COMPARISON OF MARKER AND MARKER-LESS AUTOMATED MOTION CAPTURE FOR BASEBALL PITCHING BIOMECHANICS

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The purpose of this study was to measure baseball pitching kinematics with a marker-less motion capture system and compare the results against marker-based measurements. A sample of 114 pitches were captured at 240 Hz simultaneously with a 9-camera marker-less system and a 12-camera marker system. The pitches were thrown by nine baseball pitchers (age 17.0 ± 4.0 yrs). For each trial, the data were time-synchronized between the two systems using the instant of ball release. Coefficient of Multiple Correlations (CMC) were computed to assess the similarity of waveforms between the two systems. Paired t-tests were used to compare differences between the two systems for 3 temporal and 18 kinematic measurements. The CMC for all eight time series analyzed were excellent, ranging from 0.90 to 0.99. Timing of events between the two systems varied by two frames (0.0083 s) or less. Angular positions differed between the two systems up to 14 degrees. Thus, the marker-based and marker-less motion capture systems produced similar patterns for baseball pitching kinematics. However, based on the variations between the systems, it is recommended that a database of normative ranges should be established for each system individually.

KEYWORDS: kinematics, motion capture, shoulder, elbow.

INTRODUCTION: In biomechanics, 3D motion capture technology is often used to analyze complex movements. One of the most complex biomechanical movements in athletics is baseball pitching. With the mixture of high rotational velocities, complexity, and increased joint kinetics (forces & torques), it is a perfect arrangement for the utilization of 3D motion capture. For more than 30 years, baseball pitching biomechanics have been analyzed with automated optical tracking of reflective markers. In particular, the American Sports Medicine Institute (ASMI) has evaluated thousands of baseball pitchers and published dozens of studies to advance the science and understanding of throwing biomechanics (Zheng et al., 2004). In recent years, technologies to track 3D motion without markers has emerged in the biomechanics field. The potential of this technological advance is obvious, allowing for tracking athletes during competition and in lab settings often and with ease. While several marker-less 3D tracking technologies are now commercially available, the accuracy of these systems and how the data compares to marker-based data are not well known. Thus, the purpose of this study was to compare baseball pitching kinematics measured with a marker-less system against data measured with a marker system.

METHODS: This study was approved by Sterling IRB. Nine male baseball pitchers (age 17.0 ± 4.0 yrs; height 182 ± 9 cm; mass 75.3 ± 17.0 kg) threw a total of 114 pitches from an indoor pitching mound toward a target strike zone located above home plate. Mound height and slope and the distance between the pitching rubber and home plate all conformed to MLB regulations. Each pitch was simultaneously captured by both a 12-camera marker-based motion capture system (Motion Analysis Corporation, Rohnert Park, CA) and a 9-camera marker-less motion capture system (DARI Motion, Overland Park, KS), each collecting at 240 Hz. For the marker-based system, 39 retro-reflective markers were placed on the participant’s bony landmarks as previously described (Escamilla, Slowik, Diffendaffer & Fleisig, 2018). Kinematics were calculated for both systems as previously described for marker-based data (Escamilla et al., 2018; Zheng, Fleisig, Barrentine & Andrews, 2004).

Data were time-synchronized between the two systems for each trial using the ball release frame. Ball release frame was defined as the third frame after the throwing wrist joint center passed the elbow joint center in the global X direction (i.e. direction from mound to home plate). Coefficient of Multiple Correlations (CMC) over a window 200 frames before ball release to 10 frames after ball release were evaluated between the two systems for eight kinematic variables. CMC is used to assess the similarity of waveforms between two protocols, in this case motion capture modality, accounting for the effects of differences in offset, correlation, and gain (Ferrari, Cutti & Cappello, 2010). The eight variables assessed via CMC were lead knee flexion; forward tilt, lateral tilt, and axial rotation of the trunk; abduction, horizontal adduction, and external rotation of the throwing shoulder; and throwing elbow flexion.

Three temporal and 18 kinematic measurements identified by ASMI as key indicators of pitching performance were compared between the two systems using paired t-tests ($p<0.05$). Of the 18 kinematic parameters, 9 occurred at the instant of lead foot contact, 3 during arm cocking, and 6 at the instant of ball release.

RESULTS: The CMC for the eight parameters ranged between 0.90 to 0.99 (Table 1). Thus, there was excellent agreement between the two systems in the shape of time series curves for kinematic variables.

Table 1: Coefficient of Multiple Correlation between marker-less and marker systems

Kinematic variable during pitching	CMC
Lead knee flexion	0.99
Trunk forward tilt	0.99
Trunk lateral tilt	0.92
Trunk separation	0.90
Shoulder abduction	0.97
Shoulder horizontal abduction	0.91
Shoulder rotation	0.97
Elbow flexion	0.96

Mean values and differences between the two systems are shown in Table 2. Most measurements were significantly different between marker-based and mark-less system, typically differing by 5 to 10 degrees.

Table 2: Differences between marker-based and marker-less systems

Variable	Marker-based (Mean)	Marker-less (Mean)	Standard Error of the Mean (SEM)
Timing (seconds before ball release)			
Time of maximum knee height *	-0.864	-0.862	0.006
Time of foot contact	-0.147	-0.148	0.001
Time of maximum external rotation *	-0.039	-0.035	<0.001
At foot contact (degrees, except as otherwise indicated)			
Stride length (% height) *	80	71	0.37
Lead foot position (cm) *	19	6	1.17
Lead knee flexion *	46	50	0.35
Pelvis rotation *	38	30	0.79
Trunk axial rotation *	48	36	0.68
Trunk lateral tilt *	12	-2	0.55
Shoulder abduction *	91	87	0.90
Shoulder external rotation *	-22	-27	0.69

Elbow flexion *	57	51	1.99
Arm cocking (degrees)			
Maximum shoulder external rotation *	180	175	0.61
Maximum shoulder horizontal abduction *	15	7	0.57
Maximum elbow flexion *	108	98	0.84
At Ball release (degrees)			
Lead knee flexion *	37	45	0.77
Trunk forward tilt *	37	38	0.35
Trunk lateral tilt *	31	18	0.86
Shoulder abduction	93	93	0.46
Elbow flexion *	24	16	0.36
Arm angle from vertical in frontal plane *	48	58	0.75

* Significant difference (p<0.05) between marker-based and marker-less measurements

DISCUSSION: Data were highly consistent within each system and between the two systems, as the curves demonstrated similar features and timing, leading to high CMC values. While the curves were consistent, paired t-tests indicated systematic differences between the marker-less and marker technologies. For example, Figure 1 shows shoulder rotation and elbow flexion angles for seven pitches thrown by one subject. While the shapes of the curves look consistent, repeatable differences between the two systems are noticeable.

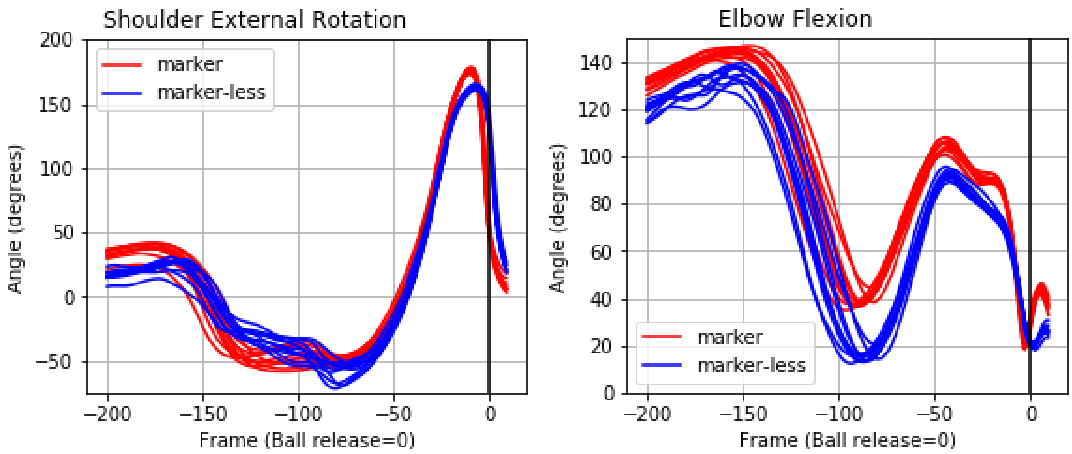

Figure 1: Sample time series graphs for two kinematic variables for one subject. Data shown for the seven pitches thrown by the subject.

Differences in measurements between the two systems varied from 0 to 14 degrees (Table 2). A previous comparison of marker-based and marker-less systems for measuring squats and standing broad jumps range in children reported range of motion differences up to 23 degree differences (Harsted, Holsgaard-Larsen, Hestbæk, Boyle & Lauridsen, 2019). Another biomechanical study, comparing gait with marker-based and marker-less systems, found differences up to 51 degrees (Ceseracciu, Sawacha & Cobelli, 2014). The large differences in that gait study were related to ankle motion; excluding ankle measurements, the gait study found differences in hip and knee motions up to 21 degrees. Thus, while marker-based and marker-less systems produce similar three-dimensional kinematic patterns, the magnitudes of the measurements between the systems have significant differences.

While there were differences between the data from the two systems, we cannot say the data from one system was more accurate than the other. There are architectural differences between the systems related to both data collection and processing that make it nearly impossible to achieve a perfect match between the two types of systems. First, joint centers were determined differently between the two systems. Marker-based systems utilize markers placed on anatomical landmarks (e.g., medial and lateral bony prominences) to define joint center locations, while marker-less systems rely on longitudinal axes of segment volumes and their relative motions. Both methods have their own inherent error. The most accurate model would require the use of dynamic imaging technology during the pitching motion; however, this is both impractical and an unnecessary level of detail for the application of basic whole-body biomechanical assessments.

Secondly, both systems may have small errors created by segment definitions and mathematical constraints placed on the segment/bone lengths. While these differences are minor, this does account for some of the variations in results between the two systems.

Future research can compare marker-less and marker-based results for a larger sample of baseball pitchers, including analysis of subsets by player level (youth, high school, collegiate, professional), body size, pitch type, and ball velocity. Future research can also compare kinetic calculations (joint forces and torques) between the two systems.

CONCLUSION: The data collected by a marker-based motion capture system and a marker-less motion capture system show similar patterns in tracking baseball pitching kinematics. However, based on the variations between the systems, it is recommended that a database of normative ranges should be established for each system individually.

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