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# A 3D MARKERLESS PROTOCOL WITH ACTION CAMERAS

## KEY PERFORMANCE INDICATORS IN BOXING



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### INTRODUCTION

Kinematic analysis in sports helps improve sports technique, prevent injuries, and reveal different motor skills among athletes.

In boxing, **punching speed is of uttermost importance**. However, it is not generated in the same way in jabs (mostly translational movement) as in hooks (mostly rotational). **Key performance indicators (KPIs)** have been determined [1], but they are usually investigated with subjective visual observation.

### PROBLEM

When finer analysis is needed, marker-based kinematics is usually employed. However, what if:

- Wearing markers is not conceivable?
- Research-grade cameras are not available?
- Classic marker-based calibration is impossible?
- Usual synchronization methods are not feasible?

Subsidiary question: Does the choice of the 2D pose estimation model matter?

### Objective:

Concurrently validating the accuracy of KPI measurements in boxing with suboptimal markerless protocols.

### METHODS

#### BOXING TASK:

Analysis of a sequence of shadow boxing: **jab, high hook, low hook**.  
3 elite boxers performed the sequence 6 times.

#### MEASURED KPIS [1]:

- Jab:**
- Lead foot translation
  - Pelvis translation
  - Lead elbow extension
  - Lead fist velocity
- Hooks:**
- Rear knee flexion
  - Pelvis rotation
  - Rear shoulder rotation
  - Rear fist velocity.

#### 4 CONDITIONS:

- Reference marker-based kinematics:**
  - 10 Qualisys MoCap cameras
  - OpenSim [2] scaling and inverse kinematics (44 markers & 12 joint centers)
- Markerless kinematics with research-grade system:**
  - 8 Qualisys Miquis video cameras,
  - Pose2Sim workflow [3] (Fig. 1) (21 keypoints)
- Markerless kinematics with light-weight system:**
  - 8 GoPros Hero7&8 cameras
  - Pose2Sim workflow (21 keypoints)
  - Post-calibration on ring dimensions (Fig. 2)
  - Post-synchronization with cross-correlation of keypoints speeds (Fig. 3)
  - Bring GoPro spatio-temporal base into Qualisys'.
- Same as previous with a different 2D pose estimation model:**
  - Same as previous protocol, but
  - With default OpenPose `body_25` model instead of `body_25b`

#### STATISTICS :

Inter-protocol coefficient of multiple correlation (CMC [4]).  
Takes into account correlation, gain, and offset.

Fig. 1: Pose2Sim workflow

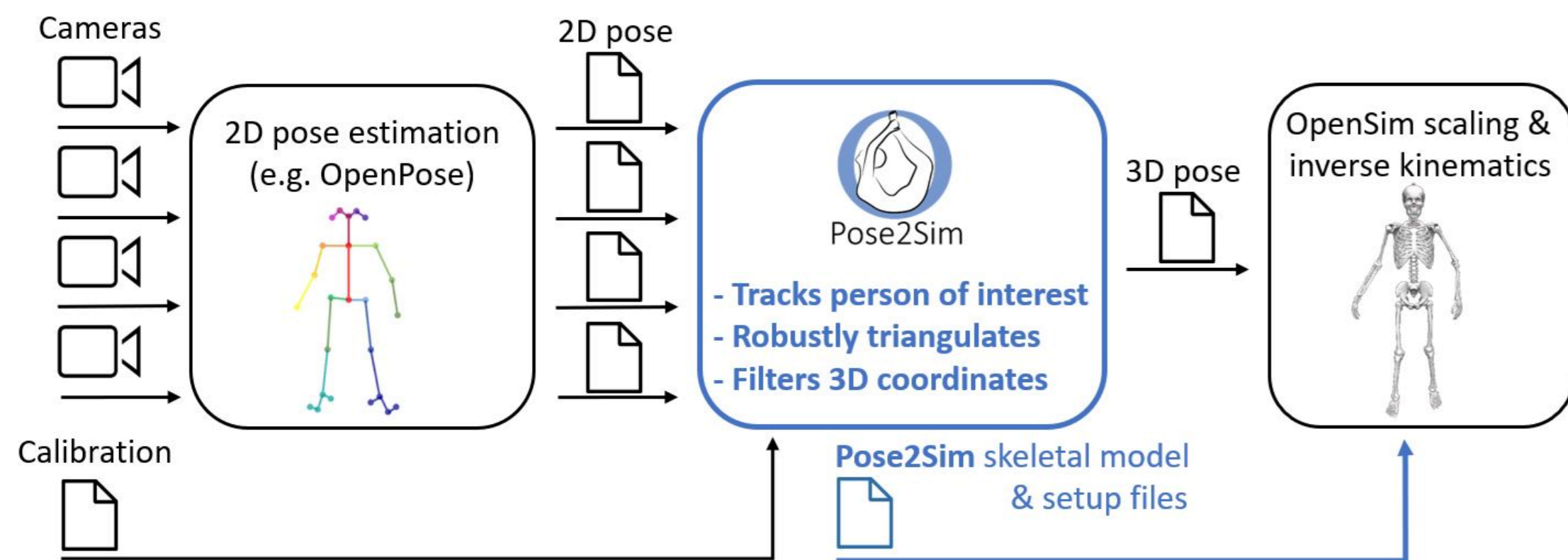


Fig. 2: Reprojection errors with calibration on ring dimensions

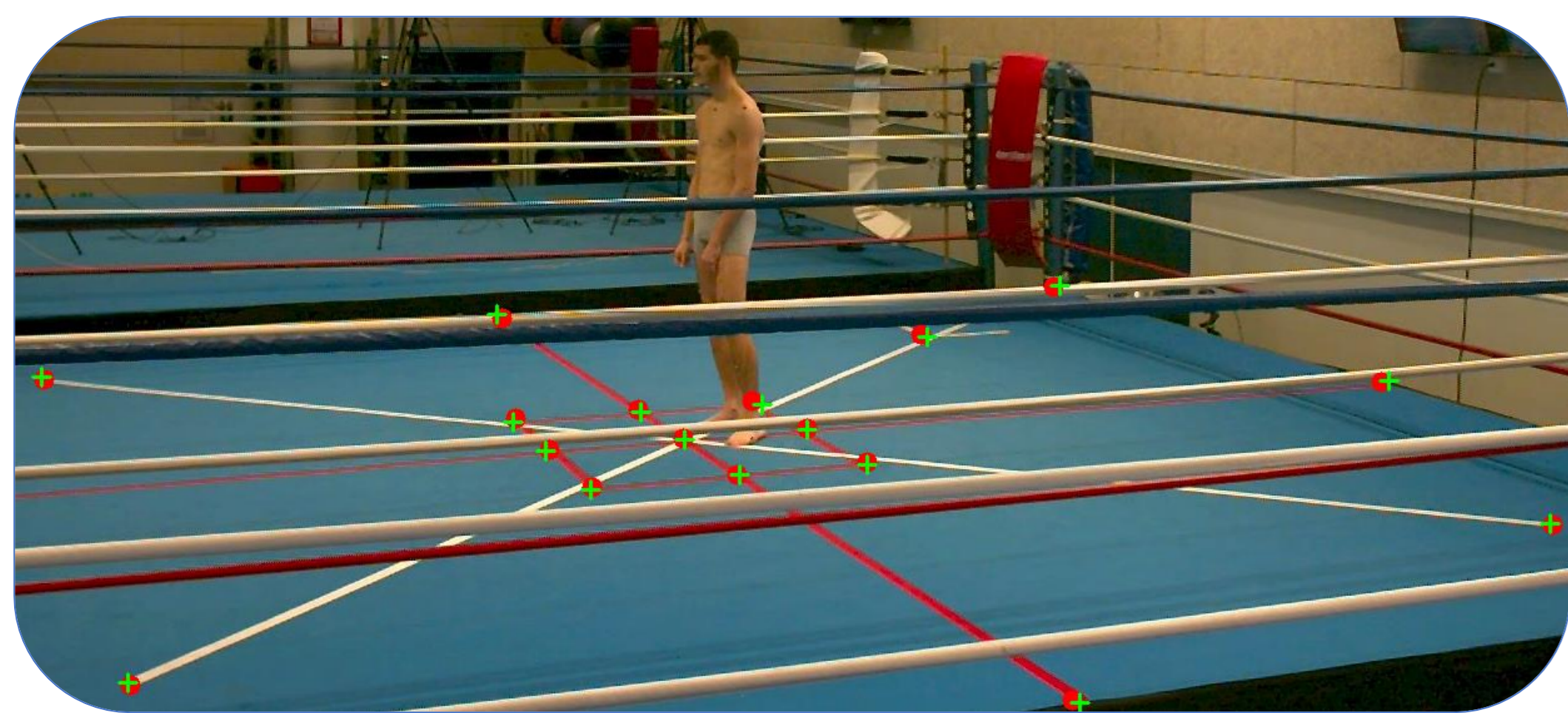
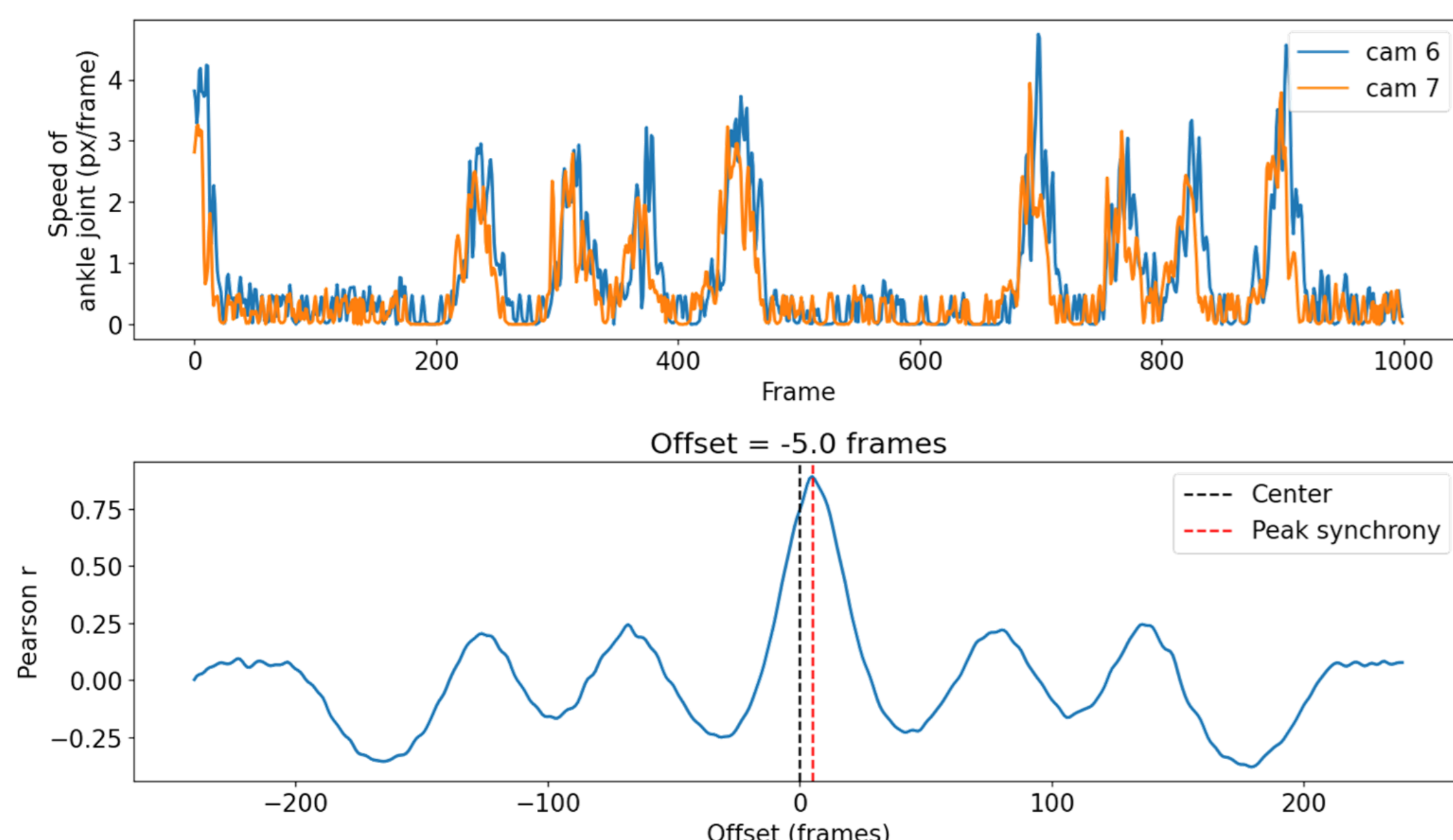
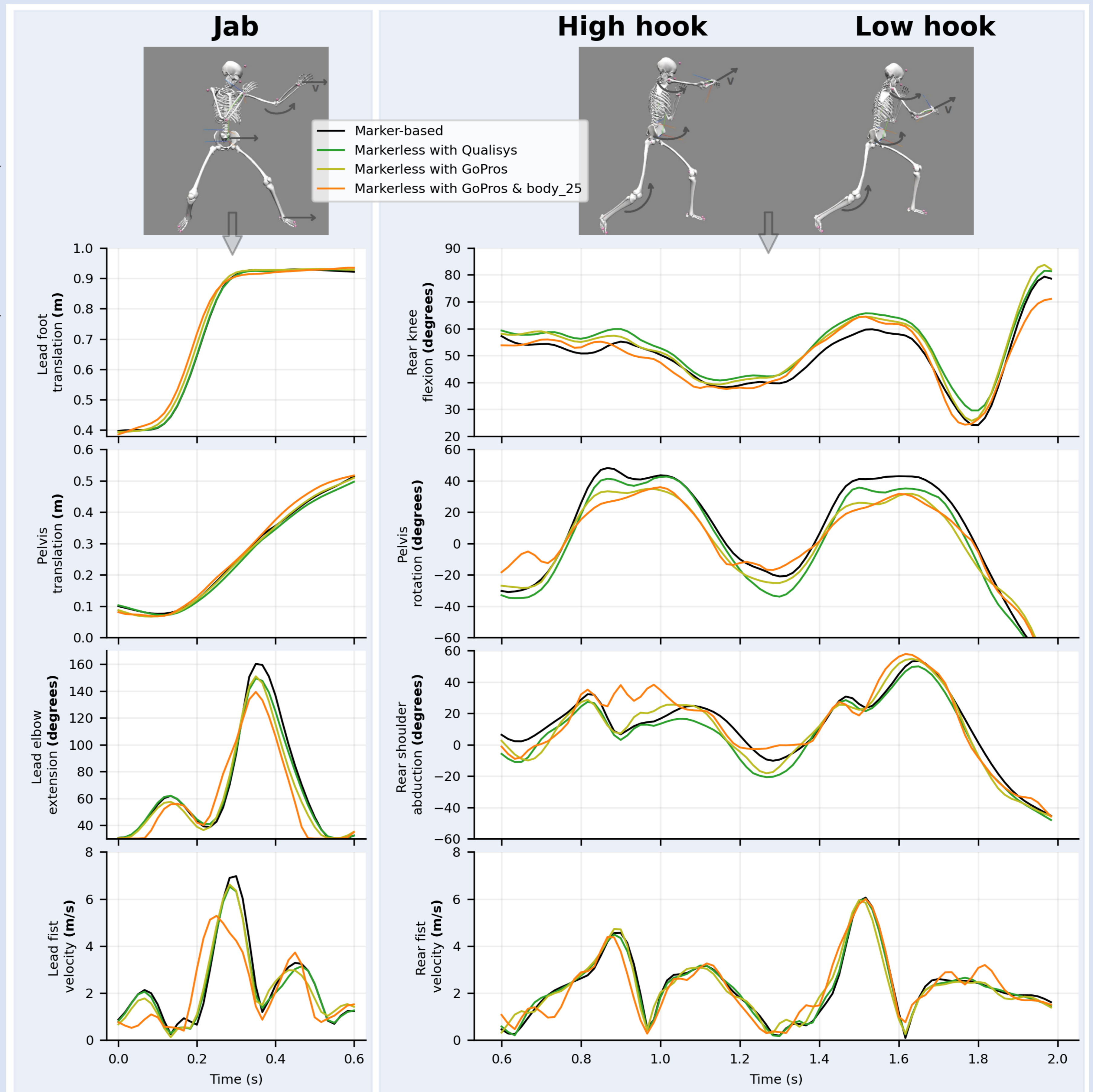


Fig. 3: Camera synchronization by time-lagged correlation on 2D keypoints speeds



### RESULTS

A representative trial by one of the boxers



CMC	JAB			HOOKS			
	Marker-based vs. →	Markerless with Qualisys	Markerless with GoPros	Marker-based vs. →	Markerless with Qualisys	Markerless with GoPros	Markerless with GoPros & body_25
Lead foot translation	1.00	1.00	1.00	Rear knee flexion	0.99	0.99	0.99
Pelvis translation	1.00	1.00	1.00	Pelvis rotation	0.99	0.98	0.96
Lead elbow extension	1.00	0.98	0.95	Rear shoulder rot.	0.98	0.97	0.91
Lead fist velocity	0.99	0.97	0.91	Rear fist velocity	0.99	0.97	0.90

- **Research-grade markerless setup:** Results almost in perfect agreement with marker-based analysis.
- **GoPro cameras with post-calibration and post-synchronization procedures:** Results in excellent agreement (CMC > 0.95).
- **Same as previous, with default OpenPose model:** Results still in very good agreement (CMC > 0.85). Velocities and shoulder rotation are the least in agreement.

### DISCUSSION

Markerless performs remarkably well in all conditions, even though boxing movements are challenging: 3D, high speed, whole body. This opens the way to sports kinematic analysis and to KPI determination in context, when marker-based analysis is not possible.

Equipment and protocol matter less than the choice of the pose estimation model, which should be chosen with special care. Some other models provided by OpenPose or other methods are less accurate [5], and may lead to divergent results.

Velocities are less exact: they derive from positions, and thus amplify these errors.

The shoulder is modeled as a ball joint in our OpenSim model, which must cause inaccuracies in all results, including marker-based ones.

References: [1] Lenetsky et al., J. Strength Cond. Res. 2020 [2] Delp et al., IEEE Trans. Biomed. Eng., 2007 [3] Pagnon et al., Sensors, 2022 [4] Ferrari et al., Gait & Posture, 2010 [5] Needham et al., Sci. Rep., 2022  
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