Plug-in Gait output specification

The following topics provide definitions to enable you to reliably reconstruct the segment co-ordinate systems using Plug-in Gait outputs in third-party modeling software.

- Global (laboratory) co-ordinate system
- Pelvis
- Femur
- Tibia
- Foot
- Joint kinematic definitions
- Joint kinetics

The Plug-in Gait model consists of seven segments (including the left and right side):

- Pelvis
- Femur (left and right)
- Tibia (left and right)
- Feet (left and right)

When **Plug-in Gait Static** calculations are performed, a scaling length for each of the 7 segments is written to the subject's *.mp* file.

The **Plug-in Gait Dynamic** process outputs joint kinematics and kinetics to a *.c3d* file, which also defines them in terms of their order and sign conventions.

For information about the definition of the Plug-in Gait model itself and the algorithms used to locate the segment co-ordinate systems and calculate the segment lengths from skin fixed marker data, see Plug-in Gait kinematic and kinetic calculations.

The marker names used here are from the standard Plug-in Gait marker definitions. For precise definitions of their location, see Plug-in Gait models and templates.

Global (laboratory) co-ordinate system

The laboratory co-ordinate system is required here as a reference for the pelvis kinematics. The lab system is also used later in the definition of the foot co-ordinate frame.

The global Z axis defines the vertical, i.e. perpendicular to the lab floor.

The global X and Y axes are in the plane of the lab floor, with X often defining the direction if normal walking along the laboratory walkway.

Pelvis

The origin of the pelvis co-ordinate system in Plug-In Gait is the midpoint of the vector connecting the two asis landmarks (LASI and RASI). The co-ordinate system of the pelvis is reconstructed from the surface markers on the ASIS and PSIS landmarks, but should be considered to be related to the bony geometry of the pelvis as follows.

The Y axis is lateral (to the left) and is directed from the right hip joint centre (RHJC) to the left hip joint centre (LHJC), where the HJC are defined as the centre of the spherical part of the femoral head:

$$\overline{Y}_{PELVIS} = \frac{\overline{LHJC} - \overline{RHJC}}{\left|\overline{LHJC} - \overline{RHJC}\right|}$$

The Z axis is then perpendicular to Y and the vector between the sacrum (SACR) and the midpoint of the asis landmarks:

$$\overline{Z}_{PELVIS} = \frac{\overline{MASI} - \overline{SACR}}{\left|\overline{MASI} - \overline{SACR}\right|} \wedge \overline{Y}_{PELVIS}$$

where:

$$\overline{MASI} = \frac{\overline{LASI} + \overline{RASI}}{2}$$

(The sacral marker is not always used, and this landmark can be calculated as being at the midpoint of the vector connecting the LPSI and RPSI markers).

The X axis is naturally the cross product of the Y and Z pelvis axes:

$$\overline{X}_{PELVIS} = \overline{Y}_{PELVIS} \wedge \overline{Z}_{PELVIS}$$

In the Plug-in Gait model, the pelvis Y axis is assumed to be parallel to the vector between the LASI and RASI markers, but the definition above is more suitable when constructing a co-ordinate system from known hip joint centers.

The length of the pelvis segment calculated by the Plug-in Gait model is equal to the inter-hip distance:

$$\bar{L}_{PELVIS} = \left|\overline{LHJC} - \overline{RHJC}\right|$$

Plug-in Gait also outputs the inter-asis distance, which can also be used to assist in reconstruction of the morphology of the pelvis.

Femur

The accuracy/validity of the femoral coordinate system is affected by the estimation of the knee joint center location as well as the knee flexion extension axis. These two estimations are reliant upon your providing accurate marker placement and subject measurements.

The co-ordinate axes are aligned with the long axis of the femurs and the knee flexion axes as follows.

The Z axis of the femur is directed from the knee joint center to the hip joint center:

$$\bar{Z}_{FEMUR} = \frac{\overline{HJC} - \overline{KJC}}{\left|\overline{HJC} - \overline{KJC}\right|}$$

The X axis is anterior and is perpendicular to the knee flexion axis, $\overline{K_F}$:

$$\bar{X}_{FEMUR} = \overline{K_F} \wedge \bar{Z}_{FEMUR}$$

Finally, the Y axis is lateral (to the left for both legs) and is given by:

$$Y_{FEMUR} = \bar{Z}_{FEMUR} \wedge \bar{X}_{FEMUR}$$

The scaling length of the femur is simply the distance from the knee joint center to the hip joint center:

$$\bar{L}_{FEMUR} = \left|\overline{HJC} - \overline{KJC}\right|$$

Tibia

The Tibia effectively has two co-ordinate systems: a proximal one for calculating knee joint angles and a distal one for calculating ankle joint angles.

Both segments have their origins at the ankle joint center (AJC) and are defined in a manner similar to the femoral segments. Again, the location of the ankle joint center and ankle flexion axis calculated by Plug-in Gait are reliant upon your providing accurate marker placement and subject measurements.

Firstly, the proximal system uses the knee joint center, ankle joint center and the knee flexion axis, $\overline{K_F}$:

$$\bar{Z}_{TIBIA} = \frac{\overline{KJC} - \overline{AJC}}{\left|\overline{KJC} - \overline{AJC}\right|}$$

$$\bar{X}_{TIBIA,P} = \overline{K_F} \wedge \bar{Z}_{TIBIA}$$

$$\bar{Y}_{TIBIA,P} = \bar{Z}_{TIBIA} \wedge \bar{X}_{TIBIA,P}$$

The distal coordinate system is then rotated about the long axis of the tibia (Z) such that it is aligned with the ankle flexion axis, $\overline{A_F}$:

$$\bar{X}_{TIBIA,D} = \overline{A_F} \wedge \bar{Z}_{TIBIA}$$

$$\bar{Y}_{TIBIA,D} = \bar{Z}_{TIBIA} \wedge \bar{X}_{TIBIA,D}$$

The scaling length of the tibia is the distance from the ankle joint center to the knee joint center:

$$\bar{L}_{TIBIA} = \left|\overline{KJC} - \overline{AJC}\right|$$

Foot

The origin of the foot segments of the Plug-in Gait model is located at the ankle joint centers. The foot co-ordinate system is defined in a rather more complex manner within the Plug-in Gait model than is necessary to recreate the motion of the bones from the Plug-in Gait kinematics output.

Firstly, the system Z axis is equal to the vector from the toe to heel markers (HEE and TOE), projected into the plane of the laboratory floor (X-Y plane):

$$\bar{Z}_{FOOT} = \left(\bar{Z}_{GLOBAL} \wedge \bar{V}_{FOOT} \wedge\right) \wedge \bar{Z}_{GLOBAL}$$

Where:

$$\bar{V}_{FOOT} = \frac{\overline{HEE} - \overline{TOE}}{\left|\overline{HEE} - \overline{TOE}\right|}$$

The X axis is then perpendicular to this and the ankle flexion axis and is directed vertically:

$$\bar{X}_{FOOT} = \overline{A_F} \wedge \bar{Z}_{FOOT}$$

And finally, the Y axis is naturally the cross product of these two axes:

$$\bar{Y}_{FOOT} = \bar{Z}_{FOOT} \wedge \bar{X}_{FOOT}$$

The scaling length of the foot is the distance from the ankle joint center to the toe marker:

$$\bar{L}_{FOOT} = \left|\overline{TOE} - \overline{AJC}\right|$$

Joint kinematic definitions

The following table specifies how the rotations within each of the joints of the model are ordered as trajectories in the *.c3d* file.

Note
Angles are always given in the *.c3d* file as degrees.

For all of the joints, the joint co-ordinate system method of reporting kinematics has been used to specify flexion, abduction, and rotation. It is difficult to give a consistent definition of these angles for all of the joints due to the differing meaning of flexion etc.

Instead, the axis in the proximal segment embedded co-ordinate system about which each of the rotations takes place (together with the order these rotations should be applied) is given in the following table showing Euler angle specification.

Joint	1st Component	2nd Component	3rd Component	Order
Global Pelvis	Tilt (Y)	Obliquity (X)	Rotation (-Z)	1,2,3
Left Hip	Flexion (-Y)	Adduction (-X)	Rotation (-Z)	1,2,3
Left Knee	Flexion (Y)	Adduction (-X)	Rotation (-Z)	1,2,3
Left Ankle	Flexion (-Y)[1]	Inversion (Z)	Rotation (X)	1,3,2
Right Hip	Flexion (-Y)	Adduction (X)	Rotation (Z)	1,2,3
Right Knee	Flexion (Y)	Adduction (X)	Rotation (Z)	1,2,3
Right Ankle	Flexion (-Y)[1]	Inversion (-Z)	Rotation (-X)	1,3,2

1. The feet segments are peculiar to the rest of the model, not only because of the different rotation order, but also because the orientation of the foot at zero degrees flexion is straight upwards, that is, the toe will point towards the knee. An offset of +90 degrees should be applied in order to point the foot forwards.

Joint kinetics

The output from Plug-in Gait also contains forces, moments and powers for each of the segments.

ⓘ **Note**
Nexus displays the Plug-in Gait units as:

- Forces - N/kg
- Moments - N.mm/kg
- Power - W/kg

Plug-in Gait outputs generated by Nexus are normalized to the subject's body mass, and their values are stored in the *.c3d* file as such. Therefore, the units in the *.c3d* file metadata should be divided by kg for these outputs (i.e. N/kg, N.mm/kg, W/kg).

For both forces and moments, the reaction frame can be specified within Plug-in Gait to be proximal, distal, or in the global frame.

For each of the forces, the components in the .c3d file match the co-ordinate directions described in this document. For the moments, however, the order they are stored in the .c3d file matches the rotation order shown in the table in Joint kinematic definitions, and therefore do not correspond to any of the segment embedded co-ordinate systems.

The following table lists the components of the moments in terms of the axes about which they act.

Joint	1st Component	2nd Component	3rd Component
Left hip	-Y	X	Z
Left knee	Y	X	Z
Left ankle (prox.)[1]	Y	X	Z
Left ankle (dist.)[1]	Y	Z	-X
Right hip	-Y	-X	-Z
Right knee	Y	-X	-Z
Right ankle (prox.)[1]	Y	-X	-Z
Right ankle (dist.)[1]	Y	-Z	X

1. Due to the differing alignment of the foot and tibia segment co-ordinate systems, the components of the ankle moment differ depending on whether they are represented in the proximal, distal or global co-ordinate systems.

References

Dempster, WT. (1955) *Space requirements of the seated operator*. WADC Technical Report 55–159, Wright-Patterson Air Force Base, OH.