

The Mechanics of Pitching

Illumin Article

Jonathan Garcia

WRIT 340

5/7/2013

Abstract

The complexity behind a baseball pitcher's delivery is something that coaches, engineers, and physicians had trouble understanding for years. With the help of science and advanced engineering techniques, a pitcher's delivery can now be analyzed at the biomechanical level. A pitcher's delivery was broken down into six distinct phases. The forces and torques that the pitcher's body generated were then examined for each of these phases. Researchers found that improper use of the body at certain phases of the delivery left the pitchers with a very high susceptibility to injury. Researchers could even break down the data and analyze what muscle group or joint was more susceptible to injury. These researchers concluded that proper pitching mechanics could increase a pitchers effectiveness as well as reduce the risk of injury.

The Science of Pitching

Have you ever watched a baseball pitcher perform his windup and thought to yourself, “Is all that stuff he’s doing with his hands and legs really necessary?” A pitcher’s delivery can be thought of as a detailed choreographed motion where the pitcher tries to utilize every muscle in his body to deliver effective pitches. How does a pitcher know whether or not his motions are effectively being used? With the help of advanced engineering techniques, athletes are discovering how to use their entire body more effectively and efficiently as well as preventing possible injuries. Engineers are using testing tools such as load cells, 3D motion analysis, and electromyography (EMG) to help analyze a pitcher’s mechanics. The mechanics of a pitcher are broken down into six distinct phases, where muscle and joint activity are analyzed. The tools then measure kinetics (forces and torques) and kinematics (timing and velocity) that a pitcher exerts during each phase. Force is the muscle activity that cause some change in the velocity of the ball and torque is the tendency of a force to rotate an object about some axis [2]. These testing tools can help a pitcher extend their career by reducing injury susceptibility, improve accuracy, and increase velocity. By understanding each phase of a pitcher’s delivery, it easier to find where the faults in the pitcher’s delivery lie.

The Phases of a Pitch

Of all sports, baseball pitchers exert the greatest amount of angular velocity on their shoulder [1]. However, the delivery of the ball is not completely dependent on the shoulder. Unlike other sports, pitchers control their own rhythm and tempo while making the pitch. Each pitch is methodical approach using different muscle groups to try and make effective pitches

with an efficient pitch count (the amount of pitches a pitcher makes in a single game). Although a pitcher's motion can seem like one continuous motion, it is actually a series of many motions. These motions a pitcher makes is broken down in to six distinctive stages: wind-up, stride, arm cocking, arm acceleration, arm deceleration, and follow-through [1].

The six phases

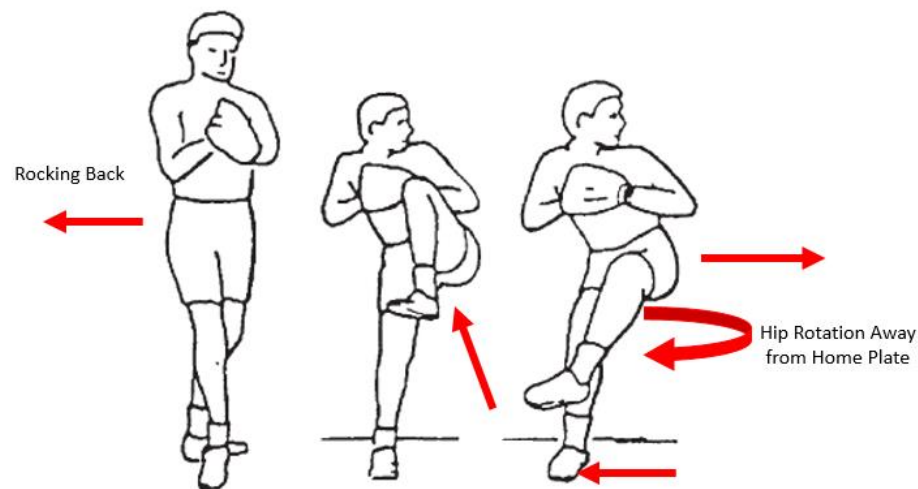


Figure 1: The wind-up phase of a pitcher's delivery. The motion starts with a rocking back away from the plate and ends with the pitcher rotating his hips away from home plate [1]

1. *Wind-up* – This is the first step in a pitcher's approach that helps put the pitcher in a good starting position. The process begins as the pitcher plants their back foot against the rubber. The pitcher then rocks back with the opposite of their plant foot, then rocks forward while raising their knee (when a pitcher pitches from "the stretch" the rock back motion is neglected and a pitcher goes straight into raising the knee). Some pitchers may even rotate the hips and shoulders away from home plate, to gather more potential energy, as seen in the last step of Figure 1. The purpose of the wind up is for the pitcher to gather up as much potential energy as possible

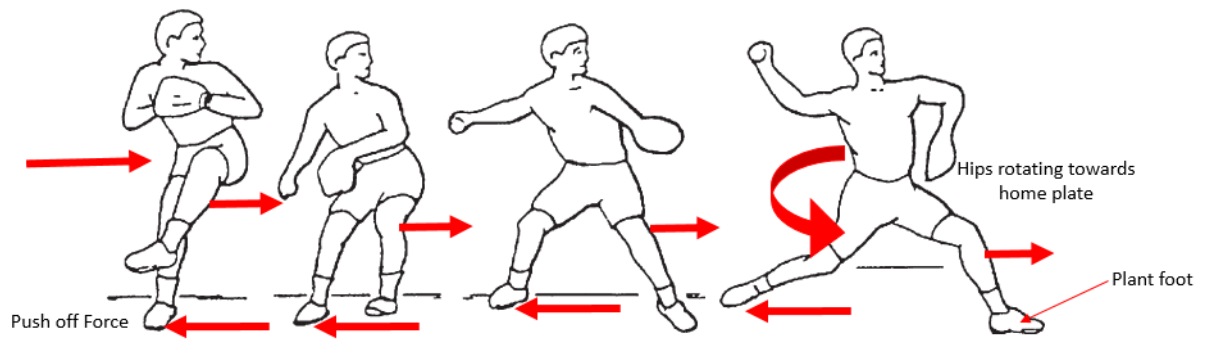


Figure 2: During the stride the pitcher begins to push off the mound and ends with the pitcher rotating his hips towards home plate [1]

2. *Stride* – The pitcher begins his movement towards the target. The lead leg starts to fall forward, and the hips begin to rotate towards the plate. The legs start to drive the body forward. As the pitcher moves forward the potential energy for the stride starts to turn into kinetic energy. At this point, the pitcher tries to utilize his entire body to drive energy towards the plate.

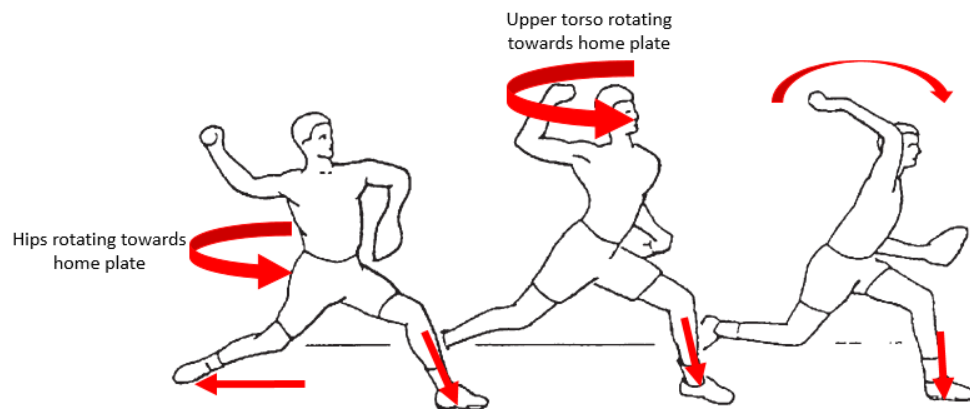


Figure 3: During the arm cocking phase the pitcher rotates the hips and torso towards home plate, while bringing the arm back in preparation for the arm acceleration phase [1]

3. *Arm Cocking*- The pitcher's arm starts to reach back, as the arm is gathering elastic energy. Elastic energy is a form of potential energy that results from the deforming or

stretching of an object e.g. stretching of a spring. In a pitcher's arm the elastic energy is stored in the tendons. During the stride and the arm cocking phase, the pelvis starts to rotate forward, quickly followed by the upper torso. Through this phase, the pelvis, upper torso, elbow, and shoulder are all working together to generate as much power as possible. The more power that is generated the faster a pitcher can throw the ball.

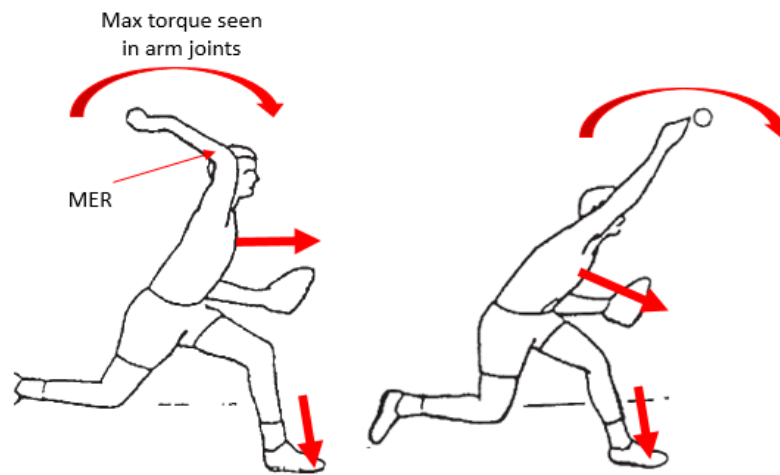


Figure 4: During the arm acceleration phase, the pitcher's arm see its maximum amount of torque through MER [1]

4. *Arm Acceleration*- During this phase the elbow starts to fully extend followed by shoulder rotation. This phase begins with what is known as maximum external rotation (MER) and ends when the ball is released. MER is the point at which the arm sees maximum rotation away from the body. During MER, the joints in the arm are seeing their highest levels of angular velocity and torque. This is the point in the delivery in which the lower extremities are transferring kinetic energy to the arm. By using the lower extremities effectively, more arm acceleration will be seen through this phase which results in higher pitching velocities.

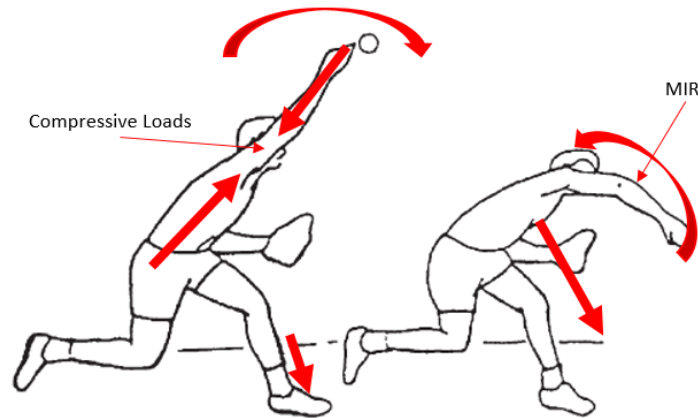


Figure 5: Through the deceleration phase, the throwing arm see maximum compressive loads on the shoulder and elbow joints [1]

5. *Arm Deceleration* – This phase begins as soon as the ball is released, and the shoulder sees maximum internal rotation (MIR). MIR is the point at which the arms see the maximum rotation towards the center of the body. During MIR large compressive loads are seen at the elbow and shoulder joints as the body tries slow the arm down. These compressive load can be thought of as a crushing effect. Many might think the most critical phase of a pitch is the arm cocking phase, but in fact it is the deceleration phase. A pitcher that doesn't effectively use the deceleration phase, will have a high risk of injury in the shoulder and elbow.

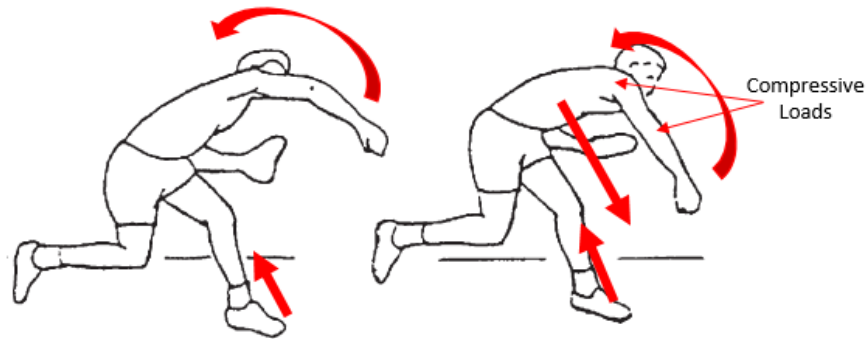


Figure 6: The key of a good follow through is to slow the momentum of the arm down to help reduce the risk of injury [1]

6. *Follow Through*- A good follow through is vital in preventing serious injury to the posterior muscles of the shoulder. Too quick of a follow through can lead high compressive loads in the shoulder in elbow joints, while a long extended follow through gives the body more time to slow down the high torques that were seen during the arm acceleration phase.

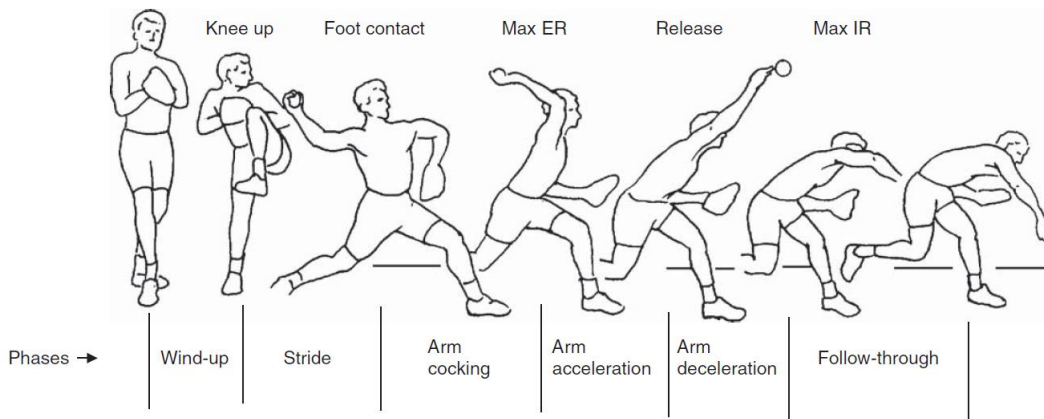


Figure 7: All of the Pitching phases and key events put together. ER=external rotation; IR=Internal Rotation [3]

The purpose of all of these motions is to gather up as much potential energy as possible (i.e. the wind-up) and turn this into as much kinetic energy as possible (i.e. stride, arm cocking, arm acceleration, and arm deceleration). The pitcher then tries to transmit as much energy as possible into the ball. Transmitting all this energy makes it possible for pitchers to throw in excess of 95 MPH.

How engineers are putting science to use in baseball

For many years, pitchers and coaches were only able to analyze a pitcher's performance through experience and statistics. Physicians were only able to see what a pitcher was doing wrong after injury had occurred. For example, if a pitcher had extensive posterior shoulder damage, the physician could tell that the damage would have more than likely occurred during the deceleration phase. The posterior muscles of the shoulder have been identified as having a paramount role in slowing the arm down [4]. Today coaches and physicians, with the help of engineers, can apply advanced measurement techniques to analyze a pitcher's mechanics. Some of these techniques use load cells, 3D motion analysis, and electromyography (EMG) [5-7].

Load cells placed at the top of the pitching mound and at the base as seen in Figure 8. These load cells are used to measure the ground reaction forces exerted by a pitcher.

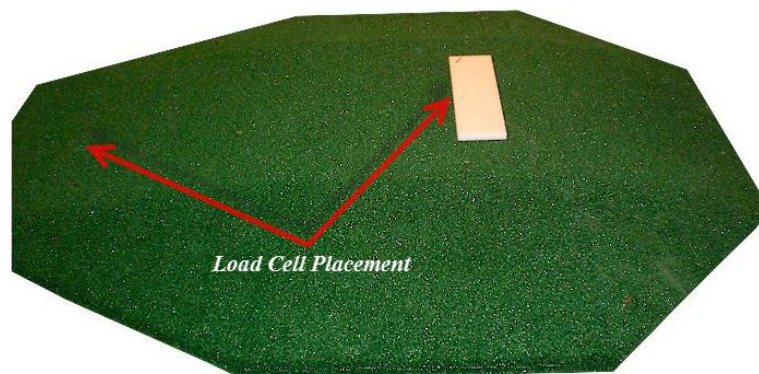


Figure 8: Load cell placement for measuring ground reaction forces

These ground reaction forces are the push off force and the landing force of the plant foot as seen in Figure 2. By measuring these forces, the efficiency of how well a pitcher is using his legs can be analyzed. It has been found that a pitcher's velocity is directly proportional to the push off and downward force of the plant foot recorded [6, 8]. By increasing a pitcher's push off and landing force, the pitcher's ball velocity can be increased.



Figure 9: Example of 3D motion analysis studio [9]

3D motion analysis or motion capture has become an invaluable tool for engineers and physicians. Motion analysis or motion capture, is the process of recording movements by placing several reflective markers on the test subject [7]. Then using special cameras, a 3D image of the subject can then be recorded and then projected on a monitor [7]. For a pitcher, these markers can be placed on joints, hips, shoulder, hands, etc. (Figure 9).

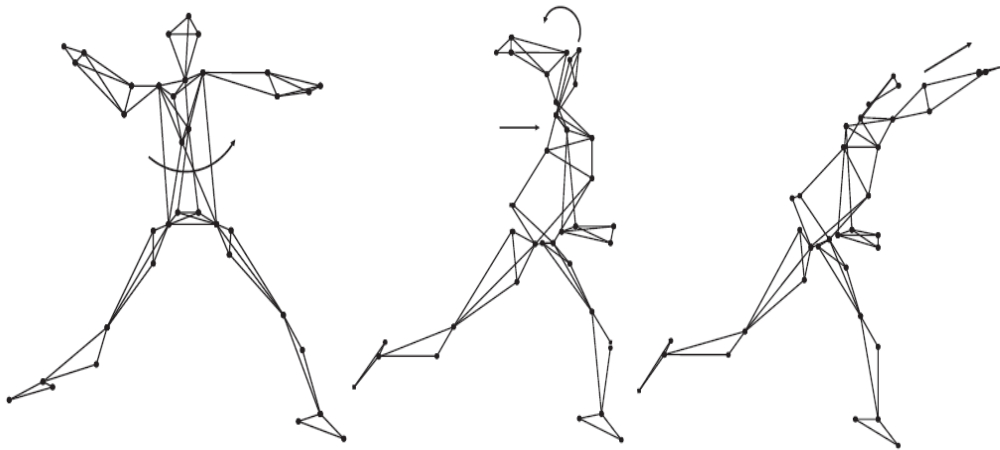


Figure 10: Projection from 3D motion analysis through stride, arm cocking, and the arm deceleration phase [10]

The data collected by these markers are then inputted into a software program that calculates the speed, timing, and angles of each particular marker. From this data, kinetic and kinematic parameters can be calculated in reference to the area it was measuring and compared to other pitchers. For example, The American Sports Medicine Institute has a databases with more than 2,000 pitchers [11]. This large sample size gives a definitive answer as to how the pitcher being evaluated compares against other pitchers who have been tested.

Another important tool that has helped revolutionize biomechanics is EMG. EMG is the science of quantifying muscle activity by recording electrical activity of the skeletal muscles using a series of sensors. These sensors can then record muscle activity while the muscles perform certain actions. For pitchers, these sensors can be placed on the shoulder, arms, back, and torso to measure different muscle activity while pitching.

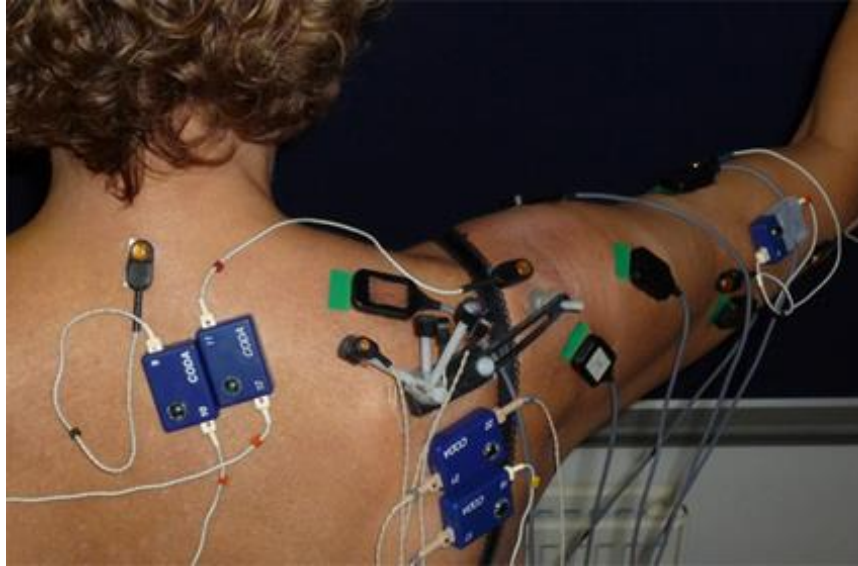


Figure 11: Analyzing Scapular movement using EMG activity during shoulder movement [12]

With EMG data, physicians can better understand why certain muscles are active during different phases of an activity, what type of muscle action occurs, and to provide insight into injury mechanisms [3]. This is how doctors know that the posterior muscles in the shoulder are heavily used in the deceleration phase or that triceps see their maximum activity during the arm acceleration phase [3]. Once engineers have had sufficient amounts of data collected, the data processed and analyzed.

How the data is analyzed

All of the data collected by these tools is combined to give a collective sense of what's happening in the pitcher's entire body. Looking at data on the throwing arm of a pitcher throwing a fastball for example, engineers plot the kinetic results from the 3D motion analysis with respect to the pitching phase the pitcher was in (Figure 11).

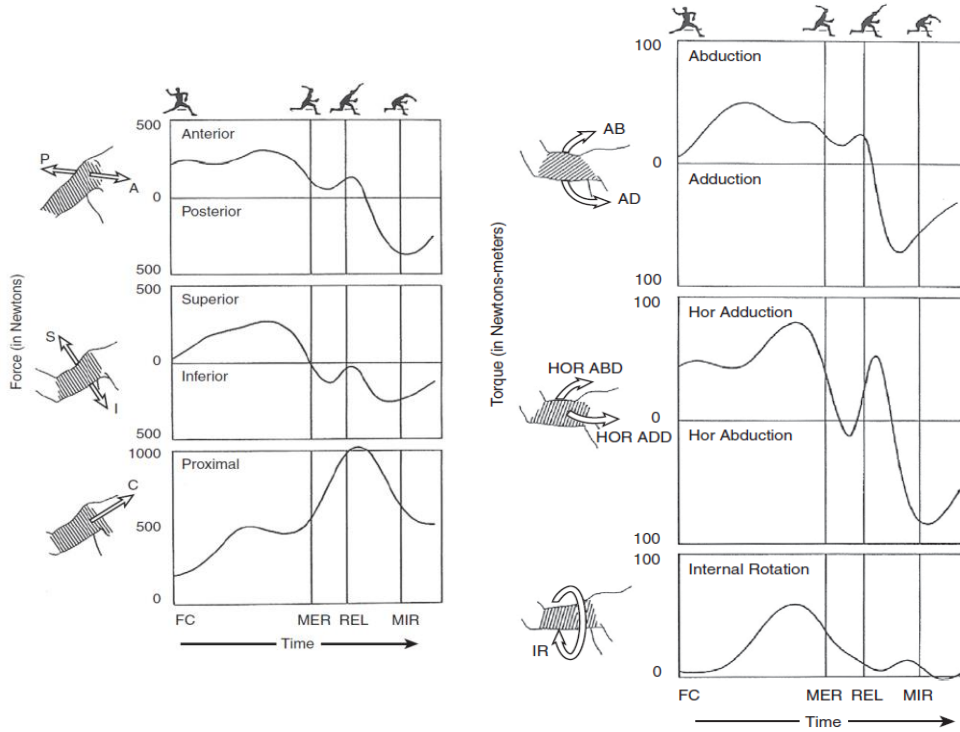


Figure 12: Forces and torques generated at the shoulder through all the pitching phases [1]

The data from the EMG is then plotted, where the muscle activity of a particular muscle is plotted on a scale called the maximal manual muscle test (MMT) against the pitching phase (Figure 12). MMT is an orthopedic standard for evaluating the function and strength of individual muscles and muscle groups based on the effective performance of a movement [13].

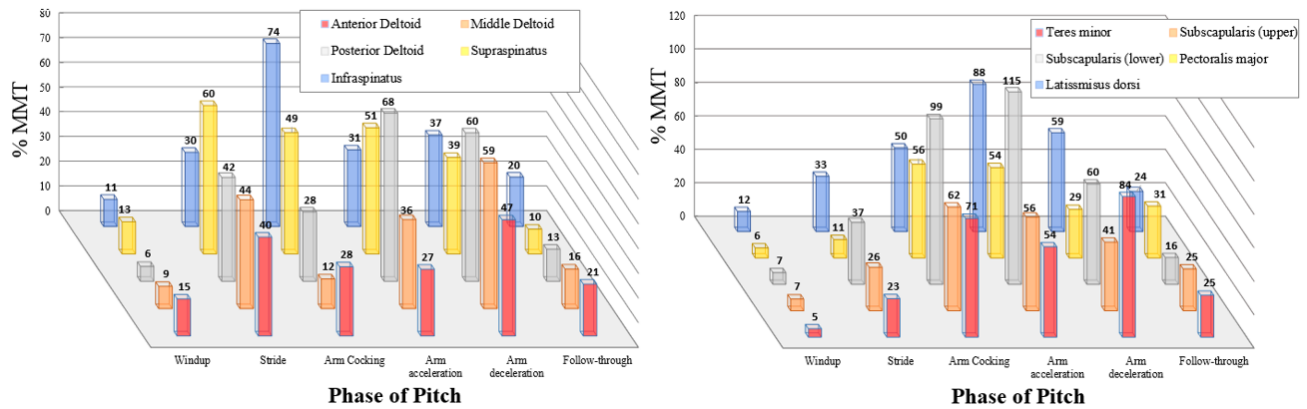


Figure 13: The shoulder muscles activity at each of the six phases. Muscle activity is recorded as an orthopedic standard known as MMT [14]

The data is then evaluated by the engineers and physicians, where it is compared to the 2,000 pitcher database. Physicians know what the maximum force or torque should be for a particular joint, tendon, or ligament. By looking at the data they can see what areas are either close to or exceeding maximum kinetics. From the data, they make recommendations to the players on areas where the physician feels the player is highly susceptible to injury or under performance. For example, if the pitcher has high muscle activity in the shoulder and low muscle activity in the torso, this information tells physicians that the pitcher is putting too much stress on the shoulder and he's not fully utilizing his body. It is then recommended to coaches to try to get the pitcher to utilize his torso more. This data can also be used for performance enhancements the same way it was used for injury prevention. If a pitcher is not using all of his muscle groups effectively, the data can tell him what muscle groups need to be utilized more, so that more power is generated.

What Physicians and Engineers Found

Physicians and engineers found that the number one thing that caused injuries, as well as impaired a pitcher's performance is pitching mechanics and fatigue. The muscles in the upper

extremities contracted in a very coordinated manner, balancing stabilization and rapid motion [14]. The stabilization during the pitch helps protect the muscles, tendon, ligaments, and joints as well as maximizing ball velocity. The rapid motion is what influences ball velocity and accuracy. Balancing the fine line between rapid movement and stabilization is very difficult, but a pitcher who can do both of those things can maximize their velocity and reduce their risk of injury. To minimize fatigue, pitchers have a set limit on how many pitches they can throw in a given amount of days known as a pitch count [11]. Pitch counts have had such an impact on preventing injuries at the professional level, that even youth levels have adopted them. Studies have shown that a pitcher that exceeds a pitch count is 36 times more likely to need surgery on the throwing arm [15].

An understanding of the kinematics and kinetics of the shoulder during athletic activity is essential for proper treatment of the shoulder. Physicians have found these studies are very useful in preventing injuries and maximizing performance. If the pitcher participates in a study before injury occurs, the physician can tell him what injuries he risks as well as make recommendations on what muscle groups are not being effectively utilized. From the physician's recommendations, the pitcher can work with a coach to help modify his pitching approach. With the help of science, a pitcher's careers can be extended as well as performance increased.

How science has illuminated baseball

The difference between good science and bad science is the difference between interpretation and observation. Interpretation is subjective, while observation is objective and based on facts. For decades coaches and physicians were basing their reasoning's for a pitcher's

injuries and performance on interpretation. They were making assumptions about injuries and performance with very little validity. Now engineers and physicians are using observational methods, where a set of results can be repeated over and over again. Science and engineering has helped bring new light to many of the myths surrounding pitching performance and injuries. A pitcher's performance can be analyzed to find faults in a pitcher's mechanics and then come up with solutions. Physicians and coaches are not just guessing anymore, they have data to validate their reasoning's. Science has helped shine light on the beautiful complexity behind pitching and thanks to science pitchers can now enjoy longer careers pitching at their highest level.

Biography

Jonathan Garcia is from Los Angeles, CA and is a junior majoring in mechanical engineering at USC's Viterbi School of Engineering. Before attending USC, he served for six years in the U.S. Air Force as well as worked for Space Exploration Technologies (SpaceX) for five years. Once graduated from USC, he hopes to return to the aerospace industry as a propulsion engineer.

Works Cited

- [1] G. S. Fleisig, S. Dun, and D. Kingsley, "CHAPTER 31 - Biomechanics of the Shoulder During Sports," in *The Athlete's Shoulder (Second Edition)*, E. W. Kevin, P.T, D.P.T, M. R. Michael, P.T, D.P.T, *et al.*, Eds., ed Philadelphia: Churchill Livingstone, 2009, pp. 365-384.
- [2] R. A. Serway and J. W. Jewett Jr, *Physics for scientists and engineers* vol. 1: Brooks/Cole Publishing Company, 2009.
- [3] R. Escamilla and J. Andrews, "Shoulder Muscle Recruitment Patterns and Related Biomechanics during Upper Extremity Sports," *Sports Medicine*, vol. 39, pp. 569-590, 2009/07/01 2009.
- [4] G. S. Fleisig, J. R. Andrews, C. J. Dillman, and R. F. Escamilla, "Kinetics of baseball pitching with implications about injury mechanisms," *The American journal of sports medicine*, vol. 23, pp. 233-239, 1995.
- [5] D. G. E. Robertson, *Research methods in biomechanics*: Human Kinetics Publishers, 2004.
- [6] B. A. MacWilliams, T. Choi, M. K. Perezous, E. Y. S. Chao, and E. G. McFarland, "Characteristic Ground-Reaction Forces in Baseball Pitching," *The American Journal of Sports Medicine*, vol. 26, pp. 66-71, January 1, 1998 1998.
- [7] G. Fleisig, "Biomechanics of Baseball Pitching," in *International Society of Biomechanics in Sports 2010 Congress*, Marquette, Michigan, 2010.
- [8] K. Nosu, Y. Yabuzaki, and K. Yamanaka, "Evaluation of baseball pitching form by ground reaction force measurement and video analysis," *Journal of Visualization*, vol. 12, pp. 293-294, 2009/12/01 2009.
- [9] B. Watson, "zFloMotion Analysis: 3D Motion Analysis," vol. 2013, zFloMotion, Ed., ed. Boston, MA: zFlo, 2012.
- [10] S. Oyama, "Baseball pitching kinematics, joint loads, and injury prevention," *Journal of Sport and Health Science*, vol. 1, pp. 80-91, 9// 2012.
- [11] J. R. Andrews, "Pitching Biomechanics Evaluation," G. Fleisig, Ed., ed. Birmingham, AL: American Sports Medicine Institute, 2012.
- [12] D. Newham, "Scapular movement and EMG activity during shoulder movement," ed. King's College London, 2013.
- [13] M. Dutton, *Orthopaedic examination, evaluation & intervention: a pocket handbook*: McGraw-Hill, 2005.
- [14] N. M. DiGiovine, F. W. Jobe, M. Pink, and J. Perry, "An electromyographic analysis of the upper extremity in pitching," *Journal of Shoulder and Elbow Surgery*, vol. 1, pp. 15-25, 1// 1992.
- [15] J. Andrews, "Protecting Young Pitching Arms," in *The Little League Pitch Count Regulation*, G. Fleisig, Ed., ed.

Multimedia Suggestions

<http://www.youtube.com/watch?v=yEpdoAZiHWQ>

<https://www.youtube.com/watch?v=ZXG9ru6T-qg>