Marker vs. Markerless Automated Motion Capture Data Comparison for Baseball Pitching

Derek Wassom, MS[1]; Patrick Moodie, MS, MBA[1]; Jonathan S. Slowik, PhD[2]; Alek Z. Diffendaffer, MS[2]; Glenn S. Fleisig, PhD[1,2]

1. DARI Motion – Overland Park, KS
2. American Sports Medicine Institute – Birmingham, AL

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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.

Historically, marker motion capture systems have been used to research and evaluate this movement. A leader in this area of expertise is the American Sports Medicine Institute (ASMI). Over the past 30+ years, their lab has produced landmark studies to advance the science and understanding of pitching biomechanical analyses.

With proven knowledge in this space, ASMI partnered with DARI Motion partnered to evaluate the DARI Motion markerless motion capture system against the marker-based motion capture system. The goal of this evaluation was to compare data from these two systems and determine if the body of knowledge from the marker-based ASMI BioPitch framework could be transferred to use with the DARI markerless motion capture system.

Methods

At the ASMI James R. Andrews, MD Biomechanics Laboratory, 9 male baseball pitchers (age 17.0 ± 4.0 yrs; height 71.7 ± 3.7 in; weight 166.0 ± 37.4 lbs) threw a total of 114 pitches during 16 capture sessions 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 markerless 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 et al., 2018).

Data was independently processed by ASMI and DARI Motion for each respective system. Kinematics and kinetics were calculated for the marker-based data as previously described (Escamilla et al., 2018; Zheng et al., 2004) using BioPitch software (ASMI, Birmingham, AL, USA). Kinematics and kinetics were calculated for the markerless data using calculations similar to BioPitch. Data from both systems were then aggregated for statistical analysis.

Data were time synchronized using the ball release frame. 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 8 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 et al., 2010). The 8 variables 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.

Standard Error of Measurement (SEM) was used to compare 3 temporal and 20 kinematic measurements identified by ASMI as key indicators of pitching performance. The standard error of measurement is an absolute estimate of the reliability of a test, meaning it has the units of the test being evaluated and is not sensitive to the between-subjects variability of the data. Of the 20 kinematic parameters, 10 occurred at the instant of lead foot contact and 6 at the instant of ball release.

Results

The CMC for the 8 parameters ranged between 0.90 to 0.99, with an average value of 0.95. These values indicate excellent agreement between the systems.

Variable	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

After synchronizing on the ball release frame identified by each system, comparison of event detection methods showed an SEM of 1.7 frames for instant of maximum knee height, 2.0 frames for instant of front foot contact and 1.3 frames for instant of maximum shoulder external rotation.

Of the 20 kinematic parameters evaluated, there were 17 angular measurements. Comparison of angular measurements between systems showed SEM values between 3.1° to 14.2°. SEM for the remaining 3 parameters were 1.6% height for maximum knee height, 5.1% height for stride length, and 3.5 cm for lead foot position.

Variable	Count	SEM	Unit
Max Knee Height Frame	114	1.7	frames
Foot Contact Frame	114	2.0	frames
Max External Rotation Frame	114	1.3	frames
Max Knee Height	114	1.6	% ht
FC: Stride Length	114	5.1	% ht
FC: Lead Foot Position	114	3.5	cm
FC: Knee Flexion	114	3.6	degrees
FC: Pelvis Rotation	114	11.0	degrees
FC: Trunk Separation	114	11.3	degrees
FC: Trunk Lateral Tilt	114	13.4	degrees
FC: Shoulder Abduction	114	5.8	degrees
FC: Shoulder Horiz Abduction	114	6.7	degrees
FC: Shoulder External Rotation	114	6.9	degrees
FC: Elbow Flexion	114	8.0	degrees
Max External Rotation	114	8.9	degrees
Max Horiz Abduction	114	11.4	degrees
Max Elbow Flexion	114	11.1	degrees
BR: Knee Flexion	114	5.0	degrees
BR: Trunk Lateral Tilt	114	14.2	degrees
BR: Trunk Forward Tilt	114	3.1	degrees
BR: Shoulder Abduction	114	5.1	degrees
BR: Elbow Flexion	114	7.1	degrees
BR: Arm Slot Angle	114	3.3	degrees

Discussion

Both types of motion capture systems track human movement well. Data are highly consistent within each system and between the two systems, there are consistent curve features and timing, leading to high correlation values. 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. In other words, while we did find some differences between the two systems, that does not mean that either system is inaccurate. Below is a list of points with explanations that support the validity of both systems being used with their own normative databases for reference.

Joint Center Determination and Definitions: Marker-based systems utilize markers placed on anatomical landmarks (e.g., medial and lateral bony prominences) to define joint center locations, while markerless 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.

Segment Lengths and Definitions: For both systems, there may be small errors due to 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.

Joint Angle Calculations: While both systems used similar definitions of the joint angles, there were slight differences in their software implementation. Furthermore, the differences from the previously two described categories can propagate due to these joint angle implementation differences.

Conclusion

The data collected by a marker-based motion capture system and a markerless motion capture system are statistically similar and can both be used to accurately track baseball pitching. However, based on the variations between the systems, it is recommended that a database of normative ranges should be established for each system individually.

References

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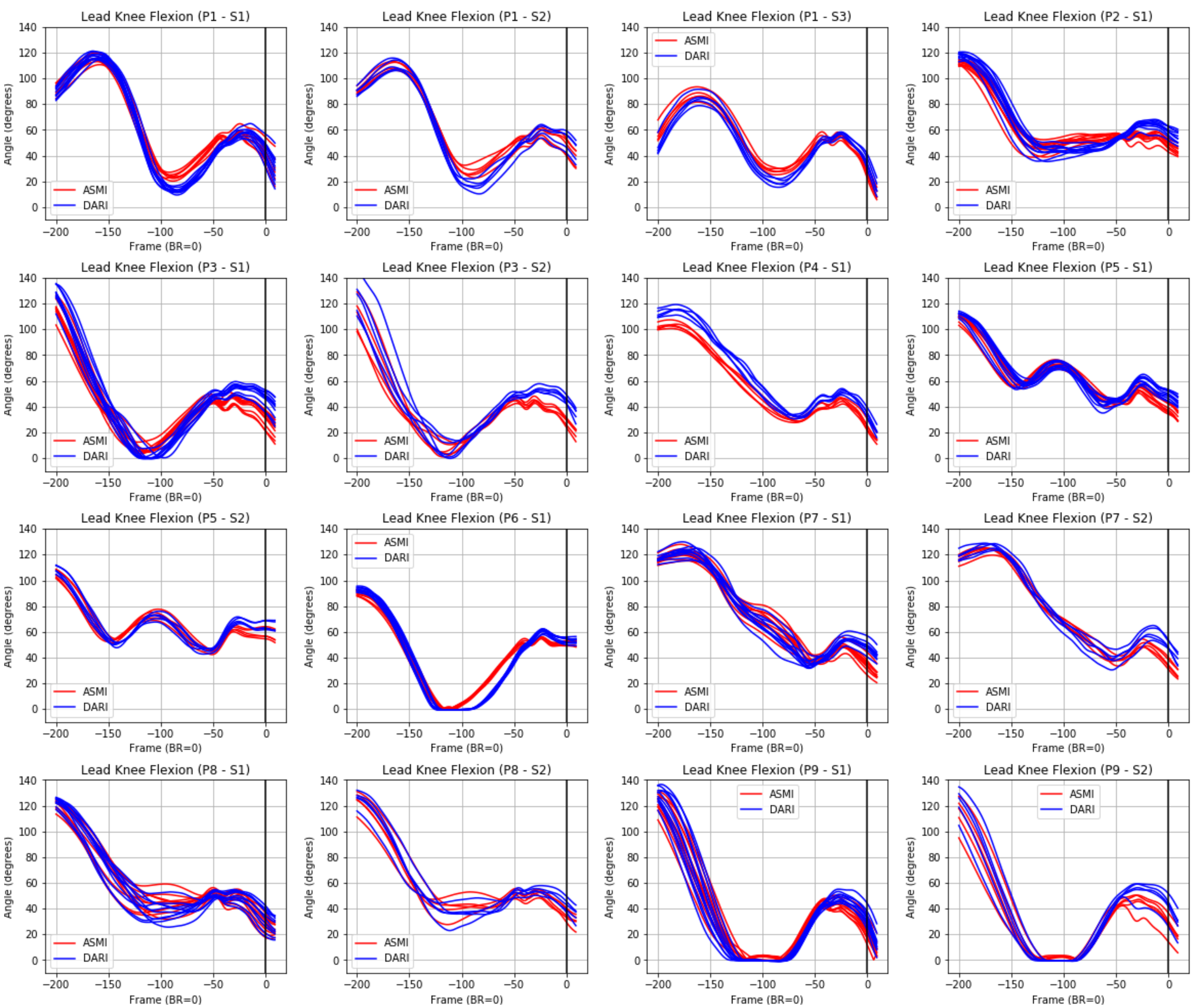
Knee Flexion Data Analysis

Pitch Cycle (BR - 200 frames to BR + 10 frames)

Coefficient of Multiple Correlation (CMC): 0.99

Standard Error of Measurement (SEM) at foot contact: 3.6°

Standard Error of Measurement (SEM) at ball release: 5.0°



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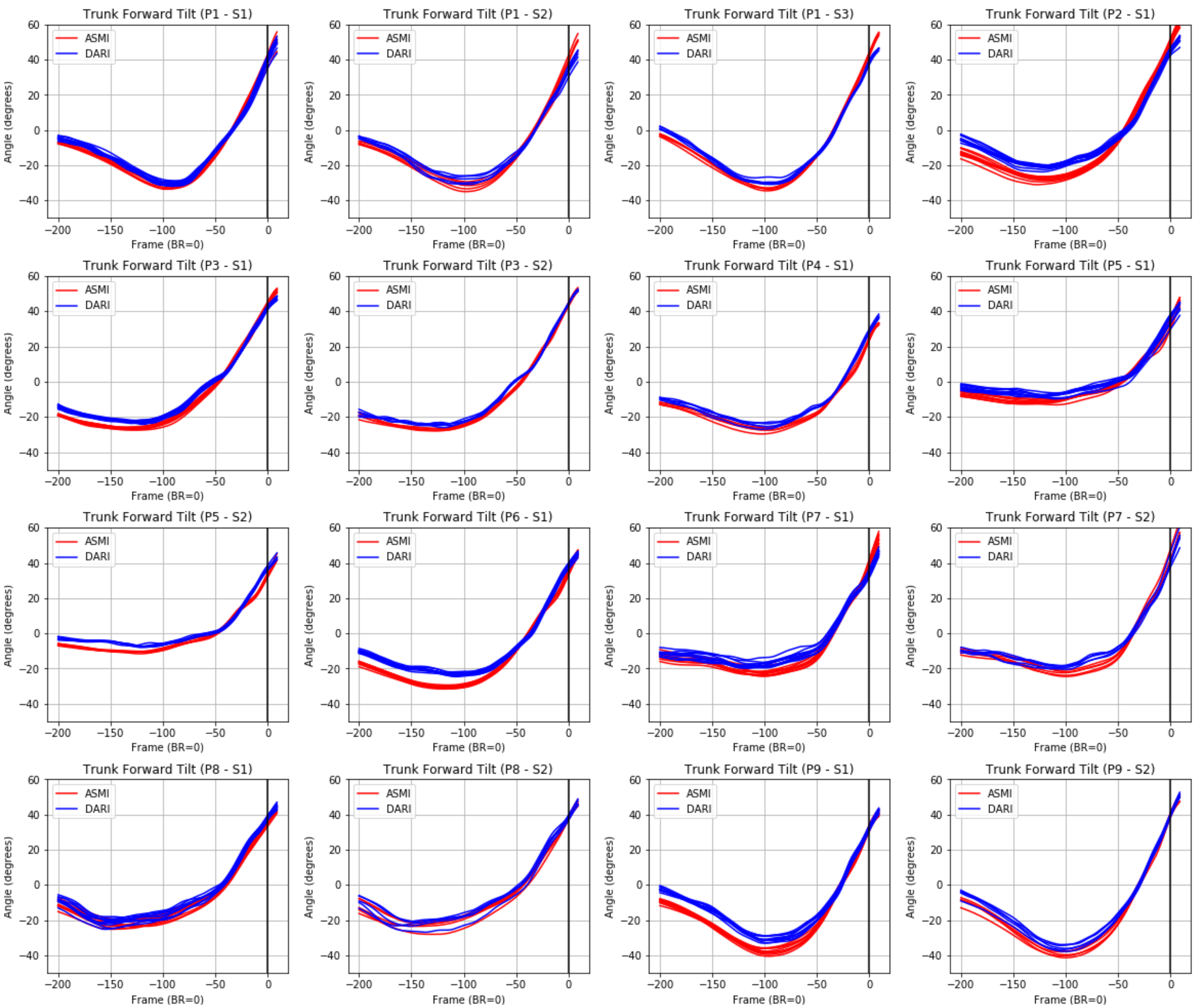
Trunk Forward Tilt Data Analysis

Pitch Cycle (BR - 200 frames to BR + 10 frames)

Coefficient of Multiple Correlation (CMC): 0.99

Standard Error of Measurement (SEM) at ball release: 3.1°



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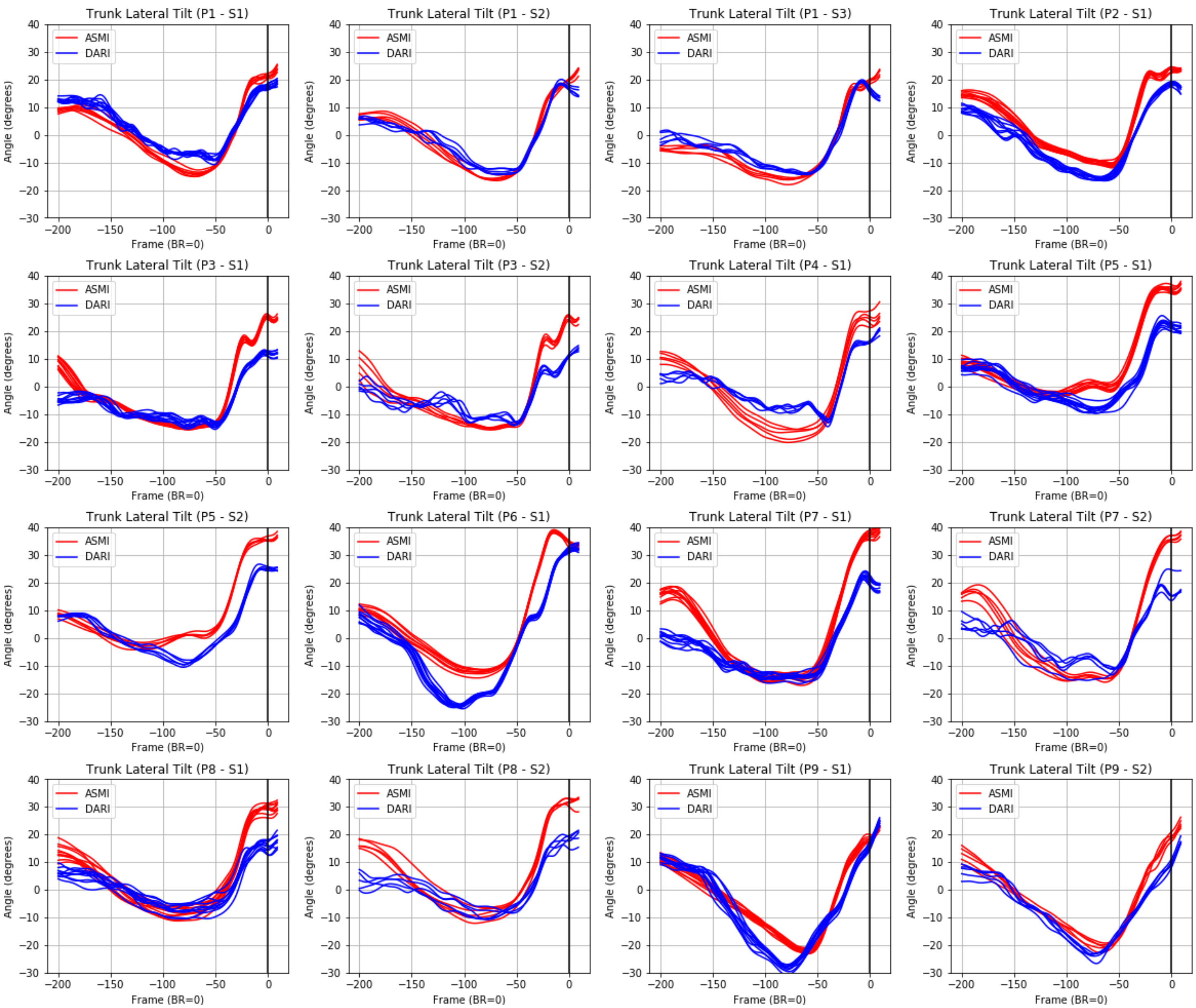
Trunk Lateral Tilt Data Analysis

Pitch Cycle (BR - 200 frames to BR + 10 frames)

Coefficient of Multiple Correlation (CMC): 0.92

Standard Error of Measurement (SEM) at foot contact: 13.4°

Standard Error of Measurement (SEM) at ball release: 14.2°



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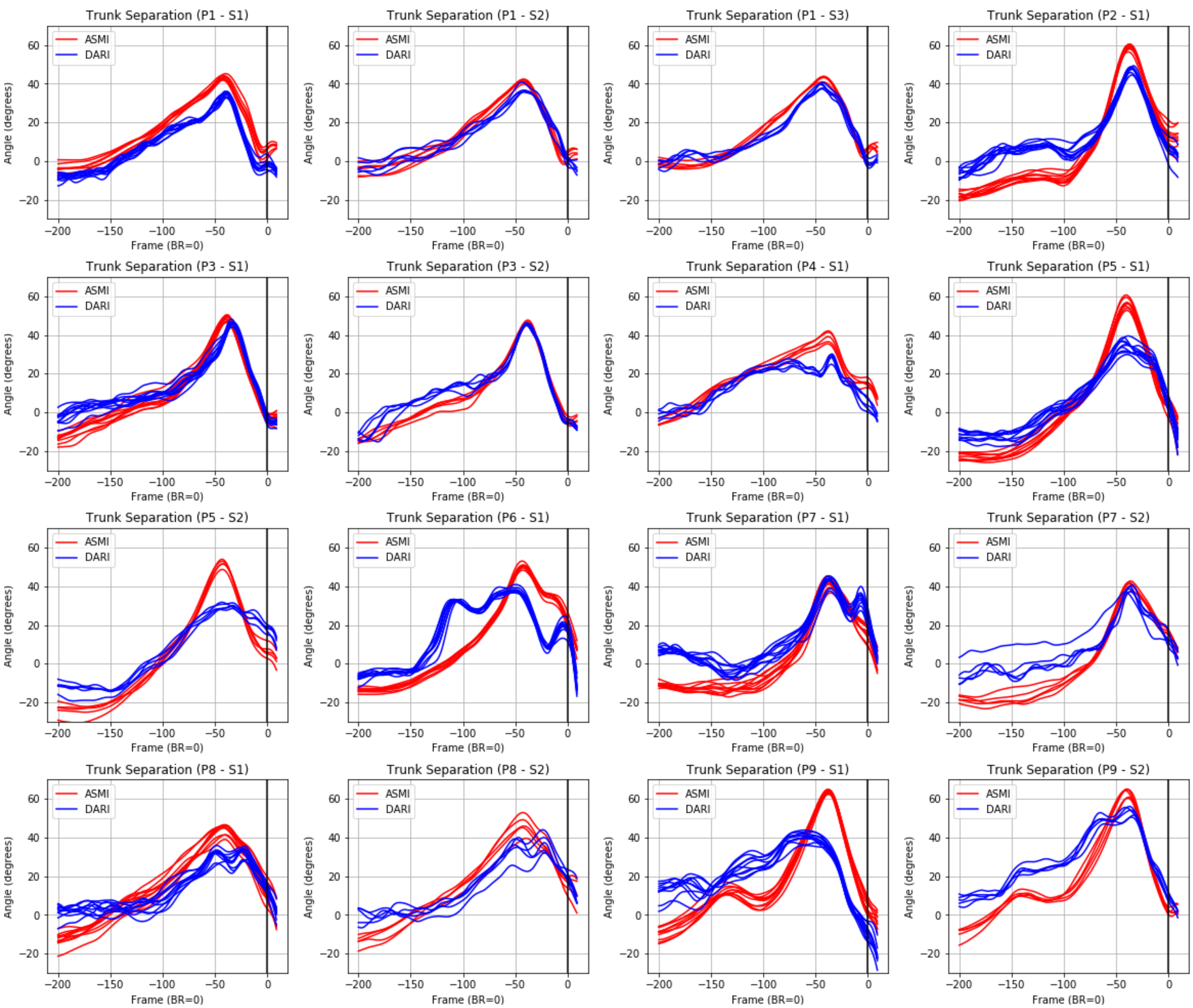
Trunk Separation Data Analysis

Pitch Cycle (BR - 200 frames to BR + 10 frames)

Coefficient of Multiple Correlation (CMC): 0.90

Standard Error of Measurement (SEM) at foot contact: 11.3°



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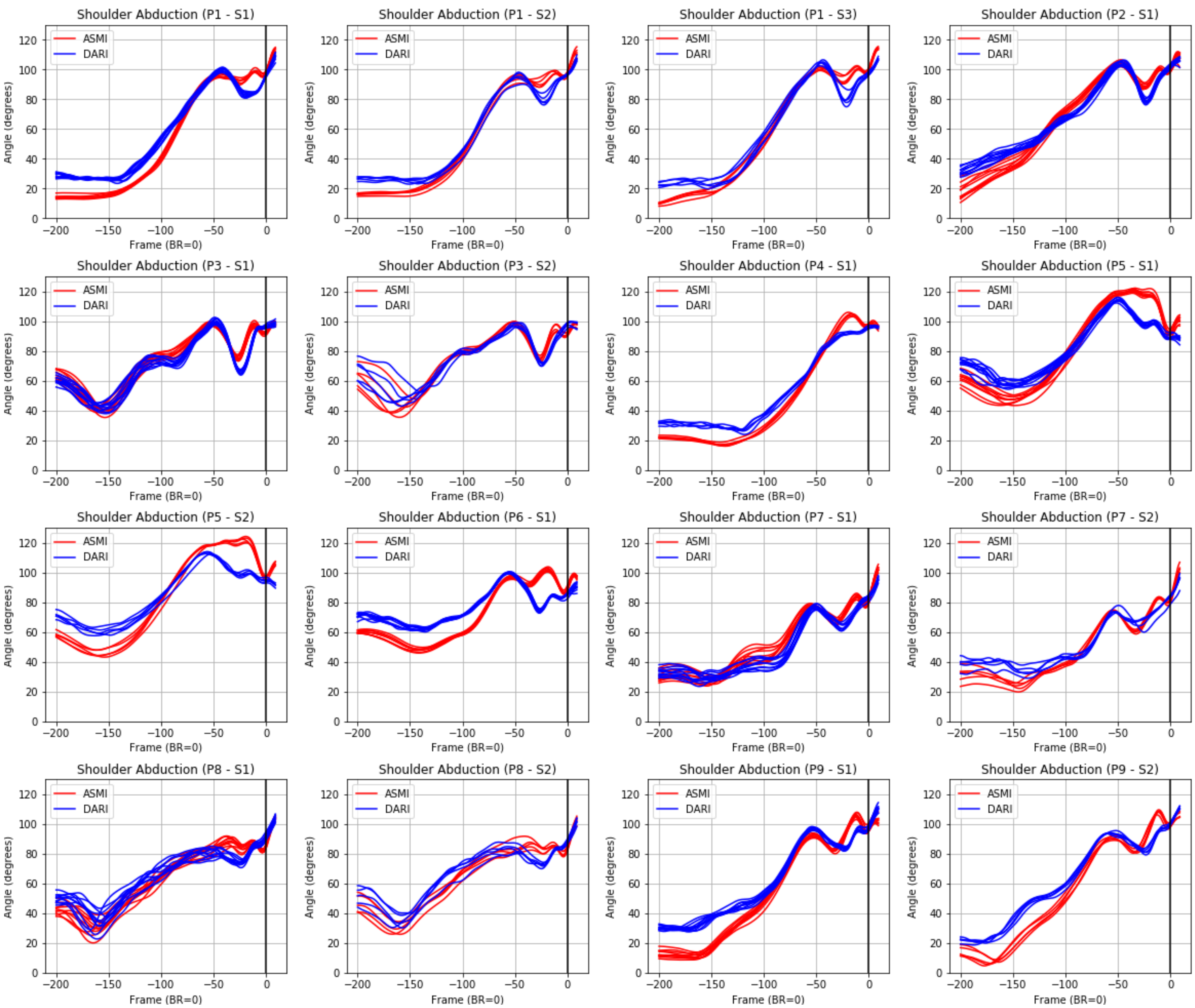
Shoulder Abduction Data Analysis

Pitch Cycle (BR - 200 frames to BR + 10 frames)

Coefficient of Multiple Correlation (CMC): 0.97

Standard Error of Measurement (SEM) at foot contact: 5.8°

Standard Error of Measurement (SEM) at ball release: 5.1°



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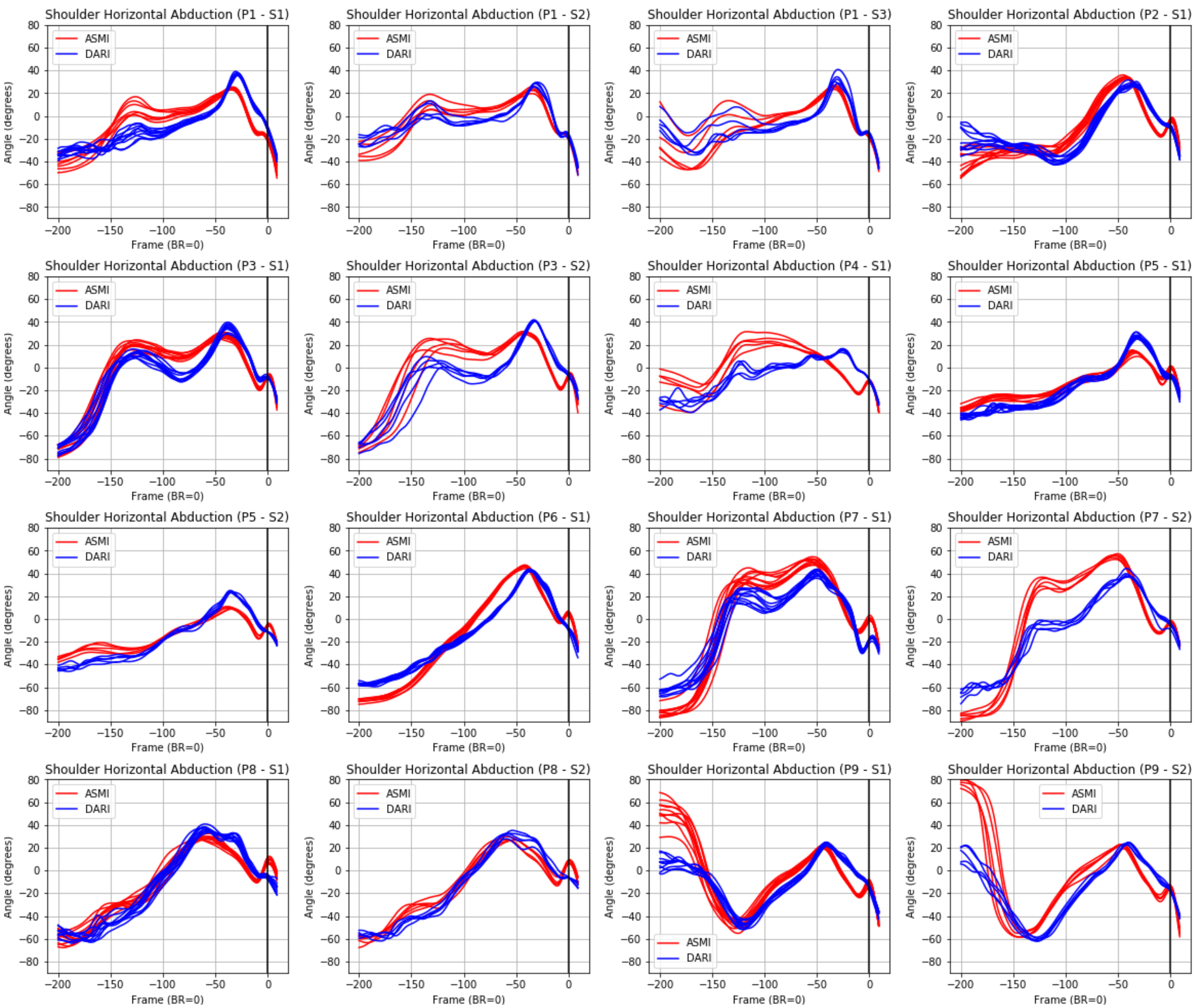
Shoulder Horizontal Abduction Data Analysis

Pitch Cycle (BR - 200 frames to BR + 10 frames)

Coefficient of Multiple Correlation (CMC): 0.91

Standard Error of Measurement (SEM) at foot contact: 6.7°

Standard Error of Measurement (SEM) at max: 11.4°



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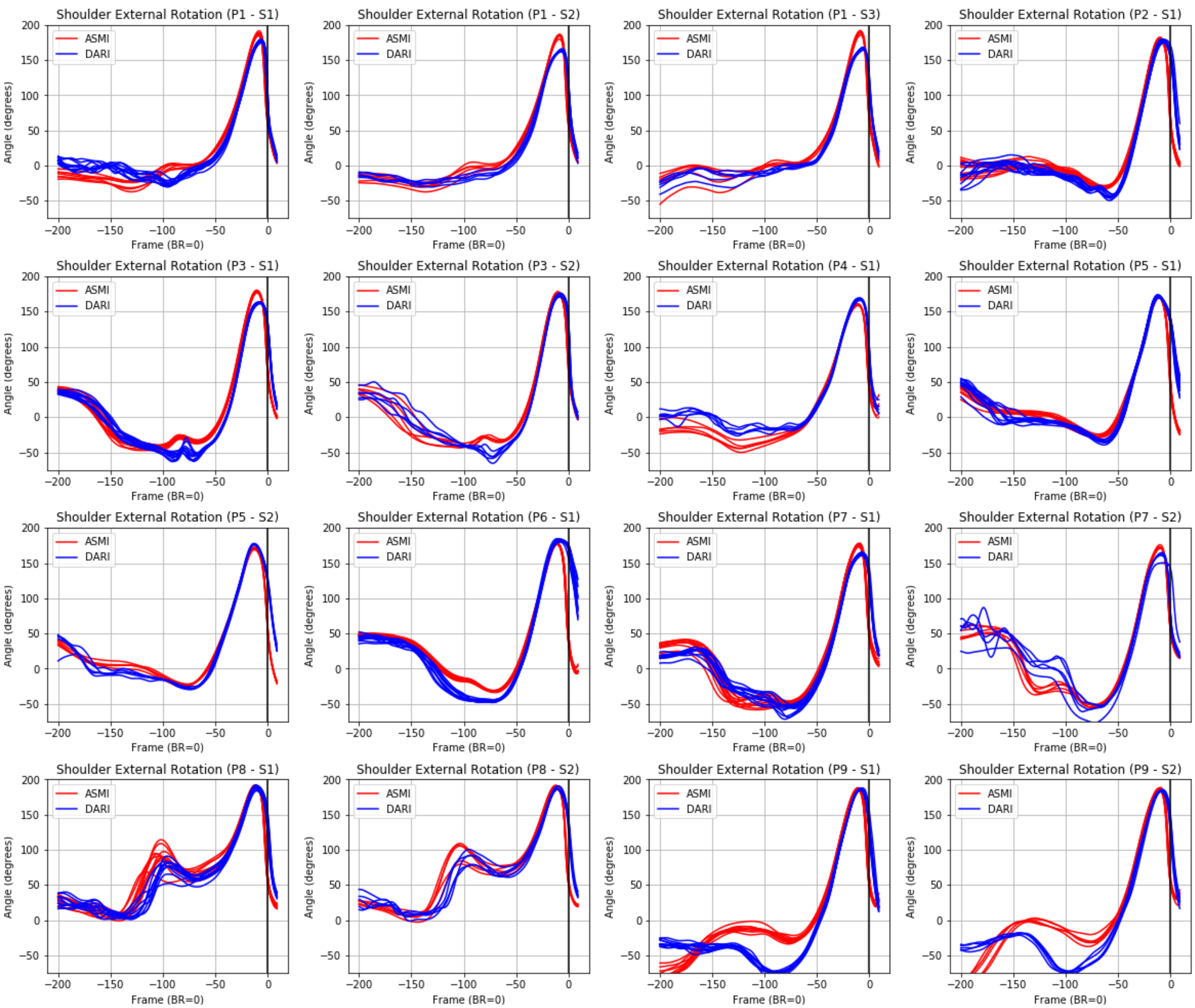
Shoulder External Rotation Data Analysis

Pitch Cycle (BR - 200 frames to BR + 10 frames)

Coefficient of Multiple Correlation (CMC): 0.97

Standard Error of Measurement (SEM) at foot contact: 6.9°

Standard Error of Measurement (SEM) at max: 8.9°



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Elbow Flexion Data Analysis

Pitch Cycle (BR - 200 frames to BR + 10 frames)

Coefficient of Multiple Correlation (CMC): 0.96

Standard Error of Measurement (SEM) at foot contact: 8.0°

Standard Error of Measurement (SEM) at max: 11.1°

Standard Error of Measurement (SEM) at ball release: 7.1°