Weighted Baseball Training Affects Arm Speed without Increasing Elbow and Shoulder Joint Kinetics

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ABSTRACT

Background. Long-term training effects of weighted ball throwing programs have been well documented. However, the mechanisms by which these effects are facilitated are poorly understood due to the difficulty of measuring biomechanics in the baseball throwing motion. The purpose of this study is to replicate previous methods investigating within-session effects of throwing overload and underload baseballs to provide mechanistic evidence for weighted baseball training methods.

Hypothesis. Varying the pitched ball weight between three, four, five, six, and seven ounces will affect pitched ball velocity, upper body kinematics, lower body kinematics, kinematic velocities, and throwing arm joint kinetics during a maximum intent throwing workout.

Methods. Twenty-six collegiate and professional level baseball pitchers ages 20-30 (mean age 23.5 ± 2.7 years) participated in a pitch velocity and biomechanical evaluation while pitching a series of leather weighted baseballs from a regulation pitching mound. A one-way repeated measures ANOVA was used to evaluate the within-subject effect of ball weight on a total of 15 parameters: pitch velocity, five kinematic positions, four kinematic velocities, and five kinetics.

Results. As ball weight increased, pitch velocity, maximum elbow flexion, maximum pelvis rotation velocity, maximum shoulder internal rotation velocity, and maximum elbow extension velocity decreased, while anterior trunk tilt at ball release increased.

Conclusions. Training with three- to seven-ounce baseballs can be used to work on increasing pitching velocity without increasing throwing arm joint kinetics or changing pitching mechanics in a practically significant way.

INTRODUCTION

As overload and underload implements grow in popularity for overhead throwing sports, it is important to understand the physical and mechanical effects of their use. Overload (OL) and underload (UL) training, in the context of overhand throwing, is when athletes complete throwing exercises with balls or objects that are heavier or lighter than the competition weight specification. The competition weight of a baseball is roughly five ounces. The concept of overload and underload training was first popularized in Russian overhead throwing sports training during the 1970s and 1980s, including in javelin throwing (Konstantinov, 1979; Vasiliev, 1983; Verkhoshansky & Tatyana, 1983)

As early as 1967, published research exhibited the benefits of training with overload implements for baseball throwing velocity (Brose & Hanson, 1967). Subsequent studies on OL and UL baseballs have shown positive training effects on the throwing velocity of regulation-weight baseballs (DeRenne et al., 1990; Derenne & Szymanski, 2009; Erickson et al., 2020; R.

Escamilla et al., 2012; Reinold et al., 2018). Conversely, a 6-week training study experimenting with a throwing program that includes the use of OL and UL training found no difference in thrown ball velocity across all participants but multiple mechanical and range of motion (ROM) changes (Marsh et al., 2018).

The mechanism by which these pitch velocity and range of motion effects occur is poorly understood. One literature review theorized that the effect of training with UL and OL balls is due to a strengthening of the musculature involved in the throwing motion (R. F. Escamilla et al., 2000), though strength measures using isometric dynamometry are inconclusive regarding this theory (Reinold et al., 2018). In the absence of causal observations from training studies, identification of potential causes for observed long-term performance and range of motion effects from OL and UL training can be done using results from acute studies. This includes within-session training effects and short-term post-session training effects.

Acute biomechanical changes in sports training are often difficult to identify due to the requirement of comprehensive motion tracking, but these effects have been investigated for a variety of ball weights in the last decade, including in sports outside of baseball. One study documented the effects of three- through twelve-ounce baseballs on pitchers' mechanics, observing increased glenohumeral (GH) flexion and abduction with heavy balls, as well as increased external rotation and pitch velocity with lighter balls (Proppe, 2017). Another experiment investigating intra-subject mechanical variability in a youth population as a result of throwing four- and five-ounce baseballs found no difference in kinematic positions, but did find differences in kinematic velocities and decreased joint kinetics with the lighter baseballs (G. S. Fleisig et al., 2006). A lack of mechanical changes was also observed in a study of the acute effects of OL and UL implements in cricket fast bowling (Wickington & Linthorne, 2017). A later study found significant effects in a high school and college level population as a result of throwing four- through seven-ounce ball weights on pitched ball velocity, kinematic positions, kinematic velocities, and arm joint kinetics during maximum intent pitches (G. Fleisig et al., 2017). Most recently, it was found that throwing OL and extreme OL balls (up to two pounds) resulted in greater passive throwing shoulder external rotation range of motion than throwing UL balls after the throwing sessions were completed (Reinold et al., 2020).

With valid and replicated intra-training session observations of OL and UL effects on the throwing motion, the mechanisms by which their long-term training effects are facilitated can be better understood. Meanwhile, aside from attempts to explain OL and UL training effects using intra-session effects, some parallels can be made from training programs used in sports outside of baseball.

Many athletic training programs attempt to emphasize overloading the body for speed and strength gain while also avoiding the promotion of undesired mechanical adaptations. This manipulation of resistance and training load has been studied thoroughly for speed training in various sports, typically by measuring sprints and jump testing for the performance outcomes (Gil et al., 2018; Girold et al., 2006; Rodriguez-Rosell et al., 2020; Suchomel et al., 2020). Previous literature has also posited that there are many options for increasing resistance and load to training exercises such as sprinting, and “the coach should use a high resistance so that the athlete experiences a large training stimulus, but not so high that the device induces substantial changes in sprinting technique” (Alcaraz et al., 2008).

Also discussed in sports training literature is the use of underload or “overspeed” training to train power output (Cook et al., 2013; Girold et al., 2006). Girold et al. observed successful training outcomes when incorporating assisted swimming sprints with elastic tubes to elicit the overspeed training stimulus; the authors concluded that “both [overstrength] and [overspeed conditions] proved to be more efficient than the traditional training program.” Cook et al. found that “eccentric training with overspeed stimuli was more effective than traditional training in increasing peak power in the countermovement jump,” where the experimenters incorporated downhill running and assisted countermovement jumps in the multi-sport training program to elicit an underload/overspeed training stimuli. Finally, the authors concluded that “it is important to target-specific aspects of both force and movement velocity to enhance functional measures of power expression” (Cook et al., 2013). Overstrength training and overspeed training in skilled movements for running and swimming speed training as well as jump training can be equated to throwing with OL and UL balls for baseball pitching training.

Finally, as these mechanisms are identified, the specific implications for health and performance can be discussed to eventually manage the risk of injury and optimize athletic performance for those who implement OL and UL training in their throwing programs. The high rate of injuries in the current state of baseball, both in professional and amateur populations, highlights the importance of understanding these aspects of athletic training methods.

The purpose of the present study was to further investigate the intra-session acute mechanical effects of throwing OL and UL baseballs at maximum intent, while also adding a three-ounce implement to a study design similar to one performed by Fleisig et al. in 2017. This replication of methods allowed for potential confirmation of previously published observations while also including the three-ounce baseball, which is commonly used in baseball throwing training programs (Marsh et al., 2018). Based on the results of existing

studies into intra-session and post-session acute effects from throwing weighted implements, we hypothesized that varying the pitched ball weight between three, four, five, six, and seven ounces would significantly affect pitched ball velocity, upper body kinematics, lower body kinematics, kinematic velocities, and throwing arm joint kinetics during a maximum intent throwing workout.

METHOD

A total of 26 healthy pitchers (mean age 23.5 ± 2.7 years) with collegiate or professional-level playing experience volunteered to participate in the study during their off-season training; 24 of the 26 pitchers were right-handed. Verbal and written explanation of the informed consent document was provided to all participants, including the potential risks and benefits associated with study participation, before their testing session. Ethical approval was granted by Hummingbird IRB (Hummingbird IRB #: WB-DLR-115). Following the explanation of the study procedure, potential risks, and potential benefits, investigators received verbal confirmation of understanding and obtained a witnessed legal signature from the athlete. Heights, weights, and level of play were recorded before initiating testing procedures.

Testing Procedure

Athletes warmed up and retroreflective markers were placed as previously described in Marsh et al. 2018. More explicitly, before preparing the motion capture apparatus, athletes were given ample time to complete a self-determined warm-up protocol. Upon completion of their warm-up, athletes were fitted with retroreflective markers in preparation for the motion capture test. 47 markers were attached bilaterally on the third distal phalanx, lateral and medial malleolus, calcaneus, tibia, lateral and medial femoral epicondyle, femur, anterior and posterior iliac spine, iliac crest, acromial joint, midpoint of the humerus, lateral and medial humeral epicondyle, midpoint of the ulna, radial styloid, ulnar styloid, distal end of index metacarpal, parietal bone, and front bone, as well as on the inferior angle of the scapula, C7 and T10 vertebrae, the sternal end of the clavicle, and the xiphoid process.

The motion capture system was calibrated as previously described in Marsh et al. 2018 using Motive:Body software (NaturalPoint/Optitrack, Corvallis, OR, USA) and the ground plane was set. Calibration typically resulted in an estimated error of one millimeter or less mean three-dimensional error, and never exceeded two millimeters.

Participants then executed a series of maximum intent fastballs with varying ball weights, totaling between eighteen and thirty total maximum intent pitches. Three to five maximum intent fastballs were thrown with each ball weight in the following order: five-ounce

regulation baseball, six-ounce OL baseball, seven-ounce OL baseball, five-ounce regulation baseball, four-ounce UL baseball, and finally a three-ounce UL baseball. This order was chosen to mimic the order of ball weights thrown in a commonly used weighted ball program (Marsh et al., 2018). Participants were given between one half and three minutes of rest between test pitches, as well as a single sub-maximal intent warm-up pitch with each ball weight to gain familiarity. Testing was concluded when the investigators determined that there were three valid pitch captures at each weight. Capture validity was determined qualitatively by evaluating the amount of marker occlusion throughout the throws and if all reflective markers remained attached to the subject's body for the duration of the throw.

Pitches were thrown from a mound of standard dimensions toward a strike zone target (Oates Specialties, LLC, Huntsville, TX, USA) located above home plate, which was 60.5 feet (18.4 meters) away. Pitch velocity was measured by a Doppler radar device (Applied Concepts/Stalker Radar, Richardson, TX, USA).

Marker position data was captured and the biomechanical model for each subject was constructed as previously described in Boddy et al. 2019. Specifically, three-dimensional retroreflective marker positions were recorded with a multi-camera motion-capture system, sampling at 240 Hz (NaturalPoint/Optitrack, Corvallis, OR, USA). This system contained a mixture of Prime 13, Prime 13W, and Prime 17W cameras totaling 15 cameras. The cameras were positioned symmetrically around the capture volume, approximately 8-12 feet from the center of the pitching mound at varying heights to minimize marker occlusion.

Joint centers of the model were estimated based on markers placed on the joint and local coordinate systems (Dillman et al., 1993). Position data were filtered using a 20 Hz fourth-order Butterworth low-pass filter, after which kinematics and kinetics were calculated in Visual3D (C-Motion Inc., Germantown, MD, USA). The model was scaled for body size, and inertial properties of the hand, forearm, and upper arm were based on cadaveric data (de Lava, 1996). The baseball was modeled as a point mass at the metacarpal marker until the ball was released, after which the mass was omitted from the model (G. Fleisig et al., 2017). The baseball mass was adjusted appropriately for each of the five ball weight conditions. All kinematic and kinetic values were calculated using the ISB recommended model of the joint coordinate systems (Wu et al., 2002). In total, 14 kinematic and kinetic values (five kinematic positions, four kinematic velocities, and five kinetics) were calculated. Cronbach's alpha was calculated for each metric to evaluate the three-throw within-subject consistency of each metric included in the analysis. Alpha values of 0-0.69, 0.7-0.79, 0.8-0.89, and 0.9-0.99 represent poor, fair, good, and excellent consistency, respectively.

Kinematic and kinetic measurements were chosen by reviewing the biomechanical effects of weighted balls observed in the aforementioned studies (G. Fleisig et al., 2017; Proppe, 2017; Reinold et al., 2020). Two kinematic position values were measured at ball release (BR): anterior trunk tilt and shoulder abduction. Three kinematic position values were taken at their global maximums: elbow flexion, shoulder horizontal abduction, and shoulder external rotation. All four velocity parameters were taken as the global maximum rotational velocities in their respective axis of joint rotation: pelvis axial rotation, trunk axial rotation, shoulder internal rotation, and elbow extension. All kinematic velocities were calculated as the rate of change in the joint angle, measured in degrees/second. Three kinetic values were taken as the global maximum of their respective moment or force axis before ball release: shoulder internal rotation moment, shoulder horizontal abduction moment, and elbow varus moment. Shoulder proximal force and elbow flexion moment were taken at the instance of ball release.

Statistical Analyses

Biomechanical measurements were binned into three categories for analysis purposes: kinematic positions, kinematic velocities, and kinetics. Pitch velocity was analyzed alone, representing the fourth category. In total, we included five kinematic position measurements, four kinematic velocity measurements, and five kinetic measurements. A one-way repeated measures ANOVA was used to test a main effect of ball weight on all measurements. To account for multiple comparisons and mitigate the risk of type-1 error, an alpha value of 0.01 was used for all ANOVA tests. Eta-squared effect size was calculated to describe how much of the variation in each measure could be explained by the ball weight condition. For all measurements that were significantly affected by ball weight, Tukey's HSD post hoc test was used to test individual comparisons of all conditions.

Results

A one-way repeated measures ANOVA revealed significant effects of ball weight on pitch velocity ($p < 0.001$, $\eta^2 = 0.944$), kinematic positions, and kinematic velocities (Table 1). Ball weight exhibited a significant effect on maximum elbow flexion ($p = 0.002$, $\eta^2 = 0.153$) and anterior trunk tilt at ball release ($p < 0.001$, $\eta^2 = 0.292$) in the kinematic position group. In the kinematic velocity category, maximum pelvis rotation angular velocity ($p < 0.001$, $\eta^2 = 0.165$), shoulder internal rotation angular velocity ($p < 0.001$, $\eta^2 = 0.206$), and elbow extension angular velocity ($p < 0.001$, $\eta^2 = 0.389$) were also significantly affected by ball weight. No significant effects were found on throwing arm kinetics during the pitching delivery. All metrics exhibited

excellent within-subject x condition consistency; the average Cronbach's alpha value was 0.981 with none of the metrics exhibiting below a 0.940.

Table 1

ANOVA Results for pitch velocity and all biomechanical measurements

Measurement	P-value	η^2 effect size
Pitch Velocity	< 0.001*	0.944
Kinematic Positions		
Maximum Elbow Flexion (°)	0.002*	0.153
Maximum Shoulder Horizontal Abduction (°)	0.513	0.030
Maximum Shoulder External Rotation (°)	0.726	0.026
Shoulder Abduction at Ball Release (°)	0.465	0.035
Anterior Trunk Tilt at Ball Release (°)	< 0.001*	0.292
Kinematic Velocities		
Pelvis Angular Velocity (°/s)	< 0.001*	0.165
Trunk Angular Velocity (°/s)	0.549	0.028
Shoulder Internal Rotation Velocity (°/s)	< 0.001*	0.206
Elbow Extension Velocity (°/s)	< 0.001*	0.389
Kinetics		
Maximum Elbow Varus Moment (Nm)	0.151	0.063
Maximum Shoulder Internal Rotation Moment (Nm)	0.178	0.060
Maximum Shoulder Horizontal Abduction Moment (Nm)	0.300	0.047
Elbow Flexion Moment at Ball Release (Nm)	0.124	0.069
Shoulder Proximal Force at Ball Release (N)	0.054	0.088

* One-way repeated measures ANOVA $p < 0.01$

Tukey's HSD post hoc testing revealed significantly different pitch velocities in every ball weight condition, with the mean pitch velocity decreasing as ball weight increased (Table 2).

Table 2.

Means of pitch velocity for each ball weight condition

	3 oz	4 oz	5 oz	6 oz	7 oz
Pitch Velocity (MPH)	90.3 ± 4.11	87.1 ± 3.82	86.2 ± 3.73	83.1 ± 3.77	80.2 ± 3.8

Note. Post hoc testing revealed significant differences in all 10 individual condition comparisons. Values reported as the mean ± standard deviation.

Subjects exhibited less elbow flexion at foot plant and more anterior trunk tilt at ball release as ball weight increased. Kinematic measurement means for each condition are displayed in Table 3.

Table 3.

Means of the five kinematic parameters for each ball weight condition

Kinematic Position Measurement	3 oz	4 oz	5 oz	6 oz	7 oz
Maximum Elbow Flexion (°)*	119.3 ± 13.7	119.8 ± 13.6	118.9 ± 13.5	117.8 ± 13.9 ^{a,b}	118.3 ± 13.9 ^a
Maximum Shoulder Horizontal Abduction (°)	49.01 ± 12.6	49.39 ± 12.2	50.45 ± 11.5	49.07 ± 11.2	48.45 ± 13.0
Maximum Shoulder External Rotation (°)	170.0 ± 9.96	169.7 ± 9.90	170.4 ± 8.99	170.2 ± 9.38	169.7 ± 9.12
Shoulder Abduction at ball release (°)	96.07 ± 7.30	95.92 ± 6.80	96.40 ± 7.94	96.08 ± 7.85	95.49 ± 8.48
Anterior Trunk Tilt at ball release (°)*	34.14 ± 10.7	34.40 ± 11.0	36.18 ± 9.8 ^{a,b}	36.16 ± 9.8 ^{a,b}	36.62 ± 10.4 ^{a,b}

Note. Values reported as the mean ± standard deviation.

* One-way repeated measures ANOVA $p < 0.01$

^a Significantly different than the 3 oz condition

^b Significantly different than the 4 oz condition

Peak pelvis angular velocity, peak shoulder internal rotation angular velocity, and elbow extension angular velocity all decreased as ball weight increased; all kinematic velocity means for each ball weight condition are presented in Table 4.

Table 4.

Means of the four peak kinematic velocity parameters for each ball weight condition

Kinematic Velocity Measurement	3 oz	4 oz	5 oz	6 oz	7 oz
Pelvis Angular Velocity (°/s)*	797.7 ± 129	796.9 ± 123	778.3 ± 134	771.3 ± 131 ^a	764.3 ± 130 ^{a,b}
Trunk Angular Velocity (°/s)	1112 ± 129	1111 ± 119	1097 ± 118	1104 ± 123	1103 ± 126
Shoulder Internal Rotational Velocity (°/s)*	4102 ± 405	3984 ± 404	4043 ± 399	3947 ± 427 ^a	3871 ± 350 ^c
Elbow Extension Velocity (°/s)*	2354 ± 264	2315 ± 269	2295 ± 253 ^a	2280 ± 264 ^a	2235 ± 267 ^c

Note. Values reported as the mean ± standard deviation.

* One-way repeated measures ANOVA $p < 0.01$

^a Significantly different than the 3 oz condition

^b Significantly different than the 4 oz condition

^c Significantly different than the 5 oz condition

None of the measured throwing arm joint kinetics exhibited significant differences between ball weight conditions.

Table 5

Means of the five kinetic parameters for each ball weight condition

Kinetic Measurement	3 oz	4 oz	5 oz	6 oz	7 oz
Maximum Elbow Varus Moment (Nm)	147.9 ± 25.8	147.9 ± 21.6	153.1 ± 26.9	149.2 ± 28.1	147.5 ± 26.5
Maximum Shoulder Internal Rotation Moment (Nm)	152.2 ± 25.1	150.7 ± 22.2	155.4 ± 26.6	152.3 ± 28.2	149.7 ± 26.5
Maximum Shoulder Horizontal Abduction Moment (Nm)	155.7 ± 46.7	156.6 ± 58.6	149.5 ± 47.5	154.5 ± 54.7	146.0 ± 45.0
Elbow Flexion Moment at Ball Release (Nm)	36.34 ± 24.2	34.79 ± 31.6	32.96 ± 25.4	32.62 ± 26.8	26.21 ± 25.2
Shoulder Proximal Force at Ball Release (N)	1195 ± 157	1154 ± 176	1159 ± 130	1189 ± 160	1142 ± 155

Note. The null hypothesis for a one-way repeated measures ANOVA was not rejected for any of the included kinetic measurements. Values reported as the mean ± standard deviation.

Discussion

The purpose of this study was to investigate the intra-session acute effects of throwing weighted baseballs on the pitching delivery. Similar to previous research by Fleisig et al. in 2017, there were significant ball velocity, kinematic position, and kinematic velocity differences between each ball weight condition (*Table. 1*). However, there was no observed effect of ball weight on arm joint kinetics.

The two measured kinematic positions included in the present study that exhibited a significant relationship with ball weight were maximum elbow flexion and anterior trunk tilt at ball release, though both showed differences in sample means of no greater than three degrees between any two conditions. Elbow flexion often reaches its maximum value just before the shoulder moves into its maximally externally rotated position during the late arm-cocking phase (Seroyer et al., 2010; S. I. Werner et al., 1993). This is after the trunk has begun its axial rotation and when the arm begins accelerating to its peak velocity. Because of the rotational movement of the trunk, shoulder, and elbow throughout this phase, the decreased elbow flexion is likely due to the added centripetal forces acting against elbow flexion as ball weight increases. This observation aligns with previously published weighted ball research (G. Fleisig et al., 2017).

The relationship between ball weight and anterior trunk tilt at ball release also aligns with previous research (G. Fleisig et al., 2017). Anterior trunk tilt at ball release exhibited a positive linear relationship with ball weight. Previous studies found that peak anterior trunk tilt kinematic velocity doesn't occur until 96% of the way between front foot contact and ball release (Matsuo et al., 2001). Since the trunk tilts forward at its greatest velocity between maximum shoulder external rotation and ball release, and heavier balls theoretically require a longer duration of time between maximum shoulder external rotation and ball release due to lower arm velocities, the authors posit that this added duration due to lower arm speeds causes the trunk to reach a more forward tilted position by the time the ball is released.

As previously mentioned, a goal for the use of added resistance in skill training programs is to “use a high resistance so that the athlete experiences a large training stimulus, but not so high that the device induces substantial changes in sprinting technique” (Alcaraz et al., 2008). Kinematic positions from the use of six- and seven-ounce OL baseballs were not significantly different from those when using a five-ounce baseball, which supports their use in overload pitching training programs.

The present study misaligned with previous literature regarding the effect of ball weight on maximum shoulder external rotation. The relationship between weighted balls, external rotation and velocity increases has been much debated among many baseball practitioners

and researchers. First, external rotation in the throw has been linked to velocity, which many researchers hypothesize is causal (R. Escamilla et al., 2002; Lyman et al., 2002; Reinold et al., 2018). Previous studies have also observed a relationship between ball weight and external rotation (Proppe, 2017; Reinold et al., 2020). The present study, however, did not observe a significant effect of ball weight on maximum shoulder external rotation. This is likely also a function of the subjects' levels of play and relatively small difference in ball weight compared to previous studies, which included ball weights of up to 2 pounds (Reinold et al., 2018, 2020). While the effect of ball weight on kinematic positions was minor, kinematic velocities showed a clear relationship with ball weight.

As hypothesized, the UL three- and four-ounce baseballs in the present study elicited higher rotational velocities than the five-ounce baseball. The effect they had on kinematic position was small, supporting their use for manipulating the training stimulus to train for power in the pitching motion. Further, the only significant difference in kinematic positions observed between UL balls and five-ounce baseballs was maximum elbow flexion, with the three-ounce ball weight condition eliciting more elbow flexion than the heavier balls. Elbow flexion at stride foot contact has been shown to be positively associated with ball velocity in previously published research (S. L. Werner et al., 2008), so this change in technique associated with throwing the three-ounce ball likely would not lead to adverse long-term training effects.

Lastly, contrary to the hypothesis and previous research, there were no significant differences in elbow or shoulder torque based on ball weight (G. Fleisig et al., 2017). Additionally, mean peak joint kinetic values were notably larger than in the study by Fleisig et al., which can likely be explained by the difference in the filtering of marker position data. A 20 Hz low-pass filter was used in the present study, whereas a 10 Hz low-pass filter was used in Fleisig et al. 2017. A higher cutoff frequency passes higher frequency components of the marker position signals used for inverse kinematics and dynamics, which subsequently affects estimated force and torque magnitudes.

There are other differences between the present study and Fleisig et al. 2017 that may explain contrasting results in the relationship between ball weight and joint kinetics. The present study only included weighted balls thrown off a mound, as opposed to both mound throws and flatground "run-n-guns". Fleisig et al. also had randomized the order of the ball weight conditions, while the present study had each participant throw them in uniform order to mimic common weighted baseball workouts. Lastly, player experience was likely a contributing factor. Previous studies included high school and collegiate level pitchers, whereas the present study included only professional and collegiate level pitchers. More trained

participants may respond differently to OL and UL implements than lesser trained participants, as previous research has observed decreasing within-subject mechanical variability in higher playing level populations (G. Fleisig et al., 2009).

The present study has several limitations. No youth athletes or position players were included in the sample, limiting its applicability to all baseball players. Second, the order of the ball weight conditions was not randomized, rendering the athlete subject to fatigue when progressing to the UL baseballs and confounding the main effect of ball weight on pitching kinematics and kinetics. Additionally, only moderate (<40%) UL and OL ball weights were included in the experiment, despite the inclusion of implements of up to two pounds in some training programs (G. Fleisig et al., 2017; Reinold et al., 2018, 2020). These results cannot be generalized to the use of more extreme OL and UL implements. Further, because the present study is cross-sectional, the results do not support significant long-term use of OL and UL training for baseball pitchers. Lastly, kinematic and kinetic measurements were based on markers placed on the skin, creating a soft tissue artifact commonly found in marker-based motion capture systems—though marker-based motion capture is considered the gold standard for accurate sports biomechanics measurements.

Conclusion

In conclusion, the results of the present study and previously published literature suggest that the training effects from implementing OL and UL methods in throwing programs could be due in part to training specific strength and power in the throwing motion. Overloading applied movements such as the baseball pitch without adversely affecting mechanics is an idea that has been discussed and sought after in sprinting research. Similarly, overspeed training in sprinting and swimming has shown to positively affect power output. The present study supports the use of overload and underload implements between three and seven ounces to achieve both of these goals without significantly increasing the arm joint loads that throwers are subject to while training and performing.

Contributions

Contributed to conception and design: MO, JM

Contributed to acquisition of data: KL, MO, JM, AB

Contributed to analysis and interpretation of data: MO, KL, JS, AB, AC

Drafted and/or revised the article: MO, KL, JM, AC

Approved the submitted version for publication: MO, KL, JM, JS

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