Study Title: Modeling Torso Kinematics in Collegiate Baseball Pitchers Using a Damped Torsion Spring Oscillator

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Sponsor or funding source: Departmental

Background, Rationale and Context

In baseball, optimal energy transfer is not well understood as it relates to the kinetic chain in the pitching delivery. This is partially due to lack of technology evaluating competitive biomechanics versus controlled laboratory studies which lack representative conditions to games. Therefore, to determine true energy leakage (altered energy generation, absorbance, or transfer) a representative study design involving potential in-game technology is required. Inefficient rotational timing, as well as altered acceleration and deceleration of the torso would represent the largest segment impacting energy flow from the ground to throwing arm, Therefore, detailed understanding of trunk kinematics that can be captured without laboratory constraints has true potential to determine biomechanical consequences that lead to poor performance and injury risk in the sport.

Research indicates that effective lower extremity and core muscle control can positively impact the kinetic contributions of the shoulder joint and avoid total energy transfer losses,[1,2] Although not clearly defined, inefficiency in torso kinematics as it relates to total energy transfer is signified by greater energy leakage which may escalate shoulder and elbow kinetics. A goal of this work is to interpret energy efficiency that differs from previous research investigating biomechanical efficiency in the pitching delivery. As it relates to energy efficiency, torso motion that reduces energy leakage will be considered more efficient than torso kinematics that gives rise to greater energetic losses.

To construct a simple model that determines energy transfer about the torso, the proposed study will involve inertial measuring units to create a clear depiction of how the delivery can change energetically in various conditions through rotational velocities for the pelvis and trunk (ie. Practice, pressure-induced practice, game competition). This proximal region of the body and its interaction in energy transfer from the ground to the throwing hand will be examined to better understand the role of the proximal body on efficient motor patterns. This work has several benefits. First, the ability to showcase appropriate technology to track in-game, or simulated competition data would be the first of its kind to make a true distinction in how rotational motion is impacted by practice and game environments. Second, by understanding such differences, the coaching community can better understand how to improve practice strategies to become more game-like. Third, biomechanical science has a gap in the literature as it relates to the efficacy of laboratory study results versus movement profiles in situations where adrenaline is heightened. As such, a new perspective of research can be derived encouraging other sports scientists to explore mechanics that are more representative of competition. Lastly, physiologic measures, such as throwing arm fatigue will be evaluated through dynamometry (force testing equipment), and therefore, this work has an opportunity to predict throwing arm fatigue based on rotational kinematic profiling for the torso. Although in-stadium markerless motion capture has emerged at the MLB level, amongst amateurs, such rigorous surveillance has not been made available due to financial constraints for which a Wearable Sensors solution may offer

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tremendous benefit in understanding how pitchers' fatigue and the true meaning behind an athlete being energetically efficient in preventing injuries and maximizing performance.

This study has 3 aims:

1. To compare trunk energetic and arm speed effects between bullpen and "game-like" situations.

2. To examine throwing arm fatigue between bullpen and inner-squad situations in association to trunk energetics.

3. To examine competitive results such as pitch velocity, ball flight outcomes and competitive performance as it relates to trunk energetic profiles.

Objectives

To determine a model for torso energetics using a damped torsion spring oscillator, as well as developing timing and utilization of hip to shoulder separation movement patterns to improve trunk kinematics when throwing a baseball.

Methods and Measures

Design

- Cohort

Setting

Rochester Institute of Technology Baseball Biomechanics Laboratory, associated with the RIT Exercise Department in Rochester, NY.

Monroe Community College Baseball Facility in Rochester, NY

Subjects' selection criteria

- **Inclusion Criteria**
  Enrolled within RIT or MCC
  A member of the University Baseball Teams in the fall of 2022
  Familiar with pitching mechanics
  Pain free
  Participating in all games and practices
  Cleared by an athletic trainer through a physical.
- **Exclusion Criteria**
  Fails to participate in all games or practices
  Current pain with throwing

Fails to pass a physical

- **Sample Size**
  This is a pilot study to obtain data to pursue a grant. A similar study examining how mound height and pitching distance affect youth pitchers' mechanics included 21 young pitchers[3]. We anticipate recruiting 12 participants.

Interventions and Interactions

This study will involve 2 visits throughout the school year. The subject will answer a basic questionnaire involving informed consent as well as verbal pain evaluations before any participation. Upon Each visit each player will have their height and weight measured and go through basic warm up routine with their team. They will throw 2-5 pitches of each pitch type under motion analysis. The one visit should take approximately 30 minutes.

- Investigators will obtain informed assent during each session
- Participant height and weight will be measured with a stadiometer and scale
- Participants will undergo a movement screening using OnBaseU Protocols
- Participant will be allowed to complete a warm-up.
- During session participants will have their maximum thorax and pelvis width measured
  - Thorax circumference measured from xiphoid process
  - Pelvis circumference measured in line of Right and Left Anterior Superior Iliac Spine (ASIS)
  - Individual modeling of each athlete's trunk to model moment of inertias' for each player.
- Each player will complete pre-testing of an isometric internal and external rotation testing before throwing to measure fatigue factors of the trunk biomechanics.
  - Using Armcare Dynamometer
- Upon Pitching Session:
  - Wearable accelerometer sensors will be strapped onto the athlete to examine rotational velocity of the pelvis and the thorax (Appendix B).
  - A Polar sensor will be attached to measure heart rate of session.
  - ProplayAi will be used to capture markerless motion capture data.
- Participants are allowed warm-up pitches with baseball, if desired, before data collection.
- The participant will throw each of their pitches at most 3 times each from a standard pitching mound to a Major League distance of 60.6 feet using PitchLogic Baseball.
- Speed and spin rate of the pitch will be recorded using a PitchLogic Baseball
- 4D Motion Vest will then be removed, and participant will complete post testing of isometric strength testing of internal and external rotation.
- Participants involvement for the session is complete.

Outcome Measure(s)

In this study we are measuring rotational velocities of the pelvis and thorax within the global space. This will be used to derive our energy equation for our torsional spring of the trunk. We will use these measurements along with the circumference measurements of the pelvis and torso to construct an individual model for each individual athlete. We will then compare these individual models to the ball

kinematic metrics to not only compare the effects of the play environment from a bullpen to a game, and to find a correlation between the calculated rotational quantities and the tangential and angular velocities of the baseball. Measurements such as hand size, grip strength, and throwing arm isometric internal and external rotation forces will be measured to further ball kinematic variables, as well as throwing arm fatigue pre and post sessions.

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Analytical Plan

Calculations

Results will be analyzed initially using descriptive statistics. Our system is defined by a separation angle and a separation rotational velocity. The Separation position and velocity is the difference of the pelvis and the thorax. The energy will be measured from front foot contact (FC) to throwing arm maximum external rotation (MER). Energy calculations are derived by dividing the difference of squares of both the separation rotational velocities and the separation angles at FC and MER. This Energy model is equal to the ratio of the torsion constant (K) and the moment of inertia (I) of our athlete's torsion spring (K/I). A repeated-measures analysis of variance (ANOVA) will be performed for torso energy flow, throwing arm fatigue, cardiovascular stress, and ball flight outcomes between competitive and practice conditions. If a significant difference ($P < .05$) is found among measured variables, pairwise differences will be analyzed with a post hoc Tukey test. This will tell us how mean values differed.

A linear regression model will be will further analyze correlations amongst observed measured outcomes for rotational biomechanics on ball flight outcomes, throwing arm fatigue and cardiovascular stress. Using this model, a residuals plot will be constructed using the linear regression model to assess the quality of each model. We will also use these models to describe the relationship amongst playing environment types in prediction of ball flight outcomes, throwing arm fatigue and cardiovascular stress.

Human Subjects Protection

Subject Recruitment Methods

The RIT Baseball Biomechanics Lab will recruit via email with the players on the RIT and MCC baseball team along with coaches involved within their fall and spring seasons. It will be emphasized that participation is completely voluntary. The study will be explained to full detail before data collection and during data collection. Data collection will take place during the normal practice hours during Pitching Session with the team captains present. Assent will be collected prior to data collection.

Informed Consent

Signed player permission and assent will be obtained from each participant. Study investigators will obtain consent at each school's facilities prior to session.

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Confidentiality and Privacy

Confidentiality will be protected by collecting only information needed to assess study outcomes, minimizing to the fullest extent possible the collection of any information that could directly identify subjects, and maintaining all study information in a secure manner. To help ensure subject privacy and confidentiality, only a unique study identifier will appear on the data collection form. Any collected patient identifying information corresponding to the unique study identifier will be maintained on a linkage file, store separately from the data. The linkage file will be kept secure, with access limited to designated study personnel. Following data collection subject identifying information will be destroyed after data entry, consistent with data validation and study design, producing an anonymous analytical data set. Data access will be limited to study staff. Data and records will be kept locked and secured, with any computer data password protected. No reference to any individual participant will appear in reports, presentations, or publications that may arise from the study.

Data and Safety Monitoring

The principal investigator will be responsible for the overall monitoring of the data and safety of study participants. The principal investigator will be assisted by other members of the study staff.

Reporting of Unanticipated Problems, Adverse Events or Deviations

Any unanticipated problems, serious and unexpected adverse events, deviations, or protocol changes will be promptly reported by the principal investigator or designated member of the research team to the IRB and sponsor or appropriate government agency if appropriate.

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Appendix
   A. -------N/A
   B. ProplayAi 4D, PitchLogic, Armcare dynamometer, Wearable Sensors and Labels
   C. Physics Documentation and sample of static model