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Human Movement Analysis « for the masses » with AI-driven computer vision

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DEPARTMENT OF
PRECISION HEALTH
DOPH

Frederic GARCIA, PhD
Technology and Data Expert, HOSD
Luxembourg Institute of Health
frederic.garcia@lih.lu

Why Human Movement Analysis?

Clinical

- Surgical decision-making
- Identify risk factors
- Optimize rehabilitation

Sports

- Improve Performance
- Prevent injury risk
- Analyze sport equipment

Video Animation

- Realistic animations
- Facial movements
- Production time

References: 1. KU Leuven Clinical Motion Analysis Laboratory, 2. Noraxon USA, 3. Mou, Keyframe or motion capture? Reflections on education of character animation, EURASIA J Math Sci Tech Ed, 2018, Volume 14, Issue 12

How Human Movement Analysis?

Kinematics

- Optical MoCap
- IMU

Joint Angles or Temporospatial parameters

Kinetics

- Force Plates

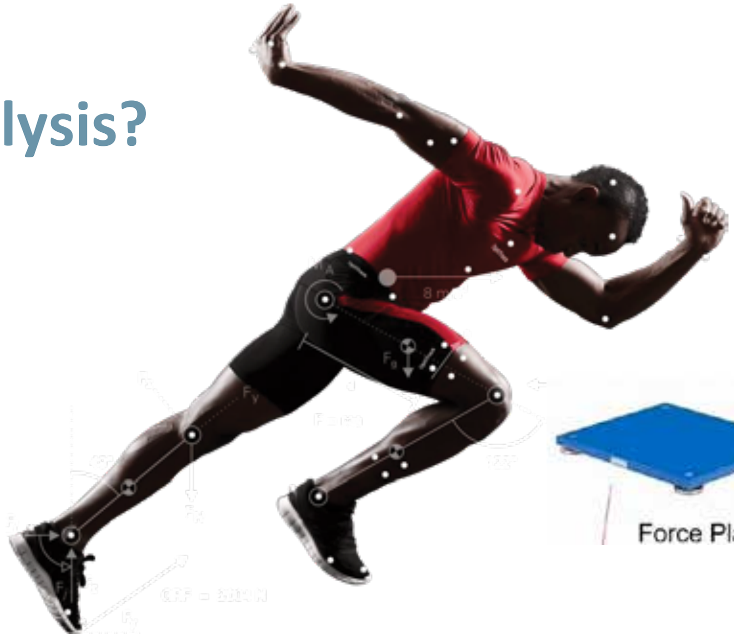
Ground Reaction Force
Center of Pressure

Muscle Activity

- EMG

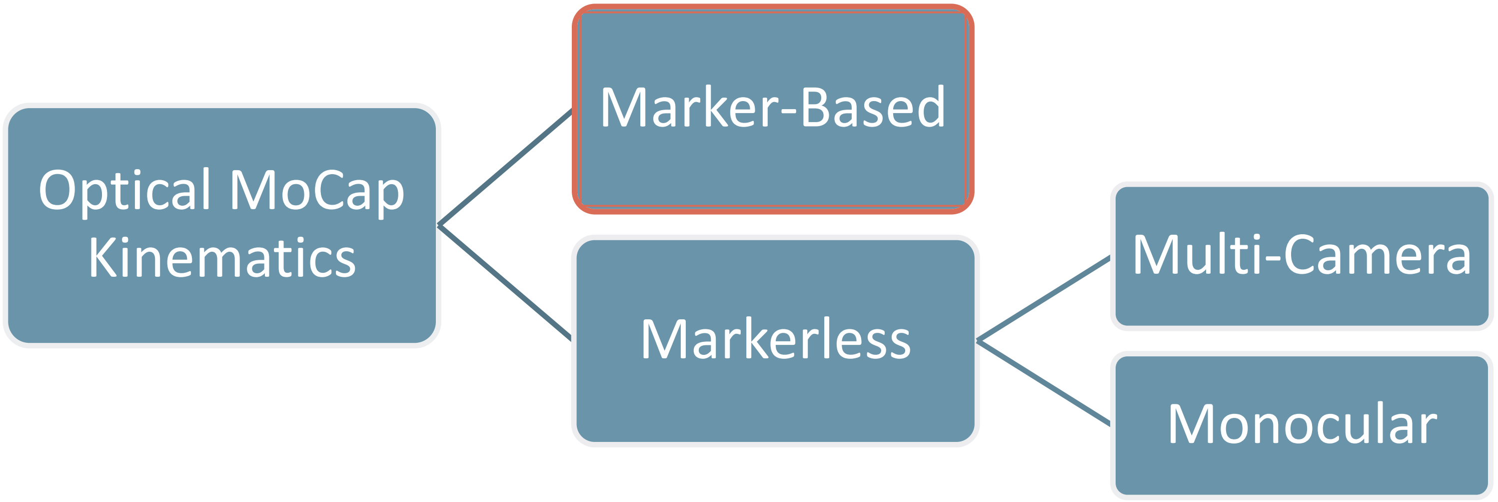
Inverse Dynamics

- MSK Modelling / Digital Twins



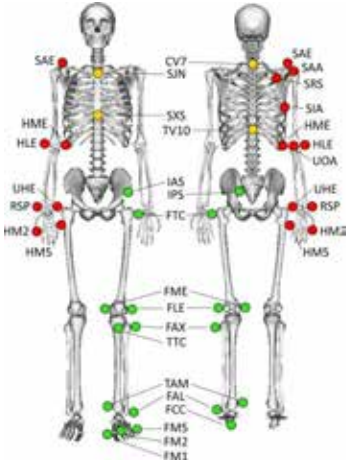
References: 1. OptiTrack Motion Capture Systems, NaturalPoint Inc, 2, 3. Noraxon USA, 4. OpenSIm, SimTK

Optical MoCap System for Kinematics



Optical Marker-Based MoCap

- Equipment :
  - Dedicated Lab
  - Non off the shelf Cameras
  - Reflective Markers
  - Expert Personnel
- Pros & Cons:
  - \+ Gold Standard
  - \+ Accurate/Precise
  - \+ Adaptable Marker Models
  - \+ Reference Data
  - – Lab-bound
  - – Expensive
  - – Setup time
  - – Repeatability
  - – Non suitable for children



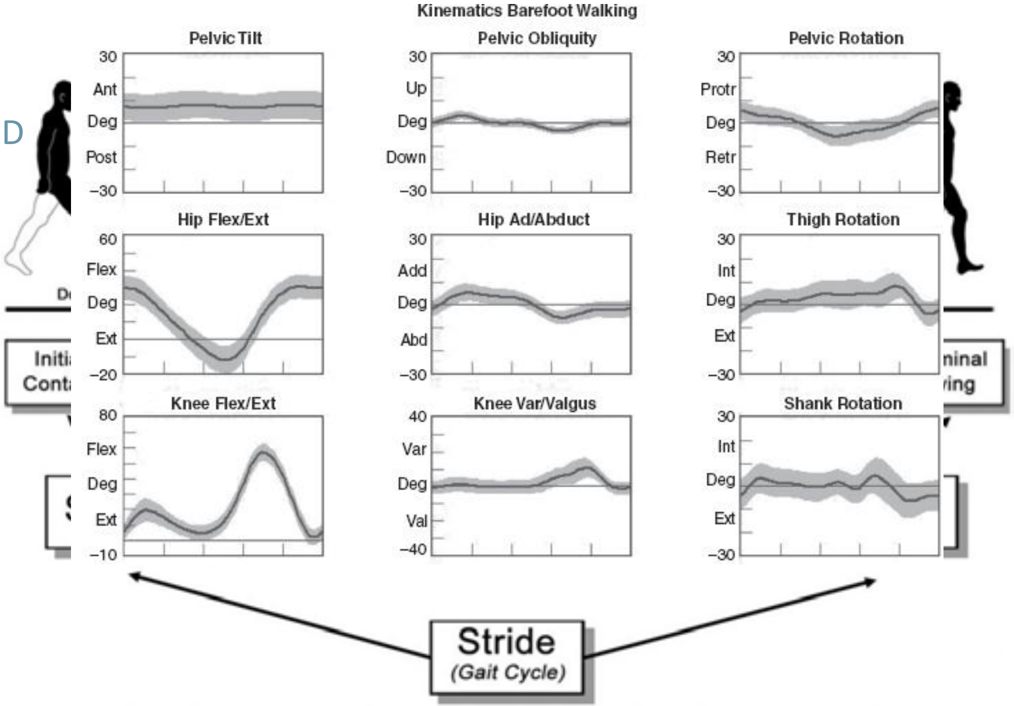
References: 1. Wade et al., Applications and limitations of current markerless motion capture methods for clinical gait biomechanics, *PeerJ* 10:e12995, 2022, 2. VICON, UK

Optical Marker-Based MoCap: Output

Eg. Gait Parameters

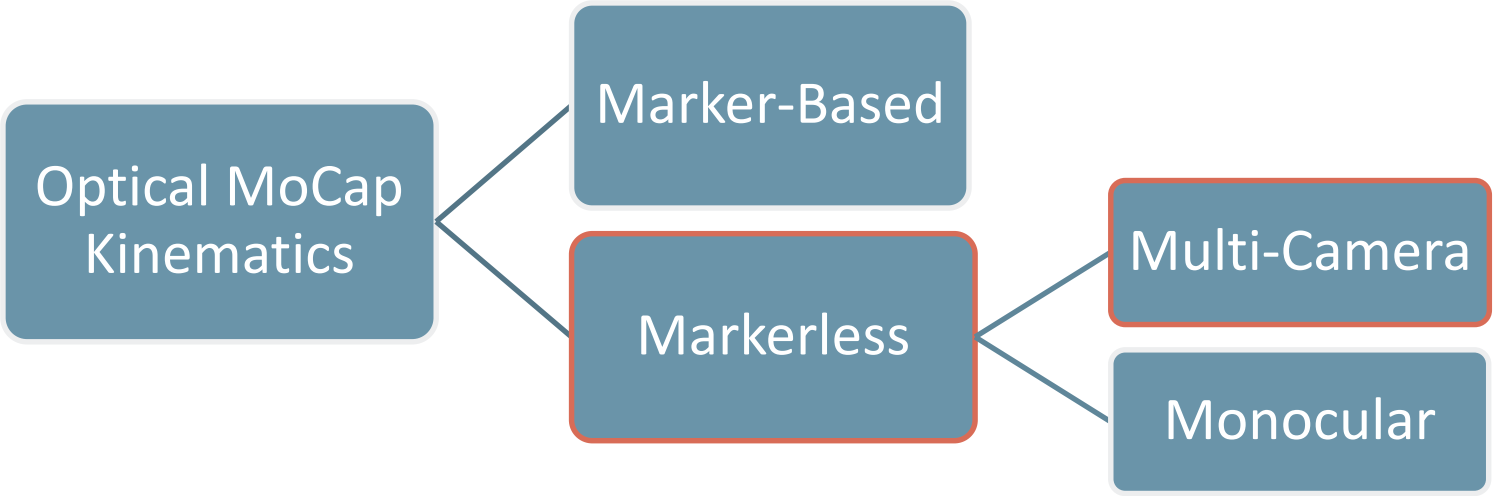
- Walking & Running is a complex 3D movement:
  - Balance
  - Coordination
  - Strength

- Gait Reference data
- Validity in 3 planes of motion



References: 1. Carello & Matthews, *Quantitative assessment of gait: a systematic approach*
Figure*: Stöckel, T. et al. The mental representation of the human gait in young and older adults*

Optical MoCap System for Kinematics



Multi-Camera Markerless MoCap

- Equipment:
  - RGB cameras (at least 6)
  - Dedicated capture zone
  - Deep learning algorithm

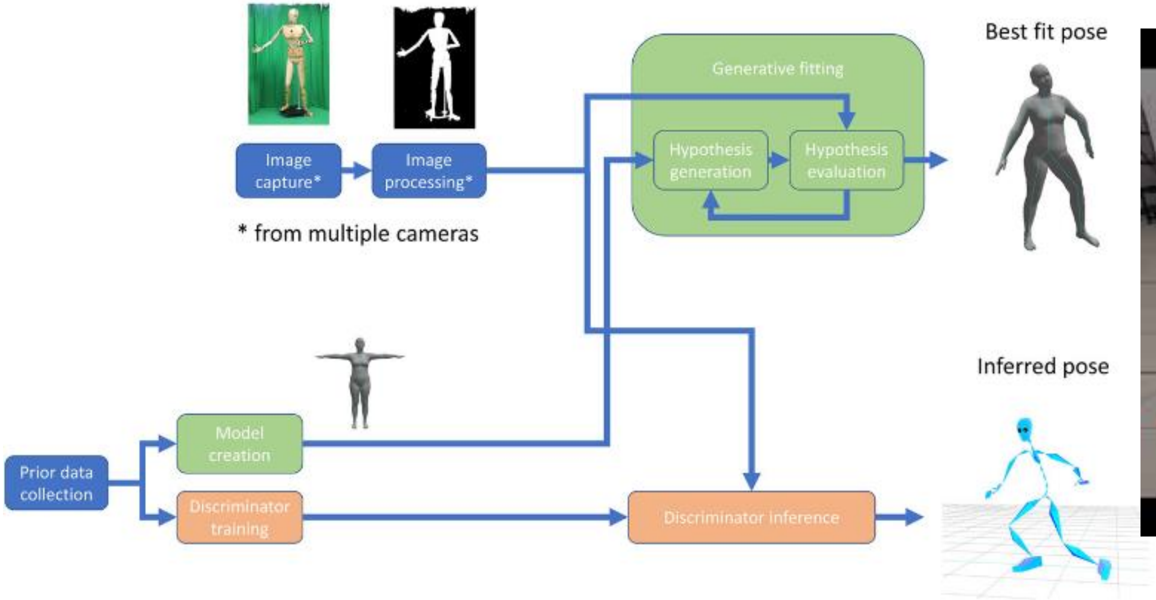
- Pros & Cons:
  + No markers needed – Non-Invasive!
  + More environments & movements
  + Multi-person capture
  + Reprocess old footage

  – “Limited to proprietary software”
  – Processing time
  – Joint centre inaccuracies
  – Validity

THEIA

References: 1. mobilemotioncap.com, 2. THEIA 3D

Multi-Camera Markerless MoCap



Colyer, S.L., Evans, M., Cosker, D.P. et al. A Review of the Evolution of Vision-Based Motion Analysis and the Integration of Advanced Computer Vision Methods Towards Developing a Markerless System. Sports Med - Open ***4****, 24 (2018)*

SportFabrik

The Human Movement Laboratory

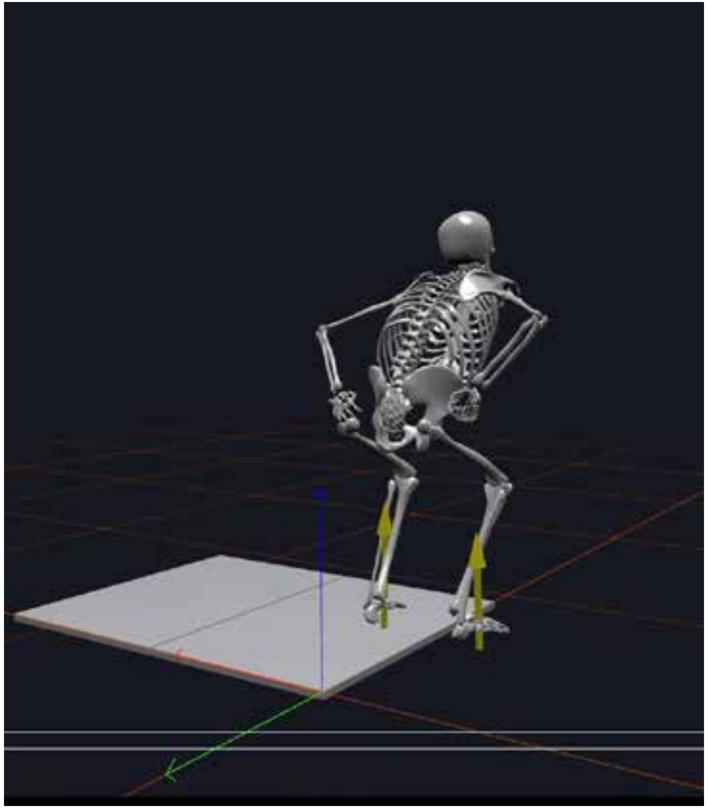
Luxembourg Institute for High Performance in Sports
LIHPS

liroms
LUXEMBOURG INSTITUTE OF RESEARCH IN ORTHOPEDICS, SPORTS MEDICINE AND SCIENCE

LUXEMBOURG INSTITUTE OF HEALTH

SportFabrik

Main Lab Sprint Tunnel



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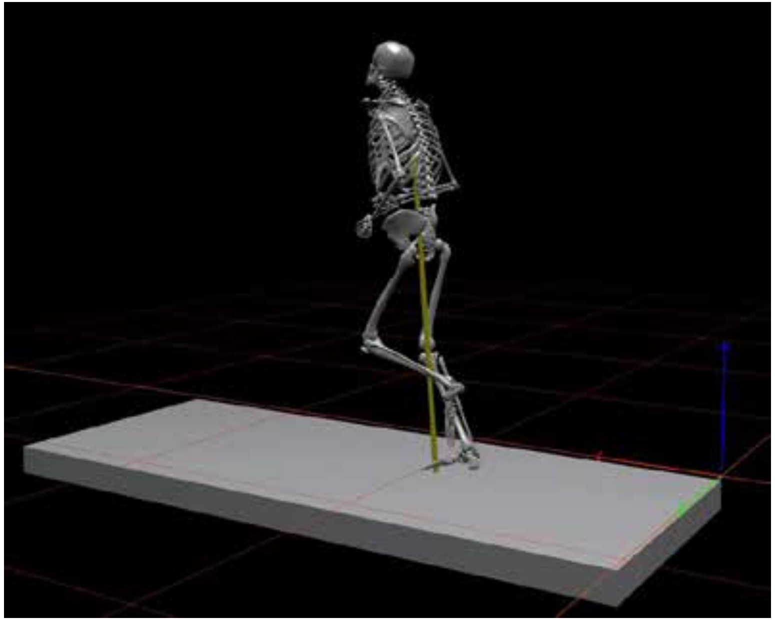
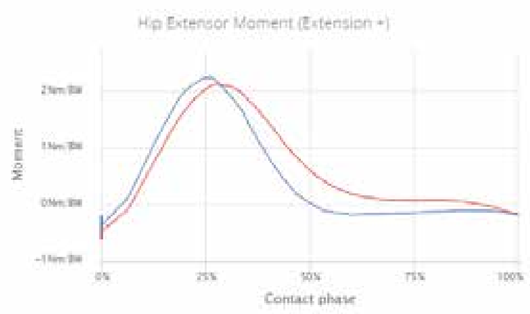


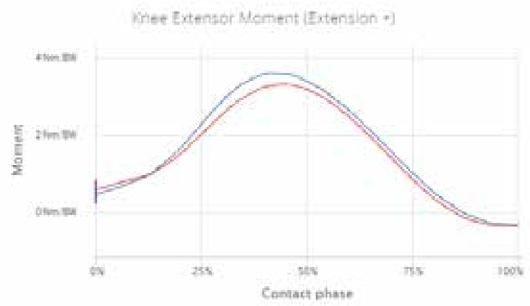
Running Lab

SportFabrik: Automatic Gait Report

HIP



KNEE



10.7 km/h
ACTUAL RUNNING SPEED

161
STEPS/MINUTE

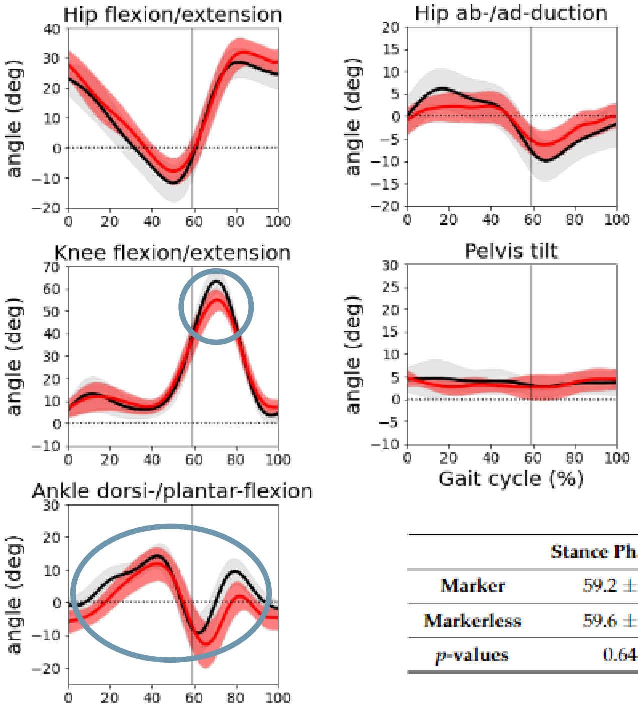
111 cm
STEP LENGTH

222 cm
STRIDE LENGTH

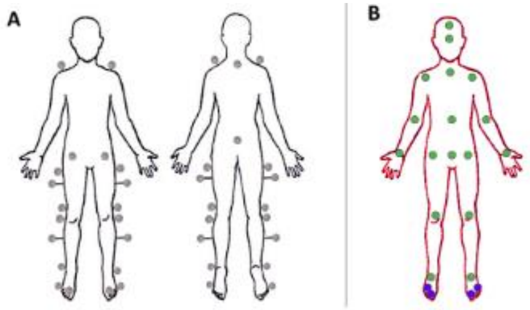
6.4 cm
STRIDE WIDTH

8.7 cm
VERTICAL PELVIS MOVEMENT

Multi-Camera Markerless MoCap: Validity on Gait



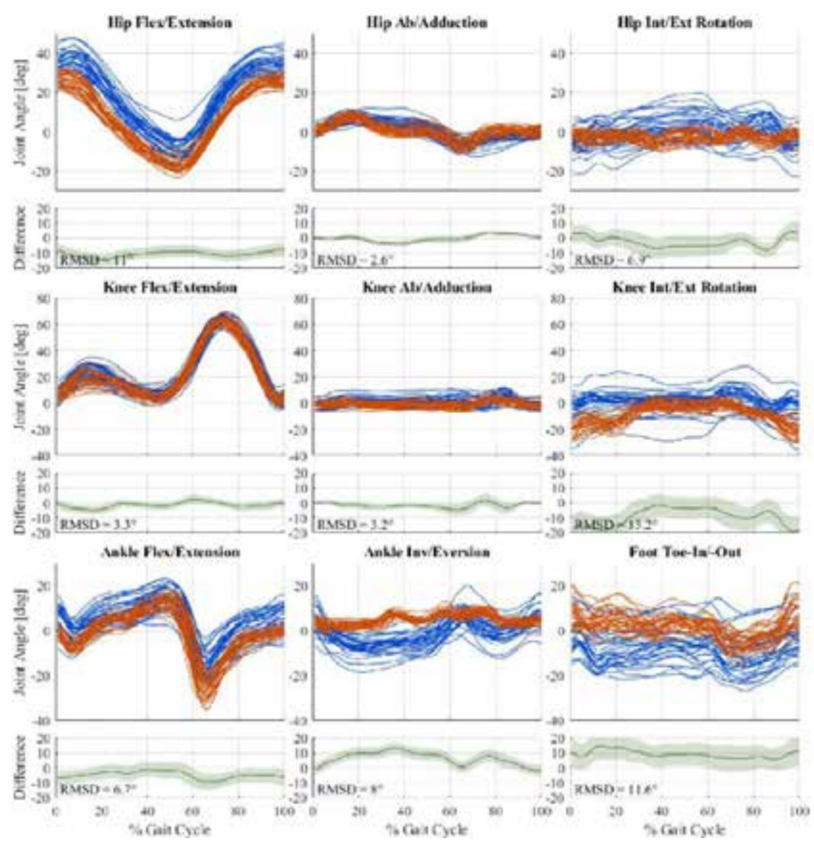
- Marker Based
- Markerless



	Stance Phase (%)	Swing Phase (%)	Stride Length (m)	Step Width (m)	Stride Time (s)	Speed (m/s)
Marker	59.2 ± 2.6	40.8 ± 2.6	1.35 ± 0.11	0.10 ± 0.02	1.13 ± 0.02	1.31 ± 0.10
Markerless	59.6 ± 3.1	40.4 ± 3.1	1.40 ± 0.21	0.12 ± 0.02	1.11 ± 0.04	1.35 ± 0.16
***p*-values**	0.644	0.644	0.474	0.132	0.291	0.341

Moro, M.; Marchesi, G.;Hesse, F.; Odone, F.; Casadio, M.Markerless vs. Marker-Based GaitAnalysis: A Proof of Concept Study. Sensors 2022,22, 201

Multi-Camera Markerless MoCap: Validity on Gait

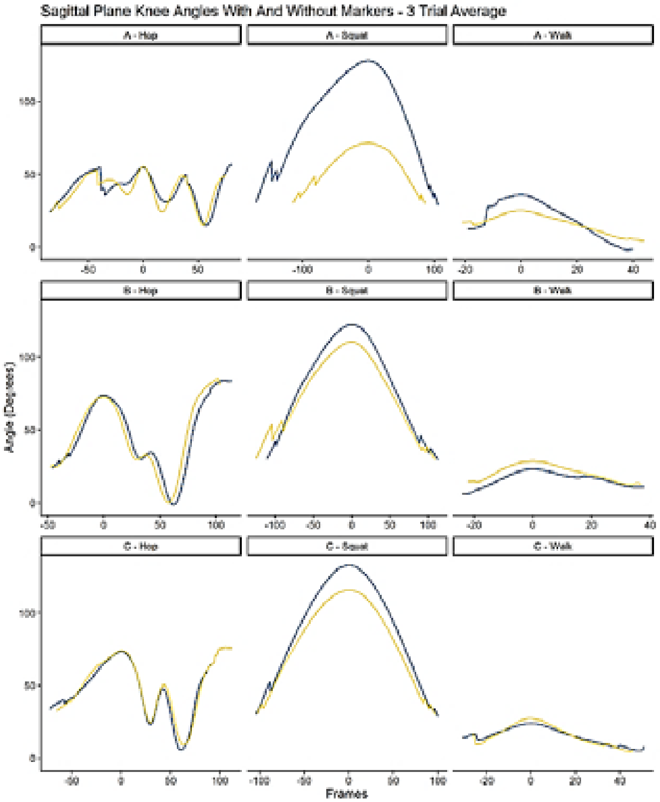


- Marker Based
- Markerless

Kanko et al., Concurrent assessment of gait kinematics using marker-based and markerless motion capture. J Biomech. 2021 Oct 11;127:110665

Multi-Camera Markerless MoCap: Validity

- Hop
- Squat
- Walk



- Marker Based
- Markerless

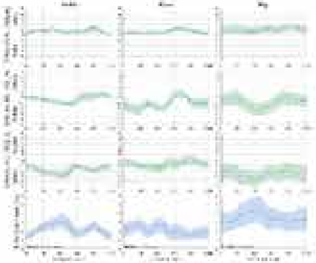
Ito et al., Markerless motion capture: What clinician-scientists need to know right now, JSAMS Plus, Volume 1, 2022, 100001

Markerless motion capture (MMC) for clinical movement analysis and the influence of clothing on gait metrics

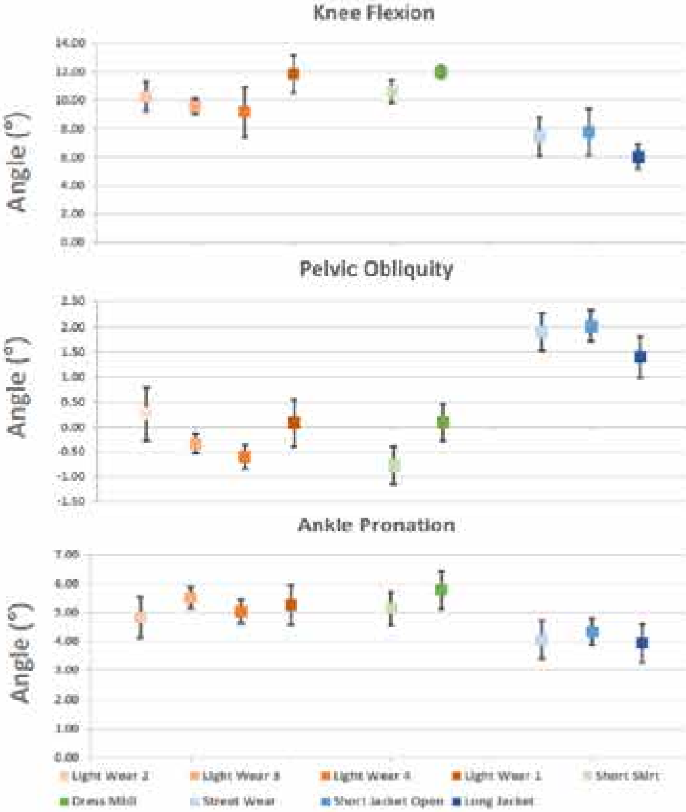
Matthew Flood[1], Paul Gette[1], Jan Cabri[2], Bernd Grimm[1]
1. Human Motion, Orthopaedics, Sports Medicine and Digital Methods, Luxembourg Institute of Health
2. Luxembourg Institute of Research in Orthopaedics, Sports Medicine and Science (LIROMS)

- The comparative performance of MMC and marker-based systems has only been examined for lightly-dressed subjects
- This pilot study investigates how different clothing styles may affect the measurement of typical gait metrics using an MMC system

Source [1]



- This study suggests that typical clothing styles only have a small effect on common gait parameters measured with MMC. Hence, patients may not need to change clothes or be instructed to wear specific garments.
- In addition to avoiding marker placement, this further increases speed, ease and economy of clinical gait analysis with MMC facilitating high volume or routine application.



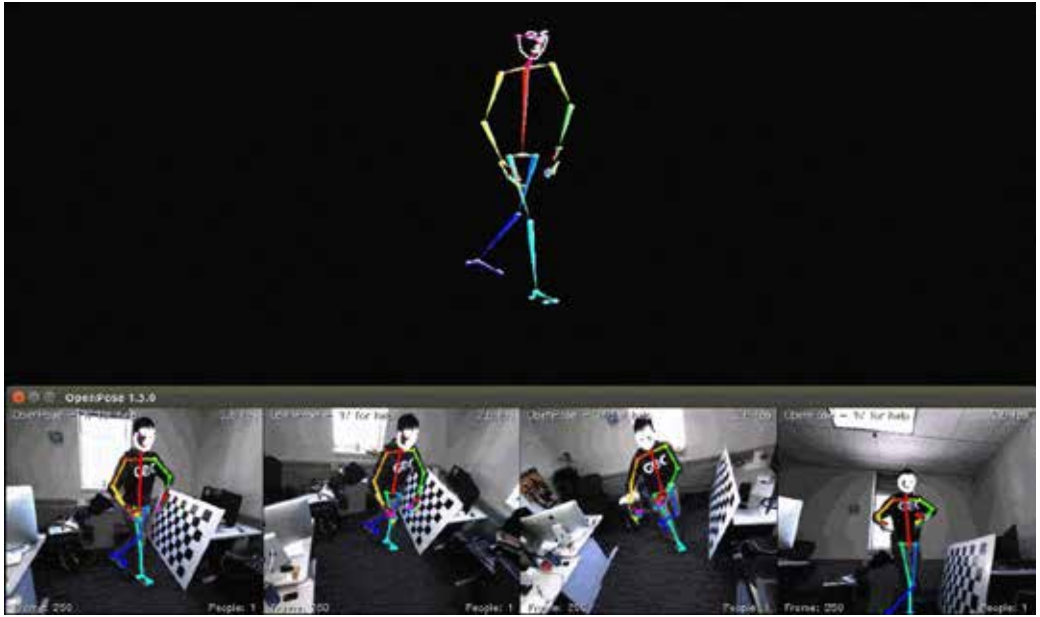
[1] Kanko, R. et al. "Concurrent assessment of gait kinematics using marker-based and markerless motion capture." *J. Biomech.* 127 (2021): 110665.

Multi-Camera Markerless MoCap

Top-8 Pose Estimation Methods

- **OpenPose** – IEEE TPAMI’21, *https://github.com/CMU-Perceptual-Computing-Lab/openpose*
- **OpenCap** – ‘22, *https://www.opencap.ai/*
- High-Resolution Net (**HRNet**) – CVPR’20, *https://github.com/HRNet/HigherHRNet-Human-Pose-Estimation*
- **DensePose** – CVPR’18, *http://densepose.org/*
- Regional Multi-Person Pose Estimation (**AlphaPose**) – ICCV’17, *https://github.com/Fang-Haoshu/RMPE*
- **DeepCut** – CVPR’16, ECCV’16, *https://github.com/eldar/deepcut*
- **Deep Pose** – CVPR’14, *https://github.com/Manchery/DeepPose (not official implementation)*
- **PoseNet** – ICCV’15 *https://github.com/tensorflow/tfjs-models/tree/master/pose-detection*

OpenPose

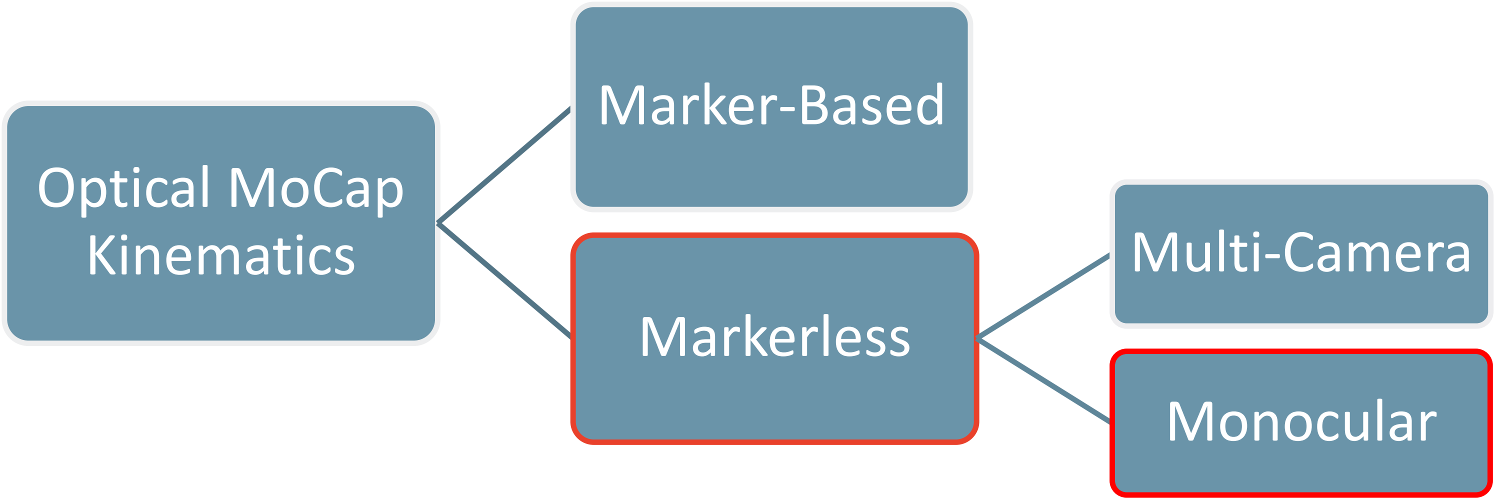


Cao, Z., Hidalgo, G., et al. *OpenPose: Realtime Multi-Person 2D Pose Estimation using Part Affinity Fields*
http://arxiv.org/abs/1812.08008 - https://github.com/CMU-Perceptual-Computing-Lab/openpose

OpenCap

Uhlrich, S.D., Falisse, A., et al. OpenCap: 3D human movement dynamics from smartphone videos
https://www.opencap.ai/

Optical MoCap System for Kinematics

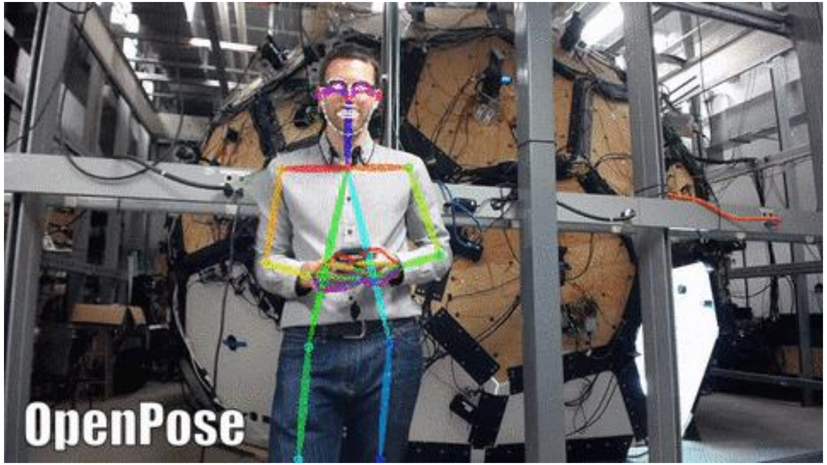


Monocular Markerless MoCap

- Equipment:
  - Consumer camera: smartphone, webcam, IP camera
  - 2D -> 3D neural network
  - Any GPU can be used (even CPU)

- Pros & Cons:
  - \+ Single Camera
  - \+ Open Source software available
  - \+ Cost & Space Efficient
  - \+ Multi-person Capture
  - \+ Fast Processing

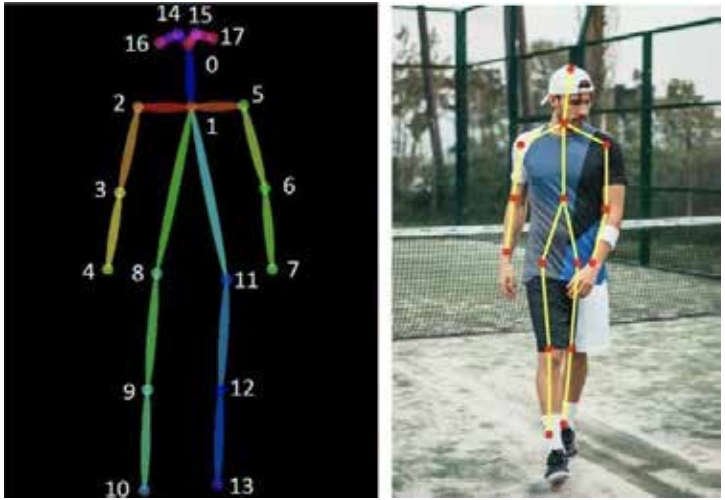
  - – “Affected by Occlusion”
  - – Accuracy/Validity
  - – Clinical Use



References: 1. viso.ai

Monocular Markerless MoCap

OpenPose



Cao, Zhe, Hidalgo, Gines. et al. *OpenPose: Realtime Multi-Person 2D Pose Estimation using Part Affinity Fields*
http://arxiv.org/abs/1812.08008 - https://github.com/CMU-Perceptual-Computing-Lab/openpose

Monocular Markerless MoCap

OpenPose: Validity

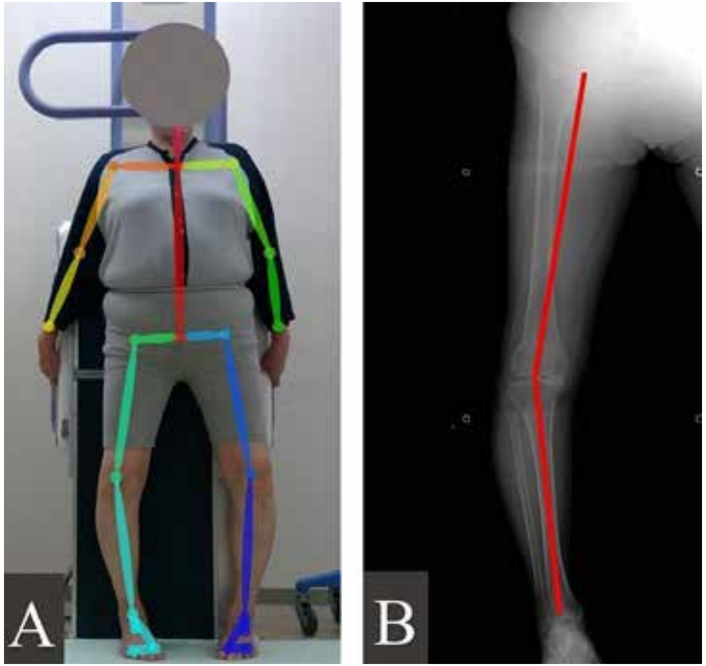
- Excellent test–retest reliability (ICC (1, 1) = 1.000)
- Excellent agreement with radiography

(ICC (2, 1) = 0.915) for HKA angle measurement

Measurement	Hip-knee-ankle angle (°)	ICCs (1, 1)	95% CI for ICCs
OpenPose	−1.59 ± 5.67	1.000	1.000–1.000
Radiography	−2.67 ± 5.90	0.996	0.994–0.998

Test-retest reliability for OpenPose and radiography.

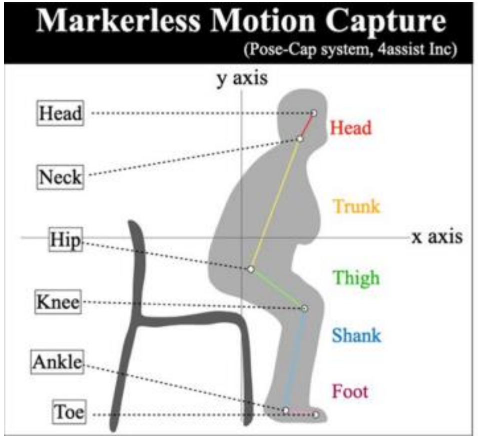
Saiki, Y. et al., Reliability and validity of OpenPose for measuring hip-knee-ankle angle in patients with knee osteoarthritis. Scientific Reports, Feb, 2023

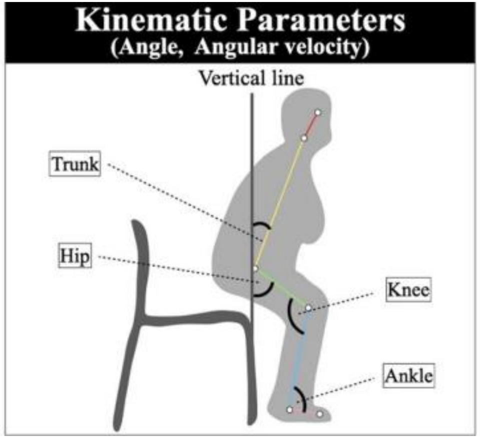


Images for hip-knee-ankle angle measurement. (**A**) OpenPose image. (**B**) Radiographic image.

Monocular Markerless MoCap

PoseCap: Validity

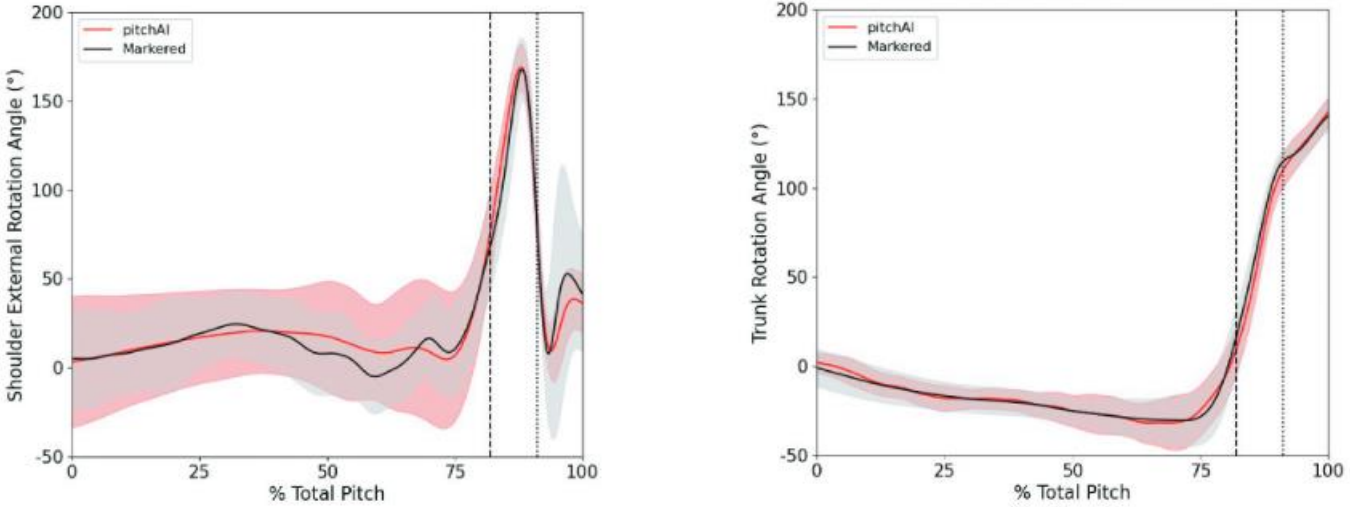




Onitsuka et al., Clinical utility of markerless motion capture for kinematic evaluation of sit-to-stand during 30 s-CST at one year post total knee arthroplasty: a retrospective study. BMC Musculoskelet Disord. 2023 Apr 1;24(1):254

Monocular Markerless MoCap

PitchAI: Validity

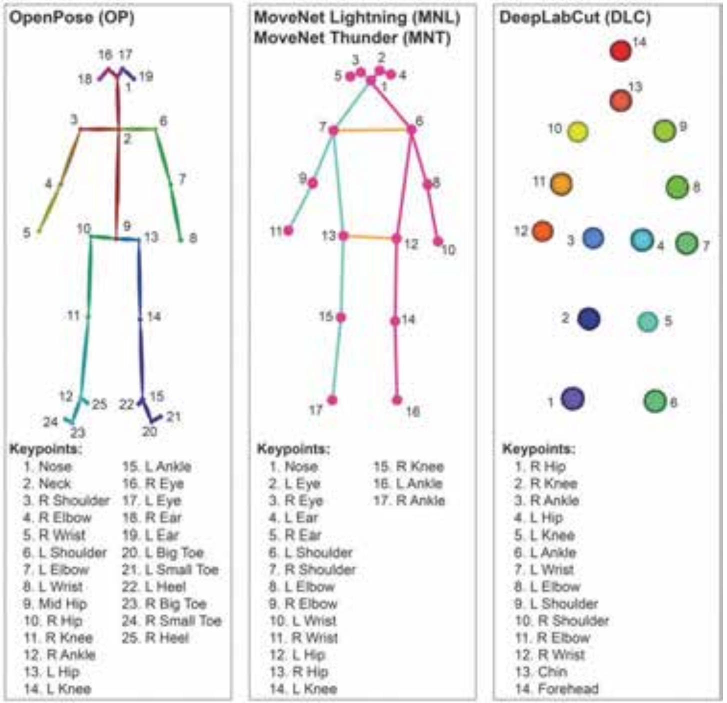


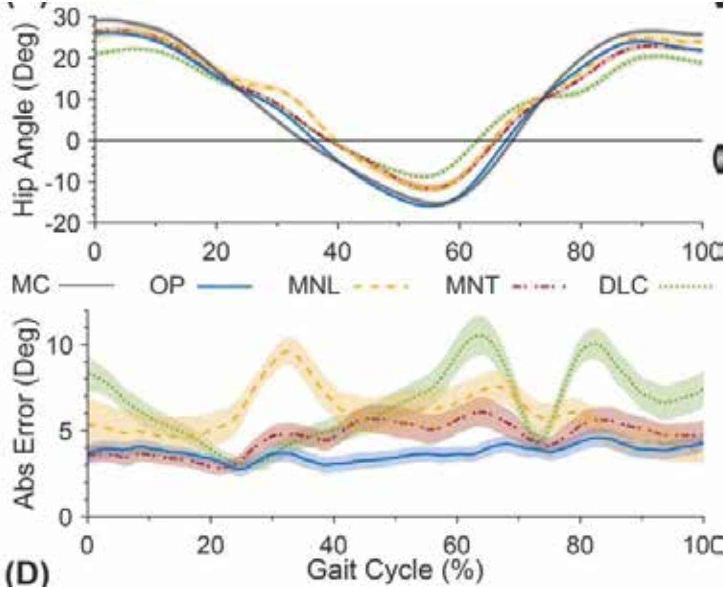
- PitchAI
- Marker Based

Dobos et al., Validation of PitchAI markerless motion capture using marker-based 3D motion capture, Sports Biomechanics, 2022, 1-21

Monocular Markerless MoCap

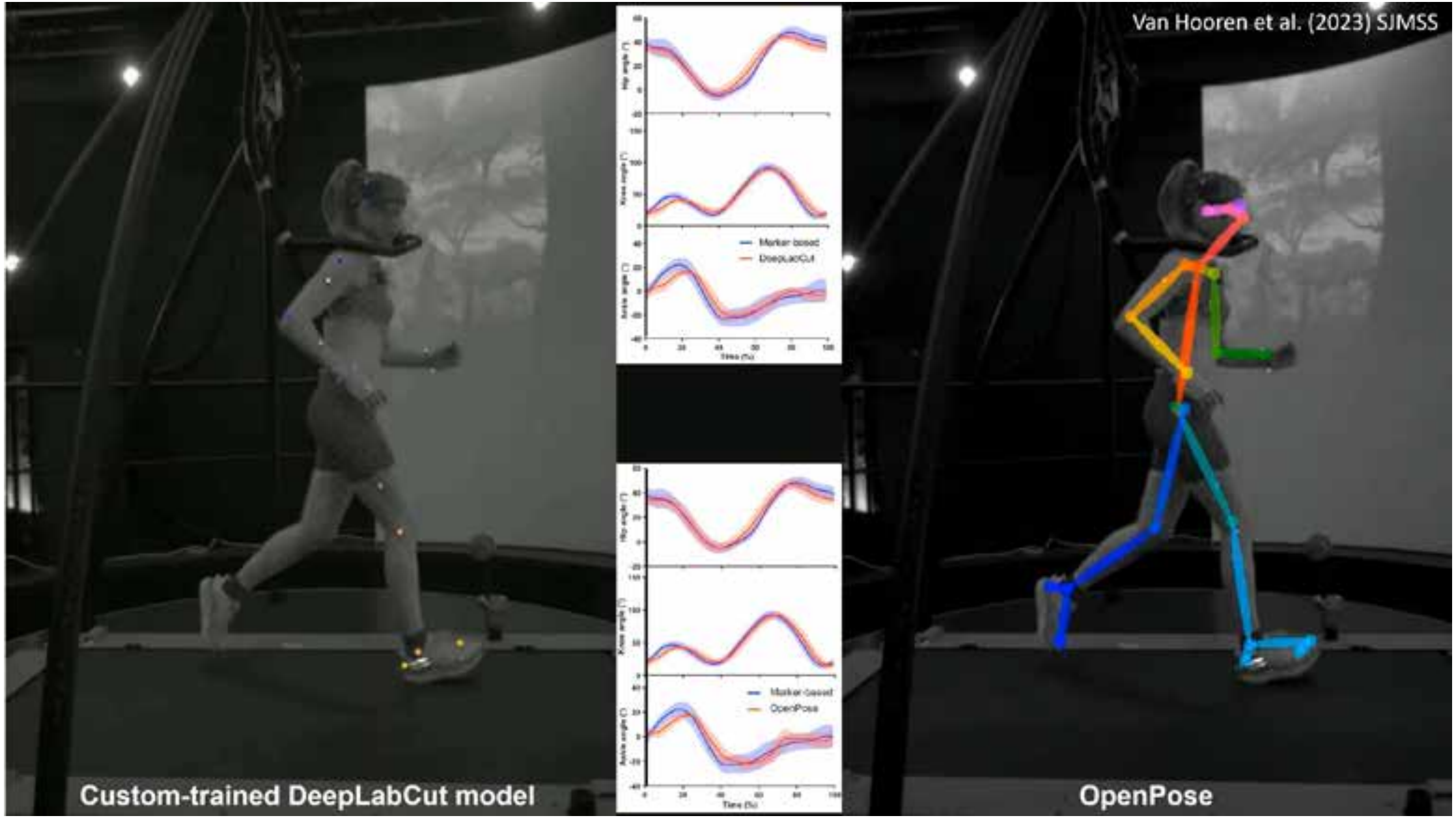
Assessment between OpenPose, MoveNet and DeepLabCut





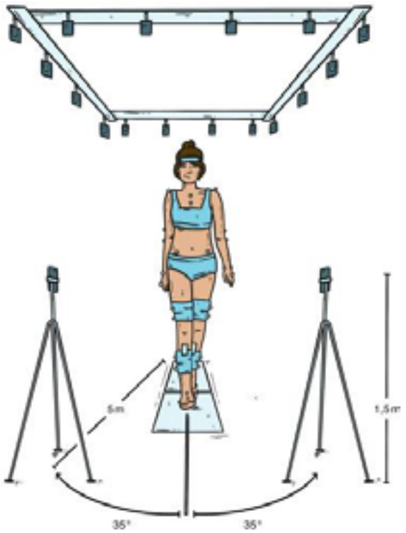
Washabaugh et al., Comparing the accuracy of open source pose estimation methods for measuring gait kinematics, Gait & Posture, Volume 97, Sept 2022, 188-95

Monocular Markerless MoCap

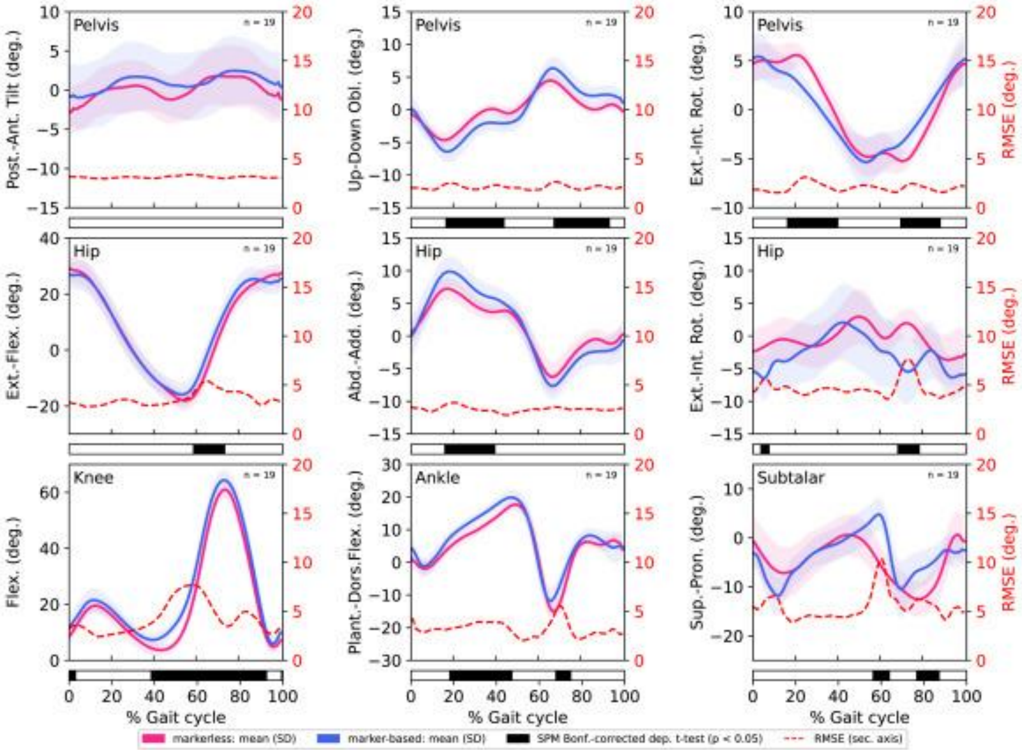


Van Hooren et al., The accuracy of Markerless motion capture combined with computer vision techniques for measuring running kinmeatics, Scand J Med Sci Sports, 2023; 33;966-978

Monocular Markerless MoCap
OpenCap



Horsak et al., Concurrent validity of smart-phone based markerless motion capturing to quantify lower-limb joint kinematics in healthy and pathological gait, Journal of Biomechanics, 159, 2023, 111801



“Near” Future of Clinical Motion Capture

Marker-Based

Markerless Multi-Camera

Markerless Monocular

References: 1. KU Leuven Clinical Motion Analysis Laboratory 2, THEIA 3D 3. Wade et al., Applications and limitations of current markerless motion capture methods for clinical gait biomechanics, *PeerJ* 10:e12995, 2022

THANK YOU

Frederic GARCIA, PhD
Technology and Data Expert, HOSD
Luxembourg Institute of Health
frederic.garcia@lih.lu

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