DOES A SINGLE PITCHING SESSION INDUCE LOWER EXTREMITY MUSCULAR FATIGUE IN HIGH SCHOOL BASEBALL PITCHERS?

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The purpose of this study was to assess hip strength changes and provide a quantifiable measurement to show muscular fatigue after pitching a single pitching session. Fifteen adolescent male baseball pitcher‘s hip external rotator, internal rotator, and extensor strength, along with a functional test were measured before and after a single pitching session. After an average of 19 pitches, all hip strength measures in both legs significantly decreased in post-pitching tests. This study showed pitching increased muscular fatigue of the hip muscles after a small number of pitches thrown. With overall fatigue being a large indicator of injury risk in baseball pitchers, monitoring lower extremity muscular fatigue may be a way to potentially reduce risk of injury.

KEYWORDS: hip strength, fatigue, adolescent, injury risk

INTRODUCTION: The causes for pitching injuries are numerous and multifactorial. Still, the biggest risk of an injury for a pitcher occurs with fatigue caused by overuse. Olsen et al. (2006) found that pitchers that were overused and perceived that they were fatigued, increased their risk for injury that would lead to surgery by thirty-six times. Monitoring a pitcher's fatigue has been long considered with Little League Baseball establishing pitch count limits in 2006. Even with pitch counts, injuries have been on the rise at a startling rate at all levels of baseball. Between 2009 and 2016, there was a 9-fold increase rate of nonsurgical cases of ulnar collateral ligament (UCL) injury in high school and collegiate athletes (Zaremski et al., 2017). Unfortunately, monitoring pitch count has not been enough to reduce injuries. There needs to be a more quantifiable metric, that can measure fatigue by the medical staff and coaches. One way to monitor fatigue quantifiably is measuring muscular fatigue while a pitcher is pitching. Muscular fatigue is defined as exercised-induced reduction in the ability of muscle to produce force or power (Enoka & Duchateau, 2008). The importance of lower extremity biomechanics is vital for reducing excessive forces at the shoulder and elbow (Davis et al., 2009). A fatigued pitcher has been shown biomechanically to exhibit the greatest effects at the lower extremity/trunk. Kung et al. (2017) found fatigue adversely affected lower extremity kinematic and temporal metrics in all phases of the pitching cycle. One of the main findings of Kung et al. (2017), was that as the pitcher fatigued, it greatly reduced the pitcher's pelvic rotation. Erickson et al. (2016) found fatigue also greatly affected hip to shoulder separation, from 90% to 40% separation. Poor hip to shoulder separation increases humeral rotation torque at the shoulder and elbow valgus forces, which lead to greater risk of injury (Davis et al., 2009).
Hip strength measurements have been correlated with pitching biomechanical metrics (Albiero et al., 2022), with those same pitching metrics found to be affected by fatigue (Kung et al., 2017 and Erickson et al., 2016). To further investigate the relationships between hip strength and fatigue, the goal of this study was to assess hip strength changes after pitching a single pitching session. It was hypothesized that hip strength measurements, which have been corelated to pitching biomechanics, will also show signs of muscular fatigue.

METHODS: Fifteen adolescent male baseball pitchers from a local competitive baseball program participated. Each pitcher had at least 3 years of pitching experience, was currently pain free, and had no history of throwing arm surgery. All subjects signed assent forms, and informed consent was obtained from their guardian before involvement. All pitchers performed approximately a 20-minute warm up that focused on the whole body, using static and dynamic stretching, and pitching drills (Albiero et al., 2022). A single certified physical therapist collected all strength measurements. Strength was assessed for each hip, labelled as lead leg and back leg based on arm dominance. A coin flip decided the leg order of testing. Isometric strength of

hip external rotation, internal rotation, and extension was measured using a MicroFET2 dynamometer (Hoggan Health Industries, West Jordan, Utah) following established standardized make test positions (Thorborg et al., 2010). The therapist was positioned directly perpendicular to the designated anatomical landmark with the hand-held dynamometer to ensure no movement of the limb occurred while testing. If the therapist moved while testing, the measurement was discarded. Three trials of a 5 second maximal isometric contraction was performed 30 seconds apart, with the mean value used for data analysis. Hip external and internal rotator strength were measured with the pitcher seated on the edge of a mat table with a 90-degree angle at both their hips and knees. For external rotators, the dynamometer was placed 5 cm proximal to the medial malleolus, with the pitcher instructed to maximally rotate externally. For internal rotators, the dynamometer was placed 5 cm proximal to the lateral malleolus, with the pitcher instructed to maximally rotate internally. Hip extensor strength was measured with the pitcher prone on the table. The dynamometer was placed posteriorly 5 cm above the medial malleolus with the pitcher instructed to maximally extend. Any compensatory actions were limited for all tests. Strength measures were normalized to pitcher's body mass.
The pitchers performed a single leg hop for distance with the arms free, aiming at a more functional execution (Ageberg & Cronström, 2018). They stood on the test leg with their toes behind a line, with the other leg lifted from the floor by flexing the knee. They were told to hop as far as possible, taking off and landing on the same foot, maintaining their balance for 2 seconds. The test was performed three times with each leg, alternating legs. Hop distance was measured from toe in the starting position to heel in the landing position with a measuring tape. One trial hop preceded the measurements. Hop distances were normalized to pitcher's height.
Immediately following clinical testing, the subjects prepared for pitching as they normally would. Once ready to begin their pitching session, pitchers threw from an artificial mound to a strike zone target set behind home plate, positioned a regulation distance of 18.4 m from the pitching rubber. The number of pitches and pitch type were self-selected by the pitcher based on their typical throwing progression. Pitch count and type were noted. Velocity was recorded using a Stalker Sport 2 radar gun (Stalker Sports Radar, Richardson, TX).
Descriptive statistics including mean and standard deviation were calculated for all variables. Shapiro-Wilk tests were used to test for normality. For metrics that were normally distributed, paired sample t-tests were used to compare pre- and post-pitching means. Wilcoxon signed-rank tests were used to compare pre- and post-pitching means for metrics that were not normally distributed. A significance level of $p < 0.05$ was chosen. SPSS statistical analysis software (version 26, IBM Corporation, Armonk, NY) was used to analyze the data.

RESULTS: The 15 pitchers (16.7 ± 0.9 years, 185.3 ± 6.2 cm, 81.4 ± 11.4 kg) threw an average of 19 ± 3 pitches during their pitching session (fastballs: count 11 ± 1, speed 35.8 ± 1.8 m/s; breaking balls: count 5 ± 2, speed 29.9 ± 2.3 m/s; change ups: count 3 ± 1, speed 32.6 ± 1.7 m/s). All hip strength measures significantly decreased in the post-pitching test (Table 1). Lead leg hop distance was the only metric that significantly increased in the post-pitching test.

Table 1: Means ± standard deviation of metrics pre- and post-pitching session

	Pre	Post	Difference	P Value	
Back Hip Extension Strength	0.19 ± 0.05	0.15 ± 0.06	0.04 ± 0.03	0.000*	A
Lead Hip Extension Strength	0.17 ± 0.05	0.15 ± 0.06	0.02 ± 0.03	0.026*	A
Back Hip External Rotation Strength	0.14 ± 0.04	0.11 ± 0.04	0.03 ± 0.03	0.002*	B
Lead Hip External Rotation Strength	0.14 ± 0.03	0.11 ± 0.04	0.02 ± 0.03	0.005*	A
Back Hip Internal Rotation Strength	0.14 ± 0.04	0.13 ± 0.04	0.02 ± 0.03	0.035*	A
Lead Hip Internal Rotation Strength	0.16 ± 0.04	0.12 ± 0.04	0.03 ± 0.03	0.003*	B
Back Leg Hop Test	1.14 ± 0.11	1.13 ± 0.12	0.02 ± 0.04	0.175	A
Lead Leg Hop Test	1.13 ± 0.11	1.15 ± 0.12	-0.02 ± 0.04	0.044*	A

*Significant at $p < 0.05$; [A] Paired Samples T-Test; [B] Wilcoxon Signed-Rank Test

DISCUSSION: The results of our study found signs of muscular fatigue in the lower extremities by showing strength changes at both hips after a relatively low count pitching session. Although not quantified, there were no observable changes in kinematics or pitch velocity from the start to end of the pitching session. Both hip extension strength measurements decreased significantly after pitching. The increased muscular fatigue at both hip extensors is likely due to the massive forces that are required to create hip to shoulder separation. Back hip extension and abduction forces are required to create inertial forces through the pelvis to create higher ball velocity (Kageyama et al., 2014). Of the back hip extensors, the gluteus maximus requires 141% activation and the biceps femoris 142% activation during the hip to shoulder separation phase of pitching (arm cocking phase) (Campbell et al., 2010). Lead hip extension strength is required to create the large ground reaction forces posteriorly and vertically to allow the pelvis to rotate underneath. According to McNally et al. (2015), the ground reaction forces that are posterior vertically are greatest during the arm cocking phase. The lead leg requires slightly less activation of the gluteus maximus at 108%, and 99% for the biceps femoris (Campbell et al., 2010), which may explain the slight increase in muscular fatigue at the back leg compared to the lead for hip extension strength.

Back and lead hip external rotation strength measures were both found to have a significant difference in the post-test. The back hip external rotator showed a slightly higher change in strength compared to lead hip external rotation. Back hip external rotators are required to be activated to help rotate the pelvis forward as the pitcher is in the arm cocking and acceleration phases. According to Oliver and Keeley (2010), during the arm cocking phase of pitching the back leg gluteus maximus activation is at the highest. The gluteus maximus is a primary external rotator and was shown to be correlated to increased rate of axial pelvis rotation throughout arm cocking to ball release phases of pitching. The lead hip external rotators likely fatigued due to the lead leg requiring multiple muscles activated to generate significant ground reaction forces posteriorly (Oliver & Keeley, 2010). Both back and lead hip internal rotation strength measures were found to have a significant difference. The lead hip internal rotator showed a slightly higher increase in strength loss compared to back hip internal rotation. The gluteus medius, the main hip internal rotator, of the lead hip had an activation near 145% of maximum voluntary isometric contraction compared to the back hip activation near 120% at shoulder maximum external rotation during pitching (Oliver & Keeley, 2010). The lead hip has also been shown to provide hip internal rotation and adduction torque during the arm cocking and acceleration phases (Kageyama et al., 2014).

A previous study by Mullaney et al. (2005) assessing fatigue at the hip did not find any significant fatigue with the lower extremity, as we have with the current study. This may be due to the differences in subjects used, with the previous study analysing college age minor league pitchers. The current study assessed high school age pitchers that likely have not matured physically with peak height or strength. Males continue to make strength gains until the age of twenty-four (Brown et al., 2017). The age group measured more likely would show muscular fatigue at both hips due to still physically maturing.

The single leg hop test was the functional test used in this study, as it was previously used to monitor fatigue (Augustsson et al. 2006). The lead leg hop distance was the only measure to increase after pitching. This may be due to the hop test performance including a significant amount of quadriceps and calf muscles activation, which may have compensated for the reduced hip strength after pitching. After administering the test, it was noted that there was a greater amount of failure rates with the hop test post-pitching with both legs. The pitcher’s lack of balance and proprioception should be further assessed. If the pitcher does indeed lose proprioception, this may cause the back leg to have increased difficulty in the wind up and stride affecting the mechanics later in the sequence. The lead leg loss of balance may lead to difficulty maintaining a stable point, so the pitcher can create the hip to shoulder separation.

This study was limited by the small sample size and low number of pitches thrown. A typical practice pitching session ranges from 20 to 50 pitches. The current session pitch count was on the low end due to it being the last pitching session before beginning their off season. Due to the low pitch count, pitch type was not stratified to determine if pitch type affects muscle strength changes. The end of the competitive season may also have influenced the strength changes seen at the hip.

CONCLUSION: This study evaluated hip strength changes pre- and post-pitching to investigate the influence of pitching-related fatigue on hip strength. The results showed pitching induces muscular fatigue at the hips after a small number of pitches thrown. With overall fatigue being a large indicator of injury risk, how hip muscular fatigue impacts a pitcher's ability to avoid injury warrants further investigation.

REFERENCES

Ageberg, E., & Cronström, A. (2018). Agreement between test procedures for the single-leg hop for distance and the single-leg mini squat as measures of lower extremity function. BMC sports science, medicine & rehabilitation, 10, 15. https://doi.org/10.1186/s13102-018-0104-6

Albiero, M., Kokott, W., Dziuk, C., Cross, J.A. (2022). Relationships between Hip Strength and Pitching biomechanics in Adolescent Baseball Pitchers; *Journal of Athletic Training*, https://doi.org/10.4085/1062-6050-0074.22

Augustsson, J., Thomeé, R., Lindén, C., Folkesson, M., Tranberg, R., & Karlsson, J. (2006). Single-leg hop testing following fatiguing exercise: reliability and biomechanical analysis. *Scandinavian journal of medicine & science in sports*, 16(2), 111–120. https://doi.org/10.1111/j.1600-0838.2005.00446.x

Brown, K. A., Patel, D. R., & Darmawan, D. (2017). Participation in sports in relation to adolescent growth and development. *Translational Pediatrics*, 6(3), 150–159. https://doi.org/10.21037/tp.2017.04.03

Campbell, B. M., Stodden, D. F., & Nixon, M. K. (2010). Lower extremity muscle activation during baseball pitching. *Journal of Strength and Conditioning Research*, 24(4), 964–971. https://doi.org/10.1519/JSC.0b013e3181cb241b

Davis, J. T., Limpisvasti, O., Fluhme, D., Mohr, K. J., Yocum, L. A., Elattrache, N. S., & Jobe, F. W. (2009). The effect of pitching biomechanics on the upper extremity in youth and adolescent baseball pitchers. *The American Journal of Sports Medicine*, 37(8), 1484–1491. https://doi.org/10.1177/0363546509340226

Enoka, R. M., & Duchateau, J. (2008). Muscle fatigue: what, why and how it influences muscle function. *The Journal of physiology*, 586(1), 11–23. https://doi.org/10.1113/jphysiol.2007.139477

Erickson, B. J., Sgori, T., Chalmers, P. N., Vignona, P., Lesniak, M., Bush-Joseph, C. A., Verma, N. N., & Romeo, A. A. (2016). The Impact of Fatigue on Baseball Pitching Mechanics in Adolescent Male Pitchers. *Arthroscopy: The Journal of Arthroscopic and Related Surgery*, 32(5), 762–771. https://doi.org/10.1016/j.arthro.2015.11.051

Kageyama, M., Sugiyama, T., Takai, Y., Kanehisa, H., & Maeda, A. (2014). Kinematic and Kinetic Profiles of Trunk and Lower Limbs during Baseball Pitching in Collegiate Pitchers. *Journal of Sports Science and Medicine*, 13(4), 742–750.

Kung, S. M., Shultz, S. P., Kontaxis, A., Kraszewski, A. P., Gibbons, M. W., Backus, S. I., Fink, P. W., Fealy, S., & Hillstrom, H. J. (2017). Changes in Lower Extremity Kinematics and Temporal Parameters of Adolescent Baseball Pitchers During an Extended Pitching Bout. *The American Journal of Sports Medicine*, 45(5), 1179–1186. https://doi.org/10.1177/0363546516687289

McHugh, M. P., Tyler, T. F., Mullaney, M. J., Mirabella, M. R., & Nicholas, S. J. (2016). The Effect of a High Pitch Volume on Musculoskeletal Adaptations in High School Baseball Pitchers. *The American Journal of Sports Medicine*, 44(9), 2246–2254. https://doi.org/10.1177/0363546516650183

Mullaney, M. J., McHugh, M. P., Donofrio, T. M., & Nicholas, S. J. (2005). Upper and lower extremity muscle fatigue after a baseball pitching performance. *The American Journal of Sports Medicine*, 33(1), 108–113. https://doi.org/10.1177/0363546504266071

McNally, M. P., Borstad, J. D., Oñate, J. A., & Chaudhari, A. M. (2015). Stride Leg Ground Reaction Forces Predict Throwing Velocity in Adult Recreational Baseball Pitchers. *Journal of Strength and Conditioning Research*, 29(10), 2708–2715. https://doi.org/10.1519/JSC.0000000000000937

Oliver, G. D., & Keeley, D. W. (2010). Gluteal muscle group activation and its relationship with pelvis and torso kinematics in high-school baseball pitchers. *Journal of Strength and Conditioning Research*, 24(11), 3015–3022. https://doi.org/10.1519/JSC.0b013e3181c865ce

Olsen, S. J., 2nd, Fleisig, G. S., Dun, S., Loftice, J., & Andrews, J. R. (2006). Risk factors for shoulder and elbow injuries in adolescent baseball pitchers. *The American Journal of Sports Medicine*, 34(6), 905–912. https://doi.org/10.1177/0363546505284188

Thorborg, K., Petersen, J., Magnusson, S. P., & Hölmich, P. (2010). Clinical assessment of hip strength using a hand-held dynamometer is reliable. *Scandinavian Journal of Medicine & Science in Sports*, 20(3), 493–501. https://doi.org/10.1111/j.1600-0838.2009.00958.x

Zaremski, J. L., McClelland, J., Vincent, H. K., & Horodyski, M. (2017). Trends in Sports-Related Elbow Ulnar Collateral Ligament Injuries. *Orthopaedic Journal of Sports Medicine*, 5(10), 2325967117731296. https://doi.org/10.1177/2325967117731296