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Adult/Child Musculoskeletal Model and Motion Analysis Comparison

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Final Project in *Medical Robotics*

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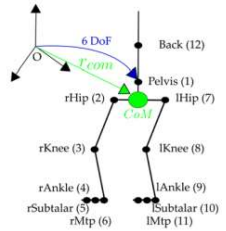
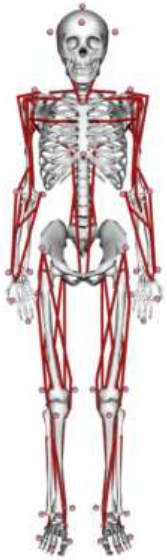
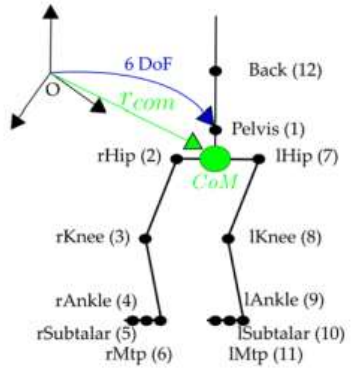
Project Goal and Overview

- Given: **Kinematic marker data** from **MOCAP system**
  - **Child (= Sirine) recording**
    - Various gait captures from Sirine
    - Marker data, inverse kinematics
    - Scaled **OpenSim model**
  - **Adult recording**
    - Kinematic data via joint frame trajectories and rotation matrices
- Goal: **Model and motion analysis comparison**
  - Provide utilities (software) and videos to visualize human motion
  - Gait properties change with age
  - **Tracking tools for evolution of marker trajectories and joint angles**



How to scale from child to adult?





Data Basis

Adult/Child Musculoskeletal Model and Motion Analysis Comparison

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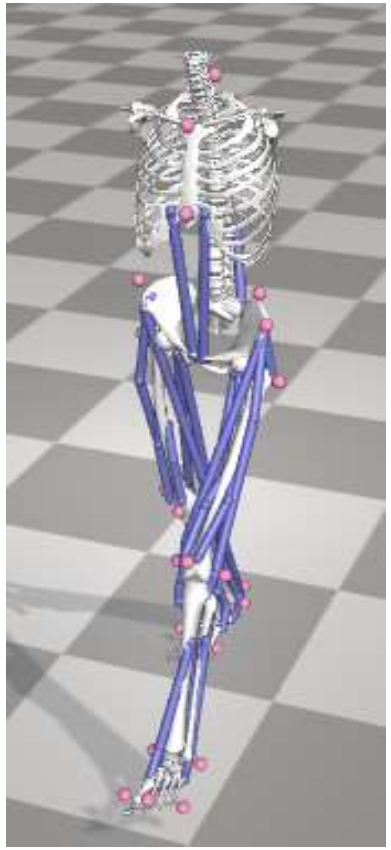
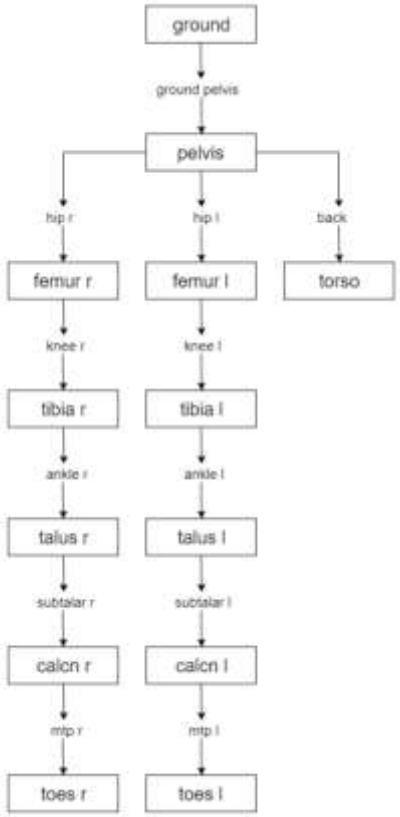
Data Basis – Sirine

- 7 years old, 1.20m height, 20kg weight
- OpenSim model
  - Defined **bodies and joints**, all scaled to one (basis model)
- Marker data in marcheN files (other files available)
  - x-y-z coordinates for **56 markers** from MOCAP system, focus on **torso and lower body** for further investigation (simplified model with 30 markers)
  - 200Hz sampling rate, in meters, recorded in **camera frame**
- Joint angles in marcheNik files (inverse kinematics)
  - Labeled in **biomedical terminology** (e.g hip flexion/ extension, adduction/abduction, external/internal rotation)





Data Basis – Sirine

- **Body marker setup** for Sirine

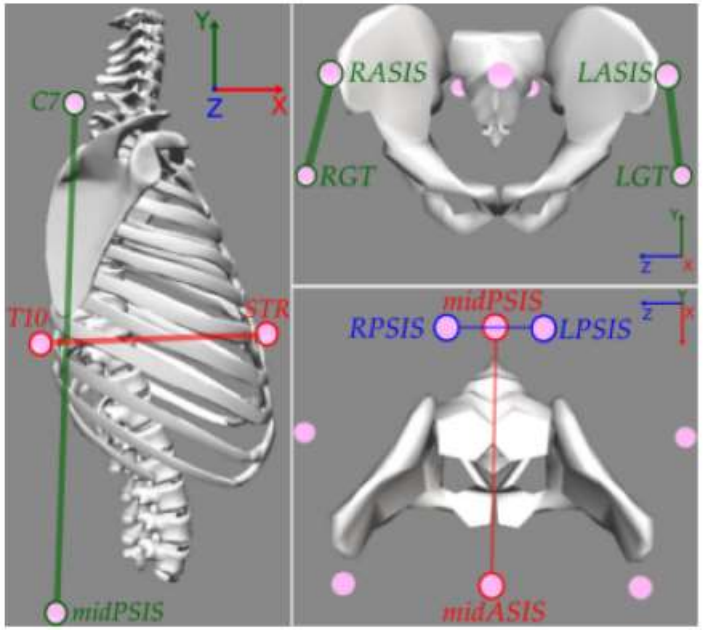
Segm	Markers
Torso	C7 T10 SUP STRN
Pelvis	LASIS/RASIS LPSIS/RPSIS
L leg	LGT LATT LMFE LLFE RAJC
R leg	RGT RATT RMFE RLFE CD
L foot	LSPH LLM LCAL LMFH5/1 LTT2
R foot	RSPH RLM RCAL RMFH5/1 RTT2

PathFileType 4 (X/Y/Z) marche3.trc

DataRate	CameraRate	NumFrames	NumMarkers	Units	OrigDataRate	OrigDataStartFrame	OrigNumFrames
200	200	500	56	m	200	1	500

Frame# Time

LTEMP		SEL		RTEMP		LA		C7		SUP		RA		STR		T10	
Frame#	Time	X1		Y1		Z1		X2		Y2		Z2		X3		Y3	
1	0.0050	-1.066544		1.130600		-0.421391		-0.971893		1.166676		-0.327726		-1.085669		1.119389	
2	0.0100	-1.060079		1.130785		-0.422000		-0.965609		1.167461		-0.328278		-1.079431		1.120116	
3	0.0150	-1.053580		1.130961		-0.422610		-0.959297		1.168248		-0.328832		-1.073161		1.120843	
4	0.0200	-1.047074		1.131134		-0.423216		-0.952982		1.169031		-0.329384		-1.066888		1.121562	
5	0.0250	-1.040579		1.131303		-0.423815		-0.946685		1.169804		-0.329930		-1.060630		1.122271	
6	0.0300	-1.034114		1.131468		-0.424400		-0.940422		1.170563		-0.330466		-1.054404		1.122966	
7	0.0350	-1.027689		1.131628		-0.424970		-0.934203		1.171304		-0.330989		-1.048222		1.123645	
8	0.0400	-1.021311		1.131785		-0.425521		-0.928037		1.172025		-0.331495		-1.042090		1.124306	
9	0.0450	-1.014985		1.131938		-0.426050		-0.921925		1.172724		-0.331982		-1.036012		1.124948	
10	0.0500	-1.008710		1.132090		-0.426554		-0.915867		1.173400		-0.332448		-1.029988		1.125573	
11	0.0550	-1.002484		1.132241		-0.427032		-0.909859		1.174053		-0.332891		-1.024013		1.126180	
12	0.0600	-0.996302		1.132394		-0.427482		-0.903895		1.174684		-0.333310		-1.018084		1.126773	
13	0.0650	-0.990159		1.132551		-0.427902		-0.897967		1.175294		-0.333703		-1.012192		1.127352	
14	0.0700	-0.984049		1.132713		-0.428291		-0.892068		1.175883		-0.334069		-1.006330		1.127921	
15	0.0750	-0.977963		1.132883		-0.428649		-0.886188		1.176453		-0.334407		-1.000491		1.128480	
16	0.0800	-0.971895		1.133062		-0.428976		-0.880319		1.177006		-0.334717		-0.994664		1.129033	
17	0.0850	-0.965839		1.133251		-0.429271		-0.874452		1.177541		-0.334998		-0.988843		1.129580	
18	0.0900	-0.959787		1.133452		-0.429534		-0.868579		1.178060		-0.335250		-0.983020		1.130123	



Data Basis – Adult

- Given data from MOCAP system
  - 71kg weight, 171 cm height
  - **Raw marker data:**
    - x-y-z coordinates for 21 **markers,** recorded in **camera frame,**

      200Hz sampling rate, in millimeters
  - **Kinematic data:**
    - x-y-z coordinates for the origins of each, **joint frame** recorded in **camera frame,** rotation matrices for each joint frame w.r.t parental one, 200Hz sampling rate, in millimeters

Segm	Markers
Torso	C7 T10 CLAV RBAK STRN
Pelvis	LASI/RASI LPSI/RPSI
L leg	LTHI LKNE LTIB LANK
R leg	RTHI RKNE RTIB RANK
L foot	LHEE LTOE
R foot	RHEE RTOE

Raw data
Sampling frequency=200 Hz

c7_x	c7_y	c7_z	t10_x	t10_y	t10_z	clav_x	clav_y	clav_z	strn_x	strn_y	strn_z
283.0	1428.6	1615.0	278.1	1202.3	1710.2	273.1	1330.2	1491.5	271.6	1176.3	1459.0
283.8	1428.9	1610.8	279.2	1202.5	1706.1	273.7	1330.2	1488.1	272.1	1176.6	1455.1
284.4	1429.0	1606.6	280.1	1202.7	1702.1	274.4	1330.1	1484.3	272.7	1176.7	1451.5
285.2	1429.0	1602.5	281.0	1202.9	1698.1	275.0	1330.1	1481.2	273.5	1176.7	1447.3
285.9	1428.9	1598.4	281.8	1202.9	1694.0	275.5	1330.1	1476.5	274.2	1176.5	1443.1
286.7	1428.9	1594.1	282.7	1203.0	1690.0	276.1	1330.0	1470.3	274.6	1176.1	1439.8
287.3	1428.9	1589.9	283.5	1203.1	1685.9	276.5	1329.9	1465.2	275.1	1176.0	1436.0
287.9	1428.7	1585.6	284.3	1203.2	1681.9	276.9	1329.9	1462.1	275.8	1176.2	1431.0
288.5	1428.6	1581.5	285.1	1203.2	1677.8	277.3	1329.6	1459.0	276.2	1176.3	1426.4
289.1	1428.5	1577.2	285.9	1203.2	1673.9	277.7	1329.4	1455.7	276.5	1176.1	1422.4
289.7	1428.4	1573.2	286.5	1203.2	1669.8	278.4	1329.4	1451.1	276.9	1175.9	1418.7
290.1	1428.1	1568.8	287.1	1203.3	1665.8	279.1	1329.4	1446.6	277.5	1175.6	1414.9

Kinematic data
Sampling frequency=200 Hz
Legend:
tk=trunk
pl=Pelvis
rfm=Right femur
lfm=Left femur
rtb=Right tibia
ltb=Left tibia
rft=Right foot
lft=Left foot
or=Origin [mm]
tk_pl_i_j=i-th row and j-th column of rotation matrix wich expresses the base of trunk in the pelvis frame
Data:

tk_or_x	tk_or_y	tk_or_z	pl_or_x	pl_or_y	pl_or_z	rfm_or_x	rfm_or_y	rfm_or_z
272.496620	1333.270162	1484.629341	279.376468	918.116549	1481.775301	361.830924	833.537582	1535.857686
273.042052	1333.454668	1480.761739	280.123572	918.009588	1478.062093	362.274893	833.522251	1532.521385
273.637988	1333.440878	1476.742571	280.723956	917.965779	1474.424185	362.661022	833.459537	1529.098634
274.207950	1333.483554	1472.870715	281.279892	917.964156	1470.701207	363.007200	833.330783	1525.429033
274.811443	1333.393002	1468.577086	281.921779	917.914512	1466.877519	363.240923	833.161808	1521.778539
275.441527	1332.991759	1464.011133	282.604220	917.873584	1463.040126	363.467891	832.988304	1518.202015
275.890211	1332.809225	1459.655885	283.163348	917.847447	1459.270084	363.757670	832.814831	1514.575511
276.336451	1333.007262	1455.623721	283.630026	917.682005	1455.571218	364.146870	832.624246	1510.950344
276.723406	1333.037365	1451.704250	284.046205	917.318759	1451.897156	364.555176	832.327712	1507.425500

Model Implementations in MATLAB

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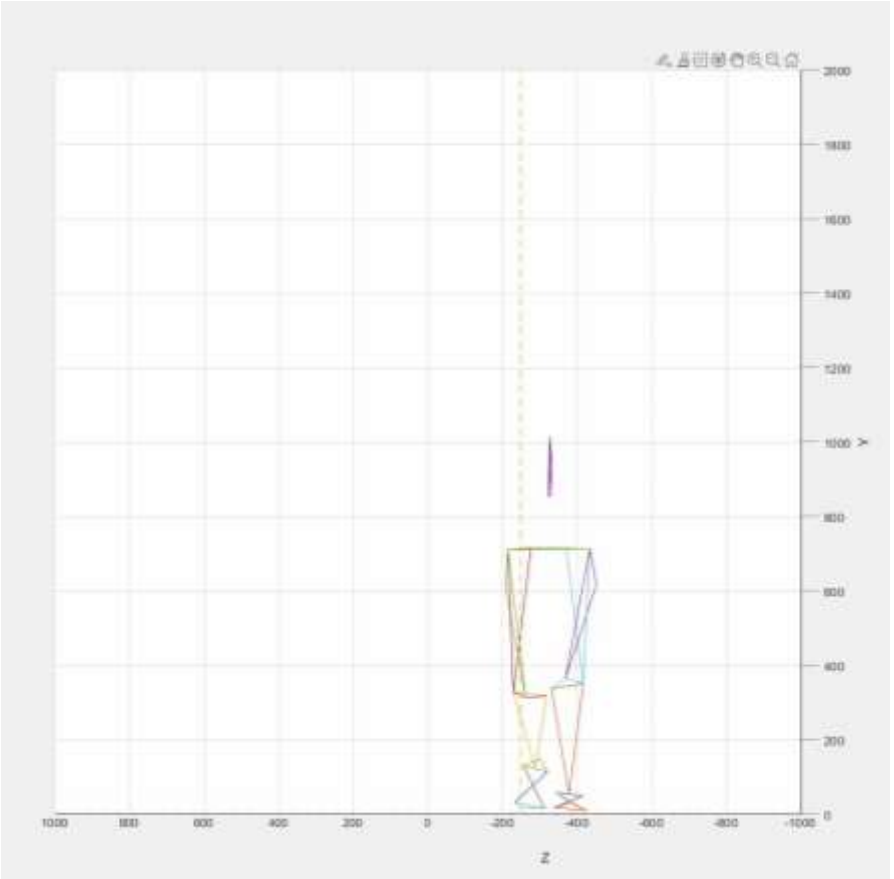
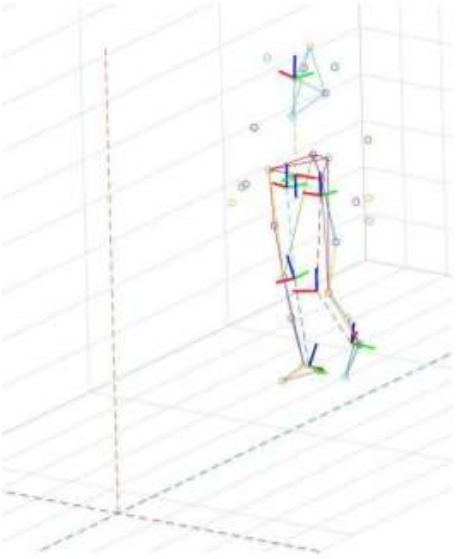
MATLAB Implementation – Model of Sirine

- File **processing** for marche files
  - Redefine tabstops (readable via `fgetl` function)
- Iterate through **timesteps of each marker channel**
- Plotting each **body part**
  - Set of coordinates connected by line segments
    → figure out fitting markers per body part
  - Body parts:
    - **Torso**, **pelvis**, **knees**, **feet (ankle, toe)**
  - Plot markers additionally
- Utility usable via **Sirine_model.m** file



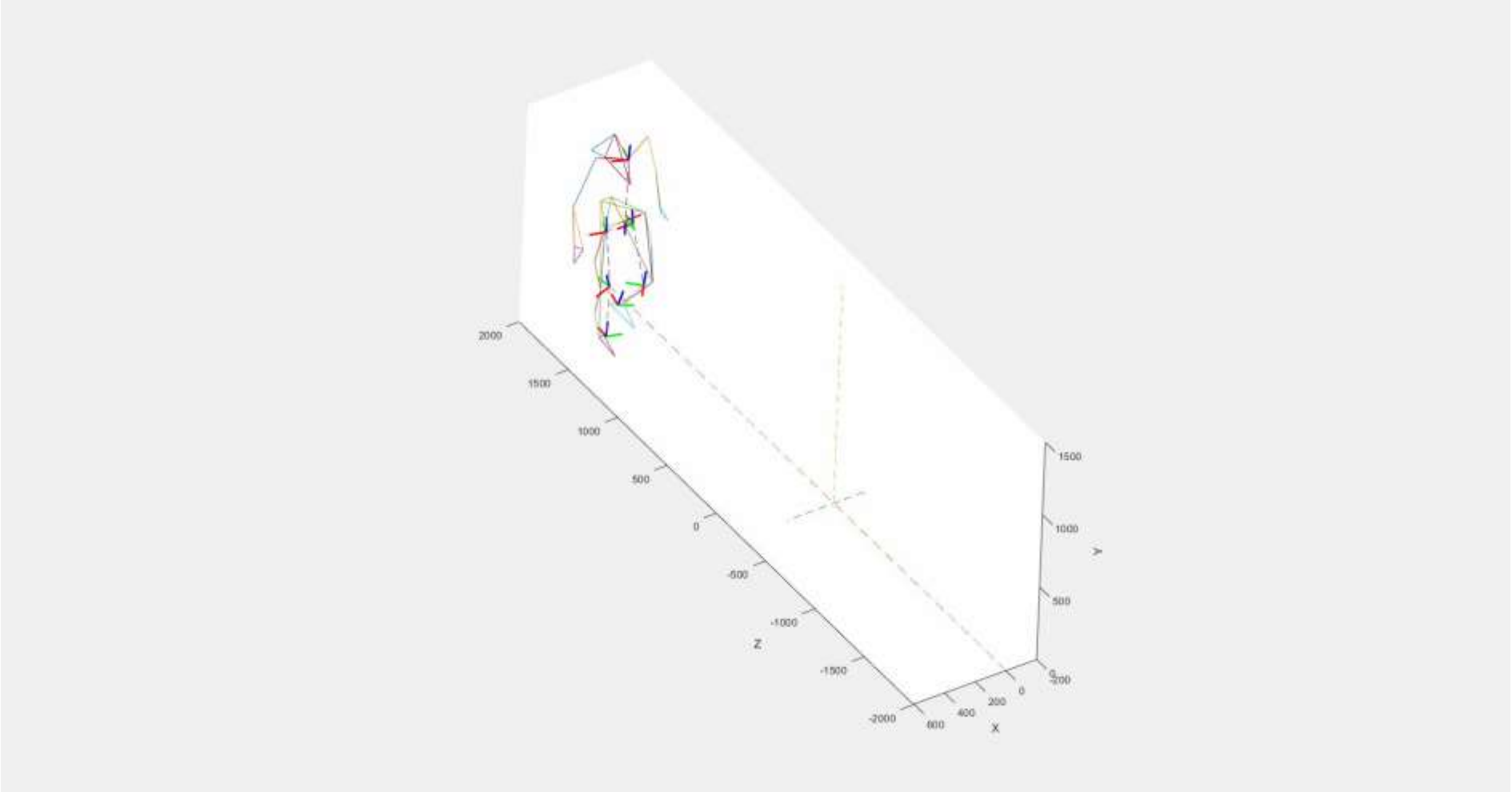
MATLAB Implementation – Adult model

- Using data from two files
  - **Kinematic data** (draw **stickman model** with 6 sticks)
    - x-y-z of body part origins for **trunk**, **pelvis**, **femurs**, **tibiae**, **feet**
    - Rotation matrices for frame orientation calculation
  - **Raw marker data** used in same manner as for Sirine
    - Plot onto stickman model
    - **Different name convention** of marker coordinates
    - Different adopted strategy for linking markers (building body segments)



- Transformed into child ground reference frame, allowing better comparison
- Utility usable via **Adult_model.m** file

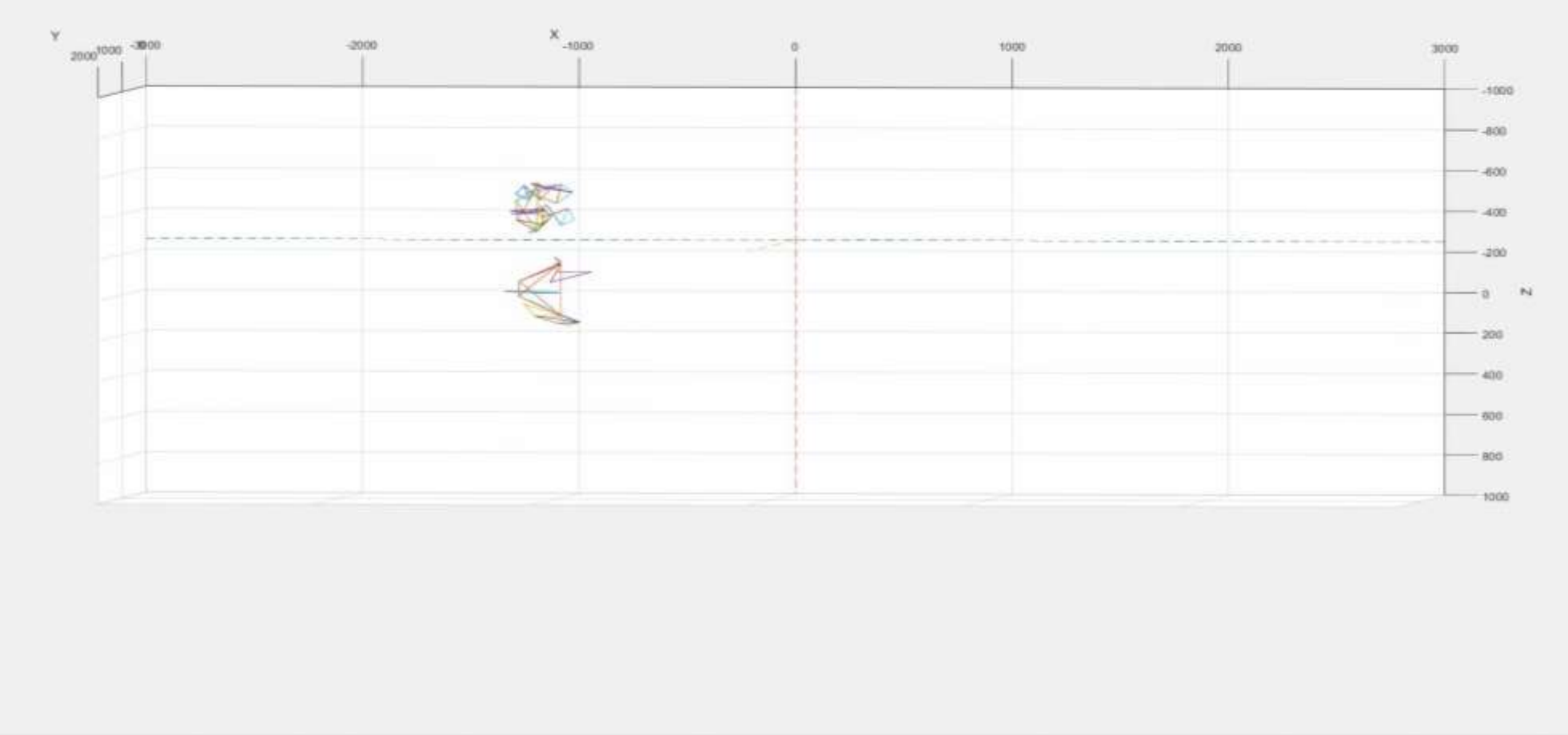
MATLAB Implementation – Adult model



MATLAB Implementation –
Utilities for Cartesian Comparison

- **Cartesian Comparison**
  - **Parallel animated simulation** of both Sirine and Adult motion
  - Sirine ground reference frame has been chosen as **word reference frame**, adult data expressed in this one (application of scaling, translation, rotation)
  - Different perspective views are possible
  - **Cartesian_comparison.m file**

Animated Cartesian Comparison



MATLAB Implementation –

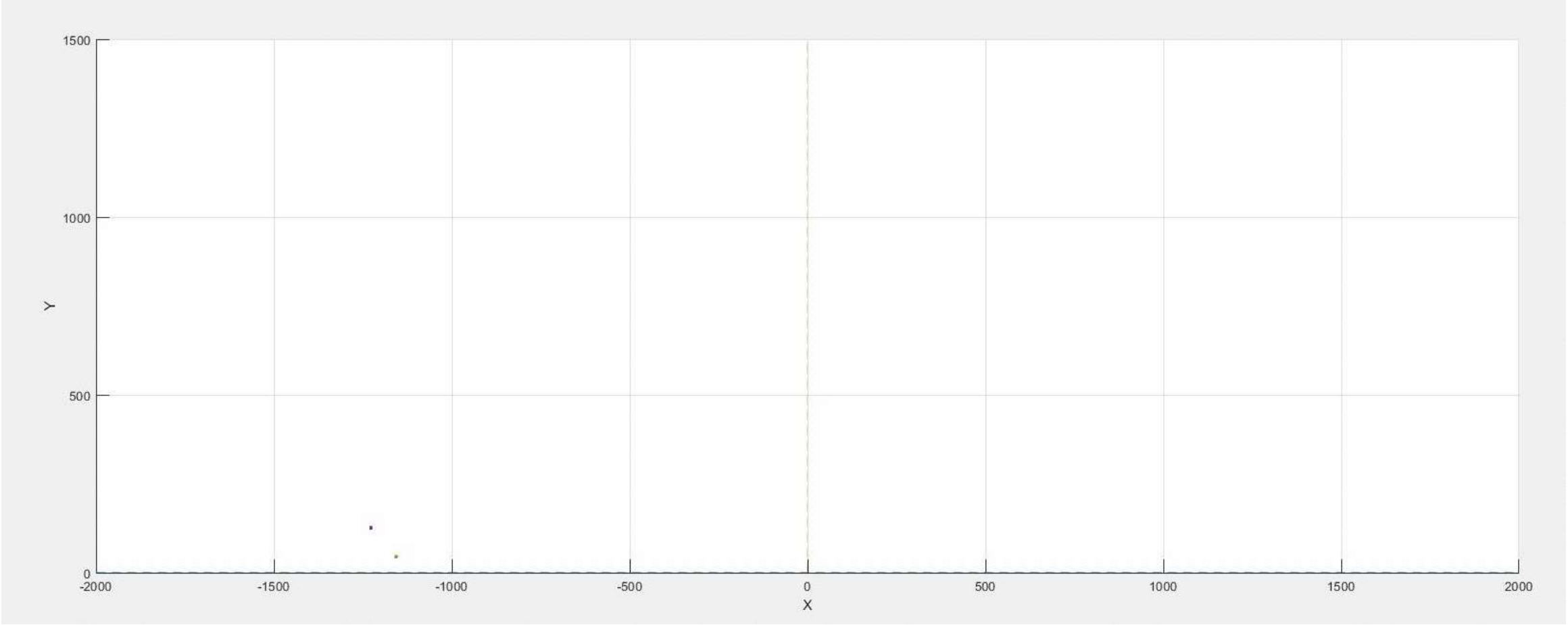
Utilities for Marker and Angle Comparison

- **Marker comparison**
  - Select specific marker trajectories to plot desired **marker time evolutions in 3D space (x,y,z)**, visualizable as 2D screenshots
  - Helpful to analyse the motion of adult and child and plot them into one plot
  - **Marker_comparison.m file**

- **Angle comparison**
  - Plotting **joint angle trajectories in 2D space (time, angle in degrees)** taken from marcheNik.mot files
  - Adult angles computed **via analytical inverse kinematics formulae** (sequential rotation transformations, roll/yaw/pitch)
  - **Angle_comparison.m file**

MATLAB Implementation –

Example of a Marker Plotting Animation for the Ankles



Motion Analysis and Comparison – Marker Trajectories

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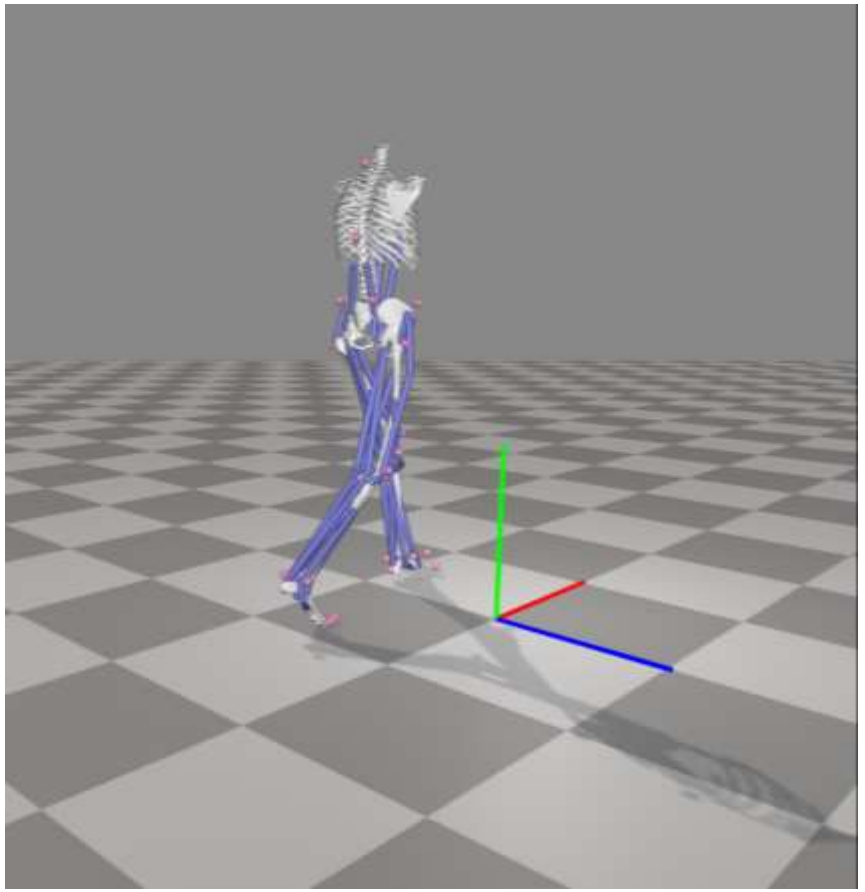
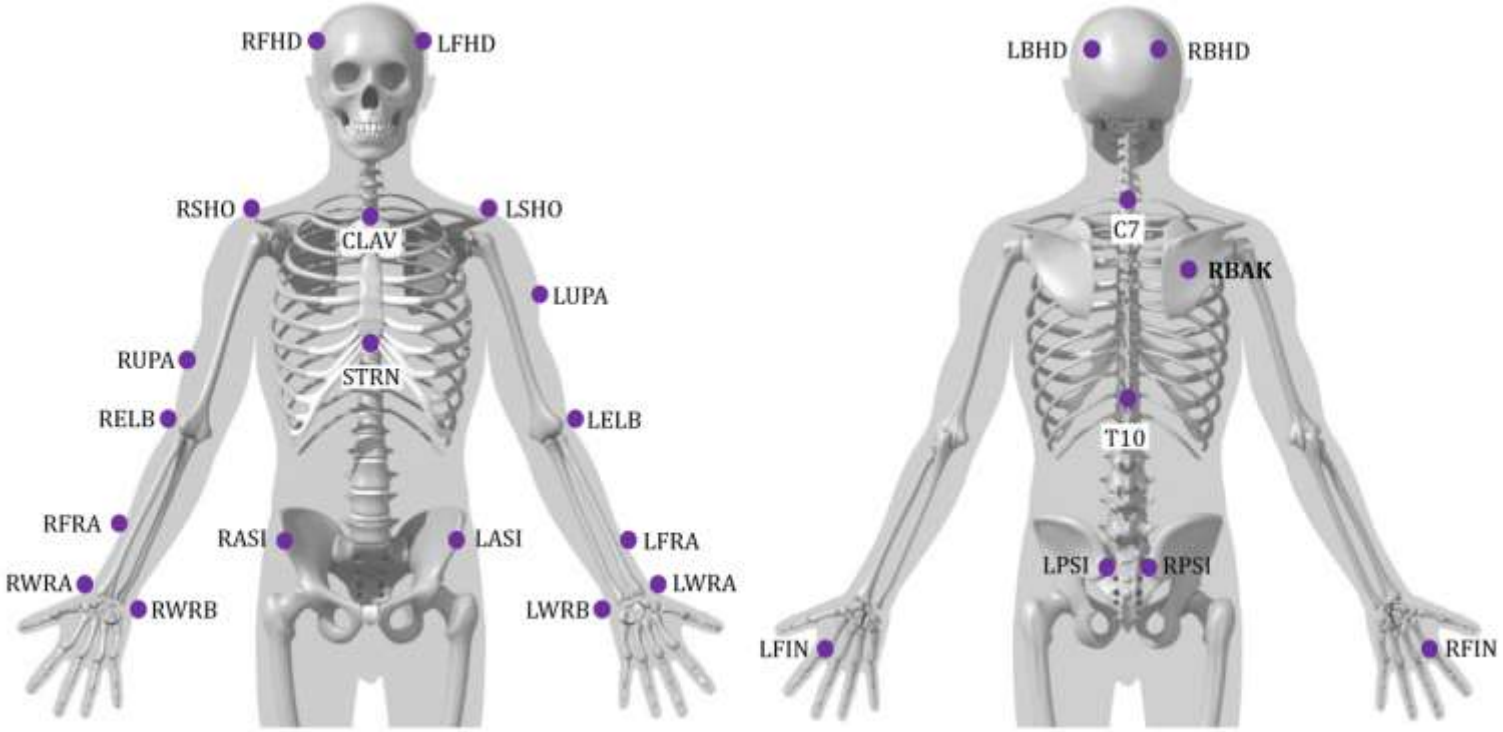
Motion Analysis – Deep Diving

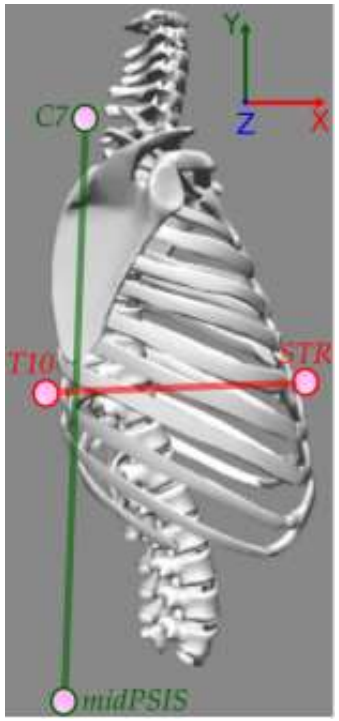
- Cartesian comparison provides good **overview**
  - Deep-dive by **comparing body parts separately**, **torso**, **pelvis** and **right/left leg** (= ankle + knee + toe) areas
- Coordinate system definition (Sirine's Camera frame)
  - **X-axis**: normal to Coronal Plane (movememt direction)
  - **Y-axis:** normal to Transverse Plane (height)
  - **Z-axis:** normal to Sagittal Plane (depth)
- Data adjustments (Adult data)
  - **Rotation** of 90 degree around the Y-axis
    Point (x, y, z) is represented as (z, y, -x) in the rotated frame
  - **Translation** along the X-axis of 500 cm
    Child and adult share the same initial positon
  - **Translation** along the Z-axis of 500 cm
    Avoid motion trajectories overlapping



Motion Analysis – Torso Segment

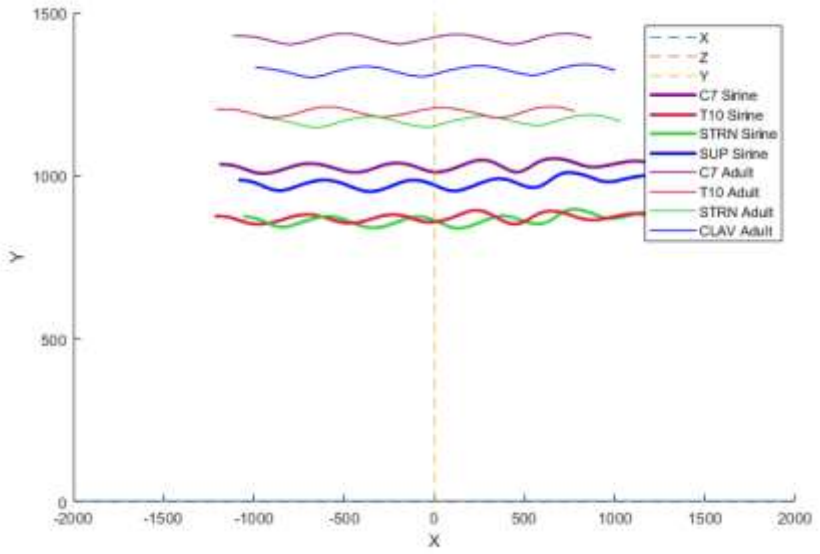


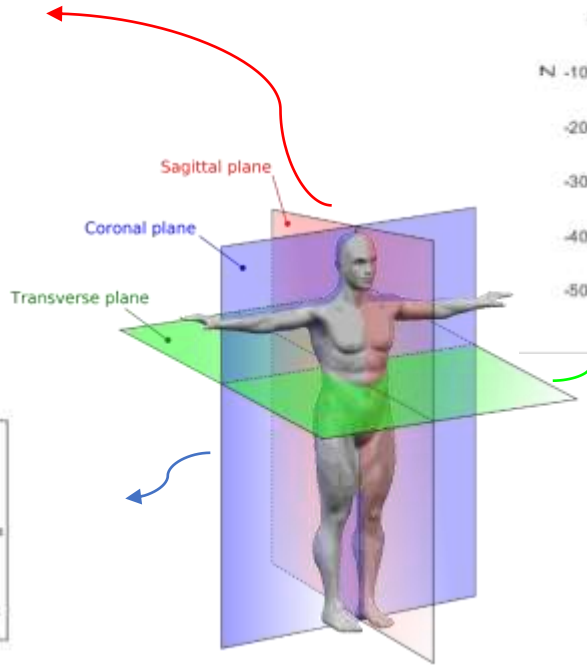
Adult (Plug-In Gait)

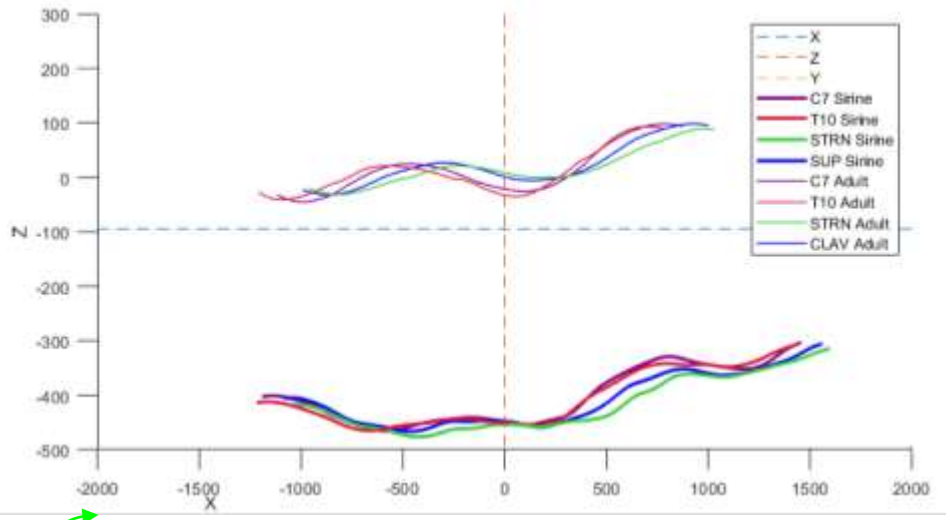


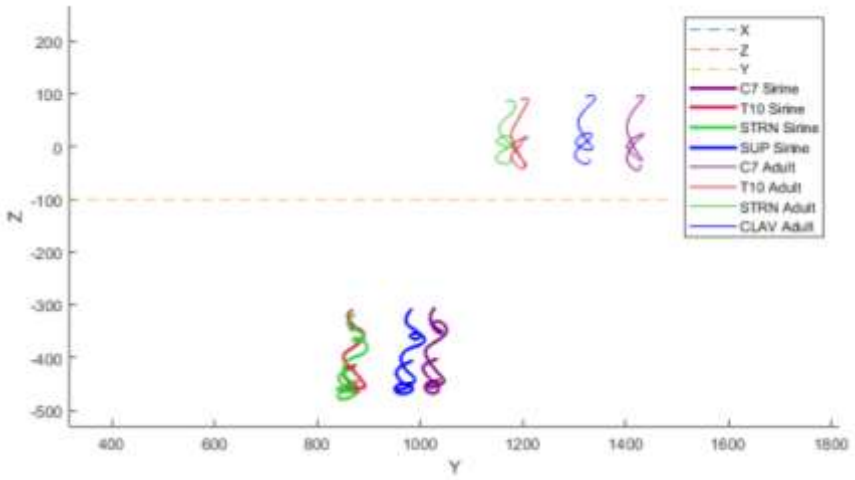
Sirine

Motion Analysis – Torso Segment



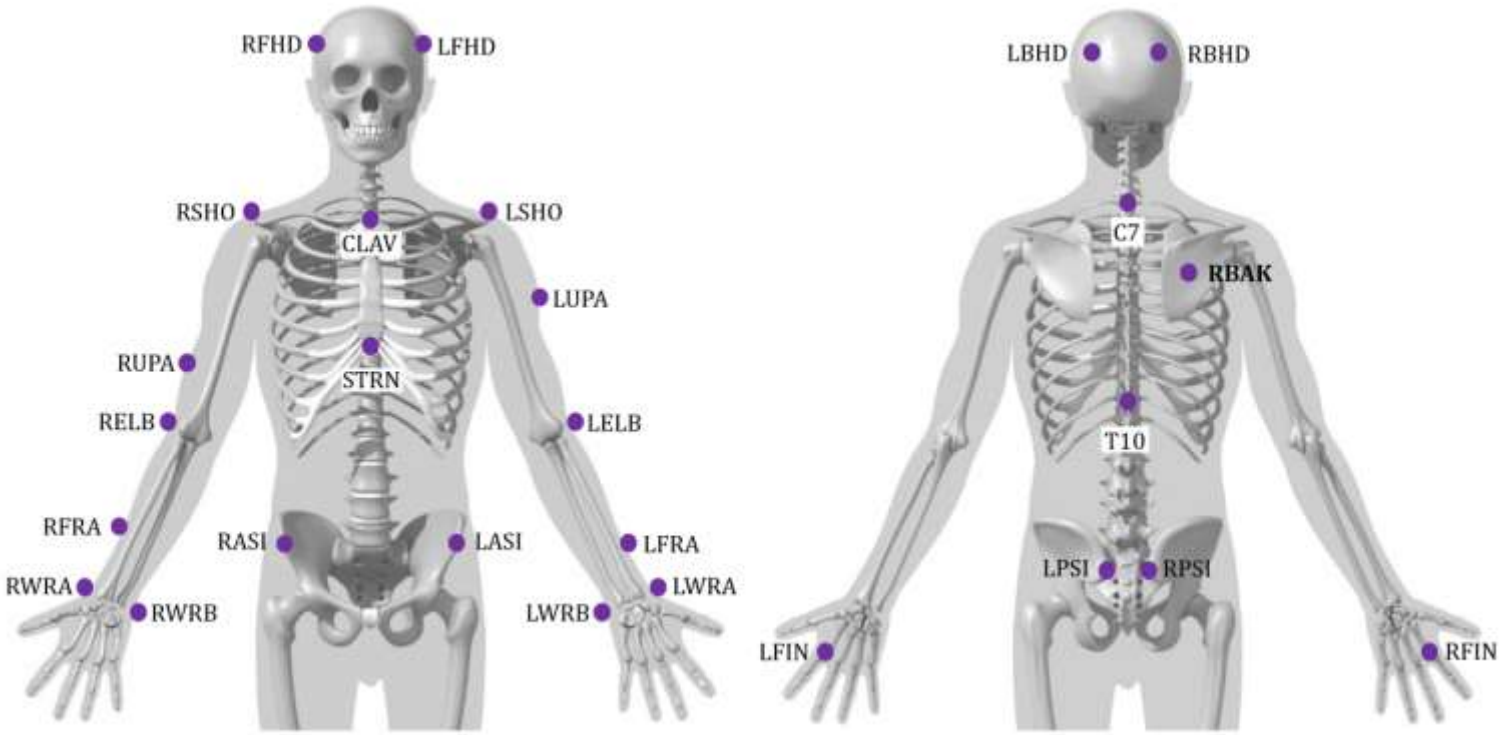




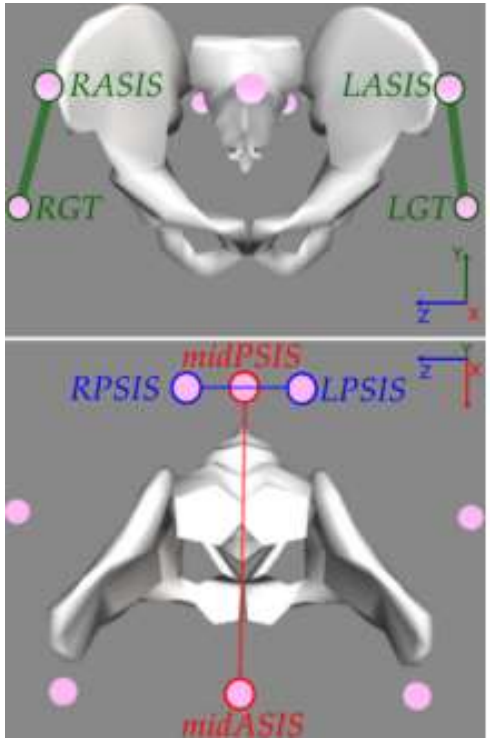


Sagittal	Transverse	Coronal
T10 and STRN overlapping	Non-straight gait	T10 and STRN overlapping
Irregularity in periodicity	Comparable behaviour	

Motion Analysis – Pelvis Segment

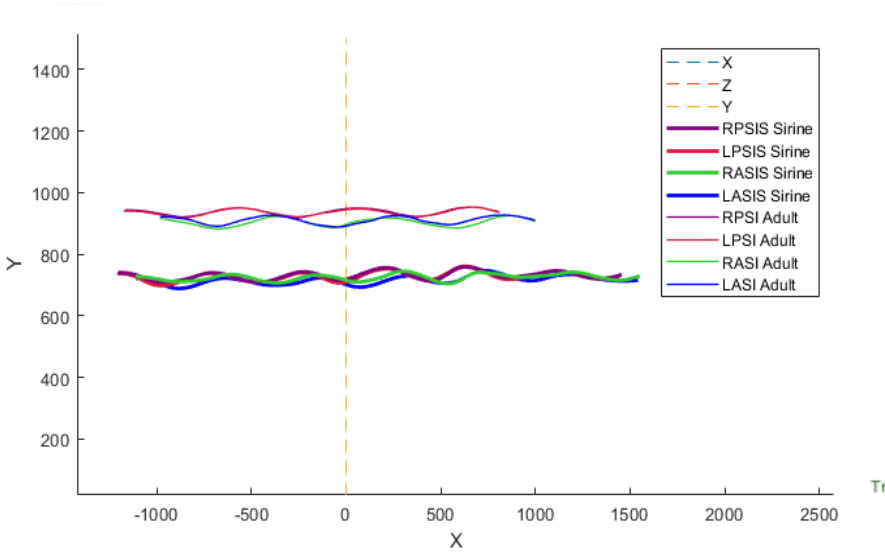


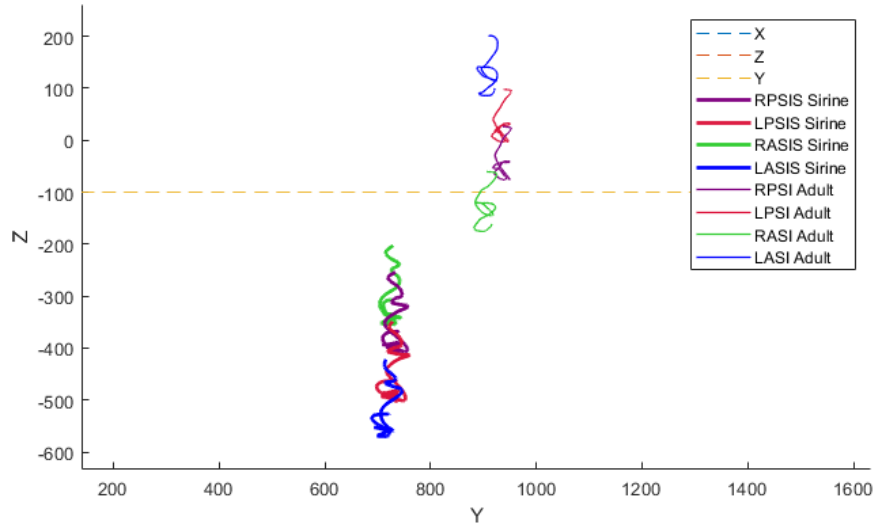
Adult (Plug-In Gait)

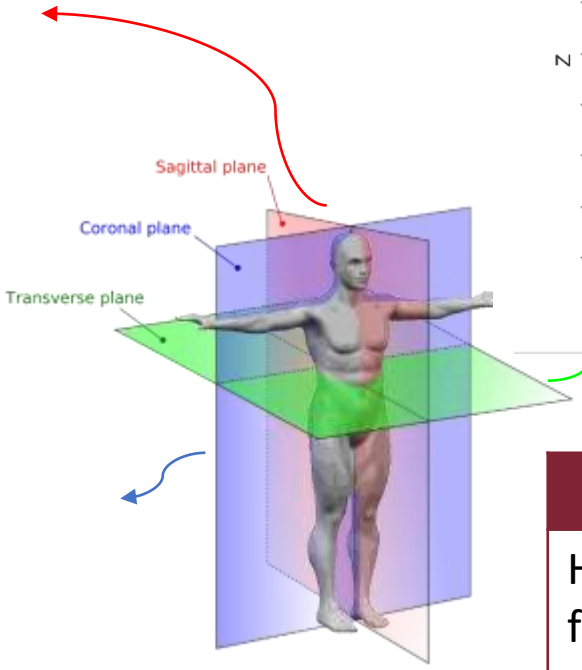


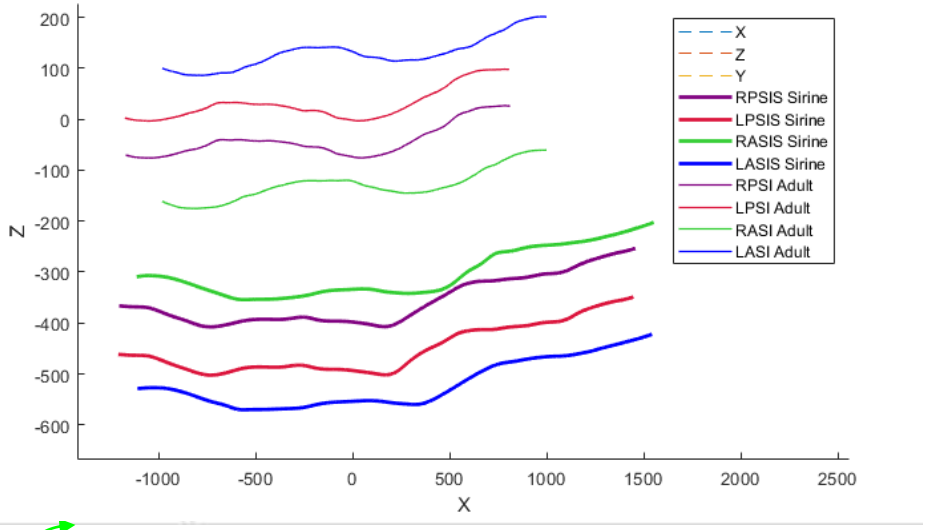
Sirine

Motion Analysis – Pelvis Segment



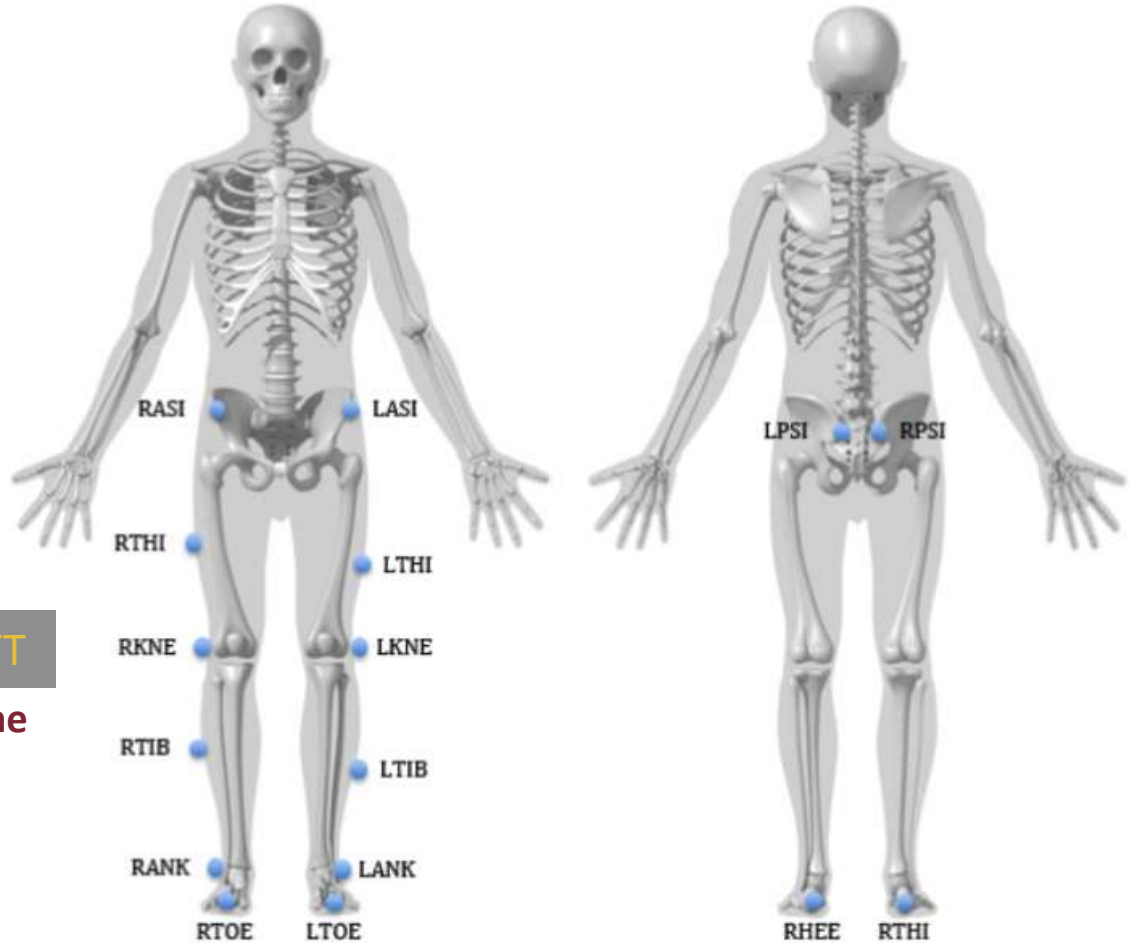






Sagittal	Transverse	Coronal
Higher frequency of oscillations	Comparable behaviour	RPSIS and LPSIS overlap in both
Irregularity in periodicity (last gait cycle)		LASIS/LPSIS (RASIS/RPSIS) overlap in both

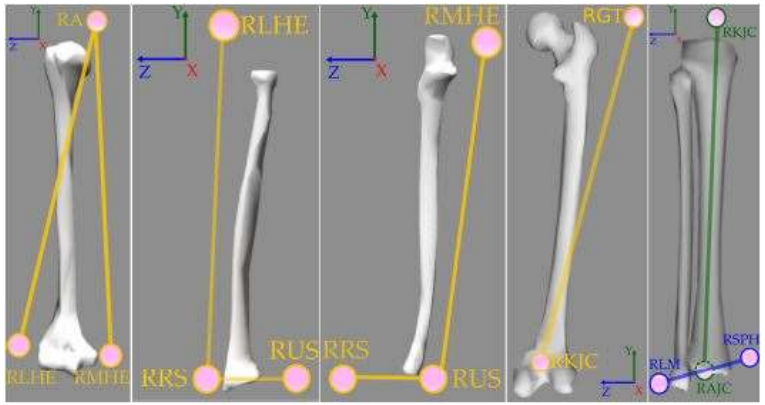
Motion Analysis – Left/Right Leg Segment

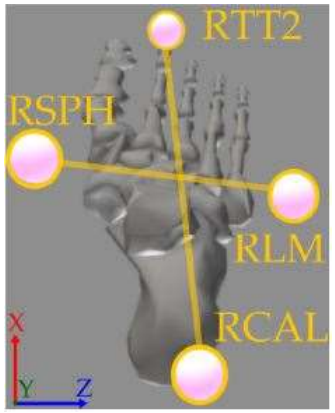


RATT

Sirine

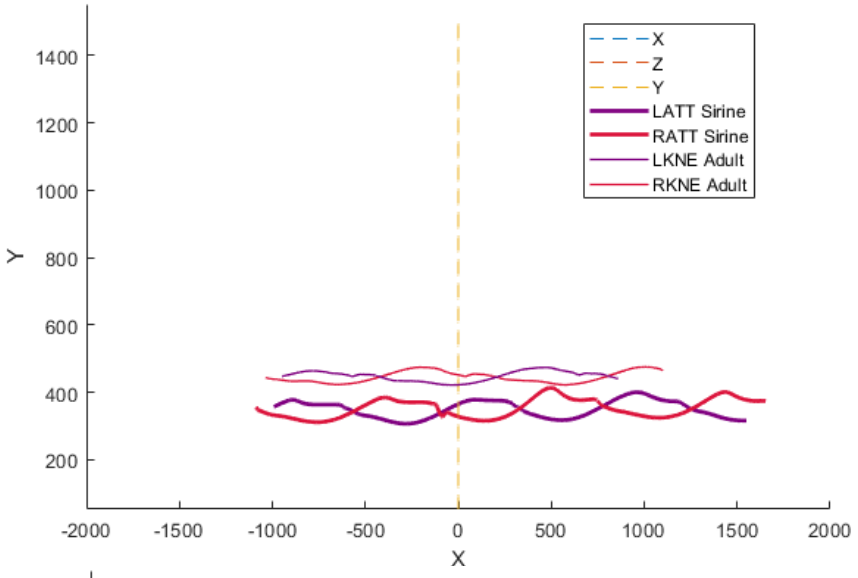
Adult (Plug-In Gait)

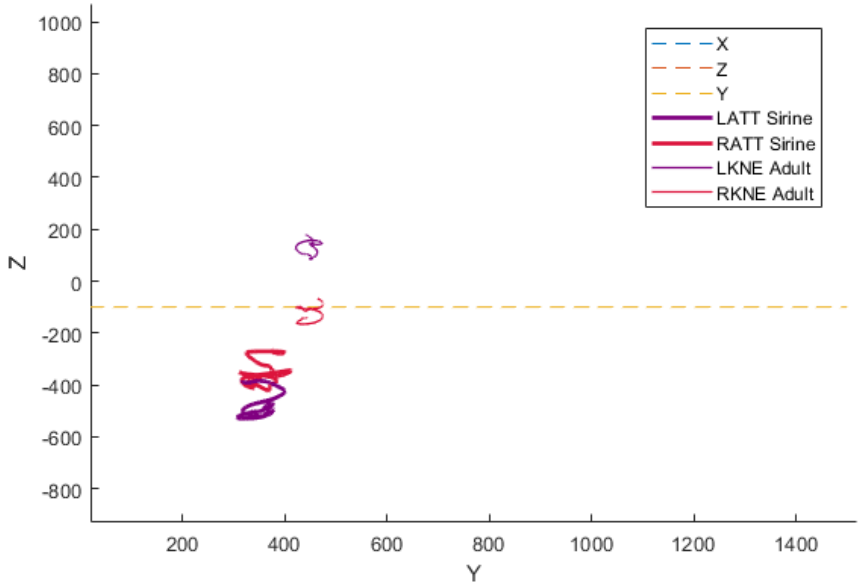


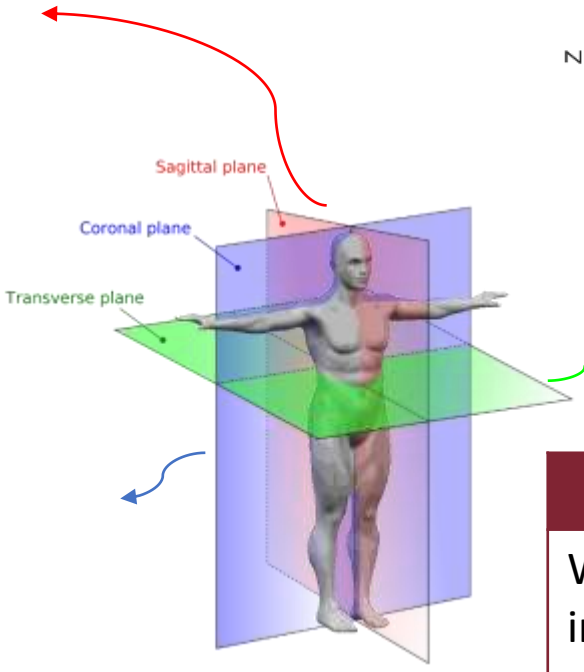


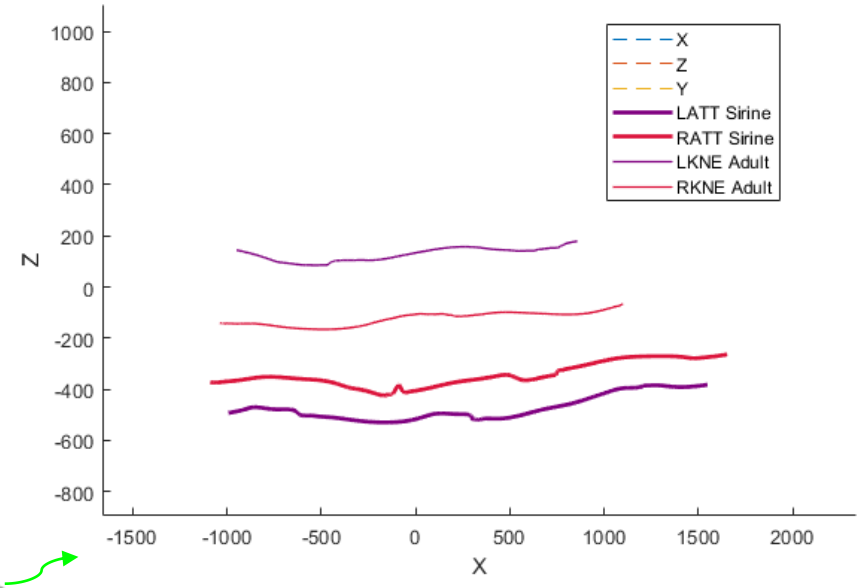
Sirine

Motion Analysis – Left/Right Knee



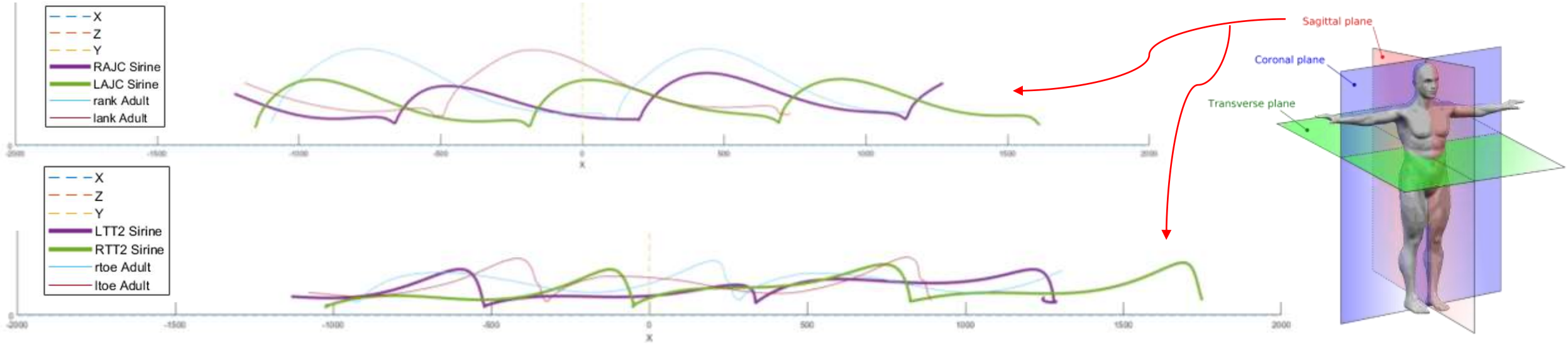






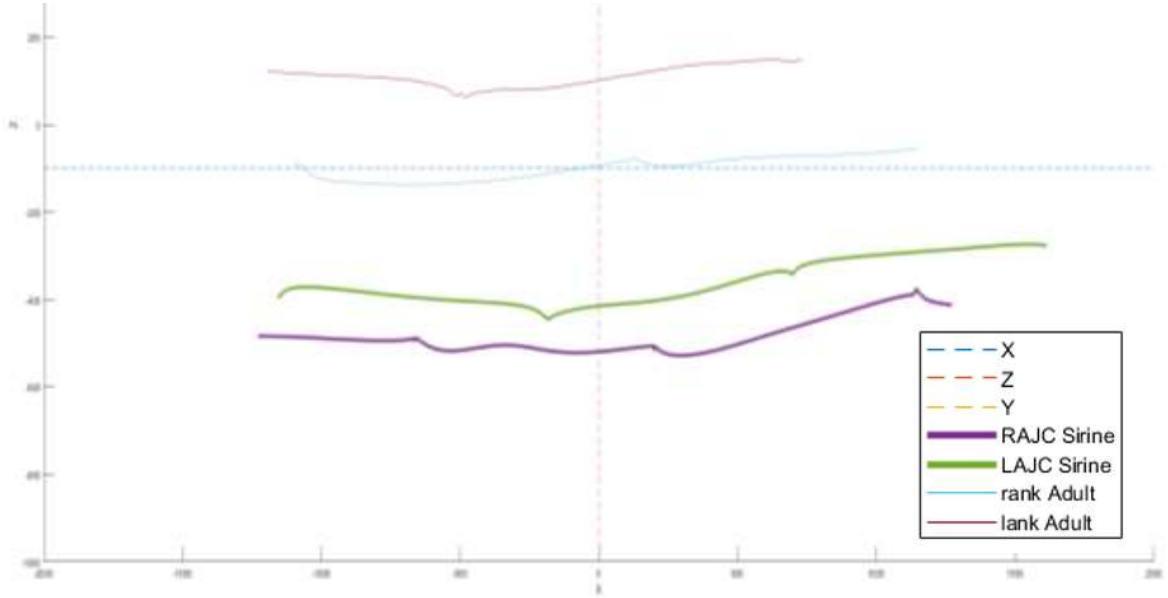
Sagittal	Transverse	Coronal
Wider amplitude in Y direction	A-periodic picks with high slopes	Overlapping of the left and right knees
Irregularity in periodicity	Unsmooth movement (knee buckling)	Non-straight gait

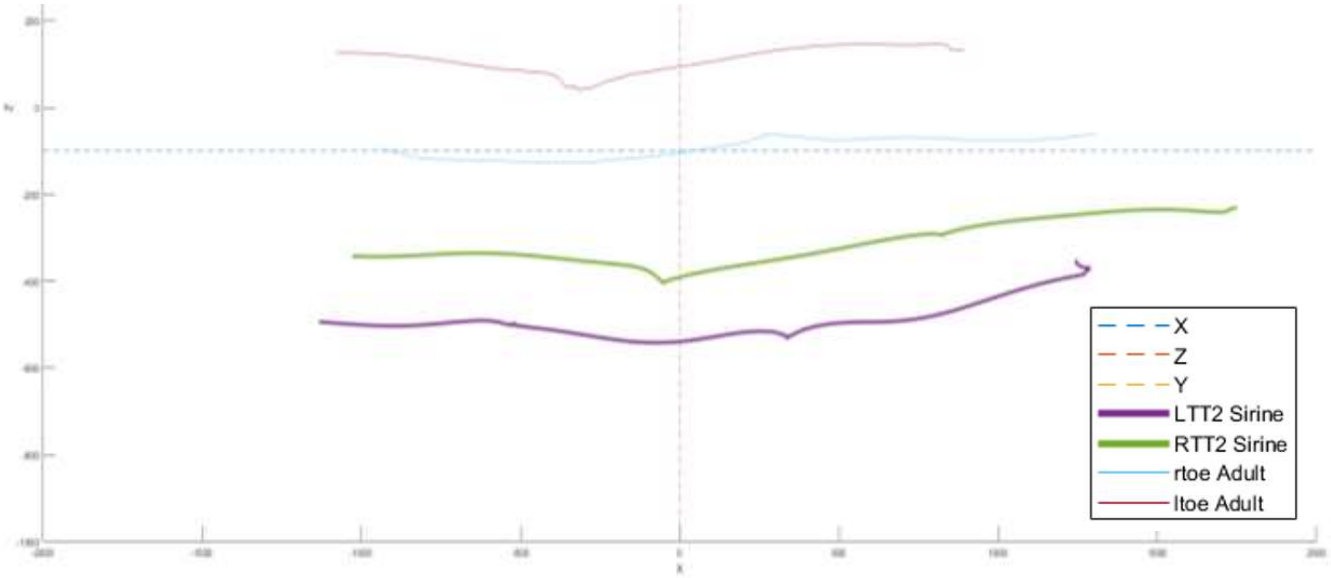
Motion Analysis – Left/Right Ankle and Toe

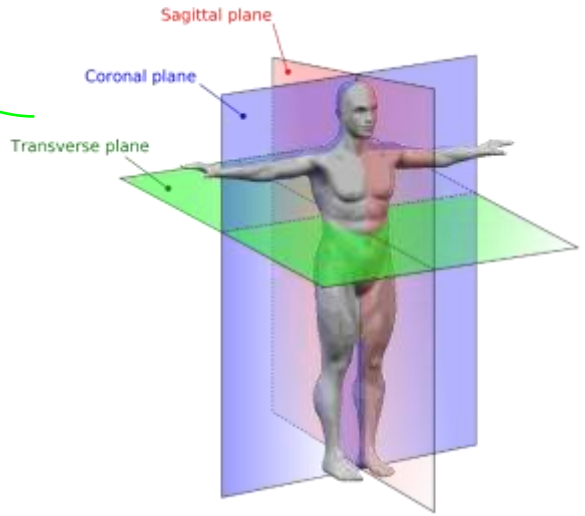


Sagittal Plane	
Ankle	Regular behaviour, differences in amplitude and periodicity due to different body part dimensions
Toe	**Low peak for LTT2 marker trajectory (purple curve) in second gait cycle**, foot drags close to the ground (unnatural motion)

Motion Analysis – Left/Right Ankle and Toe

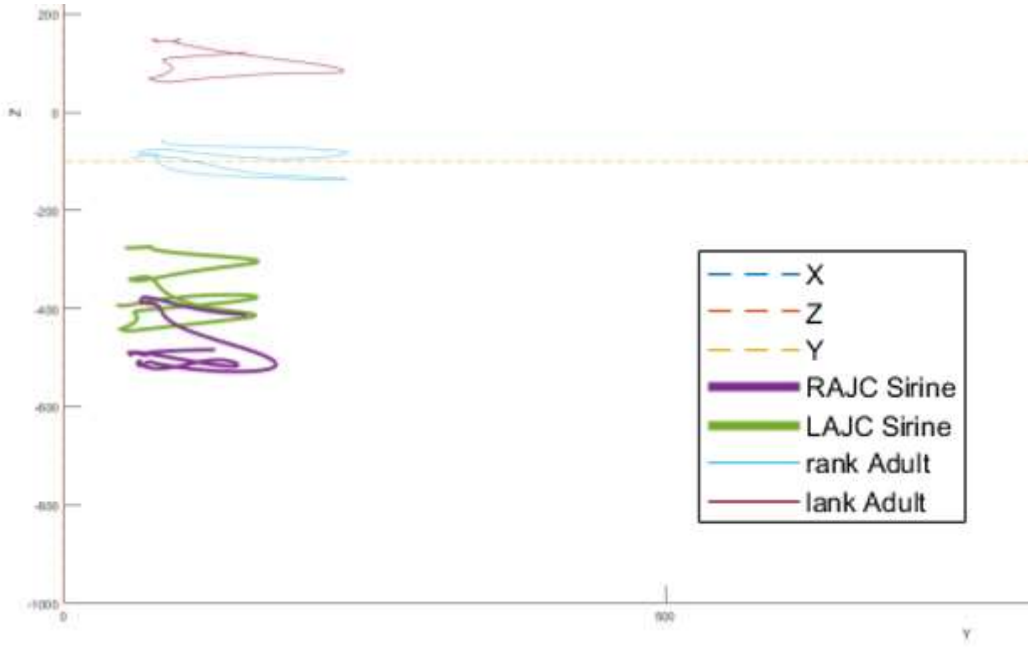


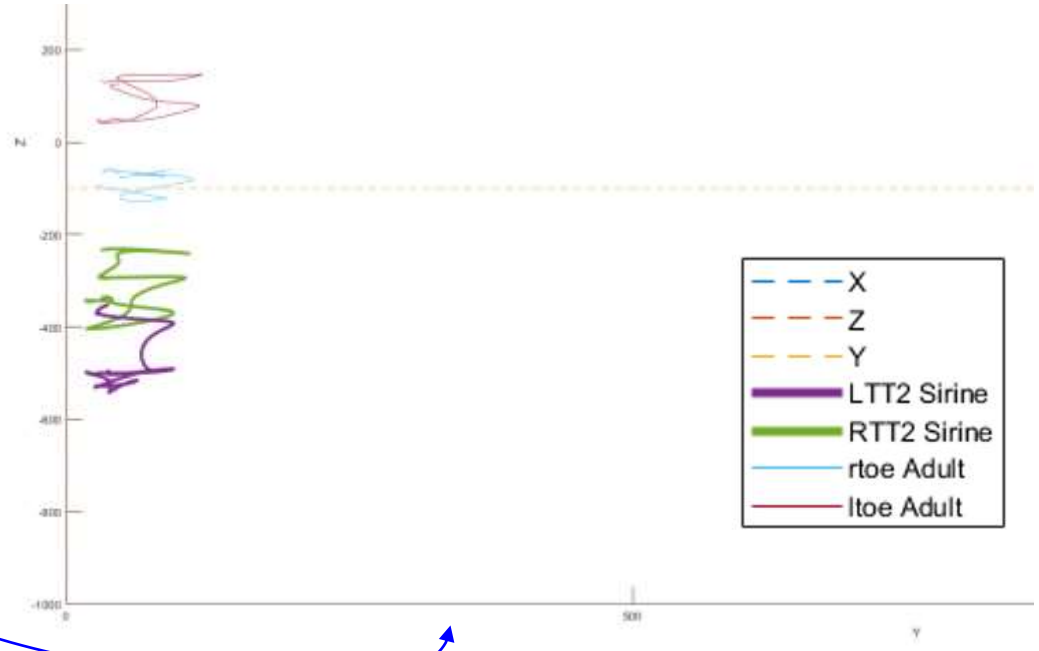


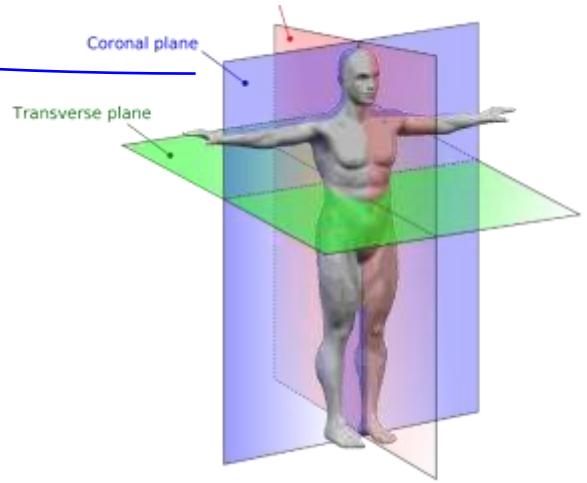


Transverse Plane	
Ankle	Behavioral patterns are the same for Sirine and the adult, **co-directed peaks** are observable
Toe	Adult has peaks in **opposite directions for each toe** (right **toe inversion** during swing), for Sirine they have the same directions (right **toe eversion** during swing)

Motion Analysis – Left/Right Ankle and Toe







Coronal Plane	
Ankle	Wider oscillation in Z direction for Sirine, overlapping of feet over time (due to non-straight gait)
Toe	Right foot appears to be dragged at an angle

Motion Analysis and Comparison – Inverse Kinematics

Adult/Child Musculoskeletal Model and Motion Analysis Comparison

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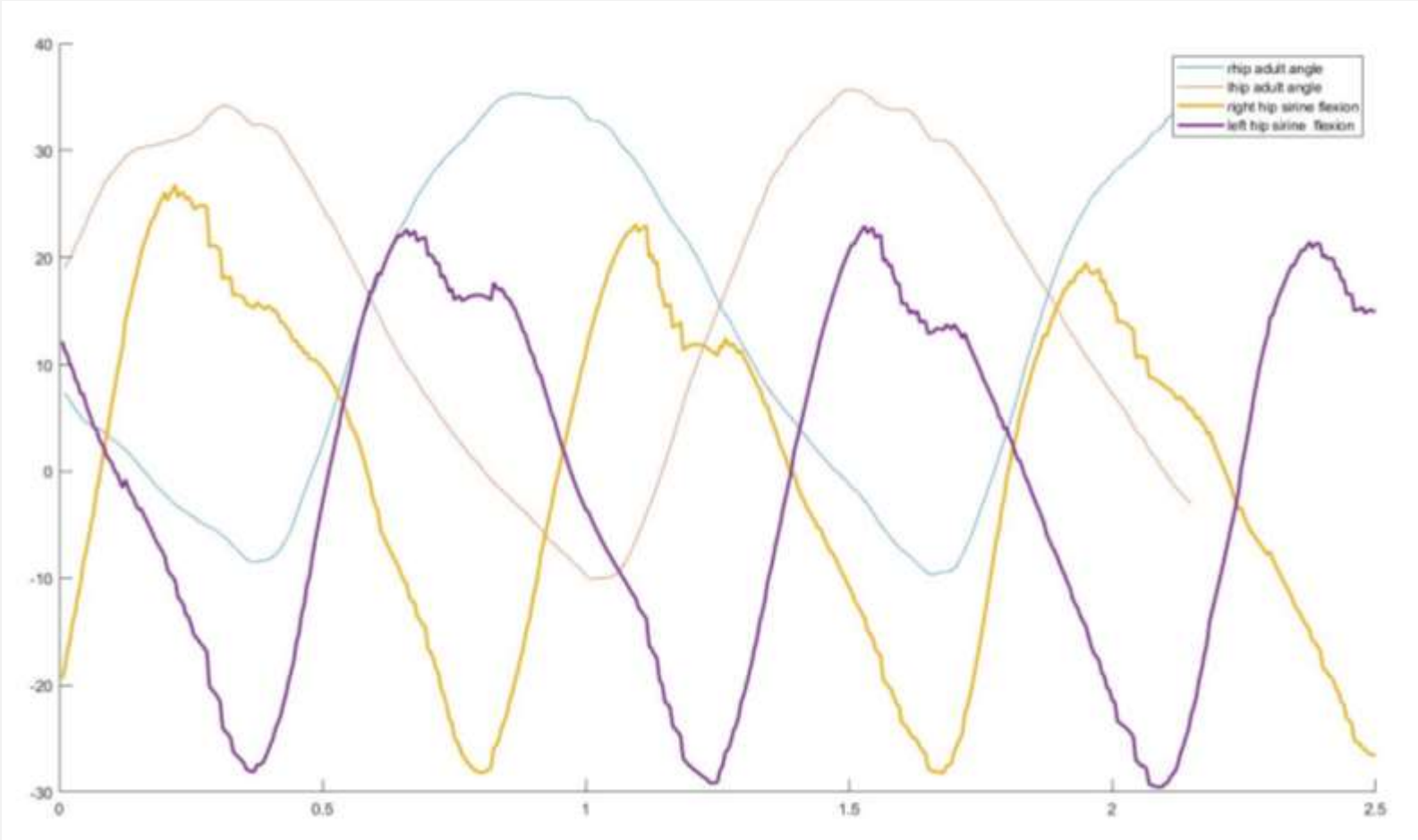
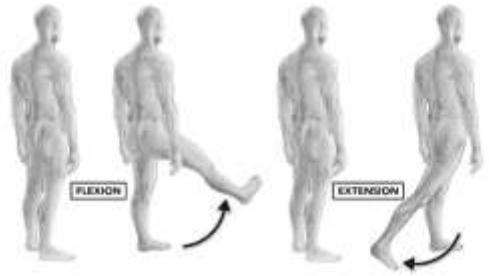
Motion Analysis – Hip Flexion/Extension



Hip flexion/extension angle (in degrees) vs. **time**

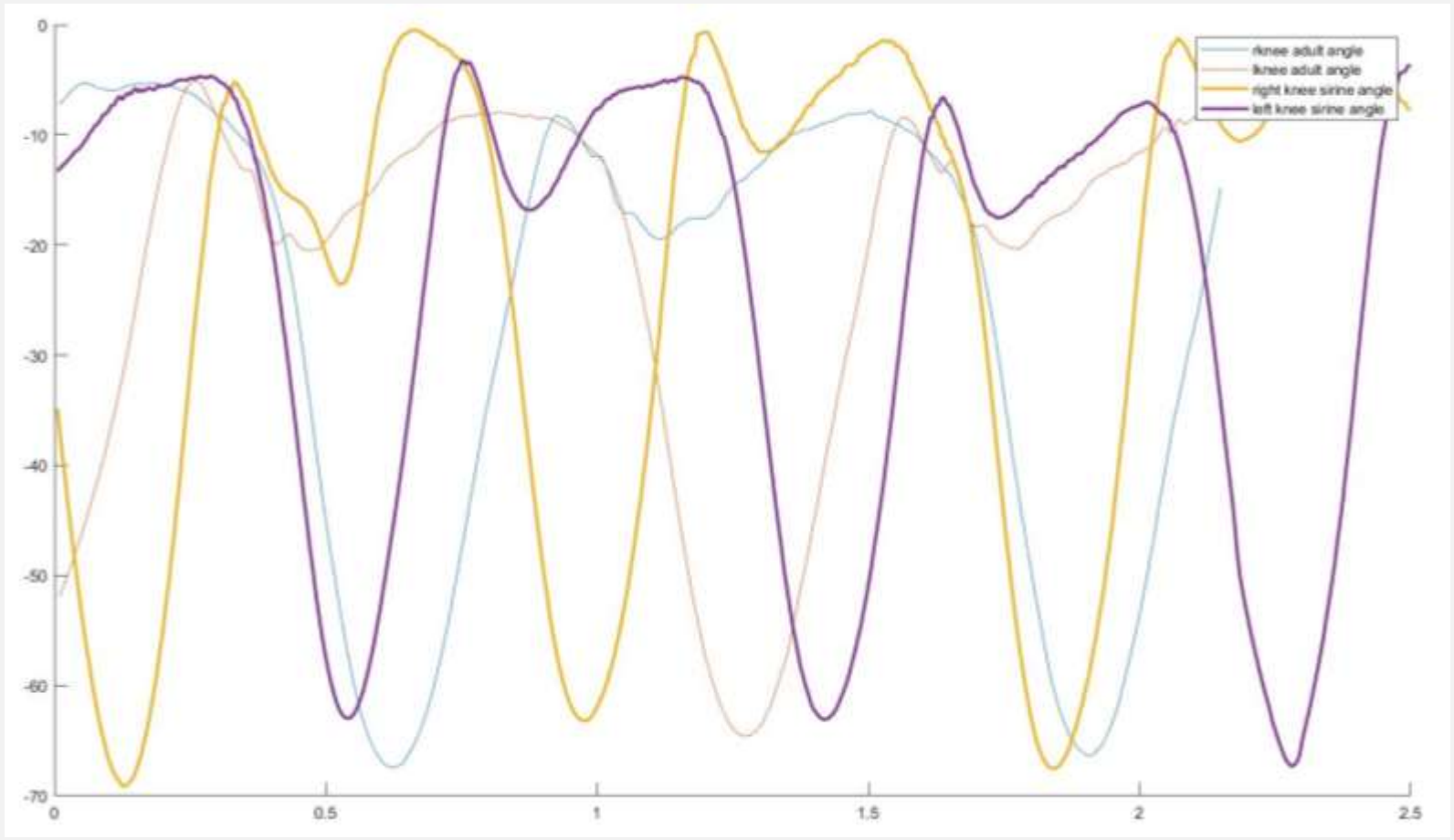


Symmetry:
Angle bias due to initial orientation of reference frame

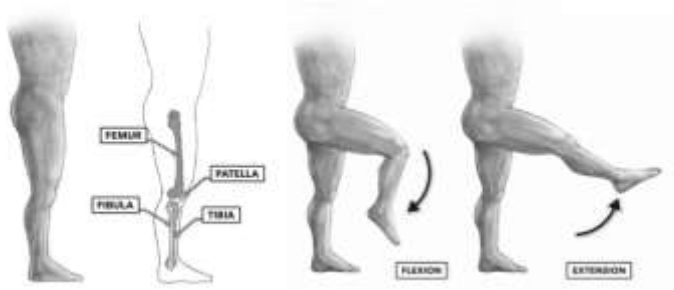
Sirine:
Higher slope conditioned by higher angular velocity along the hip (**faster hip rotation during extension phase**), flexion of hips has characteristical angular acceleration pattern

Adult:
Curves are smooth and characterize the constant joint rotation

Motion Analysis – Knee Flexion/Extension



Knee flexion/extension angle (in degrees) vs. **time**

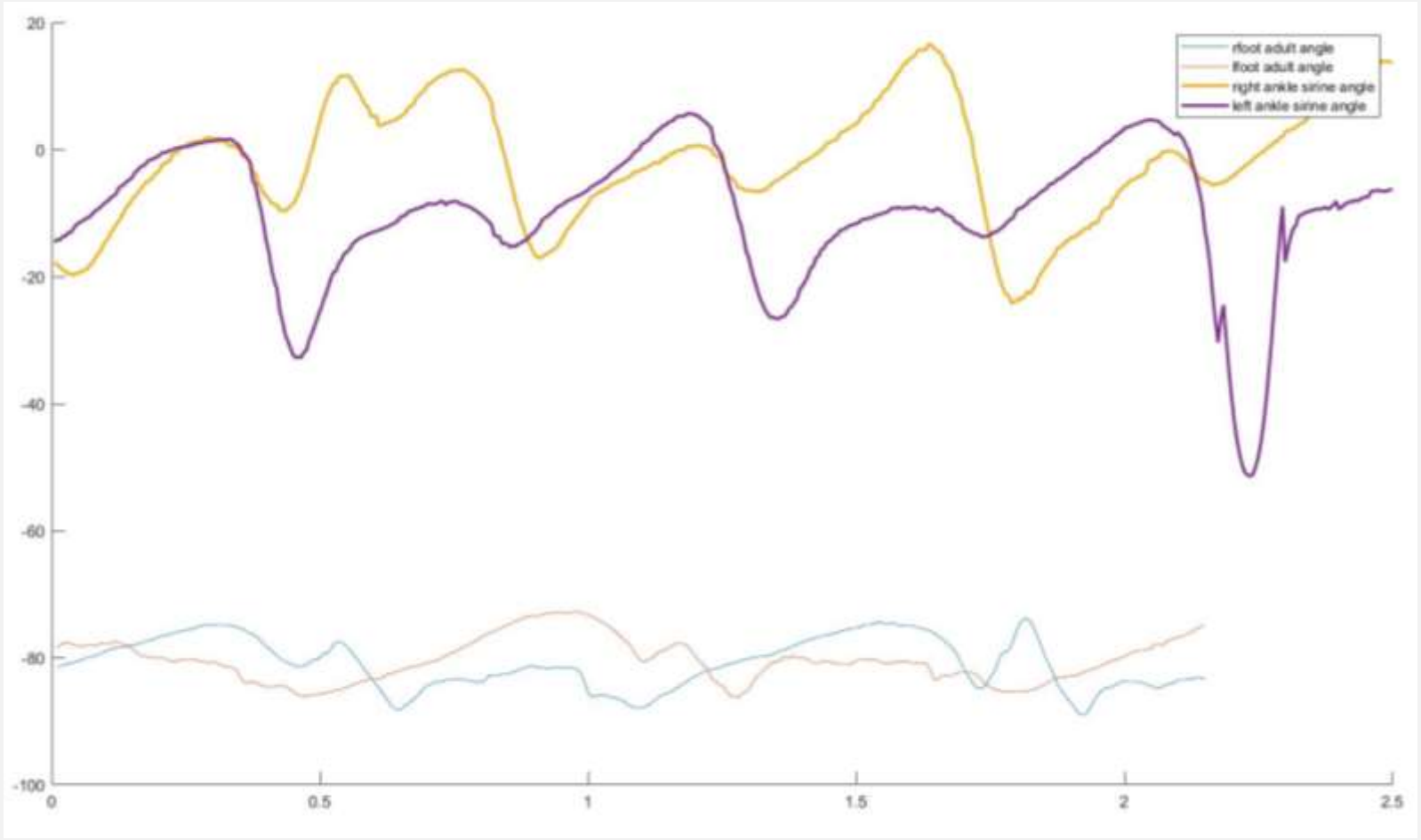


Evaluation:
Swing and step phases clearly visible for both

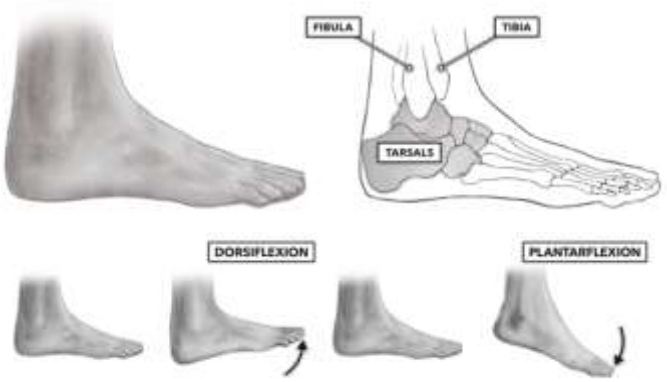
Sirine:
Amplitude of right knee higher than the left one, differences in angles during different gait cycles (again due to non-straight walk)

Adult:
Same shifts in angle curves, overall amplitude is smaller for Adult than for Sirine

Motion Analysis – Ankle Planta-/Dorsiflexion



Ankle plantaflexion/dorsiflexion (in degrees) vs. **time**



Angle shift:

Measurement in other reference frame, different angle convention

Sirine:

High angle amplitude, last gait cycle with really high angle range

Adult:

Small angle amplitude, only ranging within 15-20 degrees with consequent less rapid jumps

Motion Analysis – Conspicuities

- Plots based on **marche9**, comparable behaviour for the other recordings
- Sirine‘s **non-straight gait** complicates analysis (Coronal plane)
  - Upper body (torso and pelvis) shows **small irregularities** in oscillations and amplitues, still mainly constant and smooth motion
  - High conspicuities for knee part (**knee buckling**)
  - Unexpected: Ankle motion quite regular and periodically, right toe of Sirine **dragged wrong-sided**
  - **Angle comparison:** Child angular motion wider ranged, rotations more quick (accelerated)
- Differences between adult/child:
  - **Wide-view:** Smaller height/width leads to smaller steps and more gaits, scaling well visible for toe and ankle plot
  - **Close-view:** Motion model of Sirine can be viewed as slightly **perturbated adult one**

Wrap-up and Conclusions

Adult/Child Musculoskeletal Model and Motion Analysis Comparison

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Wrap-up and Conclusion

- Developed **Matlab-based visualization tool** for human motion analysis
- Ability to perform a **comparative analysis** between walking characteristics of children vs. adults
  - **Scaling properties** well visible (but **only to a certain extent**)
  - Children-specific motion must be **modeled separately**

- **Further steps/Future work:**
  - Include dynamical data too, analyze forces between body parts
  - **A step further than just analyzing:** Which treatments are helpful for children?
    → Strengthen biomedical viewpoint, i.e. collaboration with doctors, orthopaedists

- **All in all:** Powerful tool with good outlook for orthopedic treatments of patients

Sources

- M. Marchitto. *Motion Analysis for Children with Cerebral Palsy: Study on Twins*. Master thesis at Sapienza Università di Roma.
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  https://www.crossfit.com/essentials/movement-about-joints-part-7-the-ankle