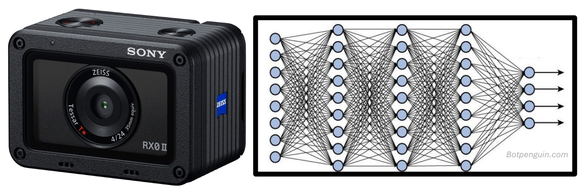
Effects of Exoskeletons on Error between Marker and Markerless Motion Capture in Children with Crouch Gait: A Pilot Study

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BACKGROUND

- Motion capture for gait analysis vital to study movement, inform clinical decisions, and assess established and emerging interventions [1]
- Marker-based motion capture gold standard for kinematic and spatiotemporal assessment, but markerless techniques offer advantages (Table 1)
- Evidence to support use of markerless motion capture in clinical populations using assistive devices remains scarce
- ***The goal of this study was to compare accuracy of marker and markerless motion capture for gait analysis of overground walking with an exoskeleton***

Table I: Comparison of Motion Capture Techniques

	Marker-Based Motion Capture (M^+)	Markerless Motion Capture (M^-)
How is it done?	Fit skeletal model to 3D position of markers on body  Vicon qualisys.com	Fit skeletal model with machine learning (trained with labeled poses) from video 
Why use it?	• High accuracy • Gold standard	• Faster setup and data collection • Easier processing • No issues with marker loss / shifts
Issues	• Long setup • Markers must be in view and stable • Challenging in children • Must reconfigure markers for use with wearable devices	• Limited validation in clinical populations [2] • ***Effect of wearable devices on accuracy unclear***

METHODS

- 2 participants (Table II)
- Steady overground walking with (Exo) and without (NoExo) exoskeleton (Fig. 1)
- Simultaneous marker (M+, Vicon) and markerless (M-, Theia3D) motion capture
- M+ and M- data processed in Visual3D (C-Motion) to compute 3D joint kinematics and gait speed
- Primary outcome measure:

Mean Absolute Difference (MAD) = $|Outcome_{M+} - Outcome_{M-}|$

Table II: Participant Demographics

	Sex	Diagnosis	Age (yo)	Height (cm)	Mass (kg)	Mobility Aid
P1	F	Cerebral palsy	6	110	18	Walker
P2	M	Spina bifida	11	146	39	Crutches

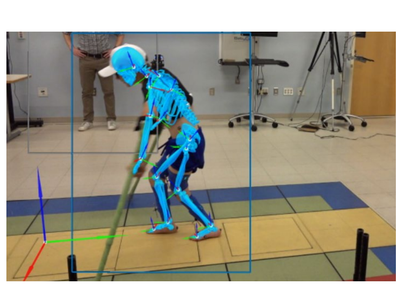
Table III: Strides Analyzed

	NoExo		Exo		
	BF	AFO	Zero	Assist	Inter-leaved
P1	54	23	8	0	26
P2	16	23	0	14	14





Figure 1: NIH-Agilik® exoskeleton (left), including knee actuator, passive articulated ankle, and battery pack (top) worn during testing.



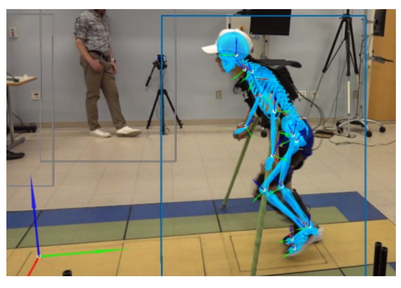


Figure 2: Video and model overlay from M- for NoExo (top) and Exo (bottom) conditions.

MAIN FINDINGS

- ***Caution is warranted for using markerless motion capture of children in crouch with wearable devices***
- Large kinematic error (1.6-17°) and underestimation of crouch (>5°) were observed
- Machine learning for markerless motion capture should include data from clinical populations with devices

RESULTS

- MAD increased from NoExo to Exo condition (0.7-8°, Fig. 3) except for sagittal (P1) and frontal (P2) hip angles
- MAD variable across conditions and joint angles (1.6-17°, Fig. 3)
- MAD similar or higher than prior studies of crouch [4], possibly due to use of mobility aids
- M- underestimated crouch (relative to M+) for θ_{init}, θ_{PKE}, & θ_{PKF} (Fig. 4)
- Very small MAD between M+ and M- for gait speed (Fig. 5)
  - Data from entire pass, exoskeleton did not span pelvis

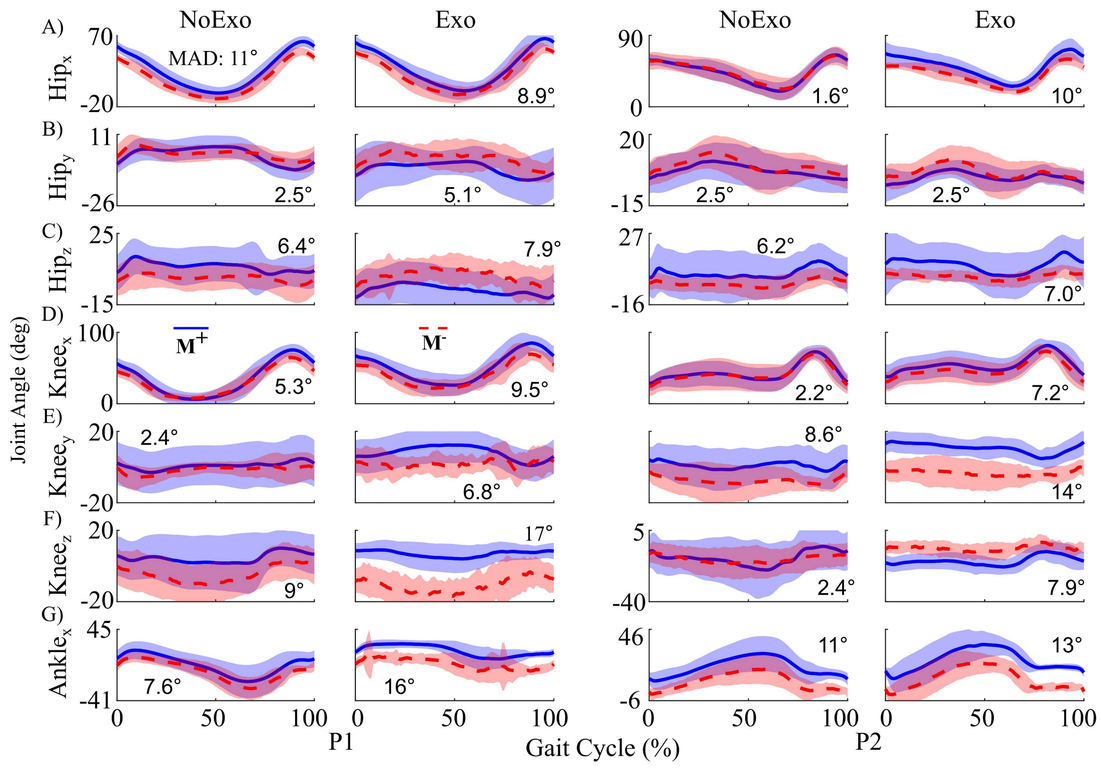


Figure 3: Mean ± 1 std dev for sagittal (X), frontal (Y), and transverse (Z) hip, knee, and ankle joint angles (degrees) computed from M+ (blue) and M- (red), with mean MAD across the gait cycle indicated in each panel.

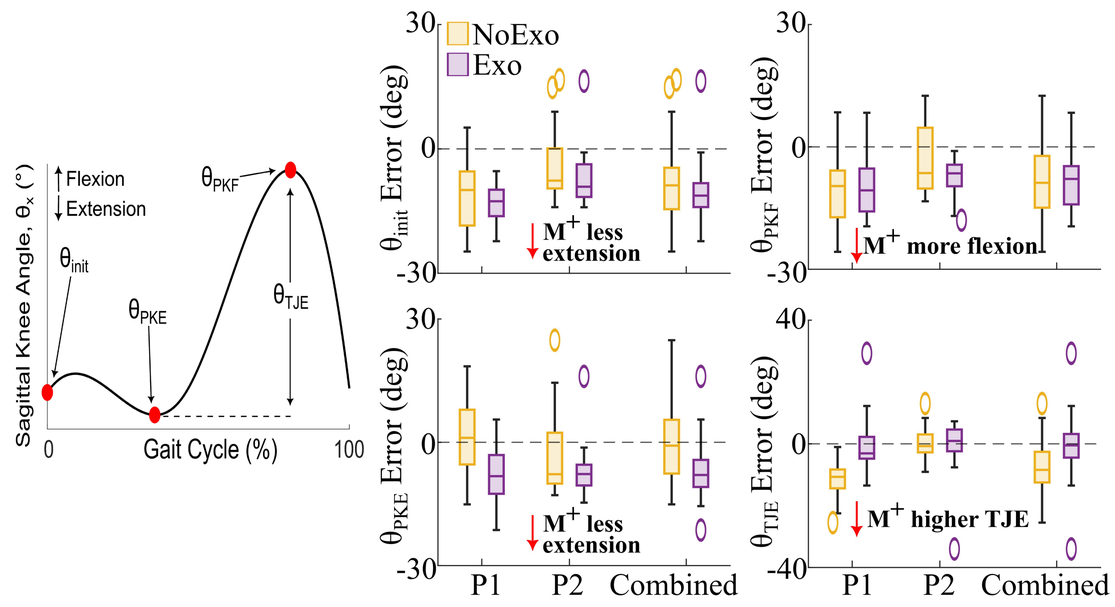


Figure 4: Left) Knee kinematic results matching outcomes of ongoing clinical trial with exoskeleton gait training [3]. Right) Raw errors between M+ and M- for each outcome across P1 and P2.

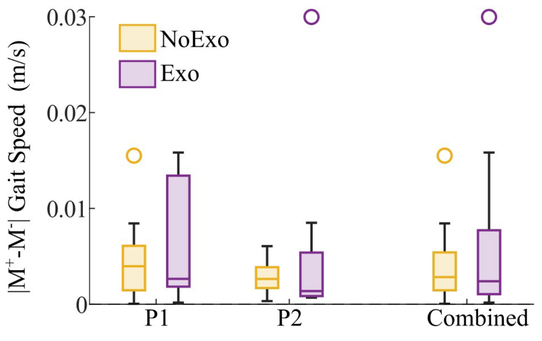


Figure 5: Small differences in gait speed were observed between M+ and M-, with minimal effect from the exoskeleton (p = 0.74).

Acknowledgments

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References

[1] T. A. Wren et al., *Gait & Posture,* 2020. **[2]** M. Pardell et al., *Biomechanics*, 2024. **[3]** T. M. Devine et al., *PLOS One*, 2024. **[4]** K. Wishaupt et al., *Scientific Reports*, 2024.