------|
| Age, yr | 11.8 ± 1.1 (9-14) |
| Height, cm | 158.0 ± 14.2 (136-187) |
| Weight, kg | 47.5 ± 11.5 (33-82) |
| BMI, kg/m ² | 18.8 ± 2.5 (16-24) |
| Total arm length, cm | 63.3 ± 6.4 (53-77) |
| Upper arm length, cm | 28.4 ± 3.3 (24-36) |
| Forearm length, cm | 23.9 ± 2.3 (20-30) |
| Elbow joint circumference, cm | 23.2 ± 1.9 (21-28) |
| Wrist circumference, cm | 15.2 ± 1.2 (13-18) |
| Handedness* | |
| Right | 16 (84) |
| Left | 3 (16) |
| Primary position* | |
| Pitcher | 12 (63) |
| Positional | 7 (37) |

BMI, body mass index.

Data are presented as mean \pm standard deviation (minimum-maximum) unless otherwise indicated.

* Data are presented as number of players (percentage).

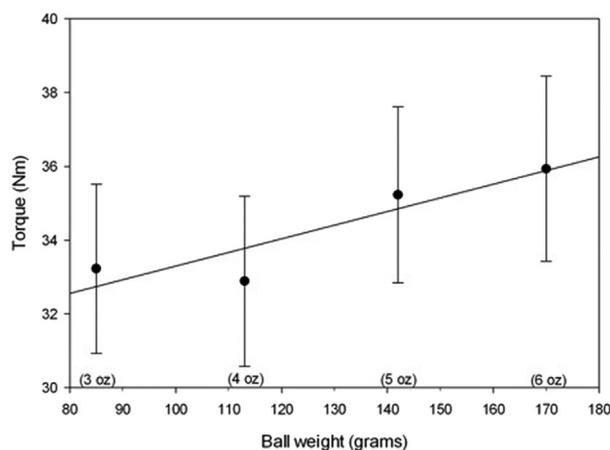


Figure 1 Effect of ball weight on medial elbow torque. Medial elbow torque increased 0.92 ± 0.37 newton meters (Nm) per 1-oz (28-g) increase in ball weight. Each point represents the mean \pm 2 standard errors generated from the mixed-effects model. The straight line represents the significant slope generated from the model ($\chi^2 = 5.36$, $P = .02$).

or standard pitch), and 38 reflective markers were positioned on participants' bodies for video analysis. Although, in general, overweight balls were associated with decreased elbow torque, elbow flexion torque was significantly greater for the 14- and 32-oz hold exercises. In addition, elbow varus torque while pitching from the flat ground (crop throw) was increased compared with mound pitching. In a study examining 34 youth baseball pitchers, underweight balls were associated with decreased elbow torque during the throwing motion, indicating a possible protective effect on injury risk.¹⁷ In a study of adolescent pitchers,

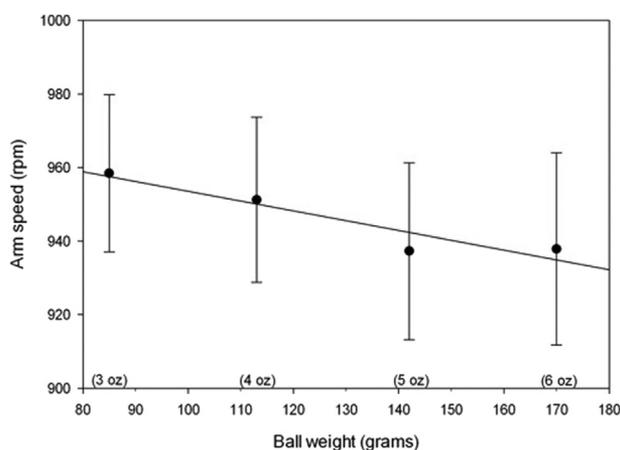


Figure 2 Effect of ball weight on arm speed. Arm speed decreased 8.52 ± 3.68 rpm per 1-oz (28-g) increase in ball weight. Each *point* represents the mean ± 2 standard errors generated from the mixed-effects model. The *straight line* represents the significant slope generated from the model ($\chi^2 = 5.03$, $P = .02$).

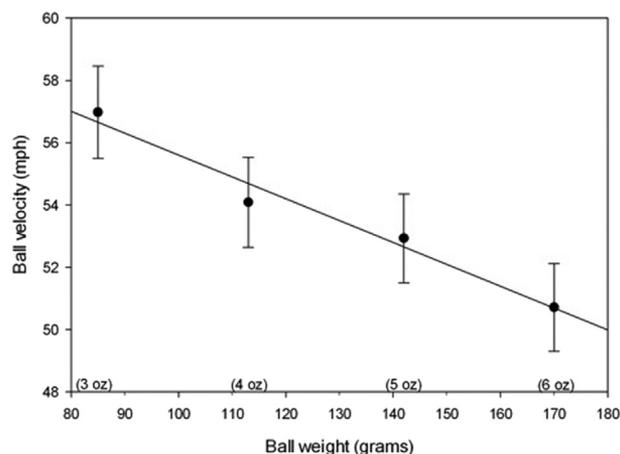


Figure 3 Effect of ball weight on pitch velocity. Ball velocity decreased 2.0 ± 0.1 mph per 1-oz (28-g) increase in ball weight. Each *point* represents the mean ± 2 standard errors generated from the mixed-effects model. The *straight line* represents the significant slope generated from the model ($\chi^2 = 52.68$, $P < .001$).

Nissen et al²² found that pitching from a mound caused increased stress on the shoulder and elbow compared with that from the flat ground. Similarly to previous reports, our study found underweight baseballs were associated with decreased medial elbow torque as measured by the mobile sensor. In contrast to previous studies, our study found an increase in medial elbow torque with increasing ball weight. Our study differs from previous studies as we evaluated the normal pitching motion in the youth athlete from the flat ground. Previous studies have not evaluated overweight-ball pitching in the youth athlete. In addition, various throws (crop throw or hold) and positions (mound or flat ground) were used in prior studies, which have been shown to affect pitcher kinematics and kinetics. Our study

also only required the use of an elbow sleeve, whereas other studies required up to 38 reactive markers positioned on the pitcher's body, which may affect pitching mechanics. This dose-response finding on elbow torque in our study is unique to youth throwers and is possibly due to skeletal immaturity and developing musculature. Although the precise impact of this finding on overuse injury risk in youth pitchers is unknown, this finding does identify that increased ball weight directly influences elbow torque.

The relationship between ball weight and arm speed, as well as pitch velocity, has been evaluated for selected ball weights. In a study by Fleisig et al,¹⁷ 2 different ball weights—standard (142 g [5 oz]) and underweight (113 g [4 oz])—were investigated with respect to arm speed and pitch velocity. Youth pitchers using the lighter, 113-g (4-oz) ball showed greater arm speed and pitch velocity compared with using the standard, 142-g (5-oz) ball. Our study confirmed that both arm speed and pitch velocity are inversely correlated with ball weight while additionally testing an overweight (170-g [6-oz]) baseball. These findings are intuitive and are consistent with models postulated in established throwing programs.¹⁵ In addition to arm speed and pitch velocity, our study investigated the impact of ball weight on throwing arm slot and shoulder rotation. Decreased arm slot and increased shoulder rotation have been found to be associated with increased risk of overuse injury in youth throwers.^{5,17,20,25} However, our study did not identify a relationship between ball weight and arm slot or shoulder rotation. This finding suggests that changes in these pitching parameters are not altered with varying ball weights.

Our study included an exit survey regarding perceived preference, pitch velocity, and accuracy associated with ball weight. The results of this survey indicated that the lighter, underweight balls were generally more preferred with a higher perceived pitch velocity. This finding confirms that of Fleisig et al,¹⁷ who reported that youth pitchers favored and had higher perceived throwing velocities with a 113-g (4-oz) baseball compared with a 142-g (5-oz) baseball. It is possible that heavier ball weights may be less preferred because of the increased difficulty and stress required; however, this cannot be definitively proved in the confines of our investigation. Finally, players may have endorsed the highest perceived accuracy with the 142-g (5-oz) baseball because of familiarity in throwing with this ball weight. The standard weight used in traditional practices and games regardless of player age is 142 g (5 oz).

This study has important limitations. First, as with all investigations of throwing biomechanics, our study used indirect means (in this case, a wearable sensor) to measure elbow stress and other pitching biomechanics.²⁴ However, this sensor has been validated in prior studies.^{5,21} Moreover, the gold standard of motion capture, which is widely used for these investigations,^{5,13,14,16,23,26} is also an indirect method of measuring pitching biomechanics and limited by potential error inherent to marker and marker-less technology.^{14,16,28} Second, we did not objectively assess pitch accuracy as it

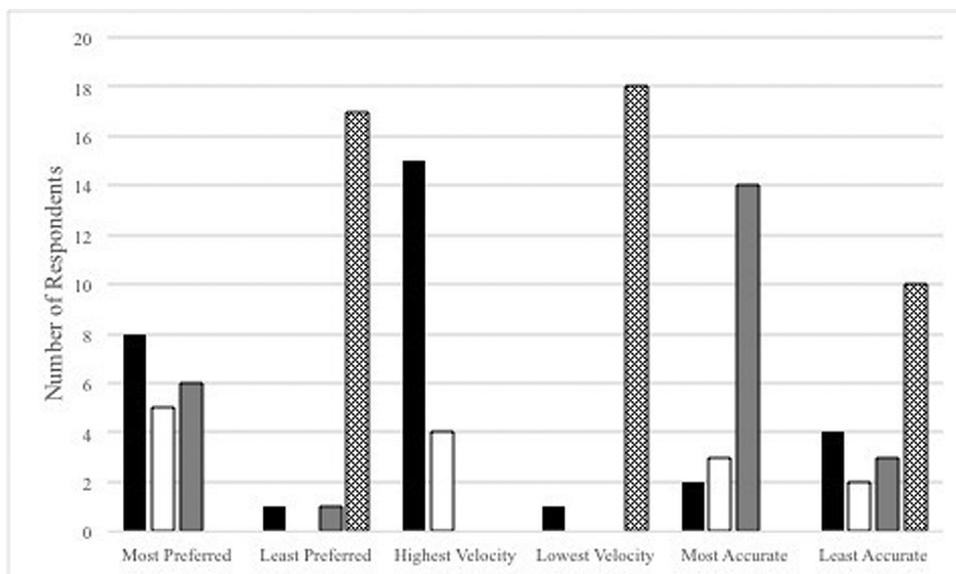


Figure 4 Ball weight exit questionnaire responses. The *black bars* represent the 85-g (3-oz) ball; *white bars*, 113-g (4-oz) ball; *gray bars*, 142-g (5-oz) ball; and *dotted bars*, 170-g (6-oz) ball.

related to ball weight. Instead, only pitch velocity was referenced. These data would have been helpful in determining the impact of ball weight on accuracy. Our study is also limited by the low number of participants, which may have resulted in the low statistical correlation between ball weight and arm slot, as well as arm external rotation. One additional limitation is that the experiment was performed under simulated conditions and no live-competition pitches were recorded. Such a methodology would have introduced additional error owing to weather, player stress, and other variables. Finally, this study cannot determine whether the stress observed according to ball weight imparts any impact on actual injury occurrence.

Conclusion

This study may demonstrate the potential risk of overuse elbow injuries in youth pitchers caused by overweight baseballs; however, further research should be conducted to determine the true effect of ball weight on elbow injuries in pitchers.

Disclaimer

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