2026-4 | 51th congress of the Société de Biomécanique
27-29 October 2026, Montpellier, France

Multidisciplinary Biomechanics Journal

Agreement of Markerless Pose Estimation with Marker-Based Motion Analysis for Pediatric Upper Limb Kinematics During Daily Living Activities

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Received date: 03/04/2026
Accepted date: 25/06/2026
Publication date: 27/10/2026

Keywords: motion analysis, kinematics, markerless, upper limb, pediatrics

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1. Introduction

Accurate assessment of upper limb kinematics is important to support pediatric clinical evaluation. Markerless motion capture is an emerging and promising tool to measure such motion in an ecological context; however, its accuracy for upper limb analysis in children remains underexplored.

A limitation of standard whole-body pose estimators is their sparse set of keypoints (Cao et al., 2018). They are typically restricted to the shoulder, elbow, and wrist joint centers, which constrains the analysis of complex upper-limb motions. Recent advances in hand-specific pose-estimation models provide hand keypoints, and their integration with whole-body detection and multisegment biomechanical modeling may enable the estimation of additional degrees of freedom (DoF) such as elbow pronation/supination and wrist flexion/extension or deviation.

This study evaluates the reliability of a RGB-based markerless pipeline, combining body and hand pose estimation, to capture upper limb kinematics in typically developing children.

2. Methods

2.1 Participants and measurement protocol

Ten typically developing children (age: 8 ± 2 years; mass: 31 ± 8 kg; height: 130 ± 10 cm) participated in this study. The study was approved by the ethics committee of the Université de Montreal and informed consent was obtained from the participants and their parents. Upper-limb movements were recorded simultaneously using 8 RGB cameras (60 Hz) and 8 optoelectronic cameras (120 Hz; OptiTrack). Anatomical markers were placed on the trunk and upper limb, including IJ, PX, C7, T10, AC, the humeral epicondyles (EL/EM), radial and ulnar styloid processes (RS/US), and the heads of the second and fifth metacarpals (M2/M5). The glenohumeral joint center was estimated using the regression method of Rab et al. (2002).

Participants performed seven representative daily-living tasks : eating a yoghurt, pour from a bottle, put a hat, play with playdoe, comb hair, reach and grasp, and play with cymbals. Tasks were selected to induce a broad range of humeral, elbow, and wrist motions.

2.2 Markerless pose estimation

RGB recordings were processed using the RTMPose (Jiang et al., 2023) pose estimator for body and hand to obtain 2D points coordinates. A weighted 3D triangulation (DLT with confidence weighting; threshold 0.5) was applied using Pose2Sim to reconstruct 3D keypoints trajectories (Pagnon et al., 2022).

2.3 Multibody segment modelling

A consistent upper-limb multisegment model was applied to both the marker-based and markerless datasets using the biorbd library (Michaud and Begon, 2021). The model included three rotational DoFs at the glenohumeral joint (humeral flexion/extension, abduction/adduction, and internal/external rotation), two DoFs

To cite this article: Julie Rozaire, Mickael Begon, Yosra Cherni, Alexandre Naaim, Agreement of Markerless Pose Estimation with Marker-Based Motion Analysis for Pediatric Upper Limb Kinematics During Daily Living Activities, *Multidisciplinary Biomechanics Journal*, 2026, vol. 4, p. 261–263, DOI: 10.46298/mbj.19189.

at the elbow (flexion/extension and pronation/supination), and two DoFs at the wrist (flexion/extension and radial/ulnar deviation).

Marker-based segment coordinate systems followed ISB recommendations. For the markerless approach, segments were defined from a static upright posture with the elbow flexed at 90° to identify the flexion–extension axis. The wrist flexion axis was aligned with the hand Z-axis, with the hand defined according to ISB. The thorax was defined with a vertical Z-axis and an anteroposterior axis orthogonal to the line between the shoulder joint centers. Joint angles were computed using the same inverse kinematics procedure.

2.4 Statistics

For each DoF and each task, angular differences between marker-based and markerless joint angles were summarized using the median, interquartile range (IQR), and minimum–maximum values calculated on all the trial of all subjects.

3. Results and discussion

Across all degrees of freedom, median errors remained close to zero, suggesting no systematic over- or under-estimation by the markerless system. The dispersion of errors, expressed through the IQR, remained generally modest for most tasks, with values between 4° and 10° for elbow and wrist motions and 8° to 14° for most shoulder angles.

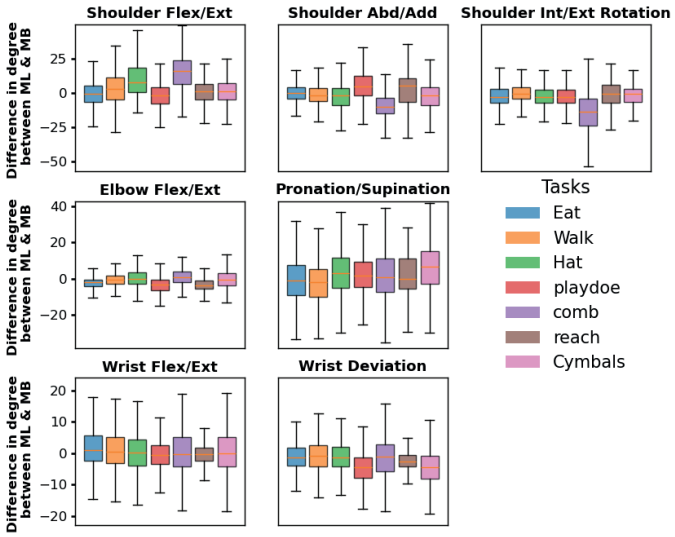

Figure 1. Kinematic difference between markerless and marker-based models across upper-limb tasks.

Elbow flexion/extension showed the smallest overall dispersion, with median errors between −3.7° and +1.0° and narrow IQRs (≈4-6°) across all tasks except comb. Similarly, wrist deviation and wrist flexion/extension demonstrated centered medians (≈−4° to +1°) and low variability (IQR ≈4-9°).

Pronation/supination and shoulder internal/external rotation, both axial motions, exhibited larger variability (IQR ≈14-19°) and broader min–max ranges (up to ±35°), consistent with their known sensitivity to small errors in segment orientation.

The "comb" task was the task producing the largest error ranges (up to −57° to +49°), probably due to complex multi-planar motion.

The pipeline produced centered joint-angle estimates with moderate variability, but precision remained limited for axial rotations and tasks with substantial occlusion. However, it represents a promising alternative to visual assessment, particularly for measuring wrist motion in settings where marker-based capture is impractical.

4. Conclusions

Although promising, the present markerless approach does not yet achieve the level of precision required for detailed upper-limb assessment. A critical question remains: is inaccuracy driven by the inability of the biomechanical model to process a small number of input points, or by the 2D and 3D errors of the reconstructed makerless keypoints.

Acknowledgements

MB, YC and AN are members of the LIA EVASYM and all authors wish to thank the participants and their families.

Contributor Roles

JR: Conceptualization, Data curation, Investigation, Writing original draft; MB: Supervision, Writing – review & editing; YC: Supervision, Writing – review & editing; AN: Conceptualization, Data Curation, Formal analysis, Software, Investigation.

Funding

This work was partly funded by a mobility grant of the Société de Biomécanique.

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