ACUTE EFFECTS OF WEARABLE RESISTANCE APPLIED TO THE THROWING ARM ON PERFORMANCE IN BASEBALL PITCHERS

ABSTRACT

This research examined the acute effects of wearable resistance (WR) placed above and below the elbow of the throwing arm of baseball pitchers on throwing characteristics. Ten high school or collegiate baseball pitchers (19.5 ± 2.4 years) performed a randomized throwing assessment with and without WR (100-g, 150-g and 200-g) secured to the throwing arm above and below the elbow. Participants wore an inertial sensor at the elbow to record arm speed, throwing velocity was measured by radar and temporal aspects (stride phase and pitch phase) measured by video. A repeated measures ANOVA with post-hoc analyses was used to test the influence of load magnitude and placement, with statistical significance set at $p<.05$. On average, loading significantly influenced arm speed and throwing velocity (η_p^2=.32-.41, $p<.05$), and the effect of loading varied by placement (i.e., above and below elbow) for the latter (η_p^2=.64, $p<.001$). Above elbow loading had no significant effect on the throwing variables measured. For below elbow, there were large decreases in arm speed for 150-g and 200-g loads compared to the unloaded trials (-5.13 to -6.52%, d=0.82-1.03, $p<.05$) and small to moderate decreases in throwing velocity with all loads (-1.8 to -2.7%, d=0.45-0.67, $p<.01$). Overall, WR did not significantly alter phase timing. Our results may indicate the effects of WR differ by placement and may have utility in providing graduated overload to throwing musculature, without clearly influencing timing while throwing.

KEY WORDS: arm speed; throwing velocity; loaded throwing; throwing athletes; throwing specific training; pitching.

INTRODUCTION

Overhead throwing is an athletic skill used in many sports such as baseball, softball, handball and American football. The speed at which a ball can be thrown is often critical to success in these sports. For example, baseball pitchers with higher throwing velocities give batters less time to identify a pitch and its location. Given the competitive advantage associated with higher pitching velocities there is a great deal of research focusing on increasing it via technical and strength training, the latter providing the focus of this article.

Pitching performance can be maximized by optimizing mechanics to efficiently transfer energy from the lower body through the trunk and throwing arm. Pitchers need adequate mobility and strength to reach throwing-specific positions and transfer force throughout the throwing motion (4, 31). Sufficient total-body strength, and specifically in the throwing arm, is necessary to withstand the demands of throwing as shoulder and elbow injuries are common in these athletes (4, 5, 28). Training to improve throwing velocity in pitchers can be achieved via non-specific methods, such as gym-based resistance training (e.g., medicine balls, rubber-based, pneumatic, iron resistance), resulting in increases of 1.2-10.7% over four to 10 weeks (22). Non-specific methods also contribute to hypertrophy, and increased muscle volume, particularly in the upper and lower throwing arm is associated to throwing velocity (partial $r=.30$-$.35$, $p<.05$) (35). Nonetheless, it is important to note that developing muscle mass takes time and other factors, such as throwing mechanics and sequencing force still play a role (4, 31, 33, 35). Non-specific methods are characteristically different than throwing, and so there is interest in more specific

means of targeted strength development that more closely mimic throwing mechanics – often by integrating load into the movement itself.

Throwing weighted balls, a specific training method, is also popular and has successfully improved throwing velocity over six to 15 weeks with balls 2- to 32-ounces by 3.1-7.3% (22). Standard baseballs are 5-ounces and throwing balls lighter or heavier allows for under- or overloading of velocity and/or force production to elicit greater throwing arm accelerative power. Throwing balls 4- to 7-ounces allowed high school and collegiate pitchers to maintain throwing technique (19). Further, training with weighted balls within 20% of standard ball mass (i.e., 4- to 6-ounces) has been shown sufficient to improve throwing velocity with high school and collegiate pitchers without injury (8-11). Ball masses within 20% of standard seem reasonable and are recommended. Normally, weighted balls are released, limiting decelerative overload to the throwing arm. Alternatively, weighted ball "holds" are utilized to train throwing deceleration by instructing athletes to keep an overweight ball secured in the hand past the release point. Although effective for overloading musculature around the elbow (19), this could potentially alter throwing mechanics or timing. It should be noted that among college and professional pitchers (n=376), 75% believe weighted balls improve performance, however, 73% also believe this tool poses risk of injury (7). Sufficient evidence suggests that weighted ball throwing protocols can be safely integrated into training (1, 8, 9, 11, 14, 19, 20), however, researchers in a six-week study utilizing a wide weighted ball range (2- to 32-ounces) reported 24% of the weighted ball group participants sustained a throwing arm injury (30). Another form of specific training is wearable resistance (WR), where micro-loads are attached to upper and lower arm compression garments.

Using WR while throwing can overcome limitations associated with weighted balls by overloading deceleration mechanics, providing more variety for progression (i.e., load placement) and can be immediately applied or removed. Compared to the distal, hand-held weighted ball, WR load can be applied more proximally (i.e., above or below elbow), which directly influences the rotational inertia and overload experienced by the athlete. Mathematically, the rotational inertia (I) is a function of mass (m) and (more importantly) the distance of the mass from the axis of rotation which is squared (r^2). Thus, moving load proximally or distally will decrease or increase rotational inertia, respectively. Accordingly, load placement allows for specific musculature to be targeted. Particularly, loads applied above the elbow will target musculature surrounding the shoulder joint, while below elbow loading will target shoulder and elbow musculature. The addition of mass will have greater effects when placed farther away from the axis of rotation (i.e., shoulder) which may decrease throwing velocity and arm speed. However, increasing mass with WR above the elbow could allow for a tapering of segmental mass which may actually act to increase arm speed in the smaller, distal segments (i.e., forearm and hand) provided the athlete might still effectively accelerate the mass, based on the conservation of angular momentum (15, 24, 32). Nonetheless, the acute effects of WR throwing with pitchers are unexplored. Investigating the effects of strategically placed throwing arm WR on throwing velocity, arm speed and temporal aspects of throwing could advise training protocols which could enhance throwing velocity, arm speed and arm strength.

Throwing a baseball can result in arm speeds over 7,000 degrees per second (deg/s) (17). Arm speed may be interesting to track during training and throwing rehabilitation, especially when utilizing specific strength training methods. In terms of WR, arm speed may be valuable to monitor because movement velocity is meant to be minimally disrupted with load (12). Traditionally this information is measured in a laboratory setting via motion capture, however, the use of inertial measurement unit (IMU) technology is becoming more prevalent in baseball to monitor throwing workload (3, 23, 25, 26, 29). An IMU device, comprised of an accelerometer and gyrometer, has reliably measured arm speed (3, 23, 25, 26) and no significant differences were reported when compared to marker-based motion capture technology (3). Using this device, it was reported that as ball mass increased ball velocity and arm speed decreased in a youth pitcher weighted ball study (29), however it has not been used with WR.

Temporal aspects of throwing have previously been reported from motion capture data in pitchers from youth to the professional level (13, 18, 27, 33). The time from front foot contact to ball release in these studies, known as pitch time (~139-150 ms), seems to be consistent across skill levels (18), high and low velocity college and professional pitchers (27), comparatively between wind-up and stretch positions (13) and within pitcher variation (33). Deviations in pitch time may provide a broad indication of alterations in technique and provide insight into the effects and subsequent utility of WR.

The purpose of this study is to determine the change in acute temporal and mechanical measurements across WR loading (unloaded, 100-g, 150-g and 200-g) and placement (above and

below elbow) of the throwing arm in baseball pitchers. The hypotheses of this study were: 1) the magnitude of the WR loading will significantly impact arm speed and throwing velocity, 2) below elbow placement will have a greater effect on these variables compared to above elbow, 3) temporal phase mechanics will not be altered with the application of WR.

METHODS

Experimental Approach to the Problem: An acute randomized cross-sectional design was used to examine effects of above and below elbow WR (unloaded, 100-g, 150-g and 200-g) applied to the throwing arm on throwing performance.

Subjects: Ten high school or college (19.5 ± 2.4 years) male baseball pitchers (height = 180.9 $\pm$ 7.7 cm; weight = 81.4 $\pm$ 10.0 kg) were recruited to participate in this study. Athletes were healthy and injury free. Written consent was obtained from each participant and their respective parent/guardian (where applicable) before participation. The institutional ethics committee approved the study (AUTEC 19/445).

Equipment and Procedures: Subjects participated in three testing sessions (familiarization and two testing sessions) that used Velcro micro-loads (unloaded, 100-g, 150-g and 200-g) affixed to arm sleeve compression garments (Lila Exogen Exoskeletons, Sportboleh Sdh Bhd, Malaysia). Anthropometrics (height and weight) were recorded prior to familiarization. Height was measured via stadiometer and weight by scale.

For each session, participants performed a standardized warm-up of jogging, skipping and dynamic stretching, and rotator cuff exercises with banded resistance. Self-selected submaximal throws were also permitted before testing. Subjects were familiarized with the WR during the first session during which they were encouraged to ask questions and give feedback upon completion. In the second and third sessions, participants were randomized into a WR above or below elbow loading protocol with randomized loads (see Figure 1; 100-g, 150-g or 200-g) which also included unloaded trials. The spectrum of loading adopted in this study was based on pilot testing, and anecdotal feedback with athletes and coaches of what would be applicable within the field. It was determined the upper limit of load that would remain attached and not inhibit athletes' experience was 200-g, in 50-g increments; these former and latter concerns were mostly applicable to the lower and upper arms, respectively, and were then standardized for both placements. Loads were placed at the midpoint of the dorsal forearm or lateral upper arm to avoid the loads rubbing against other parts of the body (i.e. torso). Loads would occasionally detach from the sleeve because of the high-speed action, and sometimes moved during testing. The sleeve's integrity was checked after each throw and if sliding occurred during testing, or loads detached, participants were asked to repeat the throw.

Insert Figure 1

Figure 1. Throwing with WR applied above elbow (left) and below elbow (right).

Data collection started once the participant communicated that he was ready for testing to begin. Data was recorded on three throws with each load (nine throws) and included three unloaded throws to start and finish the assessment, thus session workload consisted of 15 throws. Participants were allowed 30 seconds rest between throws during the testing session. During the throws, athletes wore an IMU sensor (6.9-g, Driveline, Kent, Washington, USA), which provided data on arm speed (see Figure 2). These sensors are used in baseball circles and have been reliably quantified arm speed (CV=2.9-4.3%, ICC=.79-.86) (3, 23, 26). The sensor was placed two finger widths below the participants medial humeral epicondyle, per manufacturer instructions.

Insert Figure 2

Figure 2. IMU sensor within strap worn with upper arm sleeve (left) and total arm sleeve (right).

Throwing velocity was measured via radar gun (Stalker Pro II, Applied Concepts Inc., Richardson, Texas, USA) mounted behind the throwing target. For each throw, peak throwing velocity was recorded into a spreadsheet along with data from the IMU sensor (i.e., arm speed). During the throwing trials an Apple iPad (Apple, Cupertino, CA, USA) was set up perpendicular to the throwing area directly in line with the participant. The stride phase was defined as the instant the front foot lifted off the ground to the point of front foot contact, and the pitch phase was defined as the point of front foot contact to ball release, where the ball separated from the hand. Videos were filmed at 240 frames per second, stored in a cloud system and managed by the researcher.

Data analysis:

Trials recorded from the radar and IMU were averaged for each placement and load for analysis. Video captured during trials allowed for a two-phase analysis of the throwing motion; first, when the pitcher lifted his foot off the ground to front foot contact (i.e., the stride phase); and second, from front foot contact to ball release (i.e., the pitch phase). Time spent in each phase was averaged across trials for each WR condition.

Statistical Analysis:

Means and standard deviations (mean ± SD) were calculated for variables in each testing session. To address our aims, separate two-factor [placement (2) x mass (4)] within-subjects repeated measures ANOVAs were performed on arm speed, throwing velocity and pitch and stride phases as dependent variables. Particular interest was paid to the interaction effect in the models (placement × mass) in testing our initial hypotheses. Model assumptions were tested, with violations of sphericity addressed using Greenhouse-Geisser correction (arm speed and throwing velocity). Normality was violated for throwing velocity and below elbow placement (W=.78-.85, $p<.05$), which was caused primarily by a few outliers (normality was restored upon their removal); however, since the primary results did not appear sensitive to their removal (such models are typically robust to such violations), and we lacked a clear case for their removal (e.g., they were not clearly an error), we opted to retain them in the final model. To interpret magnitude of effect on the dependent variables, partial eta-squared (η_p^2) was reported. Magnitude of effect was interpreted using the following thresholds: small (η_p^2=.01-.059), medium (η_p^2=.06-.13) or large (η_p^2>.14). Pairwise comparisons were performed between loads within placements, for the

various dependent variables, and interpreted as raw difference, 95% confidence intervals, and Cohen's d effect sizes (d). Bonferroni correction was used to adjust the acceptable error for multiple comparisons, and Cohen's d was interpreted using trivial (<0.1), very small (0.1-0.19), small (0.2-0.49), moderate (0.5-0.79), large (0.8-1.19) or very large (>1.2) thresholds of effect (6). The alpha value for all tests was considered as $p<.05$.

RESULTS

Descriptive data and the effects of WR load and placement on throwing are displayed in Table 1. Overall, load had a large effect (η_p^2=.32-.41) on arm speed and throwing velocity ($p<.05$). Placement of WR had no effect on the variables of interest. The effect of load on velocity varied to a large degree on where it was placed on the arm (η_p^2 =.64; $p<.001$).

Insert Table 1

When examining the differences between loads with unloaded trials, no significant differences were observed for any variables between loads placed above elbow. Large differences in arm speed were observed when comparing unloaded trials to 150-g and 200-g below elbow loads (d=0.82, p=.030 and d=1.03, p=.002, respectively). Small to moderate decreases in throwing velocity were observed between unloaded trials and all below elbow loads: 100-g at d=0.45, p=.009, 150-g at d=0.67, p<.001, and 200-g at d=0.62, p<.001.

Insert Table 2

DISCUSSION

In this study investigating the effects of WR on baseball throwing performance, the main findings were: 1) the effect of loading on throwing velocity varied by its placement, with small to moderate decreases in throwing velocity detected with below elbow loading exclusively, 2) large decreases in arm speed were shown with below elbow loading of 150-g and 200-g compared to unloaded conditions, and 3) otherwise, neither WR placement nor load affected temporal phase mechanics.

Unloaded throwing in this study resulted in arm speeds of 5,619-5,723 deg/s and throwing velocity at 36.2-36.3 m/s. Researchers investigating similar cohorts using the same IMU have reported comparable ranges for arm speed (5,053-5,952 deg/s) and similar throwing velocities using radar gun (33.5-38.1 m/s) when throwing from a pitching mound (2, 23, 25, 26). This is somewhat surprising, since throwing from a mound compared to flat-ground was found to have differences in arm speeds (2, 19). It is probable that these differences are simply a product of cohort specific characteristics.

Throwing velocity was the only variable to which the effect of loading strongly varied by placement (~64% variance explained by the interaction between load and placement). Accordingly, small to moderate standardized decreases (d=0.45-0.67) in throwing velocity with

below elbow loads were recorded (see Figure 3) which were smaller than the moderate to large decreases observed in the weighted ball research (-3.2 to -7.0%, d=0.55-1.3) (19). This is intuitive, since the placement of weighted balls are further from the axis of rotation compared to the placement used for the WR in this study, resulting in greater rotational inertia and therefore decreased outcome effects. Decreases in throwing velocity with below elbow loading ($p \leq .004$) were also reported in female handball athletes (21), albeit difficult to compare given differences in the throwing motion for the two sports (i.e., ball mass, controlled vs dynamic throwing, arm speeds, throwing velocity) (18, 34). Nonetheless, although statistically significant, the practical magnitude of changes observed as a product of loading was practically small (e.g., ~1 m/s decrease, from the heavier below elbow loads). Whether such small changes in throwing velocity – or otherwise the rotational overload that is not otherwise captured in macroscopic performance outcomes – signals sufficient overload to stimulate positive adaptations needs to be investigated.

Insert Figure 3

The individual effects of above (3A) and below (3B) elbow WR loading on throwing velocity.

The effects of WR on arm speed did not differ ($p > .05$) as a product of above elbow loading. This lack of change might be due to the proximity of WR loading to the axis of rotation resulting in a minor overload that we were unable to clearly detect within the constraints of our study design. Although non-significant, the load applied above the elbow decreased arm speed on average, however, some individuals increased speed with proximal loading (see Figure 4). The apparently

favorable response of some athletes to the stimulus might indicate leveraging the additional mass to conserve momentum and increase their subsequent throwing performance to a minor degree, however, this is speculative and future researchers could investigate proximal loading strategies to optimize arm speed in baseball pitchers (15, 24, 32).

Insert Figure 4 here

Individual responses to above (4A) and below (4B) elbow placements to arm speed.

Large decreases in arm speed during below elbow loading were observed with 150-g and 200-g (d=0.82-1.03). Ultimately, these findings were not surprising given that the increased segmental mass from WR loading is exponentially affected by distance from the throwing shoulder and can alter the torque required to accelerate the throwing arm forward. Despite increased load applied to the throwing arm, decreased arm speed in this study can be indicative of reduced elbow varus torque, like other observations noted with weighted balls (19). Overload from WR resulting in slower arm speeds may have positive benefits in throwing performance with repeated use over time. The micro-load arrangement distal to the shoulder joint, results in a greater disruption in arm speed given the increased rotational inertia. This increase in resisted overload requires greater force production in the arm musculature and if repeated over multiple training occasions should theoretically increase shoulder strength. Nonetheless, at present it is unknown whether the magnitude of decreases observed in this study are practically meaningful for stimulating longitudinal training adaptations.

Macroscopic throwing mechanics were analyzed via video to measure time spent during the stride phase (i.e., front foot lift to front foot strike) and the pitch phase (i.e., front foot strike to ball release). No difference ($p>.05$) in time spent during these two throwing phases across a range of loads (100-g to 200-g) and placement (above and below elbow) were observed. During the stride phase, a pitcher will raise the front leg to a height that noticeably varies among pitchers and will reach front foot strike by various strategies such as staying tall and falling down the mound or driving the body directly toward home place. Stride phase timing has not been reported in existing literature although it is expected this aspect of throwing may have more variability. Pitch phase duration (151-154 ms) was comparable to previous research (139-150 ms) (13, 18, 27, 33) suggesting that WR may not unduly disrupt sequencing compared to unloaded conditions. A common concern of many coaches is the disruption to temporal sequencing when overload is introduced into the throwing motion. Albeit low granularity, the loading and placement strategies and outcome measures used in this study do not support this concern. Indeed, the lightweight and seemingly non-invasive nature of WR allows pitchers to generally maintain technical proficiency with load at high speeds (12).

No differences ($p>.05$) were noted in temporal phase mechanics suggesting that movement sequencing with load, with either placement, was not disrupted. Training with WR is intended to maintain movement velocity similar to competition or training speeds (12). Above elbow WR load resulted in small to moderate decreases in arm speed ($d=0.42$-0.57), although non-significant, these effects may accumulate into a training effect with repeated exposure. As hypothesized, below elbow load produced more distinct differences in arm speed (-5.1% to -6.5%, $p<.05$) and

throwing velocity (-1.8% to -2.5%, $p<.05$). Below elbow loading could also be considered because sequencing was not disrupted, despite more distinct decreases in arm speed and throwing velocity. Accordingly, the influence of forearm length warrants consideration with below elbow loading because pitchers with longer forearms will have greater moments of inertia which could more distinctly differentiate between below elbow proximal and distal loading.

A number of research questions need to be answered to fully understand the effects of WR on throwing: 1) loads were placed exclusively on the throwing arm; however, it would be interesting to examine the effects of WR on the non-throwing arm and other parts of the body such as the trunk and legs; 2) the researchers exclusively sourced baseball pitchers, the effects of WR on throwing performance for other position players in baseball and other throwing athletes (i.e. softball, American football quarterbacks, javelin) warrants investigation; and, 3) high-intent throwing was the focus of this study, however understanding the effects of WR on other throwing activities such as long-toss or throwing exercises commonly used with weighted balls, would be beneficial to coaches. Furthermore, a distinctive advantage of throwing with WR is overloading the deceleration phase of throwing, which is difficult with weighted ball training. High forces are generated by the entire body while the arm accelerates forward which are absorbed, primarily by posterior shoulder musculature, during deceleration (4, 31). Progressive overload with WR could prepare the body for the demands of high intensity throwing exhibited in baseball pitchers to handle the proximal compression loads for the shoulder that can exceed body weight for highly competitive pitchers (16).

There are some limitations that warrant discussion. First, while we planned to use a broader range of loading magnitudes in this study, during piloting it became apparent that athlete arm size, sleeve integrity, and detaching loads were a problem with the commercially available units. Future researchers could investigate strategies to overcome these issues, potentially using updated securing methods, and access greater ranges of loads for analysis. Nevertheless, the practical issues encountered may signal a lack of practical utility of such loading protocols. Absolute loads were used in this study to prioritize weights that maintained placement throughout the entire throwing motion. Individualizing loads relative to body mass is worthy of examination with amended securing methods. Further, forearm length is worth consideration as relative load and distance from the shoulder could be used to normalize inertial loads. High-speed video was utilized in determining temporal features for the delivery, with the idea of using practically available tools and a macroscopic measurement. Perhaps differences may be seen in performing this work within an optical 3D tracking environment that incorporates time normalization between trials to identify differences in front foot lift off and stride foot placement. Stride time, the time by which the lead foot is airborne, could be potentially more granular for statistical interpretation with the use of force plates to determine when the lead foot unloads the ground and then when it contacts the ground a second time to denote the end of the stride phase.

PRACTICAL APPLICATIONS

Loaded throwing with WR applied to the throwing arm, within the ranges in this study appears to influence throwing velocity and arm speed – contingent on where it is applied. Specifically, below elbow loads from 100-g to 200-g appear to reduce throwing velocity to a degree which might indicate potential for training adaptation over repeated bouts. Loads applied above elbow, did not appear to influence throwing performance but may deserve consideration in training the shoulder girdle without limiting arm speed, and interesting phenomenon observed in the unique responses of some athletes who actually increased their throwing speed. Nonetheless, both contentions are speculative, and require further investigation. Ultimately, further investigation into the mechanical disruption resulting from the implementation of WR is needed, however, from a temporal perspective, mechanical integrity seems to remain unchanged with the loads used in this study. WR may offer unique strategies to incrementally overload the throwing motion in a more targeted fashion than weighted balls. Applying overload in this way may be beneficial during return to throwing rehabilitation since the shoulder can be targeted while leaving the elbow and wrist joints unloaded.

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