

Custom upper extremity model in Visual 3D

Based on International Society of Biomechanics Recommendations [1]



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Table of Contents

Contents

List of Markers.....	3
Static Posture	4
Joint Center: Shoulder.....	5
Joint Center: Elbow.....	6
Joint Center: Wrist	7
Local Coordinate Systems: Pelvis.....	10
Local Coordinate System: Trunk	11
Local Coordinate System: Right Humerus	13
Local Coordinate System: Left Humerus.....	14
Local Coordinate System: Forearm	15
Local Coordinate System: Hand	17
Joint Angles: Trunk Angle (Trunk relative to Global, Z-X-Y).....	20
Joint Angles: Shoulder Angle (Humerus relative to Trunk, Y-X-Y).....	23
Joint Angles: Elbow Angle (Forearm relative to Humerus, Z-X-Y).....	25
Joint Angles: Wrist Angle (Hand relative to Forearm, Z-X-Y)	27
Example Joint Angles: Taking can off shelf with right arm	30

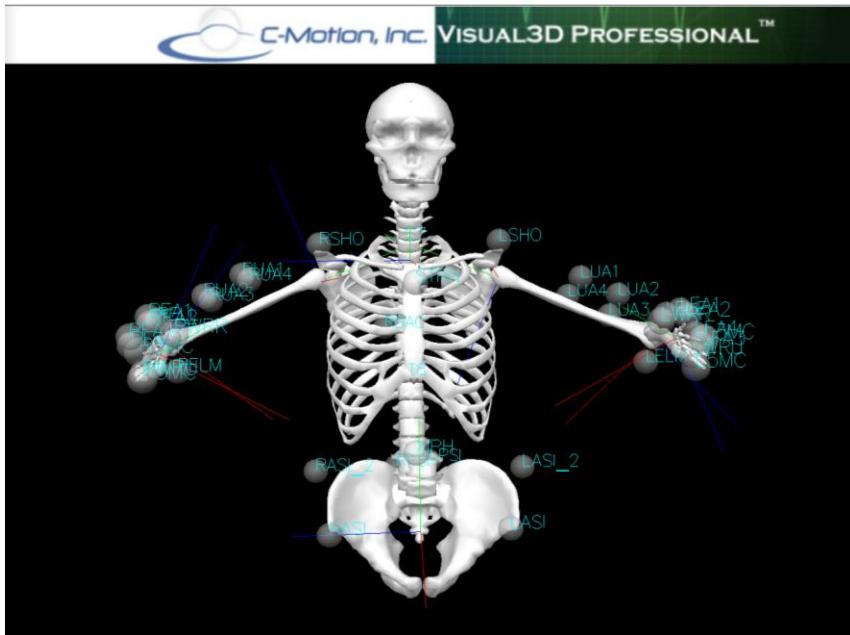
List of Markers

Marker Name	Segment / Joint	Location	Tracking only
STRN	Trunk	Suprasternal notch	
XIPH	Trunk	Xiphoid process	
C7	Trunk	7 th cervical vertebra	
T8	Trunk	8 th thoracic vertebra	
RASI	Pelvis	Right anterior superior iliac crest	
RPSI	Pelvis	Right posterior superior iliac crest	
RPSI_2	Pelvis	Right iliac crest	X
LASI	Pelvis	Left anterior superior iliac crest	
LPSI	Pelvis	Left posterior superior iliac crest	
LASI_2	Pelvis	Left iliac crest	X
RSHO	Right Humerus	Right acromion process	
RUP1	Right Humerus	Upper arm cluster	X
RUP2	Right Humerus	Upper arm cluster	X
RUP3	Right Humerus	Upper arm cluster	X
RUP4	Right Humerus	Upper arm cluster	X
RELL	Right Elbow joint	Lateral epicondyle	
RELM	Right Elbow joint	Medial epicondyle	
RFR1	Right Forearm	Forearm cluster	X
RFR2	Right Forearm	Forearm cluster	X
RFR3	Right Forearm	Forearm cluster	X
RFR4	Right Forearm	Forearm cluster	X
RWRR	Right Wrist	Most caudal-lateral point on radial styloid	
RWRU	Right Wrist	Most caudal-medial point on ulnar styloid	
R3MC	Right Hand	3 rd metacarpal head	
R5MC	Right Hand	5 th metacarpal head	
LSHO	Left Humerus	Left acromion process	
LUP1	Left Humerus	Upper arm cluster	X
LUP2	Left Humerus	Upper arm cluster	X
LUP3	Left Humerus	Upper arm cluster	X
LUP4	Left Humerus	Upper arm cluster	X
LELL	Left Elbow joint	Lateral epicondyle	
LELM	Left Elbow joint	Medial epicondyle	
LFR1	Left Forearm	Forearm cluster	X
LFR2	Left Forearm	Forearm cluster	X
LFR3	Left Forearm	Forearm cluster	X
LFR4	Left Forearm	Forearm cluster	X
LWRR	Left Wrist	Most caudal-lateral point on radial styloid	
LWRU	Left Wrist	Most caudal-medial point on ulnar styloid	
L3MC	Left Hand	3 rd metacarpal head	
L5MC	Left Hand	5 th metacarpal head	

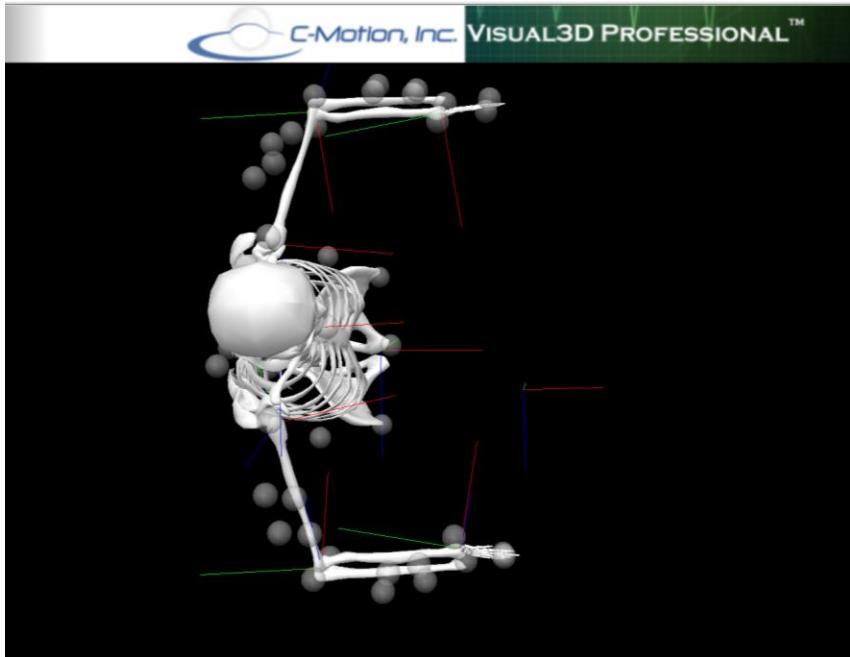
Static Posture

For the static posture, the arms are abducted, the elbows are flexed to 90 degrees and the hands are in a neutral position. The coordinate system for this model is Y up, X forward, Z right.

FRONT VIEW:



TOP DOWN VIEW:



Joint Center: Shoulder

The shoulder joint center is defined according to [2]. To determine the joint center location, the circumference of the shoulder, around the acromion and axilla was measured for each subject. From this approximated circular measurement, the radius of the shoulder was calculated:

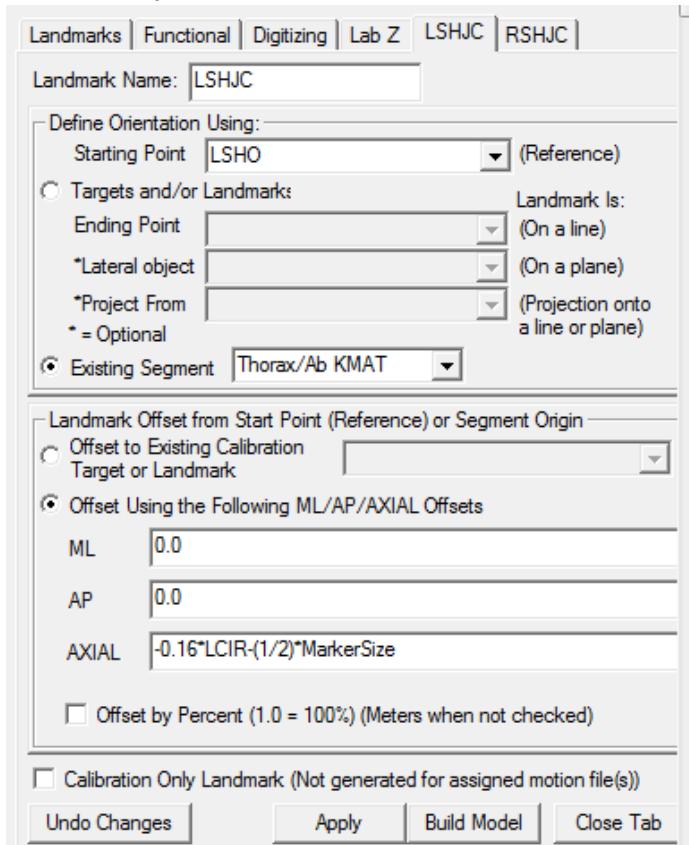
$$r = \frac{CIR}{2\pi} = 0.16 \cdot CIR$$

The joint center, SHJC, was then located inferiorly from the acromion marker, SHO, in the local coordinate system of the trunk, at the measured distance, r:

$$SHJC = SHO - r \hat{y}$$

The circumference of each arm was entered as a subject metric. RCIR = right circumference in meters, LCIR = left circumference in meters. Here, we also subtract half the height of the marker.

Left shoulder joint center (LSHJC)



Joint Center: Elbow

The elbow joint center was defined as the mid-point between the medial and lateral epicondyles during the static trial.

Visual3D Implementation:

Right Elbow Joint Center (REJC)

Segments | Landmarks | Muscles | Subject Data / Metrics

Landmarks | Functional | Digitizing | LEJC | REJC |

Landmark Name: REJC

Define Orientation Using:

Starting Point RELL (Reference)

Targets and/or Landmarks: Landmark Is:

Ending Point RELM (On a line)

*Lateral object (On a plane)

*Project From (Projection onto a line or plane)

* = Optional

Existing Segment

Landmark Offset from Start Point (Reference) or Segment Origin

Offset to Existing Calibration Target or Landmark

Offset Using the Following ML/AP/AXIAL Offsets

ML AP AXIAL 0.5

Offset by Percent (1.0 = 100%) (Meters when not checked)

Calibration Only Landmark (Not generated for assigned motion file(s))

Undo Changes Apply Build Model Close Tab

Left Elbow Joint Center (LEJC)

Segments | Landmarks | Muscles | Subject Data / Metrics

Landmarks | Functional | Digitizing | LEJC |

Landmark Name: LEJC

Define Orientation Using:

Starting Point LELL (Reference)

Targets and/or Landmarks: Landmark Is:

Ending Point LELM (On a line)

*Lateral object (On a plane)

*Project From (Projection onto a line or plane)

* = Optional

Existing Segment

Landmark Offset from Start Point (Reference) or Segment Origin

Offset to Existing Calibration Target or Landmark

Offset Using the Following ML/AP/AXIAL Offsets

ML AP AXIAL 0.5

Offset by Percent (1.0 = 100%) (Meters when not checked)

Calibration Only Landmark (Not generated for assigned motion file(s))

Undo Changes Apply Build Model Close Tab

Joint Center: Wrist

The wrist joint center was the mid-point between the ulnar and radial styloids.

Visual3D Implementation:

Right wrist joint center (RWJC)

Segments | Landmarks | Muscles | Subject Data / Metrics

Landmarks | Functional | Digitizing | LEJC | REJC | LWJC | RWJC |

Landmark Name: RWJC

Define Orientation Using:

Starting Point: RWRU (Reference)
Targets and/or Landmarks:
Ending Point: RWRR (On a line)
*Lateral object:
*Project From:
* = Optional
Existing Segment:

Landmark Offset from Start Point (Reference) or Segment Origin

Offset to Existing Calibration Target or Landmark
Offset Using the Following ML/AP/AXIAL Offsets
ML: [] AP: [] AXIAL: [0.5]
 Offset by Percent (1.0 = 100%) (Meters when not checked)

Calibration Only Landmark (Not generated for assigned motion file(s))

Undo Changes | Apply | Build Model | Close Tab

Left wrist joint center (LWJC)

Segments | Landmarks | Muscles | Subject Data / Metrics

Landmarks | Functional | Digitizing | LEJC | REJC | LWJC |

Landmark Name: LWJC

Define Orientation Using:

Starting Point: LWRU (Reference)
Targets and/or Landmarks:
Ending Point: LWRR (On a line)
*Lateral object:
*Project From:
* = Optional
Existing Segment:

Landmark Offset from Start Point (Reference) or Segment Origin

Offset to Existing Calibration Target or Landmark
Offset Using the Following ML/AP/AXIAL Offsets
ML: [] AP: [] AXIAL: [0.5]
 Offset by Percent (1.0 = 100%) (Meters when not checked)

Calibration Only Landmark (Not generated for assigned motion file(s))

Undo Changes | Apply | Build Model | Close Tab

Joint Center: Hand (3MC)

The hand joint center was calculated according to Rao et al [3]. First, we define a unit vector from the ulnar styloid (RWRU) to the radial styloid (RWRR).

$$\vec{j}_h = \frac{\overrightarrow{RWRR} - \overrightarrow{RWRU}}{\|\overrightarrow{RWRR} - \overrightarrow{RWRU}\|}$$

\vec{i}_h is perpendicular to the plane containing RWRU, RWRR, and the fifth metacarpal head (R5MC)

$$\overrightarrow{k_{temp}} = \frac{\overrightarrow{RWRR} - \overrightarrow{R5MC}}{\|\overrightarrow{RWRR} - \overrightarrow{R5MC}\|}$$

$$\overrightarrow{l_h} = \vec{j}_h \times \overrightarrow{k_{temp}}$$

$$\overrightarrow{k_h} = \overrightarrow{l_h} \times \vec{j}_h$$

Now we define a new plane with the third metacarpal

$$\overrightarrow{k_{temp}} = \frac{\overrightarrow{RWRR} - \overrightarrow{R3MC}}{\|\overrightarrow{RWRR} - \overrightarrow{R3MC}\|}$$

$$\overrightarrow{l_{h2}} = \vec{j}_h \times \overrightarrow{k_{temp}}$$

$$\overrightarrow{k_{h2}} = \overrightarrow{l_{h2}} \times \vec{j}_h$$

Then we rotate the second plane about j_h until it lies in the first plane

$$\theta = \overrightarrow{l_{h2}} \cdot \overrightarrow{j_h}$$

$$R3JC = \begin{bmatrix} \cos(\theta) & 0 & -\sin(\theta) \\ 0 & 1 & 0 \\ \sin(\theta) & 0 & \cos(\theta) \end{bmatrix} \cdot R3MC$$

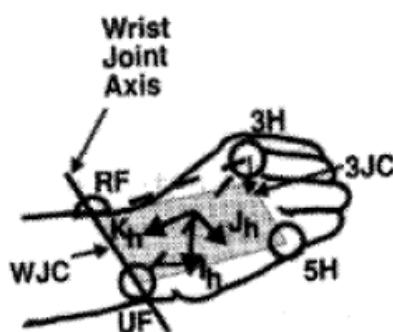


Illustration of the local coordinate system of the hand from Rao {Rao 1996}

Visual3D Implementation

Segments | Landmarks | Muscles | Subject Data / Metrics

Landmarks | Functional | Digitizing | 3JC | WJC

Landmark Name: R3JC

Define Orientation Using:

Starting Point RWRR (Reference)

Targets and/or Landmarks: Ending Point RWRU (On a line)
*Lateral object R5MC (On a plane)
*Project From R3MC (Projection onto a line or plane)
* = Optional

Existing Segment

Landmark Offset from Start Point (Reference) or Segment Origin

Offset to Existing Calibration Target or Landmark

Offset Using the Following ML/AP/AXIAL Offsets

ML [] AP [] AXIAL []

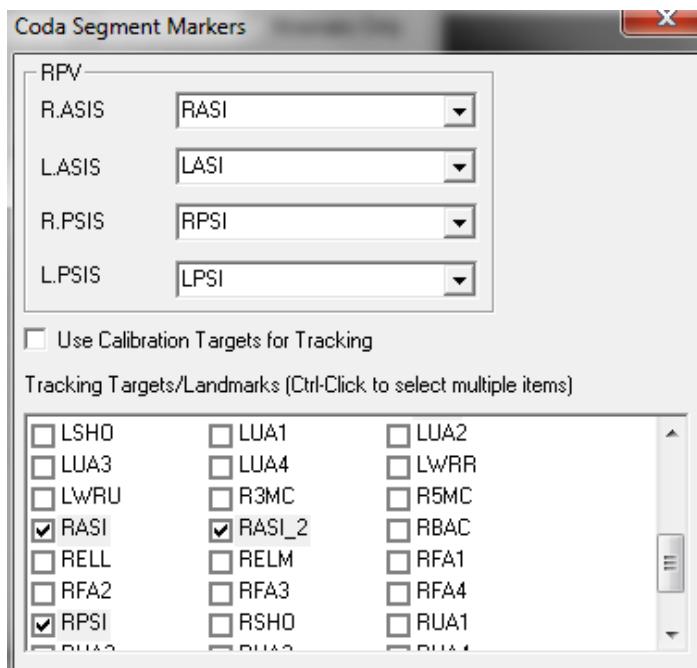
Offset by Percent (1.0 = 100%) (Meters when not checked)

Calibration Only Landmark (Not generated for assigned motion file(s))

Undo Changes | Apply | Build Model | Close Tab

Local Coordinate Systems: Pelvis

Here we use a standard CODA pelvis with the iliac crest markers (RASI_2, LPSI_2) for additional tracking.



Local Coordinate System: Trunk

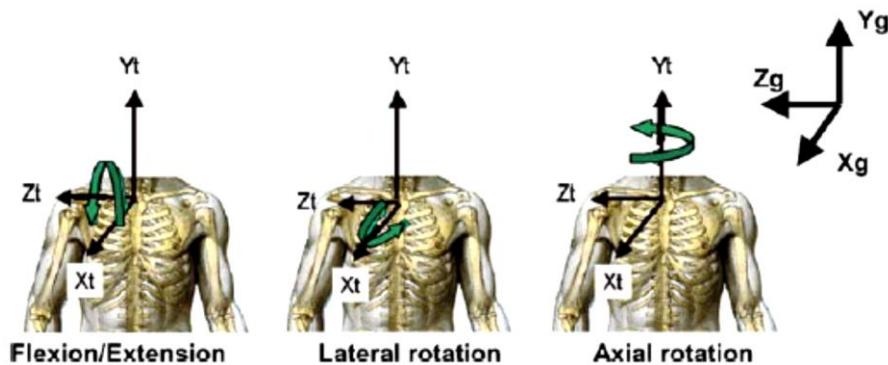
ISB Recommendation

O_t: The origin coincident with the sternum (STRN)

Y_t : The line connecting the midpoint between XIPH and T8 and the midpoint between STRN and C7, pointing upward

Z_t: The line perpendicular to the plane formed by STRN, C7, and the midpoint between XIPH and T8, pointing to the right

X_t: The common line perpendicular to the Z_t and Y_t axis, pointing forward



Visual3D Implementation

To define the segmental axes, we first calculate 2 landmarks.

1) midStrnC7: The mid-point between the STRN and C7 markers:

Landmarks | Functional | Digitizing **midStrnC7**

Landmark Name: **midStrnC7**

Define Orientation Using:

Starting Point **C7** (Reference)

Targets and/or Landmark:
Ending Point **STRN** (On a line)
*Lateral object
*Project From
* = Optional

Existing Segment

Landmark Offset from Start Point (Reference) or Segment Origin

Offset to Existing Calibration Target or Landmark

Offset Using the Following ML/AP/AXIAL Offsets

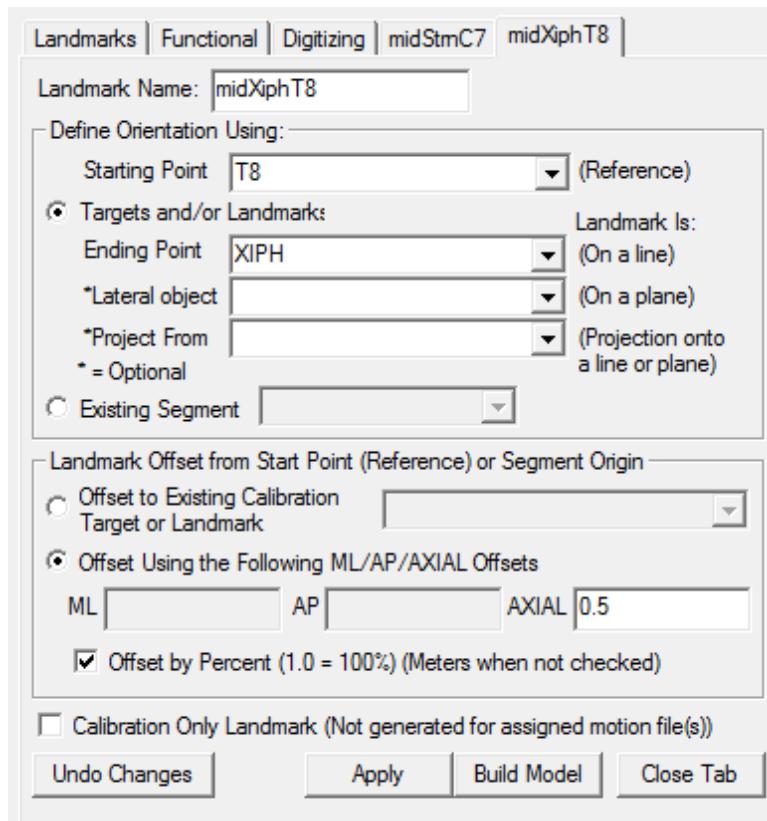
ML **0.0** AP **0.0** AXIAL **0.5**

Offset by Percent (1.0 = 100%) (Meters when not checked)

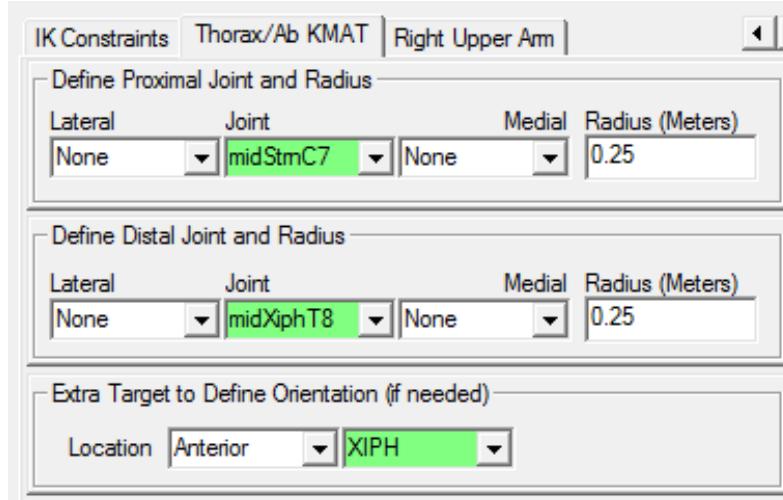
Calibration Only Landmark (Not generated for assigned motion file(s))

Undo Changes Apply Build Model Close Tab

2) midXiphT8: The midpoint between the xiphoid and T8 markers



These landmarks are then used to create the local coordinate system:



The motion of the local coordinate systems is tracked using the following markers:

1. STRN
2. XIPH
3. C7
4. T8

Local Coordinate System: Right Humerus

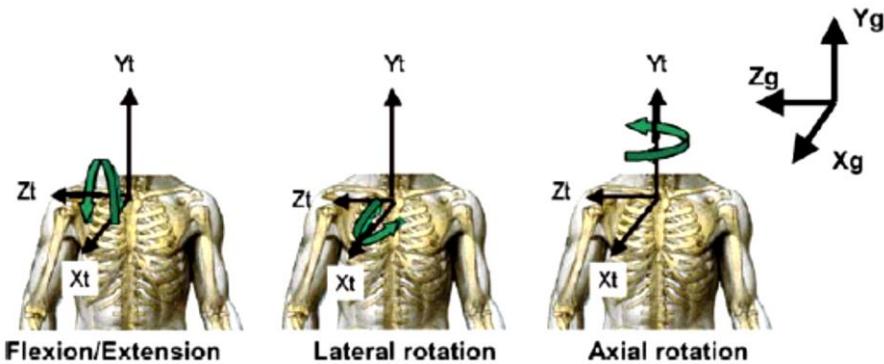
ISB Recommendation

The coordinate system of the humerus was defined using the 2nd option of ISB recommendations

Y_h : The line connecting the shoulder joint center (SHJC) and the elbow joint (EJC) center pointing toward SHJC

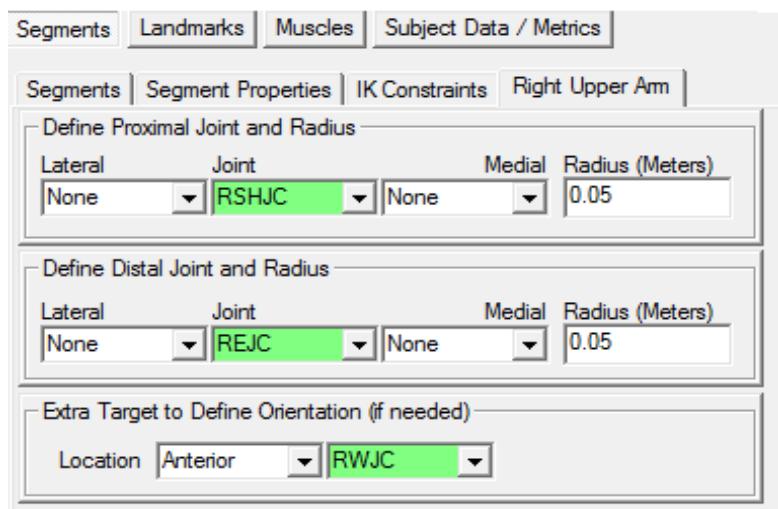
Z_h : The common line perpendicular to the plane formed by Y_h and Y_f , pointing to the right.

X_h : The common line perpendicular to the Z_h and Y_h -axis, pointing forward



Visual3D Implementation

The RSHJC, REJC, RWJC landmarks are used to create the local coordinate system:



The motion of the local coordinate systems is tracked using the following markers:

1. RUP1
2. RUP2
3. RUP3
4. RUP4

Local Coordinate System: Left Humerus

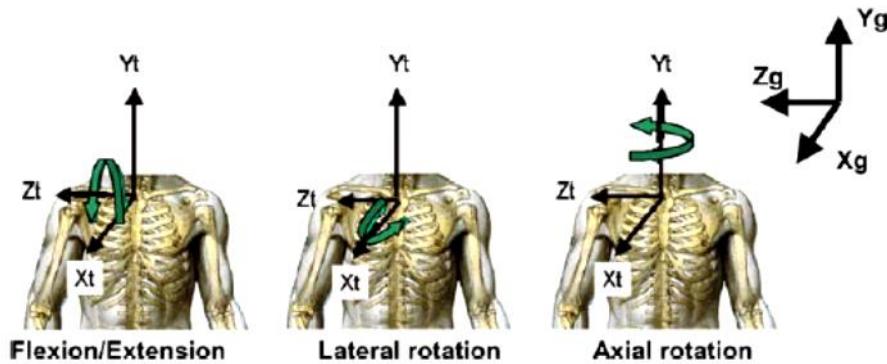
ISB Recommendation

The coordinate system of the humerus was defined using the 2nd option of ISB recommendations

Y_h : The line connecting the shoulder joint center (SHJC) and the elbow joint (EJC) center pointing toward SHJC

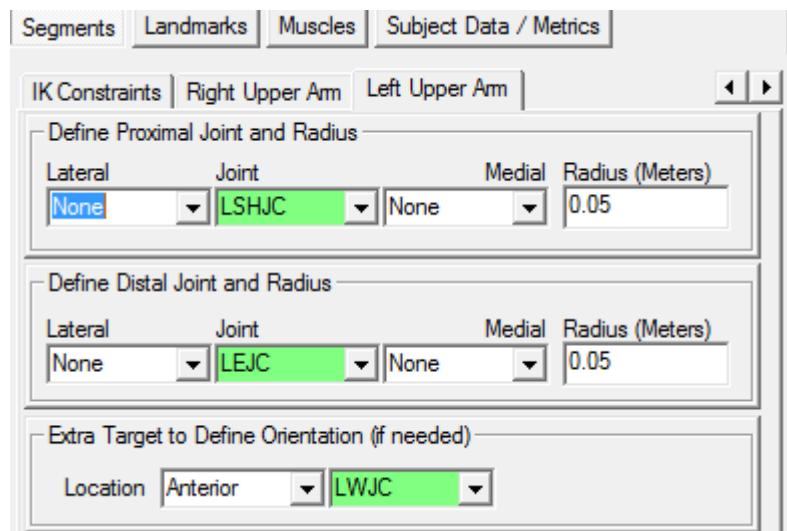
Z_h : The common line perpendicular to the plane formed by Y_h and Y_f , pointing to the right.

X_h : The common line perpendicular to the Z_h and Y_h -axis, pointing forward



Visual3D Implementation

The LSHJC, LEJC, LWJC landmarks are used to create the local coordinate system:



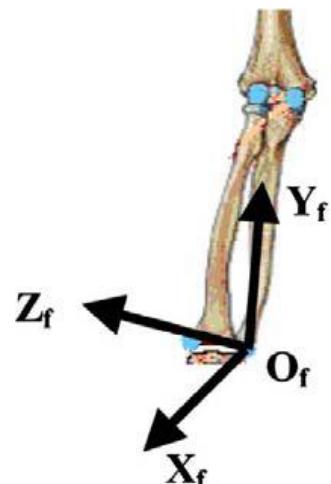
The motion of the local coordinate systems is tracked using the following markers:

1. LUP1
2. LUP2
3. LUP3
4. LUP4

Local Coordinate System: Forearm

ISB Recommendation

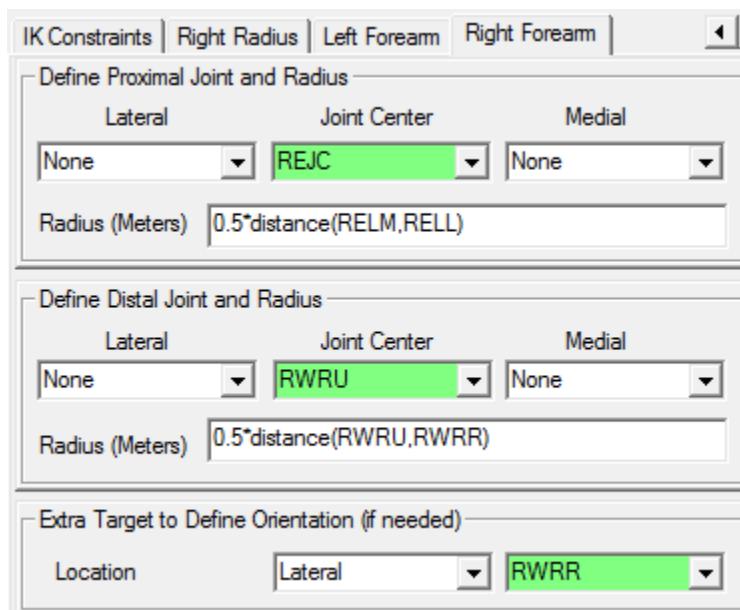
- O_f: The origin is at the ulnar styloid
Y_f: The line connecting the ulnar styloid to the joint center of the elbow pointing proximally
X_f: The line perpendicular to the plane through the ulnar styloid, radial styloid and midpoint between lateral and medial epicondyles, pointing forward
Z_f: The common line perpendicular to the X_f and Y_f axis, pointing to the right



Visual3D Implementation

Right Forearm

The REJC landmark and the two wrist markers (RWRU, RWRR) are used to create the local coordinate system:



The screenshot shows the 'Right Forearm' tab selected in the top navigation bar. The dialog is divided into three sections: 'Define Proximal Joint and Radius', 'Define Distal Joint and Radius', and 'Extra Target to Define Orientation (if needed)'. In the first section, 'Joint Center' is set to 'REJC'. In the second section, 'Joint Center' is set to 'RWRU'. In the third section, 'Location' is set to 'Lateral' and 'Target' is set to 'RWRR'.

The motion of the local coordinate system is tracked using the following markers:

1. RFR1
2. RFR2
3. RFR3
4. RFR4

Optional

5. RWRR
6. RWRU

Left Forearm

Define Proximal Joint and Radius		
Lateral	Joint Center	Medial
None	LEJC	None
Radius (Meters) $0.5 * \text{distance}(LLEM, LELL)$		
Define Distal Joint and Radius		
Lateral	Joint Center	Medial
None	LWRU	None
Radius (Meters) $0.5 * \text{distance}(LWRU, LWRR)$		
Extra Target to Define Orientation (if needed)		
Location	Lateral	LWRR

The motion of the local coordinate system is tracked using the following markers:

1. LFR1
2. LFR2
3. LFR3
4. LFR4

Optional

5. LWRR
6. LWRU

Local Coordinate System: Radius

The coordinate system of the hand was defined according to ISB recommendations. This segment is equivalent to the forearm, except that the Y-axis runs from the elbow to the wrist joint center, rather than ulnar styloid. This segment is used for determining wrist motion.

IK Constraints Right Radius Left Forearm Right Forearm

Define Proximal Joint and Radius

Lateral	Joint Center	Medial
None	REJC	None

Radius (Meters) $0.5 * \text{distance}(RELM, RELL)$

Define Distal Joint and Radius

Lateral	Joint Center	Medial
None	RWJC	None

Radius (Meters) $0.5 * \text{distance}(RWRR, RWRU)$

Extra Target to Define Orientation (if needed)

Location	Lateral	Medial
Location	Lateral	RWRR

Local Coordinate System: Hand

Recommendation

The coordinate system of the hand was defined according to Rao et al. (Rao et al., 1996).

Y_h : The line from the wrist joint center (WJC) to 3JC

X_h : The line perpendicular to the plane formed by Y_h , radial styloid and ulnar styloid

Z_h : The common line perpendicular to the X_h and Y_h axis

Visual3D Implementation

The two wrist markers and the two hand markers are used to create the local coordinate system:

Right Hand:

The screenshot shows three stacked configuration panels for defining the right hand's local coordinate system in Visual3D:

- Define Proximal Joint and Radius:** This panel defines the proximal joint as the Wrist Joint Center (RWJC). The radius is set to 0.5 times the distance between the RWRU and RWRR markers.
- Define Distal Joint and Radius:** This panel defines the distal joint as the 3rd Metacarpal Center (R3JC). The radius is set to the distance between the R5MC and R3MC markers.
- Extra Target to Define Orientation (if needed):** This panel specifies an extra target, the RWRR marker, to define the orientation of the hand segment.

This segment is tracked using the following markers and landmarks:

1. RWJC
2. R5MC
3. R3MC

Left Hand:

Define Proximal Joint and Radius		
Lateral	Joint Center	Medial
None	LWJC	None
Radius (Meters) <input type="text" value="0.5*distance(LWRU,LWRR)"/>		
Define Distal Joint and Radius		
Lateral	Joint Center	Medial
None	L3JC	None
Radius (Meters) <input type="text" value="distance(L5MC,L3MC)"/>		
Extra Target to Define Orientation (if needed)		
Location	Medial	LWRR

This segment is tracked using the following markers:

1. LWRU
2. LWRR
3. L5MC
4. L3MC

Joint Angles: Trunk Angle (Trunk relative to Global, X-Y-Z)

Motion of the thorax relative to the global coordinate system (X-Y-Z order).

e1: The common axis perpendicular to e1 and e3, i.e., the rotated X_t -axis of the thorax.

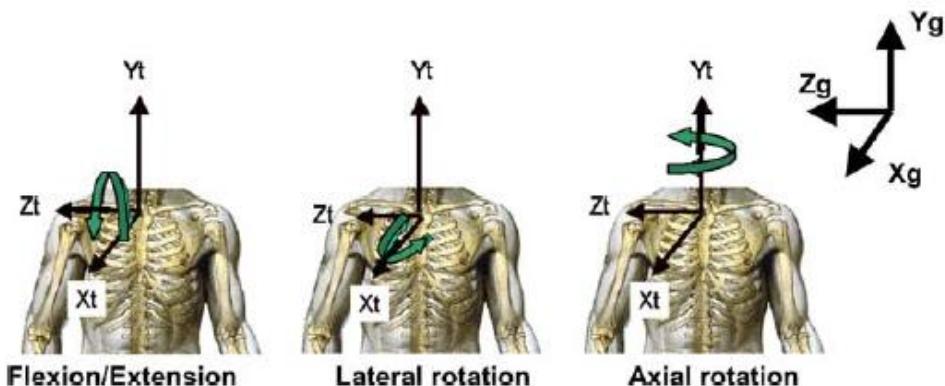
Rotation (X-axis): Lateral flexion rotation of the thorax, to the right is positive, to the left is negative.

e2: The axis fixed to the thorax and coincident with the Y_t -axis of the thorax coordinate system.

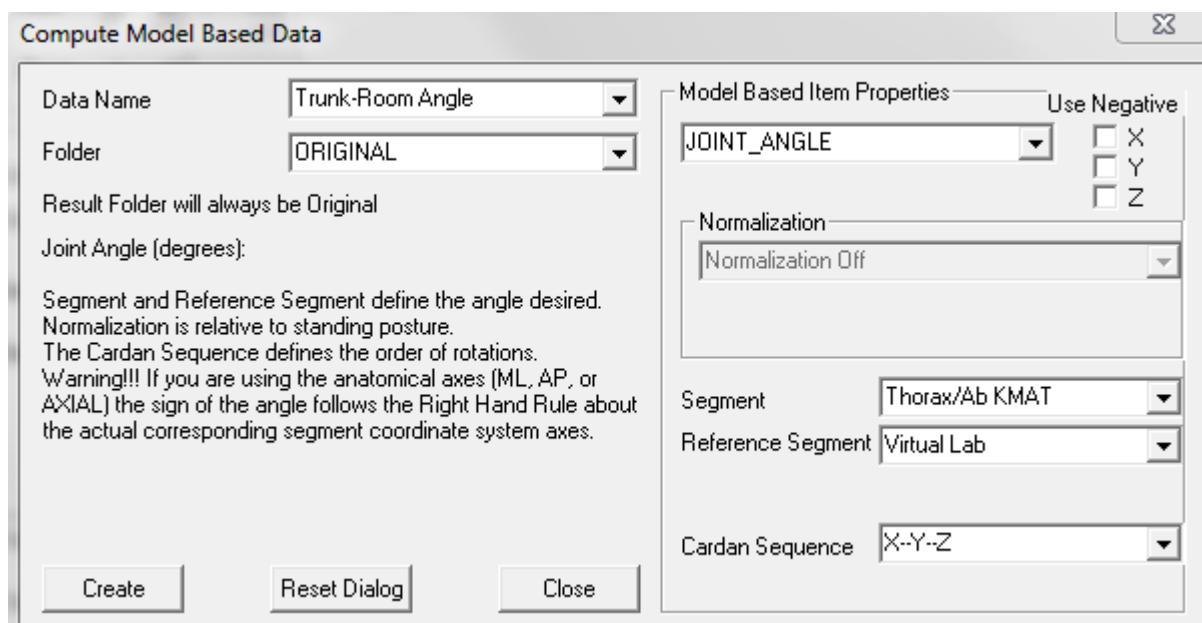
Rotation (Y-axis): Axial rotation to the left (positive) or to the right (negative).

e3: The axis coincident with the Z_g -axis of the global coordinate system.

Rotation (Z-axis): Flexion (negative) or extension (positive).

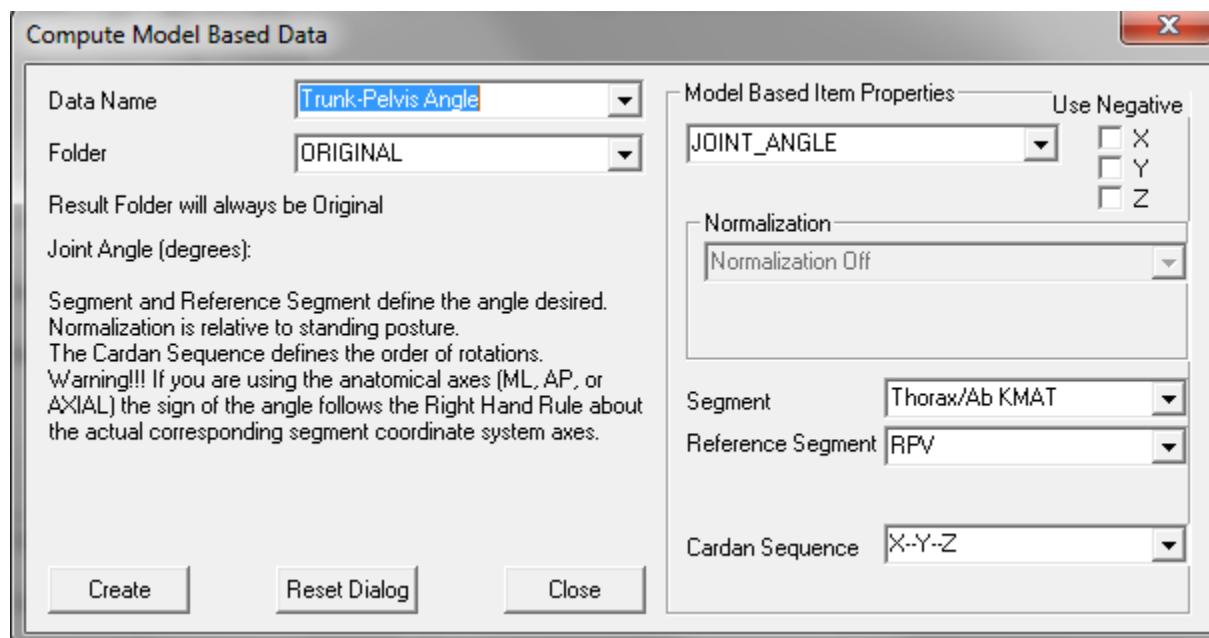


Visual3D Implementation

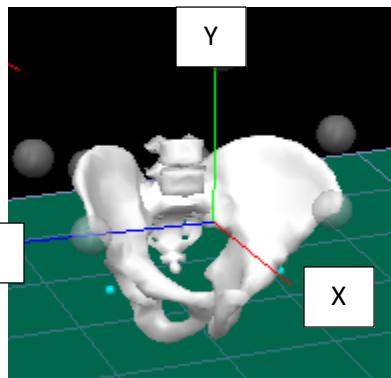


Joint Angles: Trunk-Pelvis Angle (Trunk relative to Pelvis, X-Y-Z)

Motion of the thorax relative to the pelvis coordinate system: ‘lateral flexion (X)’ – ‘axial rotation (Y)’ - ‘flexion/extension (Z)’.



Joint Angles: Pelvic Angle (Pelvis relative to global, Y-X-Z)



Motion of the pelvis relative to the global coordinate system:

‘Pelvic rotation (Y)’ – right forward (+) / right back (-)

‘Obliquity (X)’ – right up (+) / right down (-)

‘Pelvic tilt (Z)’ – anterior (+) / posterior (-)

Compute Model Based Data

Data Name: <input type="text" value="Pelvic Angle"/>	Model Based Item Properties: <input type="text" value="JOINT_ANGLE"/>	Use Negative: <input type="checkbox"/> X <input type="checkbox"/> Y <input type="checkbox"/> Z
Folder: <input type="text" value="ORIGINAL"/>	Normalization: <input type="text" value="Normalization Off"/>	
Result Folder will always be Original		
Joint Angle (degrees):		
Segment and Reference Segment define the angle desired. Normalization is relative to standing posture. The Cardan Sequence defines the order of rotations. Warning!!! If you are using the anatomical axes (ML, AP, or AXIAL) the sign of the angle follows the Right Hand Rule about the actual corresponding segment coordinate system axes.		
<input type="button" value="Create"/>	<input type="button" value="Reset Dialog"/>	<input type="button" value="Close"/>

Joint Angles: Shoulder Angle (Humerus relative to Trunk, Y'-X-Y'')

ISB Recommendation

- e1: The axis fixed to the thorax and coincident with the Y_t -axis of the thorax coordinate system.
Rotation (Y-axis): Plane of elevation, 0° is abduction, 90° is forward flexion.
- e2: The axis fixed to the humerus and coincident with the X_h -axis of the humerus coordinate system.
Rotation (X-axis): elevation (negative).
- e3: Axial rotation around the Y_h -axis.
Rotation (Y-axis): axial rotation, internal rotation (positive) and external rotation (negative).

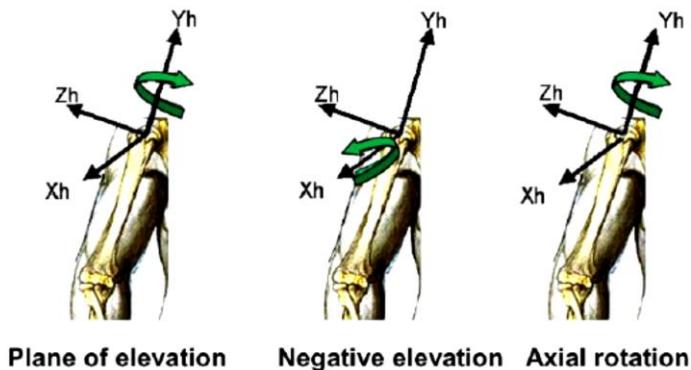
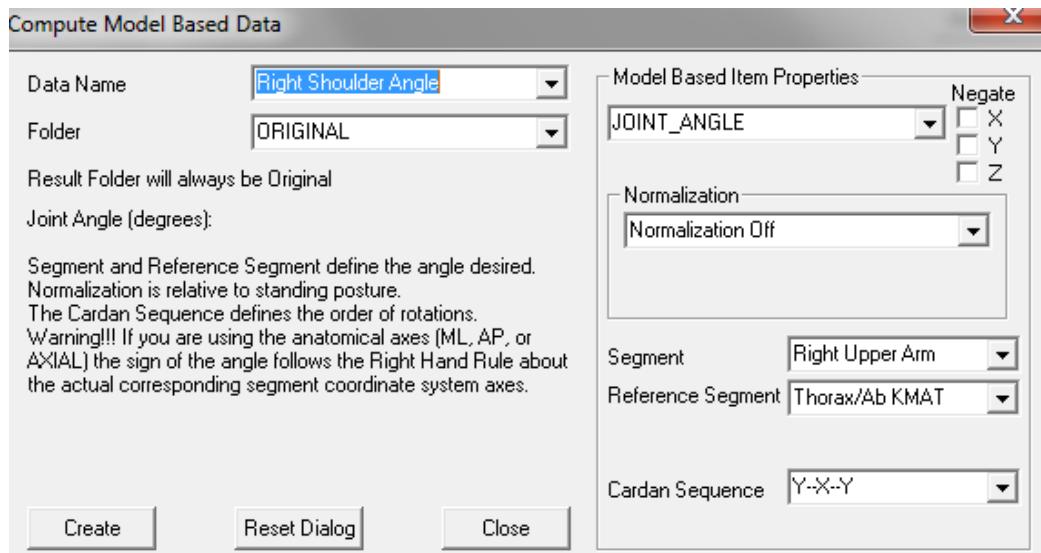


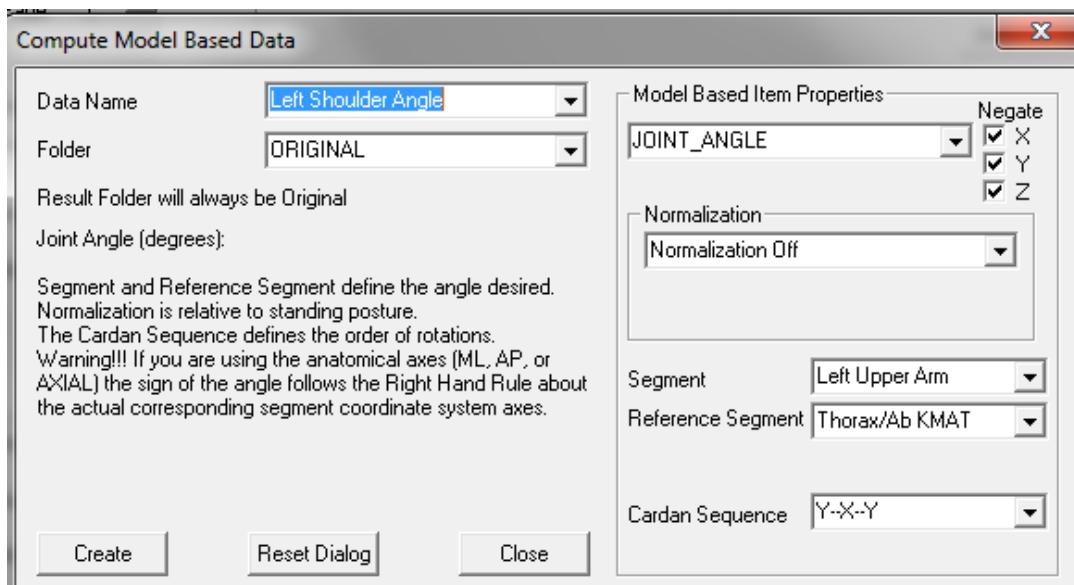
Fig. 7. Definition of thoracohumeral rotations.

Visual3D Implementation

Right Arm



Left Arm



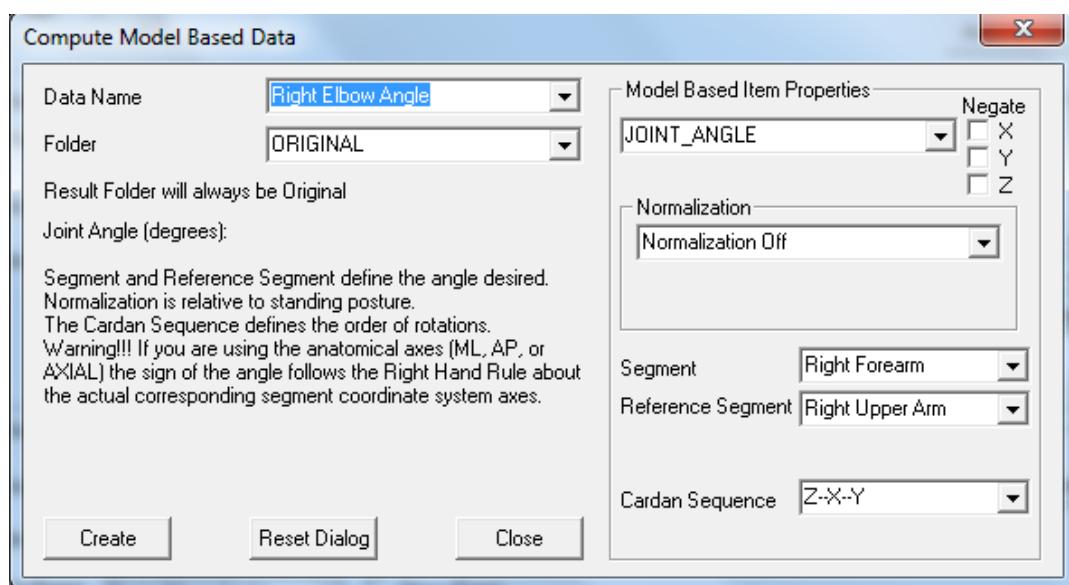
Joint Angles: Elbow Angle (Forearm relative to Humerus, Z-X-Y)

ISB Recommendation

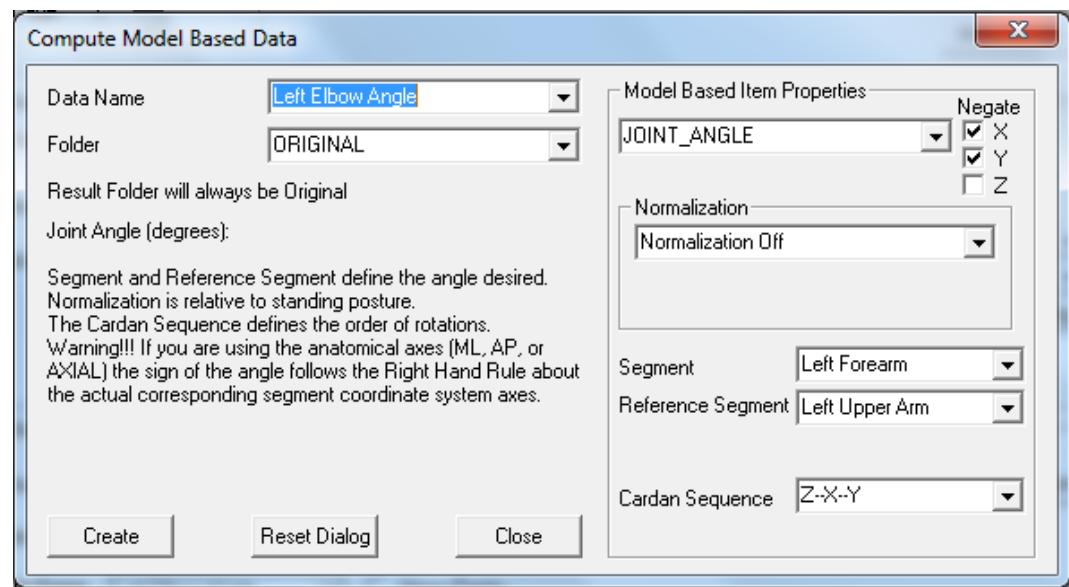
- e1: The axis fixed to the proximal segment and coincident with the Zh-axis of the humerus coordinate system (preferably an approximation of the elbow flexion/extension axis).
Rotation (Z-axis): flexion (positive) and hyperextension (negative).
- e2: The floating axis, the common axis perpendicular to e1 and e3, the rotated Xf -axis of the forearm coordinate system.
Rotation (Y-axis): carrying angle, the angle between the longitudinal axis of the forearm and the plane perpendicular to the flexion/extansion axis.
- e3: The axis fixed to the distal segment and coincident with the Yf -axis of the forearm coordinate system.
Rotation (X-axis): axial rotation of the forearm. *

Visual3D Implementation

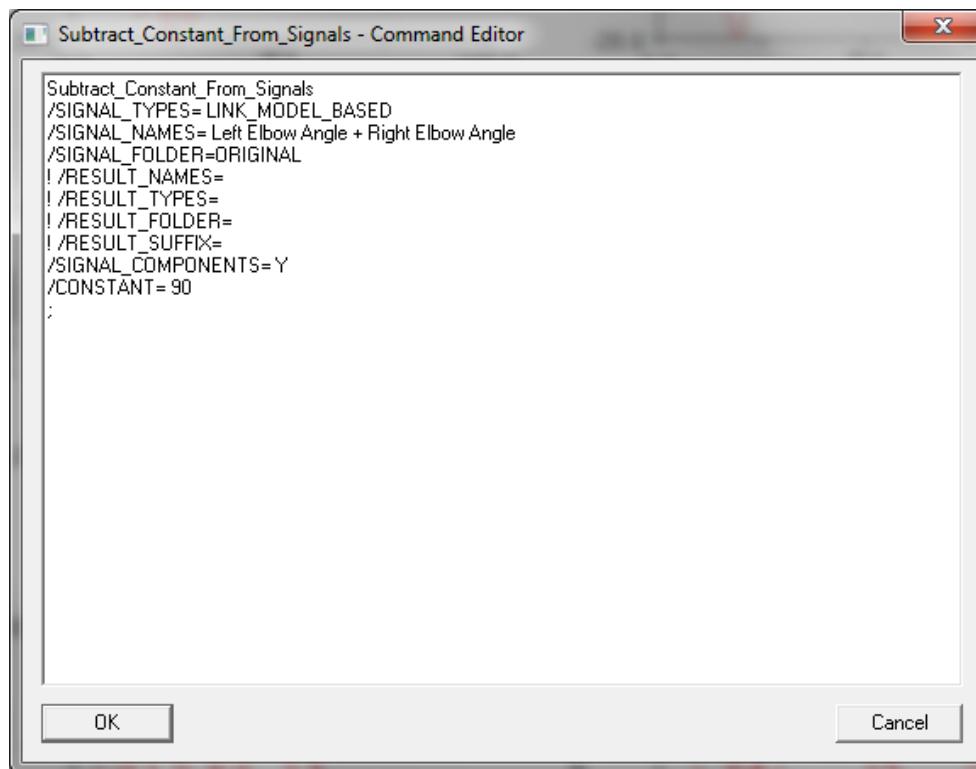
Right Arm



Left Arm



* Zero degrees of rotation is defined to be at the neutral forearm position. Pronation is a positive rotation while supination is a negative rotation. To translate this, we subtract 90 degrees from the measured elbow angle from the Y-rotation.



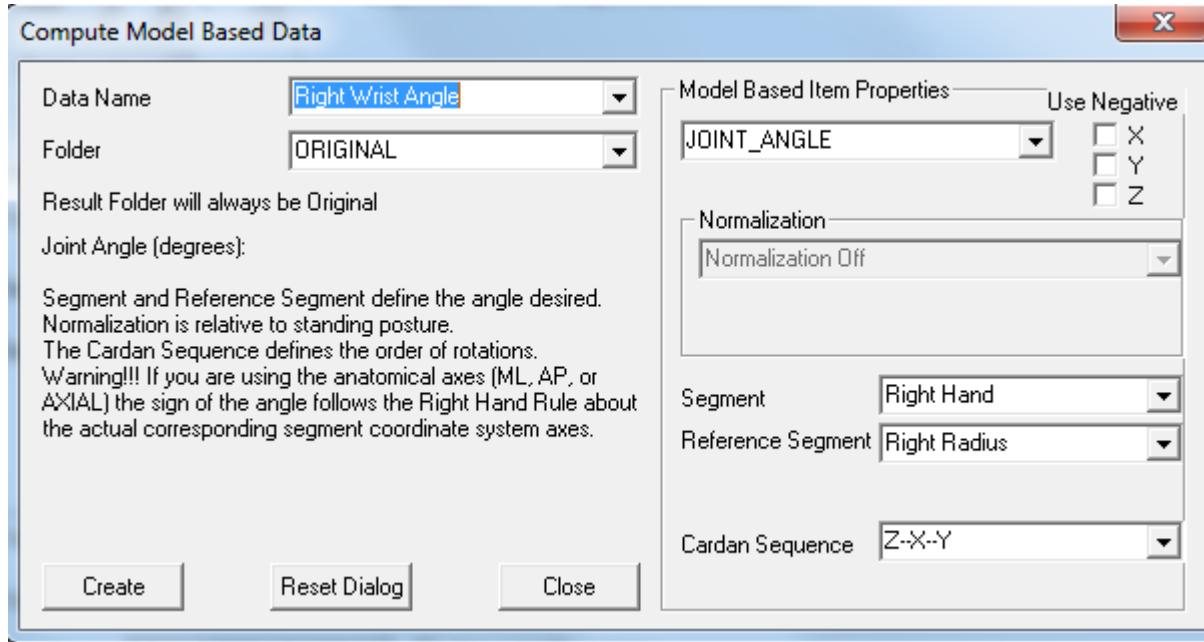
Joint Angles: Wrist Angle (Hand relative to Radius, Z-X-Y)

ISB Recommendation (4.4.1. JCS and motion for the interphalangeal, metacarpophalangeal, intercarpal, radiocarpal, and carpometacarpal joints)

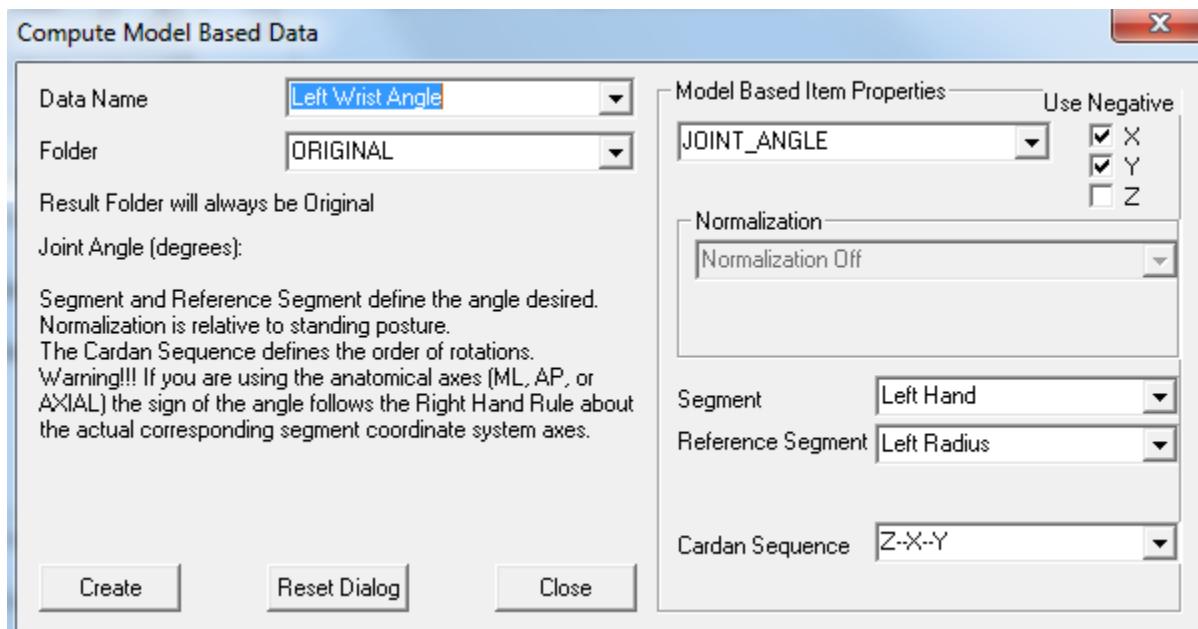
- e1: The axis fixed to the proximal segment and coincident with the Z-axis of the proximal segment coordinate system.
Rotation (Z-axis): flexion (positive) or extension (negative)
- e2: The common axis perpendicular to e1 and e3.
Rotation (X-axis): adduction or abduction, or radial or ulnar deviation (ulnar deviation is positive).
- e3: The axis fixed to the distal segment and coincident with the Y-axis of the distal segment coordinate system.
Rotation (Y-axis): rotation (pronation–supination).

Visual3D Implementation

Right Arm



Left Arm



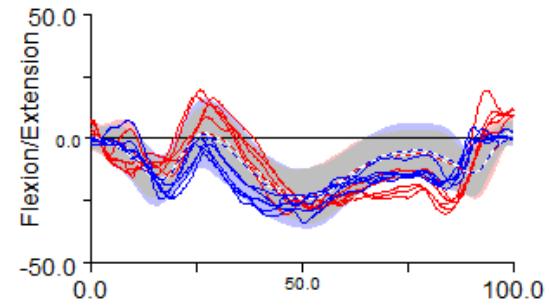
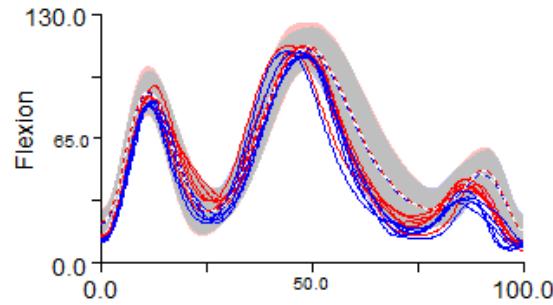
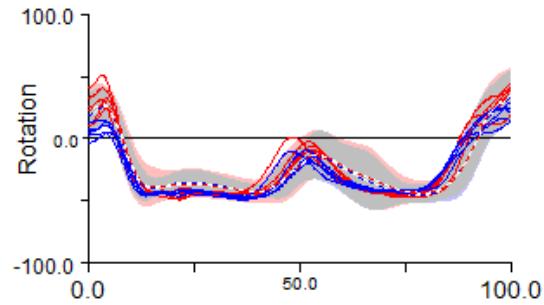
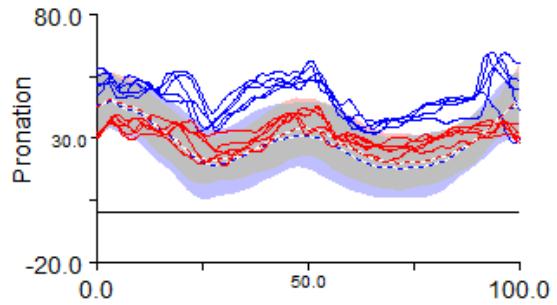
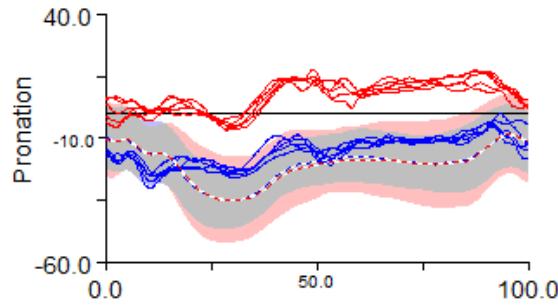
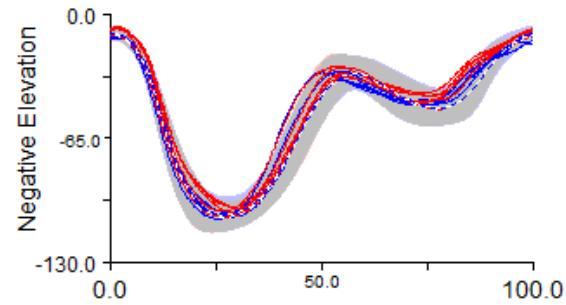
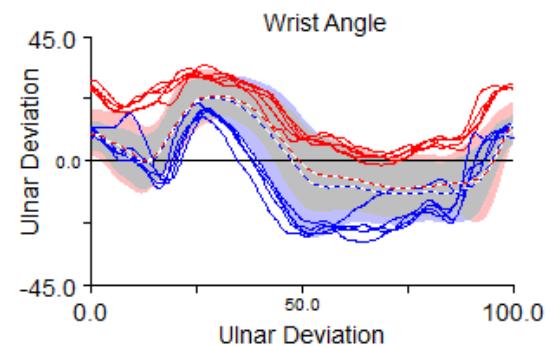
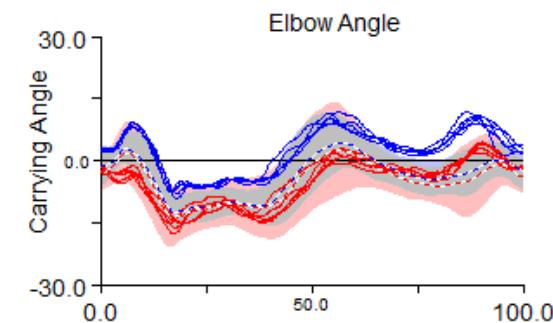
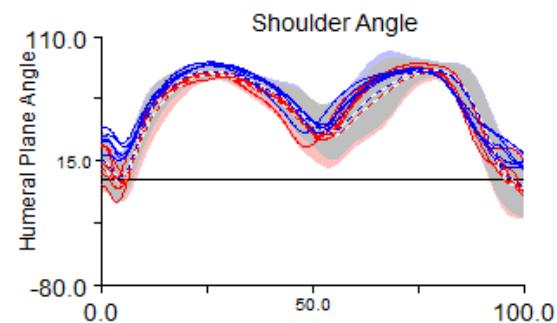
References

- [1] Wu G, van der Helm FC, Veeger HE, Makhsoos M, Van Roy P, Anglin C, Nagels J, Karduna AR, McQuade K, Wang X, Werner FW, Buchholz B, ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion--Part II: shoulder, elbow, wrist and hand. *J Biomech*, 2005; 38: 981-992.
- [2] Hingtgen B, McGuire JR, Wang M, Harris GF, An upper extremity kinematic model for evaluation of hemiparetic stroke. *J Biomech*, 2006; 39: 681-8.
- [3] Rao SS, Bontrager EL, Gronley JK, Newsam CJ, Perry J, Three-dimensional kinematics of wheelchair propulsion. *IEEE Trans Rehabil Eng*, 1996; 4: 152-60.

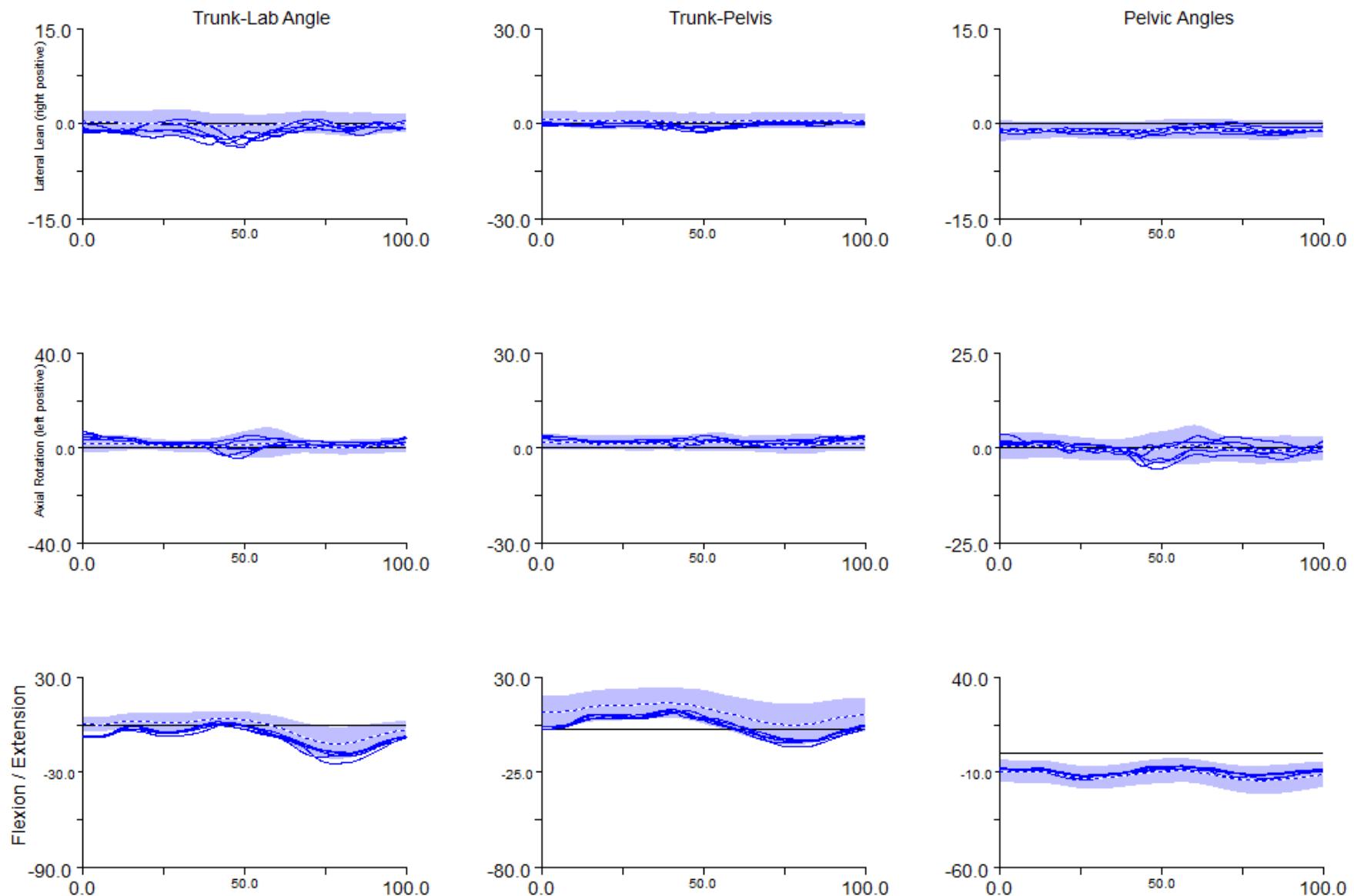
Example Joint Angles: Box off shelf task

Right arm is shown in red, while the left arm is shown in blue. Data are shown as a percent of the total movement time.

Box Off Shelf - Arm Angles



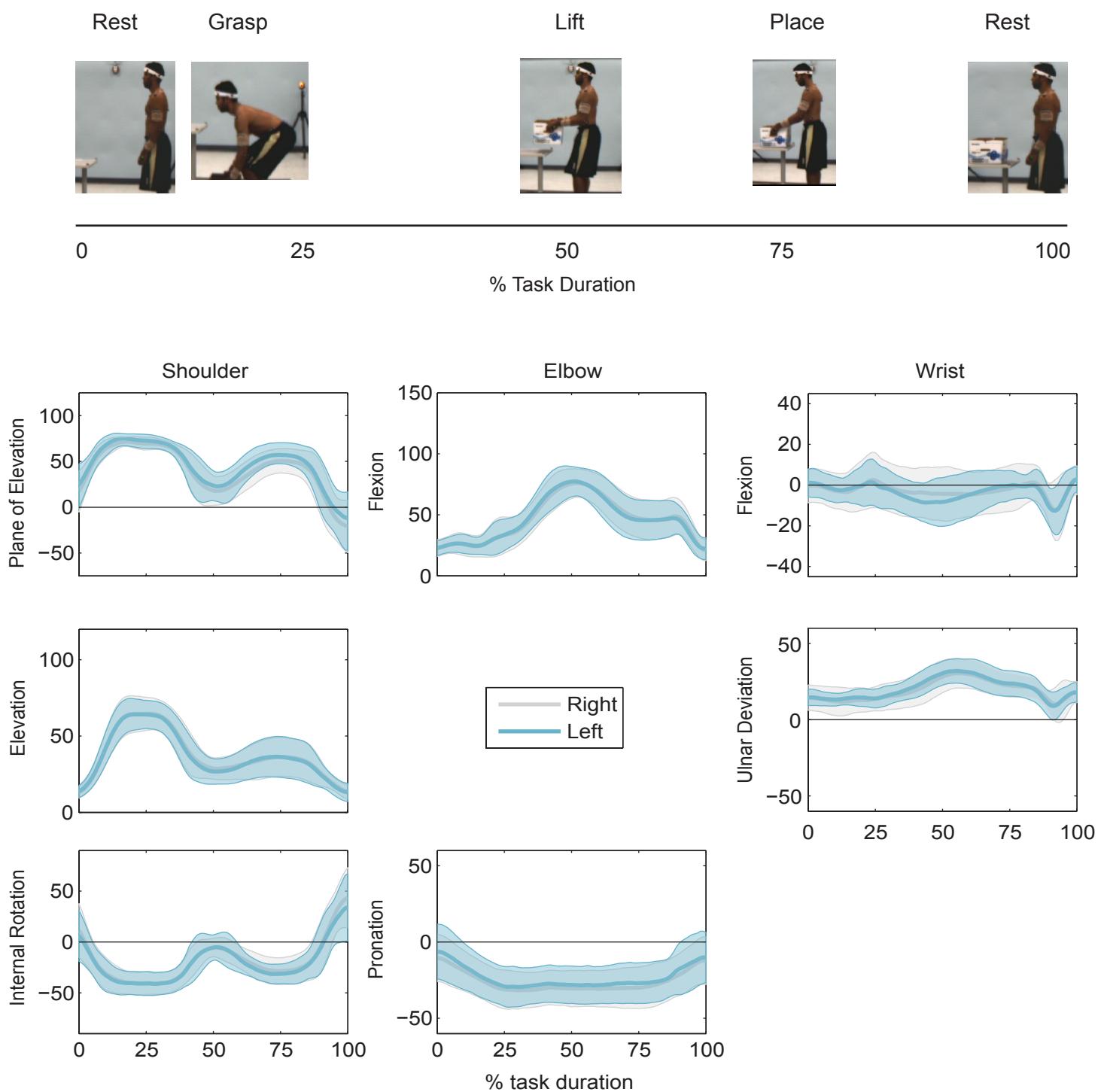
Box Off Shelf - Trunk Pelvis



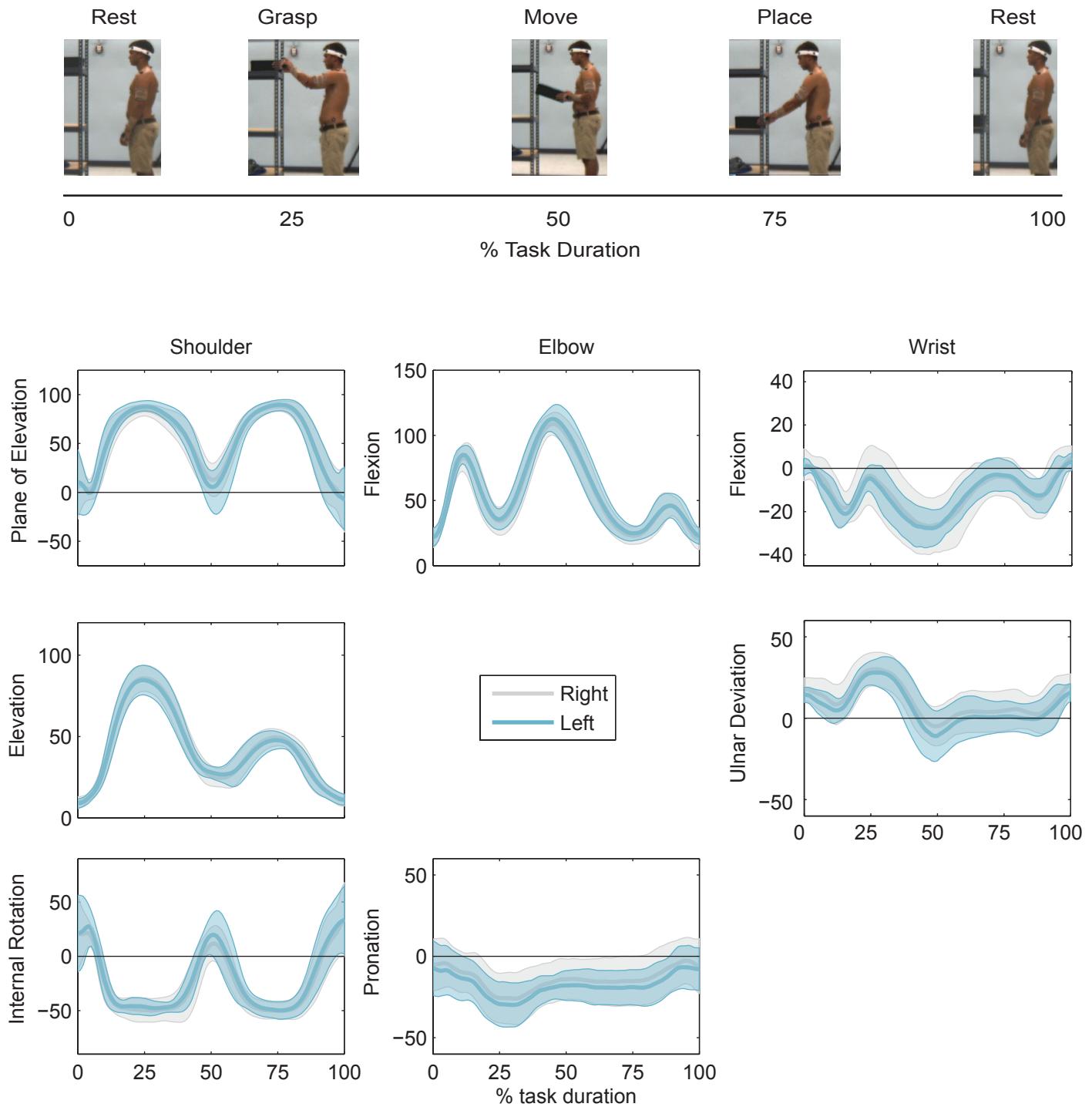
Suggested citation: Gates, D. H., Smurr Walters, L., Cowley, J., Wilken, J. M., & Resnik, L. (2016). Brief Report—Range of motion requirements for upper-limb activities of daily living (Suppl. Appendix 1). *American Journal of Occupational Therapy*, 70, 7001350010. <http://dx.doi.org/10.5014/ajot.2016.015487>

Supplemental Appendix 2. Figures for All Tasks

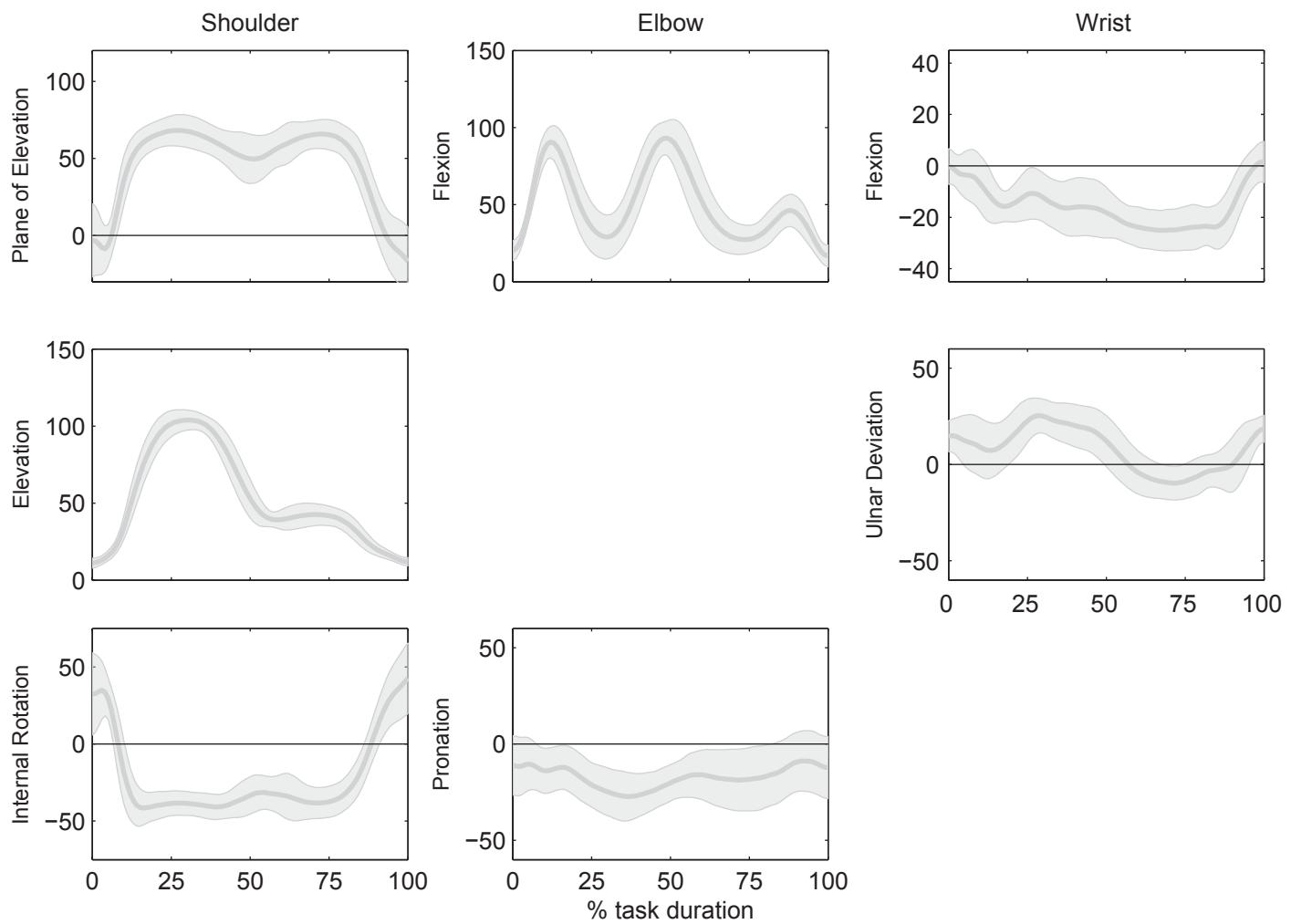
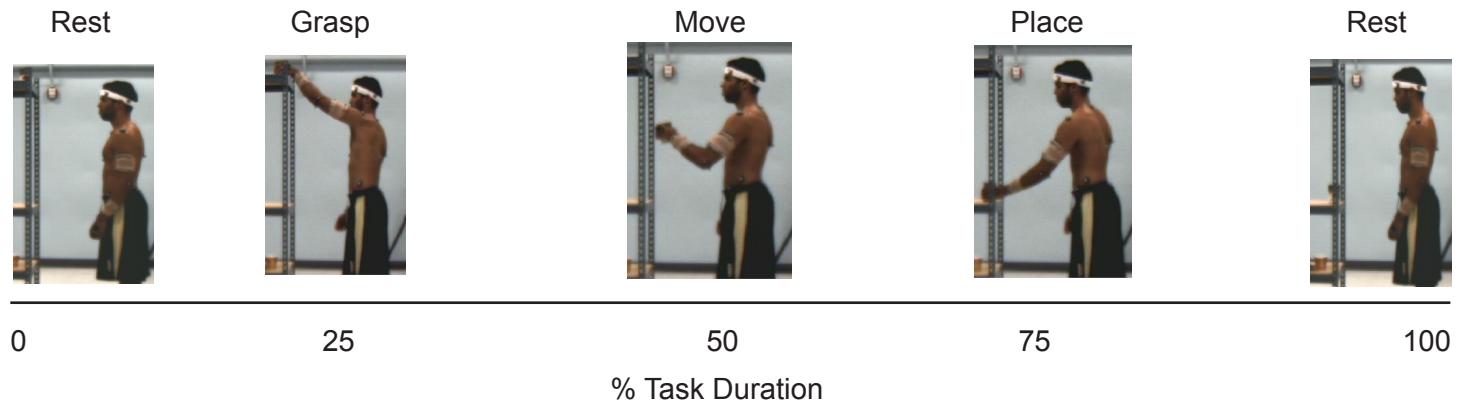
Box off ground task.



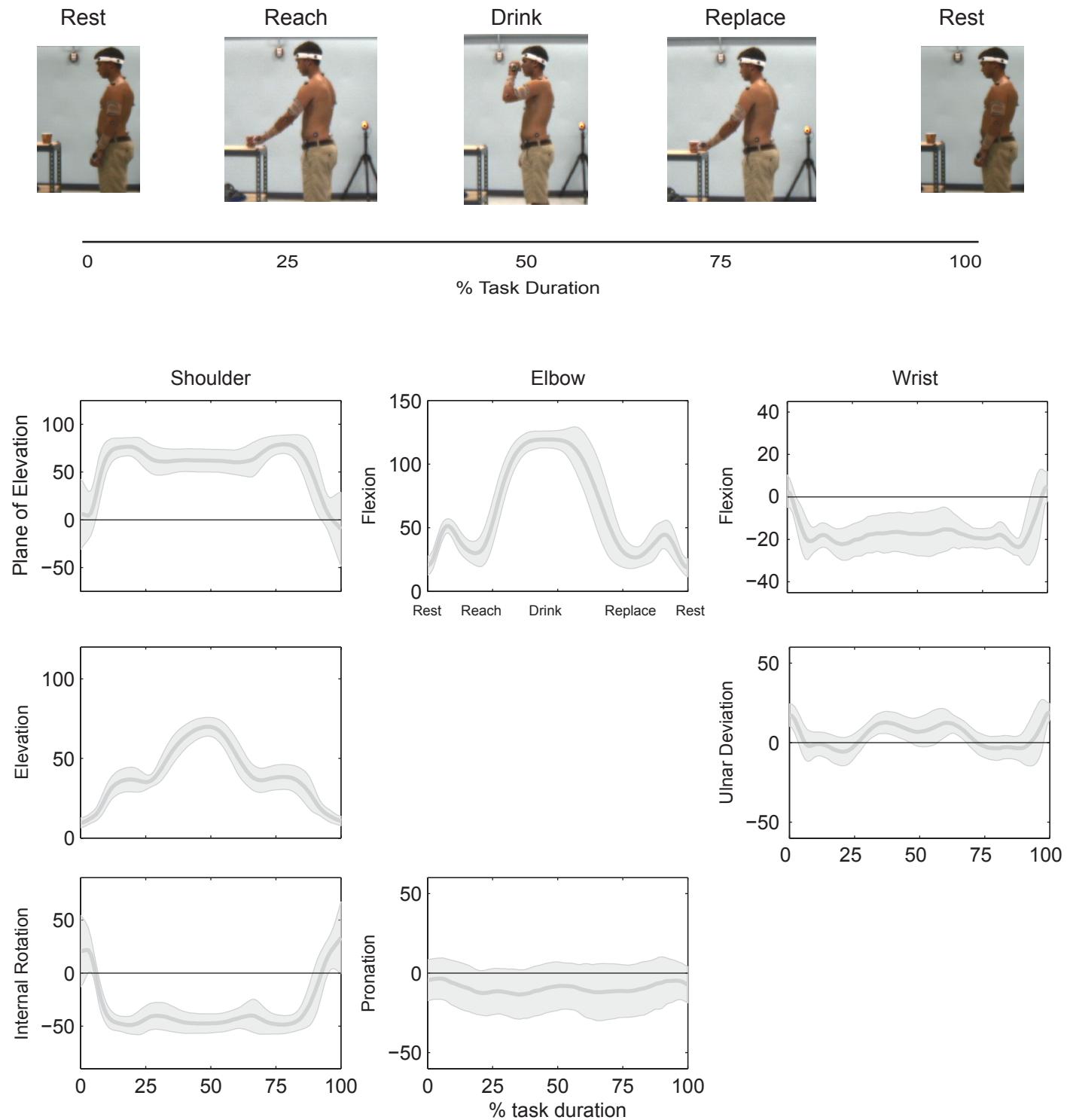
Box off (low) shelf task.



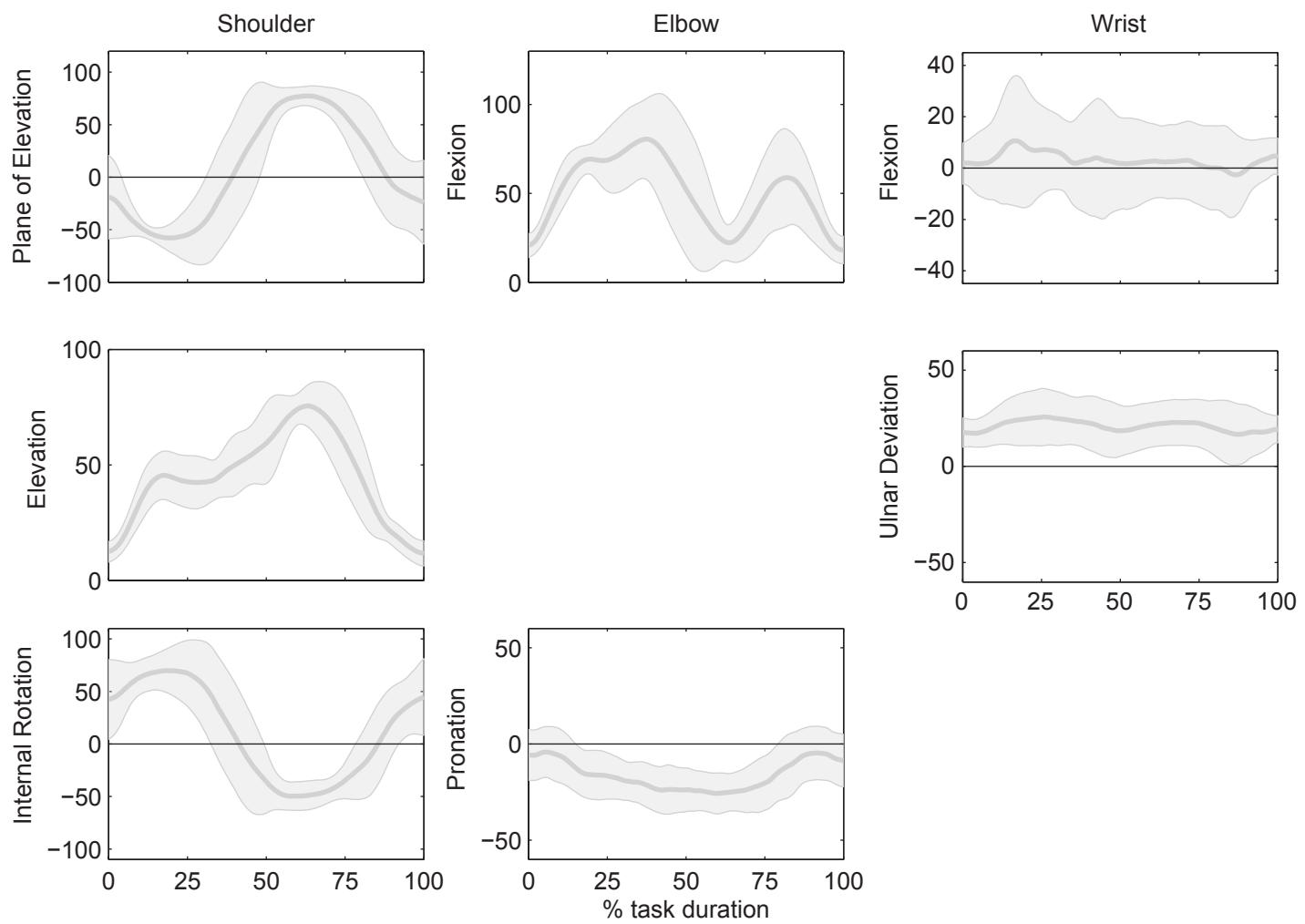
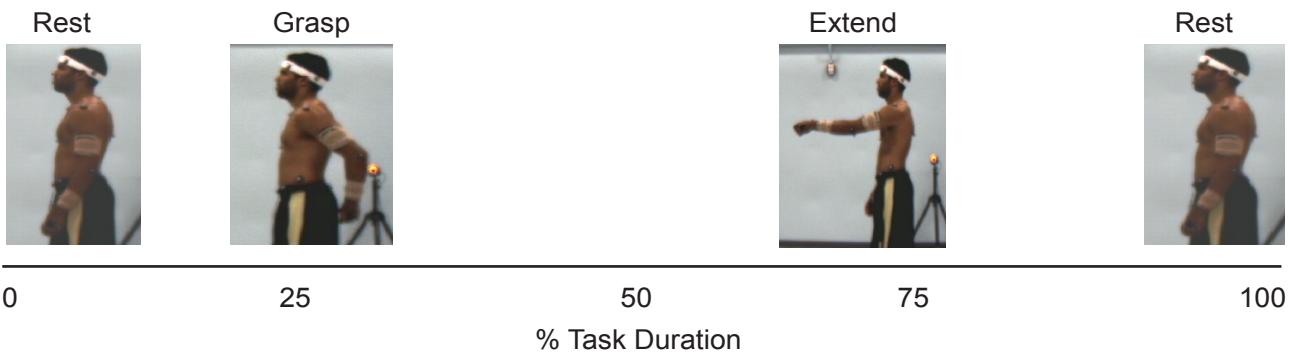
Can off shelf task.



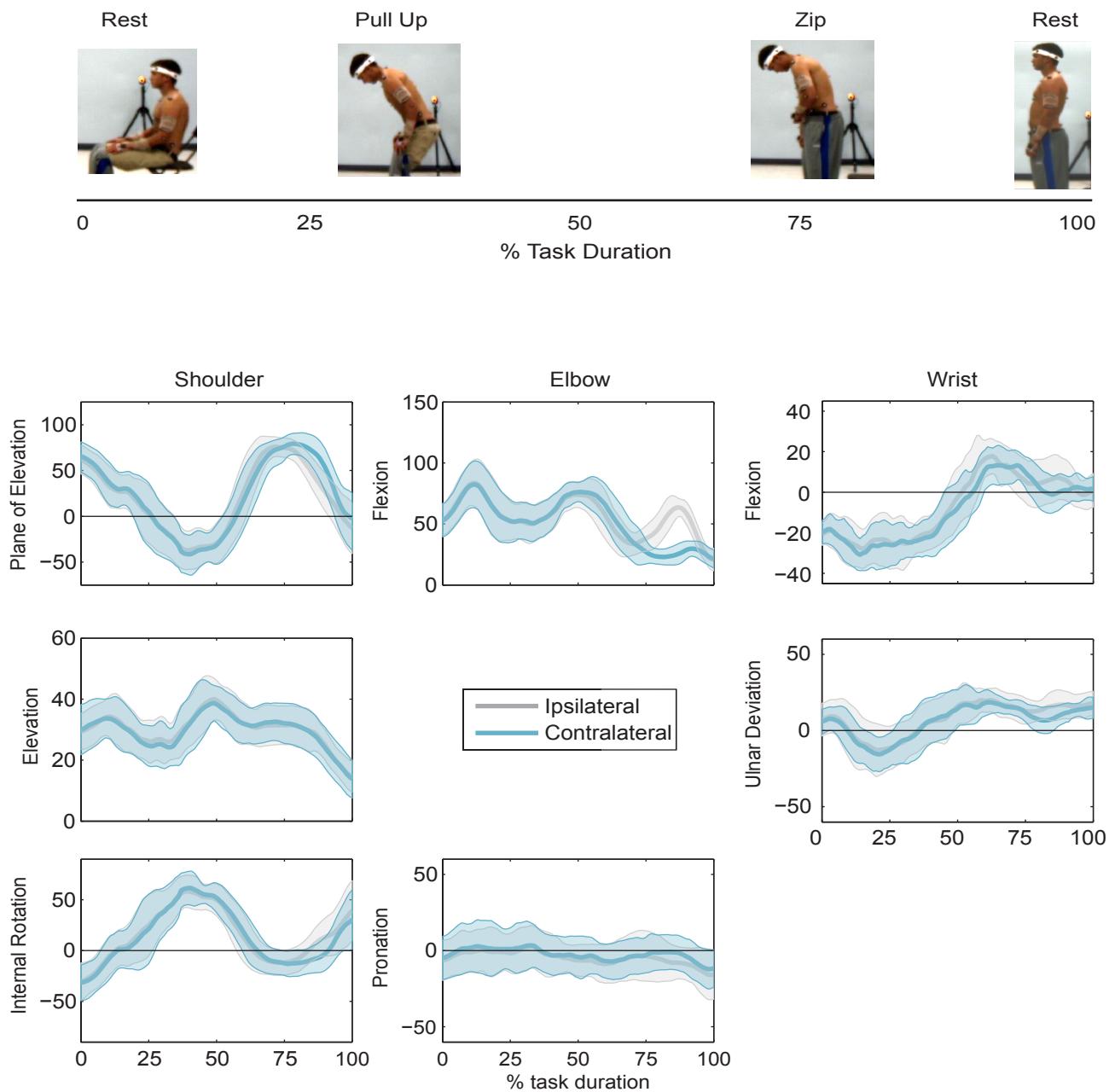
Drinking from a cup.



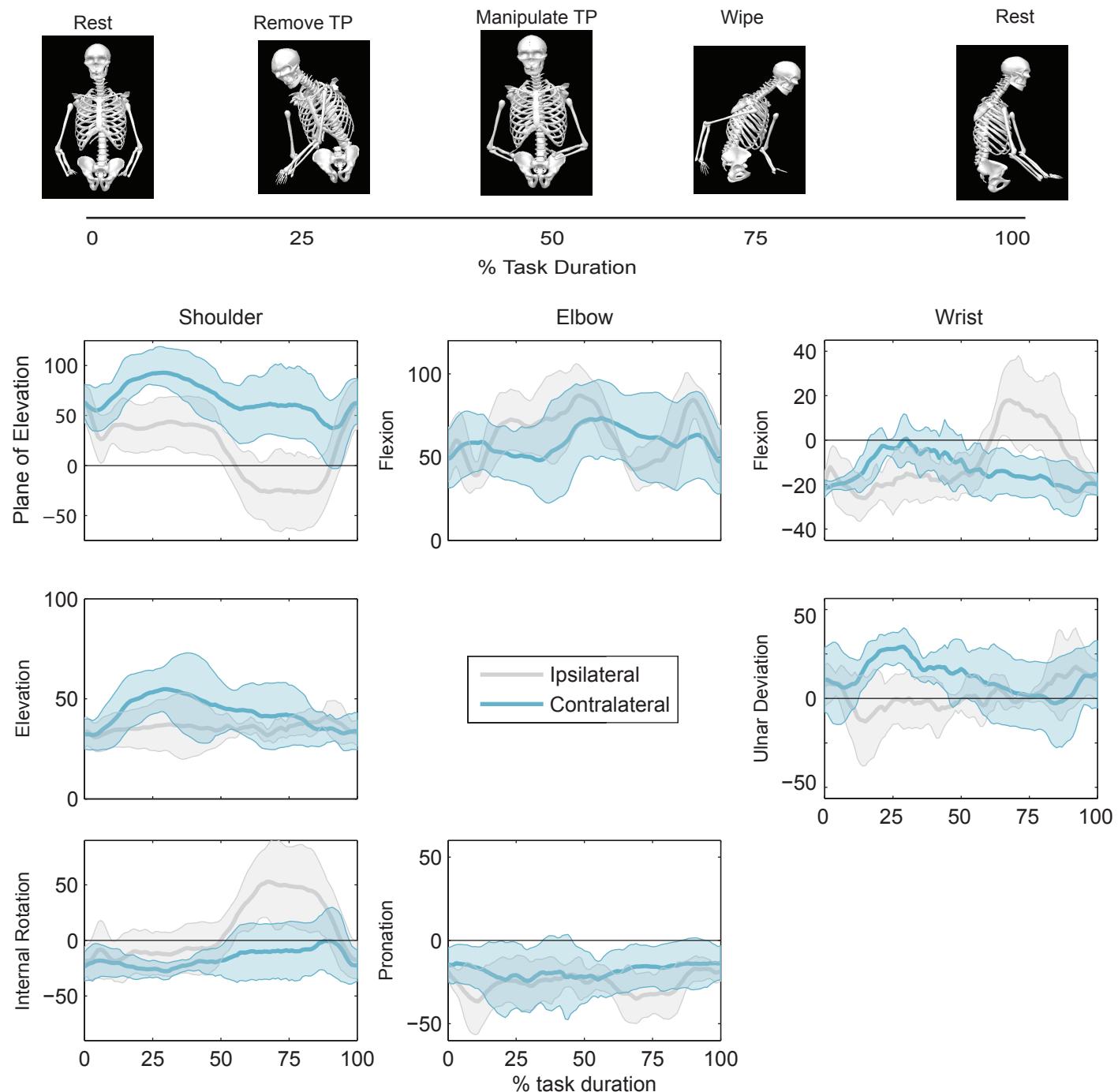
Hand to back pocket.



Donning Pants Task.



Perineal Care Task.



Suggested citation: Gates, D. H., Smurr Walters, L., Cowley, J., Wilken, J. M., & Resnik, L. (2016). Brief Report—Range of motion requirements for upper-limb activities of daily living (Suppl. Appendix 2). *American Journal of Occupational Therapy*, 70, 7001350010. <http://dx.doi.org/10.5014/ajot.2016.015487>

Supplemental Appendix 3

Table A1. Range of Motion for the Trunk and Pelvis.

Task Name	N	Segmental Trunk Angle											
		Lateral Lean				Axial Rotation				Flexion / Extension			
		Mean	Median	5th	95th	Mean	Median	5th	95th	Mean	Median	5th	95th
Box off ground	15	6	5	5	7	11	11	9	12	59	59	51	67
Donning and zippering pants	15	10	10	9	12	10	11	8	11	50	52	44	55
Perineal care	5	23	19	13	32	32	32	25	39	42	35	11	74
Box off shelf - Head height	15	3	3	2	4	7	6	4	10	18	16	13	23
Box off shelf - Fixed height	9	3	2	1	4	5	4	3	7	12	12	9	15
Deodorant	14	7	5	3	11	18	17	13	22	12	7	5	18
Can off shelf - Head height	15	9	9	8	11	22	20	18	27	11	10	9	13
Can off shelf - Fixed height	9	7	6	4	9	19	17	14	25	8	7	6	9
Drinking from a cup	9	5	4	3	6	14	14	11	17	6	5	4	8
Hand to back pocket	9	4	3	2	5	15	13	9	21	5	5	4	6
Trunk-Pelvis Angle													
		Lateral Lean				Axial Rotation				Flexion / Extension			
		Mean	Median	5th	95th	Mean	Median	5th	95th	Mean	Median	5th	95th
Donning and zippering pants	15	9	8	8	10	7	8	6	8	38	36	34	43
Box off ground	15	6	6	5	7	6	6	5	7	36	32	29	42
Perineal care	5	27	29	16	39	21	19	18	24	29	37	13	46
Box off shelf - Head height	15	3	3	2	4	4	3	3	5	14	10	10	18
Box off shelf - Fixed height	9	2	2	1	4	3	3	2	4	10	9	8	12
Can off shelf - Head height	15	8	7	7	9	9	9	7	11	8	7	7	10
Deodorant	14	5	5	4	7	7	7	6	8	7	6	4	10
Can off shelf - Fixed height	9	6	5	4	8	9	8	6	11	6	6	5	7
Drinking from a cup	9	3	4	3	4	6	7	4	7	5	5	4	6
Hand to back pocket	9	4	4	2	6	9	9	7	11	5	4	4	6
Segmental Pelvic Angle													
		Obliquity				Rotation				A-P Tilt			
		Mean	Median	5th	95th	Mean	Median	5th	95th	Mean	Median	5th	95th
Donning and zippering pants	15	5	5	4	6	9	9	7	11	43	41	38	48
Box off ground	15	6	6	5	6	13	14	11	15	32	32	28	36
Perineal care	5	17	18	9	25	18	20	10	25	31	28	8	53
Box off shelf - Head height	15	2	2	1	2	6	5	4	8	7	8	6	9
Box off shelf - Fixed height	9	1	1	1	2	4	4	3	6	4	5	3	6
Deodorant	14	2	2	1	4	13	11	8	18	4	4	3	6
Can off shelf - Head height	15	2	2	1	2	15	13	11	19	4	3	3	5
Drinking from a cup	9	1	2	1	2	9	9	7	12	3	2	2	3
Can off shelf - Fixed height	9	2	1	1	2	12	10	7	17	3	2	2	3
Hand to back pocket	9	1	1	1	2	9	6	4	13	2	2	2	3

Note. Trunk angles are calculated as segmental angles (trunk motion with respect to the global coordinate system) and relative trunk-pelvis angles (trunk motion with respect to the pelvis).

Suggested citation: Gates, D. H., Smurr Walters, L., Cowley, J., Wilken, J. M., & Resnik, L. (2016). Brief Report—Range of motion requirements for upper-limb activities of daily living (Suppl. Appendix 3). *American Journal of Occupational Therapy*, 70, 7001350010. <http://dx.doi.org/10.5014.ajot.2016.015487>

Supplemental Appendix 4

Table A2. Comparison With Previous Studies

Task Category	Task description	Study	Shoulder			Elbow		Wrist	
			Plane of Elevation	Elevation	Rotation	Flexion	Supination (-) / Pronation (+)	Extension (-) / Flexion (+)	Radial(-) / Ulnar (+) deviation
Perineal care	Perineal care	Magermans, 2005*	-67.2 (24.3)	35.0 (10.3)	105.4 (25.2)	61.0 (20.1)	-4.4 (36.1)		
	Touch perineum	Aizawa, 2010	-86 (18)	41 (8)	135 (17)	56 (22)	-78 (12)	-1 (17)	-5 (8)
	Hand to back pocket	van Andel 2008 +	-63	48	101.7	85.6	36.2	-5.4 / 8.5	-1 / 15.5
	Perineal care	Current Study	-46	55	65	107	-20	-38 / 34	-28 / 38
	Hand to back pocket	Current Study	-65	80^	79	101^	-28	-15 / 28	7 / 35
Deodorant Application	Wash contralateral axilla	Magermans, 2005*	99.6 (8.9)	53.0 (10.8)	-15.2 (6.8)	117.5(8.9)			
	Touch contralateral axilla	Aizawa, 2010	109 (12)	42 (13)	-11 (24)	100 (10)	-12.7 (23.0)	32 (19)	18 (9)
	Deodorant application	Current Study	100	55	-39	104	-63 (25)	11 / -27	-12 / 23
Feeding Tasks	Eating with spoon	Magermans, 2005*	60.0 (14.4)	63.6 (22.8)	-49.3 (14)	131.5 (7.5)	-53		
	Drinking from glass	Aizawa, 2010	80 (14)	87 (12)	-62 (17)	115 (5)		-15 (13)	-3 (12)
	Drinking from cup	Current Study	81	71	-53	121	-18.1 (31.4)	-33 / 8	-11 / 23
Lifting tasks	Lift 4 kg bag from ground	Magermans, 2005*	79.2 (18.8)	63.6 (22.8)	-47.7 (25.3)	93.4 (23.9)	20 (20)		
	Lift 20-lb box from ground	Current Study	75	69	-45	81	6		
Reaching	Reach above shoulder level	Magermans 2005	72.6 (11.7)	121.4 (6.5)	-60.6 (36.4)	39.3(18.2)	30.8 (17.4)		
	Reach to can - head height	Current Study	72	105	-46	105	-29		
	Reach to box - head height	Current Study	86	108	-48	120	-32		

Note. Data in parentheses represent standard deviations if provided.

* Shoulder angles were measured as motion of the humerus relative to scapula, rather than humerus relative to thorax.

+ Values from supplemental material.

^ Occurs as the hand the wallet to the investigator (not done in other studies).

Suggested citation: Gates, D. H., Smurr Walters, L., Cowley, J., Wilken, J. M., & Resnik, L. (2016). Brief Report—Range of motion requirements for upper-limb activities of daily living (Suppl. Appendix 4). *American Journal of Occupational Therapy*, 70, 7001350010. <http://dx.doi.org/10.5014.ajot.2016.015487>