Citation (APA)
Gasparutto, X., Van Der Graaff, E., van Der Helm, F. C. T., & Veeger, H. E. J. (2016). Elite athlete motor and loading actions on the upper limb in baseball pitching. In FCT. van der Helm, & AJ. Jansen (Eds.), *Procedia Engineering - The Engineering of Sport 11* (Vol. 147, pp. 181-185). (Procedia Engineering; Vol. 147). Elsevier. https://doi.org/10.1016/j.proeng.2016.06.210

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ScienceDirect

Procedia Engineering 147 (2016) 181 – 185

Procedia Engineering

www.elsevier.com/locate/procedia

11th conference of the International Sports Engineering Association, ISEA 2016

Elite Athlete Motor and Loading Actions on The Upper Limb in Baseball Pitching

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Abstract

In baseball, pitchers are the players that are most prone to injury. Most injuries occur at the elbow and shoulder of the throwing upper limb. It is widely accepted that understanding the loading in the joints during pitching is a key factor to prevent injuries. To deepen the understanding of the joint actions this study proposes to split the net joint actions into two part: the motor actions and the stability actions representing respectively the actions generating the joint motion and the actions maintaining the joint integrity. The actions represent the actions applied on the distal segment of the joint. Eight youth elite pitchers participated the study and performed 5 fastball pitches while equipped with skin markers. Three pitches per pitchers were used to compute the joint actions with an inverse dynamics method. The results indicate at the elbow a maximal elbow stability moment in adduction (52±5Nm) on the lower arm at maximal external rotation and a motor action in flexion (38±10Nm) during the acceleration phase. At maximal internal rotation the maximal stability shoulder loading occurred, with a pulling force of 520±80N, a downward force of -290±95N and a depression moment of 65±17Nm. The motor actions at the shoulder were mainly a forward force (93±46N) and an exorotation moment (24±12Nm) during the arm acceleration phase. This study suggest that the main action of the shoulder is to stabilise the joint, with a maximal load at maximal internal rotation, and that the main action at the elbow is avoiding hyperextension, with a critical phase at maximal external rotation. Further study is needed to link the stability actions to injury risk.

Peer-review under responsibility of the organizing committee of ISEA 2016
Keywords: pitching, baseball, joint loading, joint moment, elbow, shoulder

1. Introduction

In baseball, pitchers are the players that are most prone to injury. Indeed, between 1989 and 1999, 48% of injured players in MLB were pitchers [1]. In those 48%, shoulder and elbow represented the most frequently injured joints with respectively 27.8% and 22% of the days spent injured. In a longitudinal study over 2 years with 298 youth pitchers between 8 and 12 years old, Lyman et al. [2] showed that 31.9% of the pitchers had shoulder pain (29% in superior aspect) and 25% had elbow pain (68% on the medial side). These injury rates are very high and occur at any age, thus efforts should be made to reduce those rates.

It is widely accepted [3] that understanding the loading occurring at the shoulder and elbow during pitching is a key factor to prevent injuries. Correlations between pitching technique and increased joint loading has been conducted [4] showing, as an example, that an open lead foot angle at foot contact and an excessive shoulder exo-rotation and horizontal adduction was linked to increased joint loading. However most studies consider only the net intersegmental actions [5–8] in the upper limb joints. The net actions represent the sum of every intersegmental actions (muscle actions, articular surface actions, ligaments actions…) at one joint.

For a better understanding of the joint actions, the net joint actions can be split up into two components, the motor actions and the stability actions. The motor actions are defined as the actions of the proximal segment generating the joint motion (rotation and translation) of the distal segment with respect to the proximal one. The stability actions are defined as the actions of the

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Peer-review under responsibility of the organizing committee of ISEA 2016
doi:10.1016/j.proeng.2016.06.210

proximal segment on the distal segment maintaining the joint integrity. This study will describe the method used to obtain the motor and stability moment and will quantify these mechanical parameters to gain insight in the upper limb pitching mechanics.

2. Method

First, for the sake of clarity, the pitching motion phase and events are pictured in fig. 1.

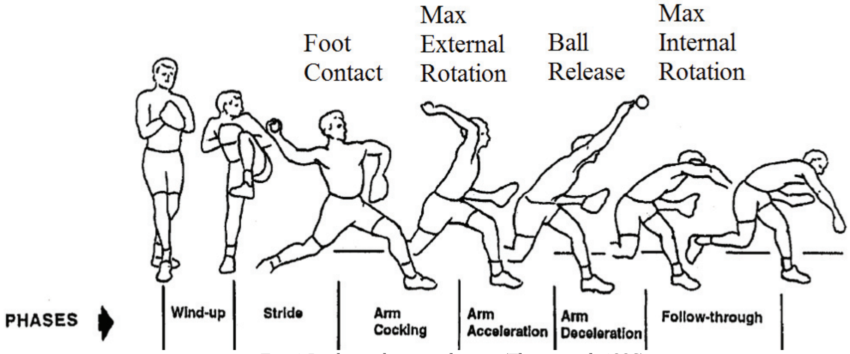

Fig. 1:Pitching phases and event (Fleisig et al. 1996)

2.1. Measurements

Eight right-handed pitchers from the Dutch AAA team (age: 16.1 ± 0.7years, size: 1.82 ± 0.8m, weight: 76.9 ± 8.1 kg) participated in this study. After having been informed of the aims and procedures of the experiment, all players and/or their legal representatives signed an informed consent form. The Faculty of Human Movement Sciences' local ethical committee approved this research projects.

The pitchers were equipped with skin markers on the full body. For the present study, only the upper limb (UL) and thorax markers where used. These markers include four markers on the thorax (Incisura Jugularis, Xiphoid Process, 7^{th} Cervical Vertebrae and 10^{th} Thoracic Vertebrae), and six on the throwing upper limb (Acromion, Medial and Lateral Humerus Epicondyle, Radial and Ulnar Styloid, Interphalangealis Proximal III). Each pitcher performed five fastball pitches from a pitching mound. Three pitches among the five performed were used in the study leading to a total of 24 pitches. The pitches were selected on the basis of the quality of the kinematic data. The motion of the markers was recorded by a 10-camera (T40S, 100Hz) VICON system.

2.2. Rigid-Body Model

A rigid-body model of the upper limb and thorax was used. The proposal from the ISB [9] was used for the definition of the local coordinate systems (LCS) and joint coordinate systems (JCS) (fig. 2). The glenohumeral (GH) joint position, the position of the segment centre of mass, the segment mass and the segment matrices of inertia were determined with regression equations [10]. The wrist, elbow and GH joints were modelled as spherical joints. To model the motion of the scapular girdle in a simplified way, the GH joint position with respect to the thorax was not constrained and thus, the shoulder joint also had three degrees of freedom in translation.

The ball was modelled as an homogeneous sphere of 145g and 36.8mm radius according to the Major League Baseball rules. The ball centre of mass was assumed to be overlapping with the hand centre of mass. The ball release (BR) was modelled by linearly decreasing the ball mass (from 100% to 0% of mass) during the 20ms before ball release. This time period is the mean value of the last half of the acceleration phase of the upper limb.

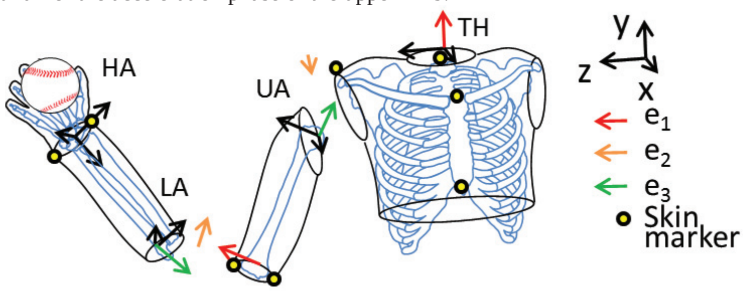

Fig. 2. LCS & JCS of the upper limb (HA: Hand, LA: Lower Arm, UA: Upper Arm, TH: Thorax), e_1, e_2 and e_3 represent the 3 axis of the corresponding JCS

2.3. Joint Actions

Inverse dynamics was performed iteratively using the wrench and quaternion method [11] to determine the net actions (force and moment) at the wrist, elbow and shoulder. The net actions represent the actions of the proximal segment on the distal segment. As an example, at the elbow the joint moment represents the action of the upper arm on the lower arm. The net actions were then separated into two contribution, the motor actions and the stability actions.

At the elbow, the joint model is a spherical joint, there is no displacement, thus the motor actions are only motor moments. As forearm pronation is lumped to the elbow, the model elbow joint has two degrees of freedom, flexion-extension and pronation-supination. Thus, the motor moments were computed as the orthogonal projection of the elbow net moment expressed at the elbow joint centre on the flexion-extension (FE) axis and pronation-supination (PS) axis. Due to the limited number of markers per segment, the FE axis was estimated by the normalised vector from the medial humeral epicondyle to the lateral humeral epicondyle. The PS axis was estimated by the normalised vector between the ulnar styloid and midpoint between the lateral and medial humeral epicondyles. As the FE and PS axis are part of a non-orthogonal coordinate system, the dual Euler basis was used to compute the motor moment vector (1) [12,13]:

$$\mathbf{M}_m^E = (\mathbf{M}_{net}^E.\mathbf{e}_1).\mathbf{e}^1 + (\mathbf{M}_{net}^E.\mathbf{e}_3).\mathbf{e}^3 \qquad (1)$$

With $\mathbf{M}_m^E$ the motor moment of the elbow, $\mathbf{M}_{net}^E$ the net moment of the elbow, $\mathbf{e}_1$ the flexion-extension axis, $\mathbf{e}_3$ the pronation-supination axis and $\mathbf{e}^1$ and $\mathbf{e}^3$ the associated axis of the dual Euler basis [12]. The first component of this motor moment $\left(\mathbf{M}_{net}^E.\mathbf{e}_1\right)$ is the flexion-extension motor moment. The second component $\left(\mathbf{M}_{net}^E.\mathbf{e}_3\right)$ was defined as the axial motor moment generating the pronation-supination in the forearm. Please note that this moment is the pronation-supination moment computed at the elbow joint centre and thus might differ in magnitude with the prono-supination moment that occurs in the radial-ulnar joints.

At the shoulder, the joint model was not constrained and thus had three degrees of freedom in rotation and three in translation. Contrary to the elbow joint, the instantaneous axis of rotation is not composed of axis from the JCS and thus was identified with the angular velocity of the upper limb with respect to the thorax. The translation direction of GH was identified with the linear velocity of GH with respect to the thorax. The motor moment was computed as the net moment projected orthogonally on the instantaneous axis of rotation (2) and the motor force was computed as the net force projected orthogonally on the normalised vector representing the translation direction (3).

$$\begin{cases} \mathbf{e}_{\boldsymbol{\Omega}} = \boldsymbol{\Omega}_{ua/th} / \left\| \boldsymbol{\Omega}_{ua/th} \right\| \\ \mathbf{M}_m^S = \left(\mathbf{M}_{net}^S.\mathbf{e}_{\boldsymbol{\Omega}}\right).\mathbf{e}_{\boldsymbol{\Omega}} \end{cases} \qquad (2)$$

With $\boldsymbol{\Omega}_{ua/th}$ the angular velocity of the upper arm with respect to the thorax, $\mathbf{M}_{net}^S$ the net moment of the shoulder and $\mathbf{M}_m^S$ the motor moment of the shoulder.

$$\begin{cases} \mathbf{e}_{\mathbf{V}} = \mathbf{V}_{gh/th} / \left\| \mathbf{V}_{gh/th} \right\| \\ \mathbf{F}_m^s = \left(\mathbf{F}_{net}^S.\mathbf{e}_{\mathbf{V}}\right).\mathbf{e}_{\mathbf{V}} \end{cases} \qquad (3)$$

With $\mathbf{V}_{gh/th}$ the linear velocity of GH with respect to the thorax, $\mathbf{F}_m^S$ the motor moment of the shoulder and $\mathbf{F}_{net}^S$ the net force of the shoulder joint.

At the elbow and shoulder, the stability actions were defined as the differences between the net actions and the motor actions. They represent the actions that maintain the integrity of the joint. Finally, to give an anatomical meaning to the component of the net, motor and stability actions, the net, these actions were projected in the JCS of the elbow and shoulder. In this way, the component of the actions can be associated to anatomical axis of the joint.

The results section present the mean results across the 24 pitches selected.

3. Results

3.1. Elbow

The elbow net, motor and stability moments associated with the elbow JCS are depicted in figure 3. The flexion-extension and axial moments are only motor moments. The maximal axial moment of pronation and supination are below ±5Nm and thus it is negligible. The flexion and extension moment has a mean maximal flexion peak (38±10Nm) 10ms before BR during the arm acceleration phase, followed by a decrease during the arm deceleration phase and a second peak (16±10Nm) at the time of maximal internal rotation of the shoulder (MIR). Then, this moment decreases during the follow-up phase.

The adduction-abduction moment is only a stability moment with a mean maximal adduction peak (52±5Nm) at the time of maximal external rotation of the shoulder (MER) followed by a large decrease and a mean peak abduction moment (-10±5Nm) at BR. During the arm deceleration phase, it reaches a second smaller adduction peak (11±4Nm).

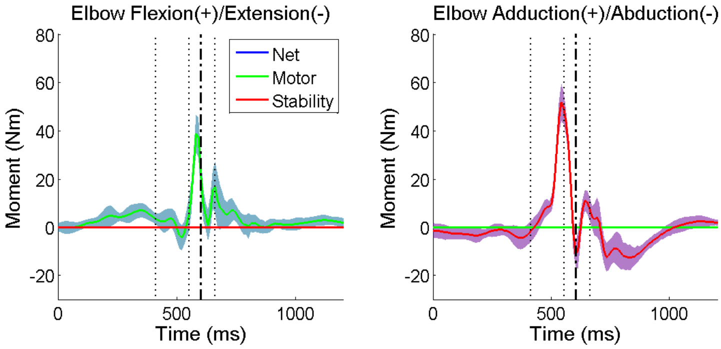

Fig3: Elbow Moments (mean±1standar deviation)

3.2. Shoulder

The main motor moments (fig. 4) are in exorotation and endorotation with an exorotation peak (24±12Nm) at MER, an endorotation peak (-20±7Nm) 20ms after BR and an exorotation peak (15±7Nm) during the follow up, 20ms after MIR. The second main motor moment is in the backward direction with a peak (23±16Nm) 10ms before MIR. Apart from these peaks, the shoulder motor moments are low. The shoulder depression motor moments are below 5Nm and the elevation motor moment are below 10 Nm.

Concerning the stability moment (fig. 4), the maximal moments occur at MER and MIR. At MER, the maximal moments are forward rotation (85±13Nm) and elevation (-48±11Nm). At MIR, the maximal moments are forward rotation (15±7Nm) and depression (65±17Nm). At BR the occurs a maximal backward rotation moment (-56±14Nm).

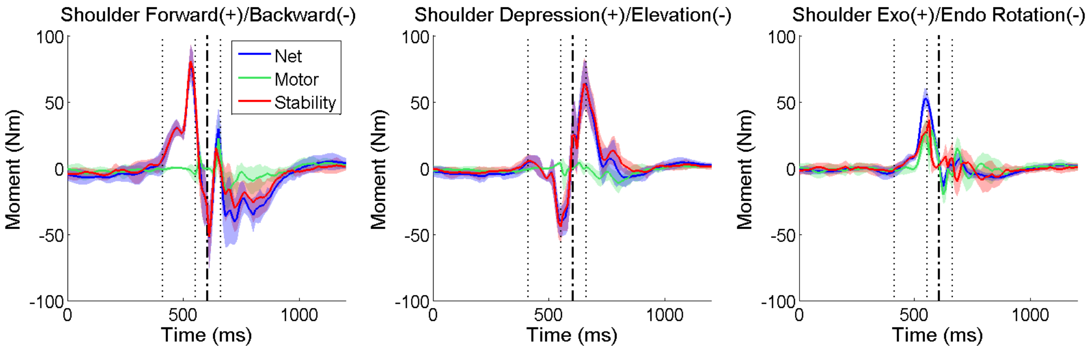

Fig4: Shoulder Moments (mean±1standar deviation)

The main motor force (fig. 5) is occurs at MER with a peak of forward motor force (148±11N) followed by a peak upward force (55±12N) 10ms later during the arm acceleration phase.

The maximal stability forces (fig. 5) occurs at MIR with a peak pulling force (520±80N), a peak downward force (-290±95N) and a peak forward force (93±46N). At BR occurs the second maximal stability force with a peak pulling force (560±60N), a peak downward force (-160±80N) and a backward force of (95±65Nm).

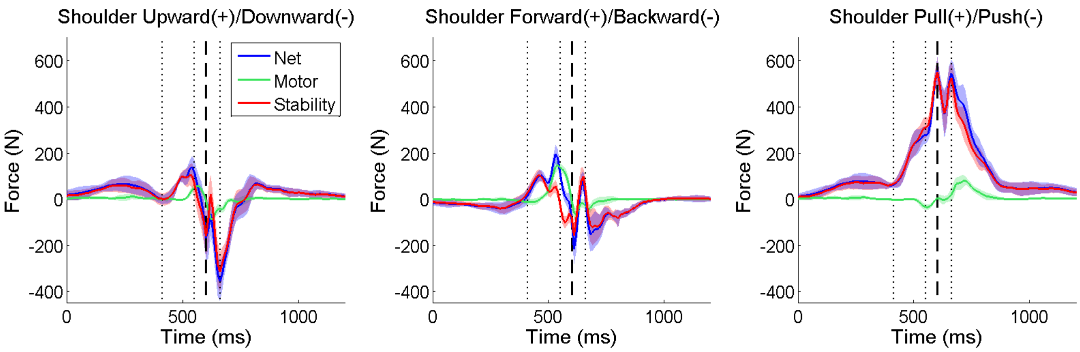

Fig5: Shoulder Force (mean±1standar deviation)

4. Discussion

This study proposed a method to gain insight in the upper limb dynamics by identifying the motor and stability actions. Looking only at net actions might underestimate the loading on the anatomical structure as the motor and stability actions might be compensating each other inside the value of the net moment.

At the elbow, the motor moment is in flexion between MER and BR, suggesting that the elbow extension occurring between MER and BR is passive and that the pitcher action is likely avoiding hyperextension of the elbow. As expected the highest elbow stability loading occurs at MER and is an adduction moment followed by an abduction moment at BR. These moments are mainly counteracted by the action of the ulnar and radial collateral ligament respectively and consequently they should be reduced, if possible, to avoid overuse injury at the elbow. Further study is planned to continue the investigation [14] relating these actions to the ball velocity and pitching technique.

At the shoulder, most of the net actions are stability actions that maintain the coaptation of the joint, especially for the forward/backward rotation and depression/elevation. This suggests that the pitching power is mainly transmitted and not produced by the shoulder and confirms results from previous study [15]. The main motor action before BR is the exorotation moment at MER that manages the orientation of the forearm and the forward force peak at MER that initiate the shoulder forward motion. This suggests that the endorotation between MER and BR is mainly passive and produced by the dynamics of other segments. These results also shows that the deceleration phase and follow-up phase (after BR) are critical as the highest stability actions occurs at MIR with peak in the forward and pulling direction combined with peak depression and forward moment combined with peak depression and forward moments.

5. Conclusion

This study suggests that the main action of the shoulder in baseball pitching is transmitting power and positioning the forearm during the arm cocking phase and that the deceleration and follow up phase are critical due to high load in the shoulder. Concerning the elbow joint, the critical event seems to be MER where the maximal adduction moment occurs. The results also suggest that the elbow action is mainly avoiding hyperextension during the acceleration and deceleration phases.

Further study is needed to link the stability and motor actions to injury risk and pitching technique.

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