

## Custom upper extremity model in Visual 3D

Based on International Society of Biomechanics Recommendations [1]



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## List of Markers

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





## 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)

Landmarks | Functional | Digitizing | Lab Z | LSHJC | RSHJC

Landmark Name: LSHJC

Define Orientation Using:

Starting Point: LSHO (Reference)

Targets and/or Landmark:

Ending Point: (On a line)

\*Lateral object: (On a plane)

\*Project From: (Projection onto a line or plane)

\* = Optional

Existing Segment: Thorax/Ab KMAT

Landmark Offset from Start Point (Reference) or Segment Origin

Offset to Existing Calibration Target or Landmark: (On a line)

Offset Using the Following ML/AP/AXIAL Offsets

ML: 0.0

AP: 0.0

AXIAL: -0.16\*LCIR-(1/2)\*MarkerSize

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: 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:

Define Orientation Using:

Starting Point  (Reference)

Targets and/or Landmarks: Ending Point  (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   
 Offset by Percent (1.0 = 100%) (Meters when not checked)

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

#### Left Elbow Joint Center (LEJC)

Segments | Landmarks | Muscles | Subject Data / Metrics

Landmarks | Functional | Digitizing | LEJC

Landmark Name:

Define Orientation Using:

Starting Point  (Reference)

Targets and/or Landmarks: Ending Point  (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   
 Offset by Percent (1.0 = 100%) (Meters when not checked)

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

## Joint Center: Wrist

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

### Visual3D Implementation:

Right wrist joint center (RWJC)

The screenshot shows the 'Landmarks' tab in the Visual3D software. The 'Landmark Name' is 'RWJC'. Under 'Define Orientation Using:', 'Starting Point' is 'RWRU' (Reference), 'Ending Point' is 'RWRR' (On a line), and 'Lateral object' is empty (On a plane). 'Project From' is empty (Projection onto a line or plane). Under 'Landmark Offset from Start Point (Reference) or Segment Origin', 'Offset Using the Following ML/AP/AXIAL Offsets' is selected, with ML, AP, and AXIAL values of 0.5. 'Offset by Percent (1.0 = 100%) (Meters when not checked)' is checked. 'Calibration Only Landmark' is unchecked. Buttons at the bottom include 'Undo Changes', 'Apply', 'Build Model', and 'Close Tab'.

Left wrist joint center (LWJC)

The screenshot shows the 'Landmarks' tab in the Visual3D software. The 'Landmark Name' is 'LWJC'. Under 'Define Orientation Using:', 'Starting Point' is 'LWRU' (Reference), 'Ending Point' is 'LWRR' (On a line), and 'Lateral object' is empty (On a plane). 'Project From' is empty (Projection onto a line or plane). Under 'Landmark Offset from Start Point (Reference) or Segment Origin', 'Offset Using the Following ML/AP/AXIAL Offsets' is selected, with ML, AP, and AXIAL values of 0.5. 'Offset by Percent (1.0 = 100%) (Meters when not checked)' is checked. 'Calibration Only Landmark' is unchecked. Buttons at the bottom include 'Undo Changes', 'Apply', 'Build Model', and '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).

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

$i_h$  is perpendicular to the plane containing RWRU, RWRR, and the fifth metacarpal head (R5MC)

$$\vec{k}_{temp} = \frac{\overrightarrow{RWRR} - \overrightarrow{R5MC}}{\|\overrightarrow{RWRR} - \overrightarrow{R5MC}\|}$$

$$\vec{i}_h = \vec{j}_h \times \vec{k}_{temp}$$

$$\vec{k}_h = \vec{i}_h \times \vec{j}_h$$

Now we define a new plane with the third metacarpal

$$\vec{k}_{temp} = \frac{\overrightarrow{RWRR} - \overrightarrow{R3MC}}{\|\overrightarrow{RWRR} - \overrightarrow{R3MC}\|}$$

$$\vec{i}_{h2} = \vec{j}_h \times \vec{k}_{temp}$$

$$\vec{k}_{h2} = \vec{i}_{h2} \times \vec{j}_h$$

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

$$\theta = \vec{i}_{h2} \cdot \vec{i}_h$$

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

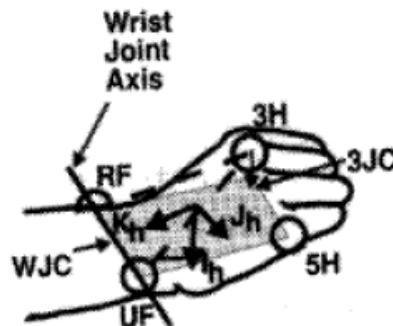


Illustration of the local coordinate system of the hand from Rao {Rao 1996}

## 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) Landmark Is:

\*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:

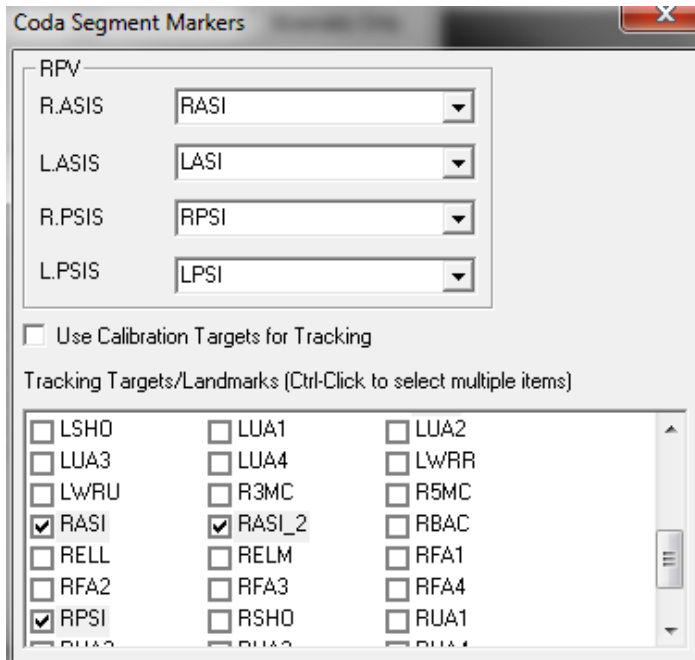
Offset by Percent (1.0 = 100%) (Meters when not checked)

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

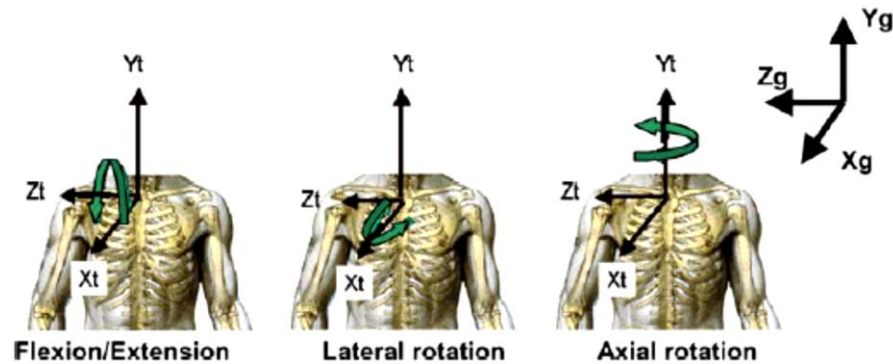
### ISB Recommendation

O: 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:

The screenshot shows the 'midStrnC7' landmark definition window in Visual3D. The 'Landmark Name' field contains 'midStrnC7'. Under 'Define Orientation Using:', 'Starting Point' is 'C7' (Reference) and 'Ending Point' is 'STRN' (On a line). The 'Offset Using the Following ML/AP/AXIAL Offsets' section has 'AXIAL' set to 0.5 and 'Offset by Percent' checked. At the bottom, there are buttons for 'Undo Changes', 'Apply', 'Build Model', and 'Close Tab'.

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

Landmarks | Functional | Digitizing | midStmC7 | midXiphT8

Landmark Name: midXiphT8

Define Orientation Using:

Starting Point T8 (Reference)

Targets and/or Landmark: Ending Point XIPH (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

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

IK Constraints | Thorax/Ab KMAT | Right Upper Arm

Define Proximal Joint and Radius

Lateral	Joint	Medial	Radius (Meters)
None	midStmC7	None	0.25

Define Distal Joint and Radius

Lateral	Joint	Medial	Radius (Meters)
None	midXiphT8	None	0.25

Extra Target to Define Orientation (if needed)

Location	Target
Anterior	XIPH

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

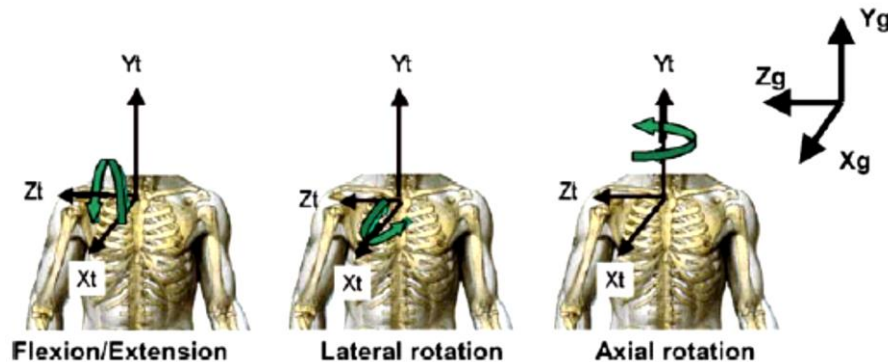
### ISB Recommendation

The coordinate system of the humerus was defined using the 2<sup>nd</sup> 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 image shows a screenshot of the Visual3D software interface. The 'Segments' tab is active, and the 'Right Upper Arm' segment is selected. The 'Define Proximal Joint and Radius' section has 'None' for Lateral, 'RSHJC' for Joint, 'None' for Medial, and '0.05' for Radius (Meters). The 'Define Distal Joint and Radius' section has 'None' for Lateral, 'REJC' for Joint, 'None' for Medial, and '0.05' for Radius (Meters). The 'Extra Target to Define Orientation (if needed)' section has 'Anterior' for Location and 'RWJC' for the target.

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

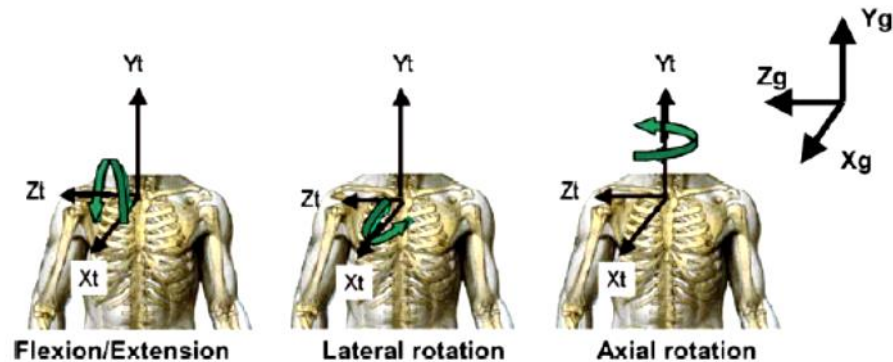
### ISB Recommendation

The coordinate system of the humerus was defined using the 2<sup>nd</sup> option of ISB recommendations

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

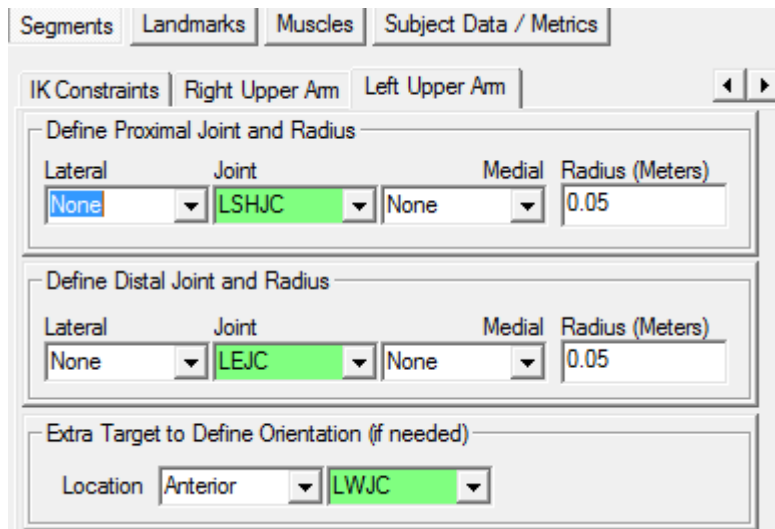
$Z_h$ : The common line perpendicular to the plane formed by  $Y_h$  and  $Y_f$ , pointing to the right.

$X_h$ : 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:



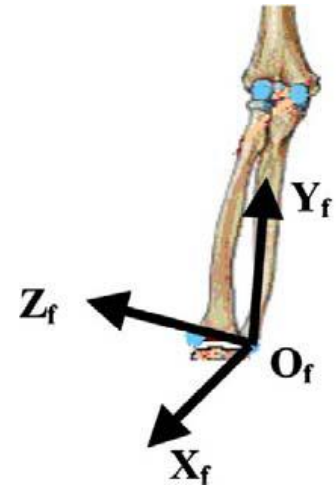
The motion of the local coordinate systems is tracked using the following markers:

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:

IK Constraints	Right Radius	Left Forearm	Right Forearm
Define Proximal Joint and Radius			
Lateral	Joint Center	Medial	
None	REJC	None	
Radius (Meters) 0.5*distance(RELM,RELL)			
Define Distal Joint and Radius			
Lateral	Joint Center	Medial	
None	RWRU	None	
Radius (Meters) 0.5*distance(RWRU,RWRR)			
Extra Target to Define Orientation (if needed)			
Location	Lateral	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) $0.5 * \text{distance}(\text{LELM}, \text{LELL})$		

Define Distal Joint and Radius		
Lateral	Joint Center	Medial
None	LWRU	None
Radius (Meters) $0.5 * \text{distance}(\text{LWRU}, \text{LWRR})$		

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.

The screenshot shows a software interface with a tabbed menu at the top containing 'IK Constraints', 'Right Radius', 'Left Forearm', and 'Right Forearm'. The 'Right Radius' tab is selected. Below the tabs are three sections for defining joints and radii:

- Define Proximal Joint and Radius:** This section has three dropdown menus labeled 'Lateral', 'Joint Center', and 'Medial'. The 'Lateral' dropdown is set to 'None', the 'Joint Center' dropdown is set to 'REJC', and the 'Medial' dropdown is set to 'None'. Below these is a text input field for 'Radius (Meters)' containing the formula  $0.5 * \text{distance}(\text{RELM}, \text{RELL})$ .
- Define Distal Joint and Radius:** This section has three dropdown menus labeled 'Lateral', 'Joint Center', and 'Medial'. The 'Lateral' dropdown is set to 'None', the 'Joint Center' dropdown is set to 'RWJC', and the 'Medial' dropdown is set to 'None'. Below these is a text input field for 'Radius (Meters)' containing the formula  $0.5 * \text{distance}(\text{RWRR}, \text{RWRU})$ .
- Extra Target to Define Orientation (if needed):** This section has a 'Location' dropdown set to 'Lateral' and another dropdown set to '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 displays three configuration panels for defining the local coordinate system for the right hand:

- Define Proximal Joint and Radius:**
  - Lateral: None
  - Joint Center: RWJC
  - Medial: None
  - Radius (Meters):  $0.5 * \text{distance}(\text{RWRU}, \text{RWRR})$
- Define Distal Joint and Radius:**
  - Lateral: None
  - Joint Center: R3JC
  - Medial: None
  - Radius (Meters):  $\text{distance}(\text{R5MC}, \text{R3MC})$
- Extra Target to Define Orientation (if needed):**
  - Location: Medial
  - Target: RWRR

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) $0.5 * \text{distance}(\text{LWRU}, \text{LWRR})$		

Define Distal Joint and Radius		
Lateral	Joint Center	Medial
None	L3JC	None
Radius (Meters) $\text{distance}(\text{L5MC}, \text{L3MC})$		

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.

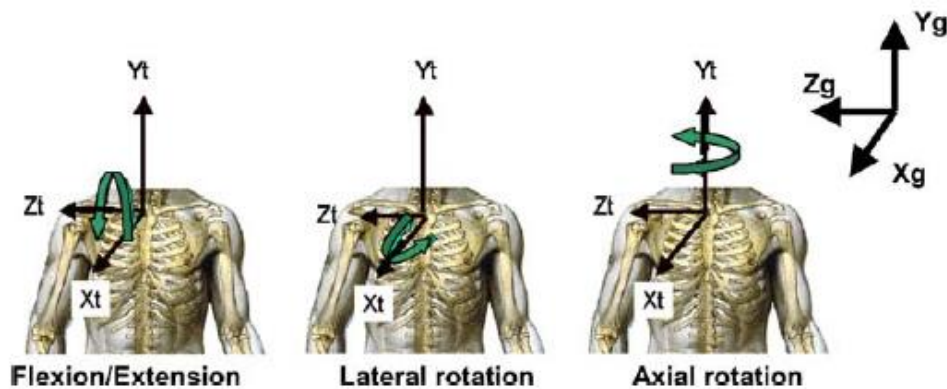
Rotation (X-axis): Lateral flexion rotation of the thorax, to the right is positive, to the left is negative.

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

Compute Model Based Data

Data Name: Trunk-Room Angle

Folder: ORIGINAL

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.

Model Based Item Properties: JOINT\_ANGLE Use Negative

Normalization: Normalization Off

Segment: Thorax/Ab KMAT

Reference Segment: Virtual Lab

Cardan Sequence: X-Y-Z

Buttons: Create, Reset Dialog, Close



## 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)'.

Compute Model Based Data

Data Name: Trunk-Pelvis Angle

Folder: ORIGINAL

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.

Model Based Item Properties

Use Negative

JOINT\_ANGLE

X  
 Y  
 Z

Normalization

Normalization Off

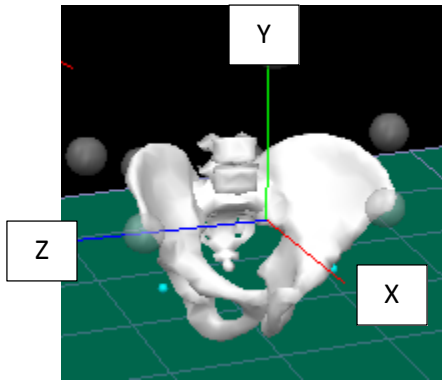
Segment: Thorax/Ab KMAT

Reference Segment: RPV

Cardan Sequence: X-Y-Z

Create    Reset Dialog    Close

## 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:

Folder:

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.

Model Based Item Properties:  Use Negative

JOINT\_ANGLE X  
 Y  
 Z

Normalization:

Segment:

Reference Segment:

Cardan Sequence:

## 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,  $0^\circ$  is abduction,  $90^\circ$  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).

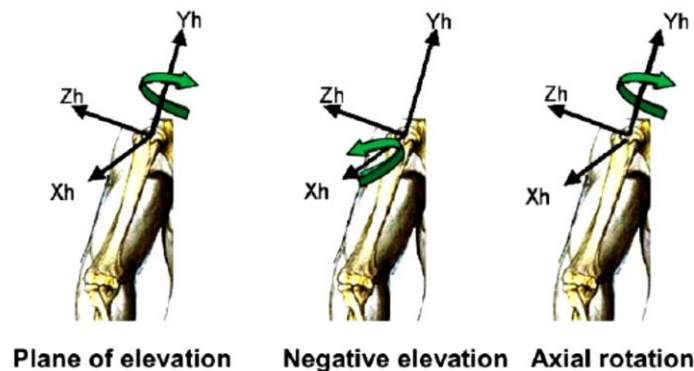


Fig. 7. Definition of thoracohumeral rotations.

### Visual3D Implementation

#### Right Arm

Compute Model Based Data

Data Name:

Folder:

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.

Model Based Item Properties

JOINT\_ANGLE  Negate  
 X  
 Y  
 Z

Normalization

Segment:

Reference Segment:

Cardan Sequence:

## Left Arm

Compute Model Based Data

Data Name:

Folder:

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.

Model Based Item Properties

JOINT\_ANGLE  Negate X  
 Y  
 Z

Normalization:

Segment:

Reference Segment:

Cardan Sequence:

## 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/extension 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

**Compute Model Based Data**

Data Name:

Folder:

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.

Model Based Item Properties

JOINT\_ANGLE  X  Y  Z

Negate

Normalization:

Segment:

Reference Segment:

Cardan Sequence:

#### Left Arm

**Compute Model Based Data**

Data Name:

Folder:

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.

Model Based Item Properties

JOINT\_ANGLE  X  Y  Z

Negate

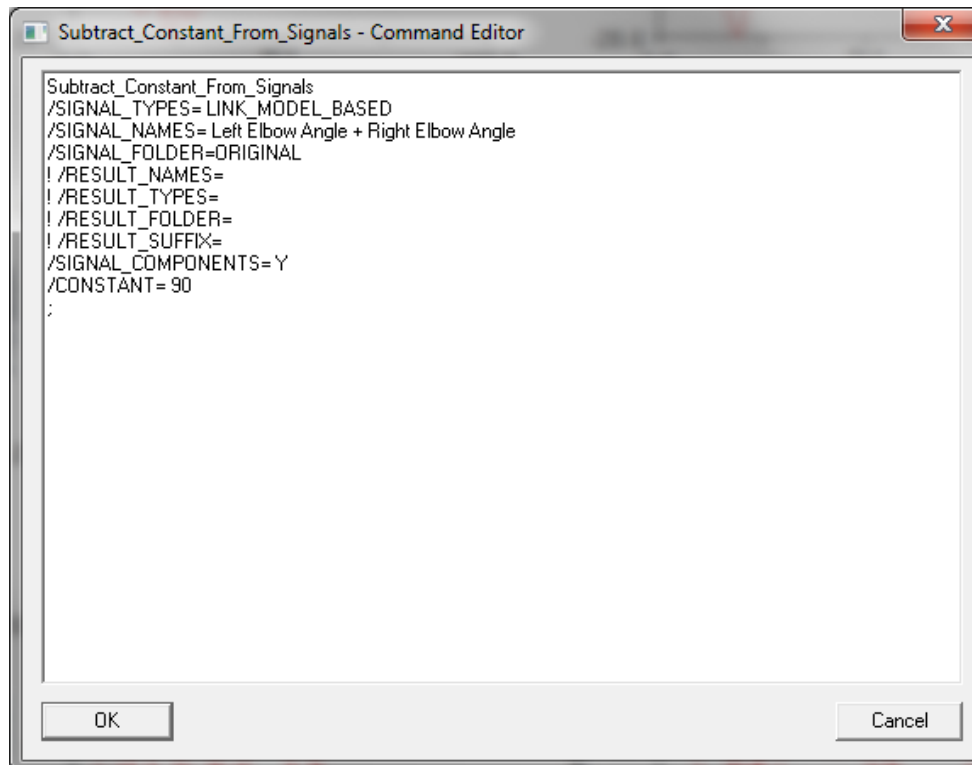
Normalization:

Segment:

Reference Segment:

Cardan Sequence:

\* 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

Compute Model Based Data

Data Name: Right Wrist Angle

Folder: ORIGINAL

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.

Model Based Item Properties

Use Negative

JOINT\_ANGLE

X  
 Y  
 Z

Normalization

Normalization Off

Segment: Right Hand

Reference Segment: Right Radius

Cardan Sequence: Z-X-Y

Create    Reset Dialog    Close

## Left Arm

Compute Model Based Data X

Data Name:

Folder:

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.

Model Based Item Properties:  Use Negative

X  
 Y  
 Z

Normalization:

Segment:

Reference Segment:

Cardan Sequence:



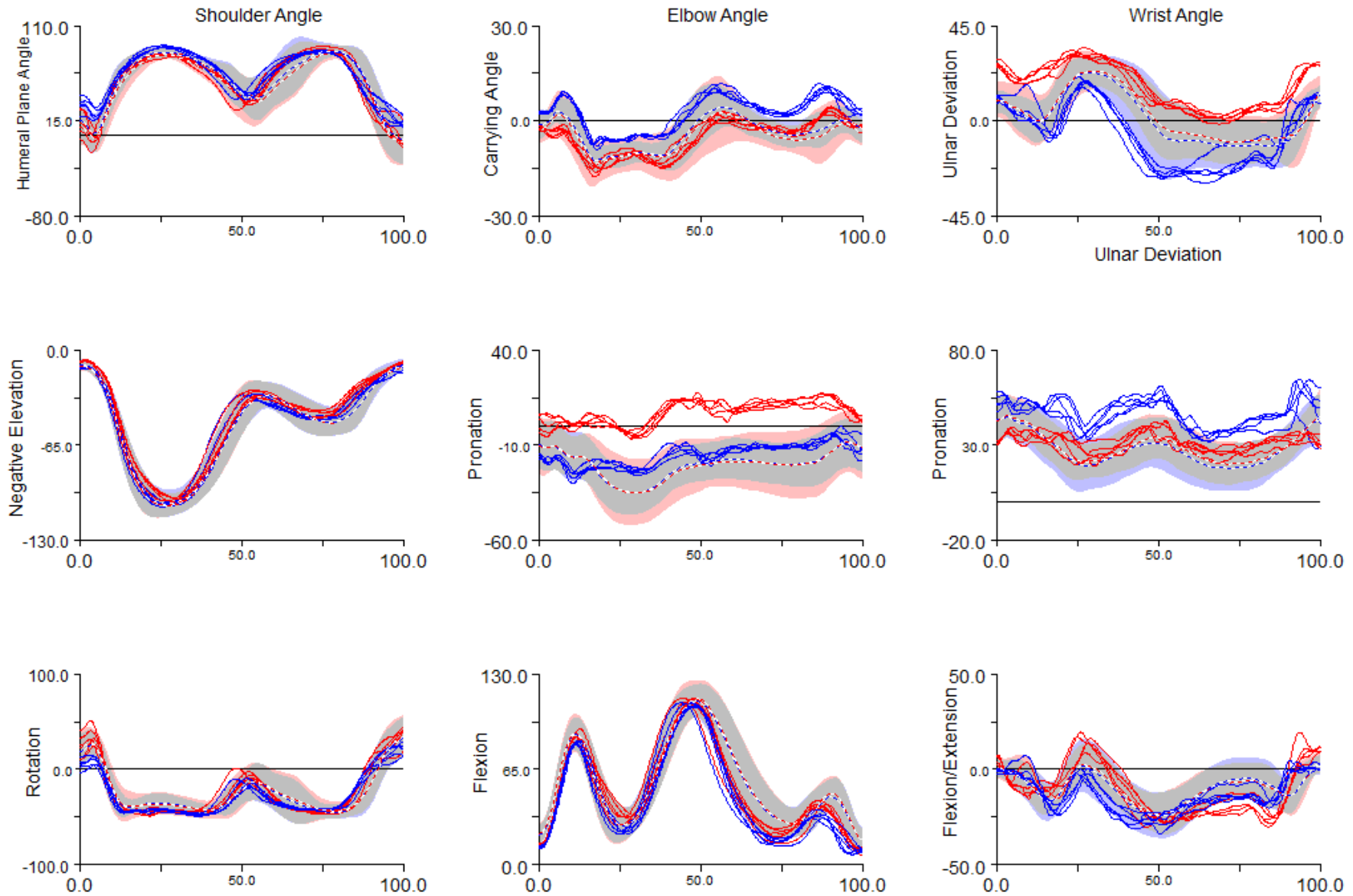
## References

- [1] Wu G, van der Helm FC, Veeger HE, Makhsous 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.

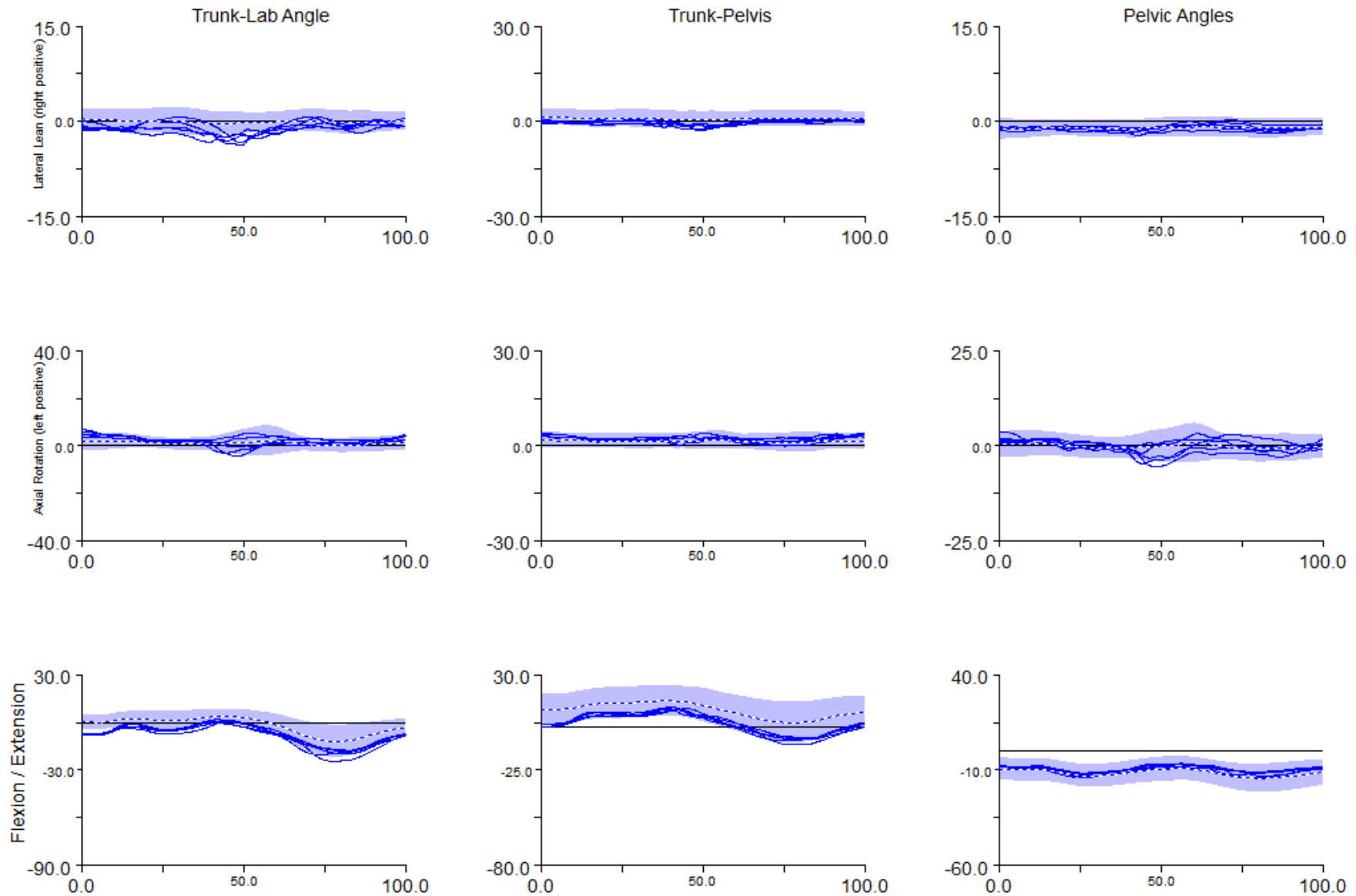
## Example Joint Angles: Box off shelf task

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



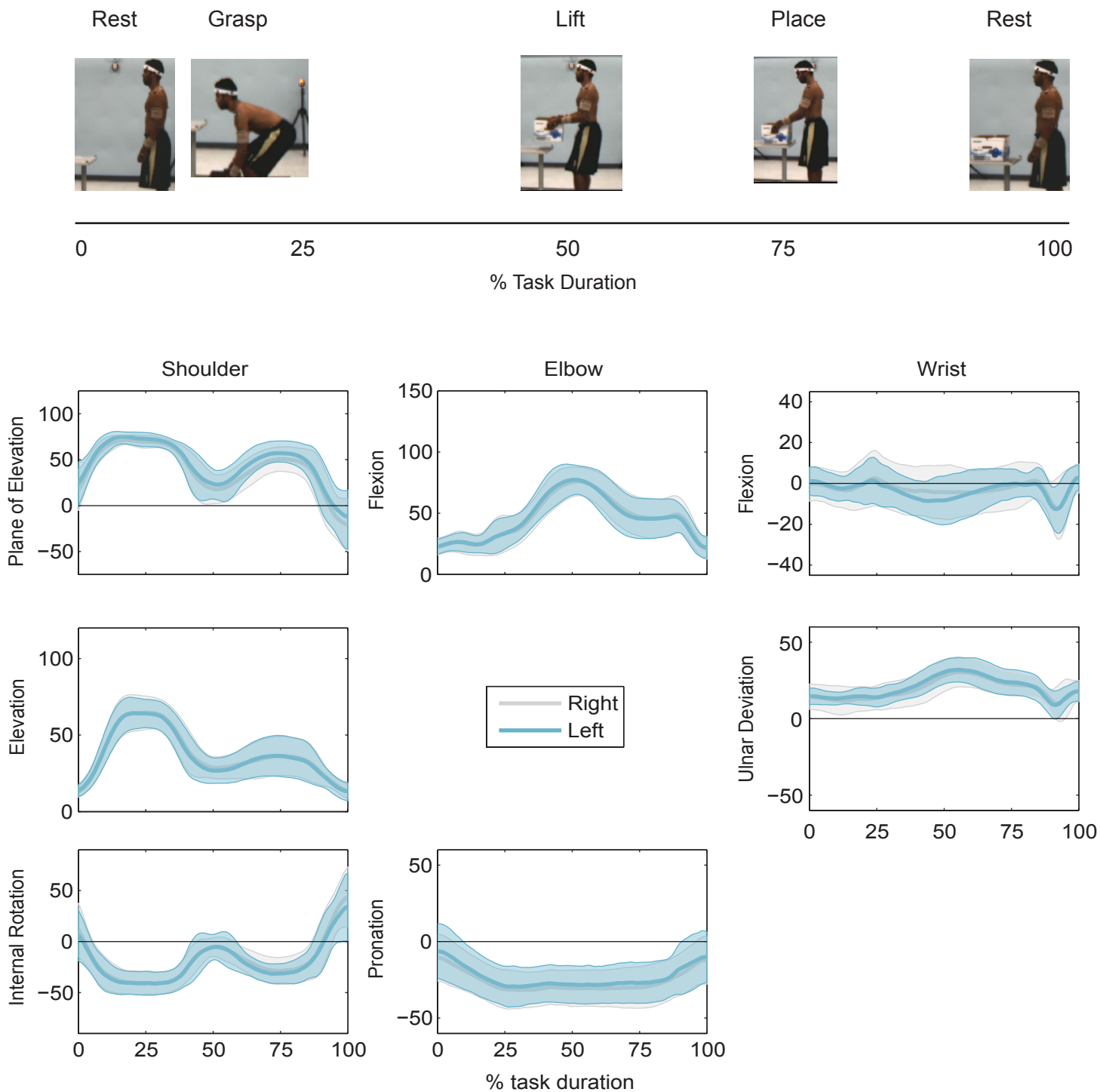
## Box Off Shelf - Trunk Pelvis



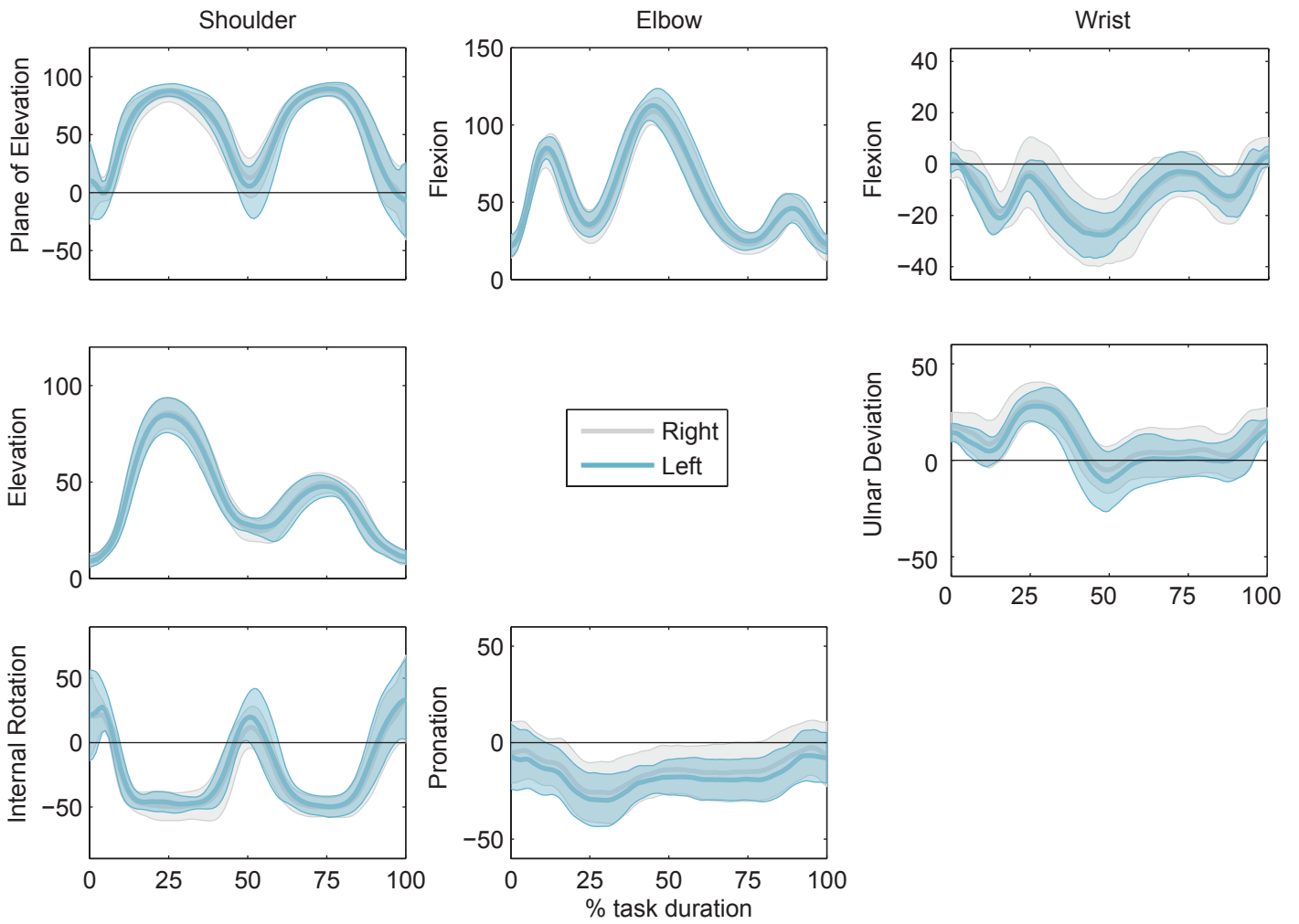
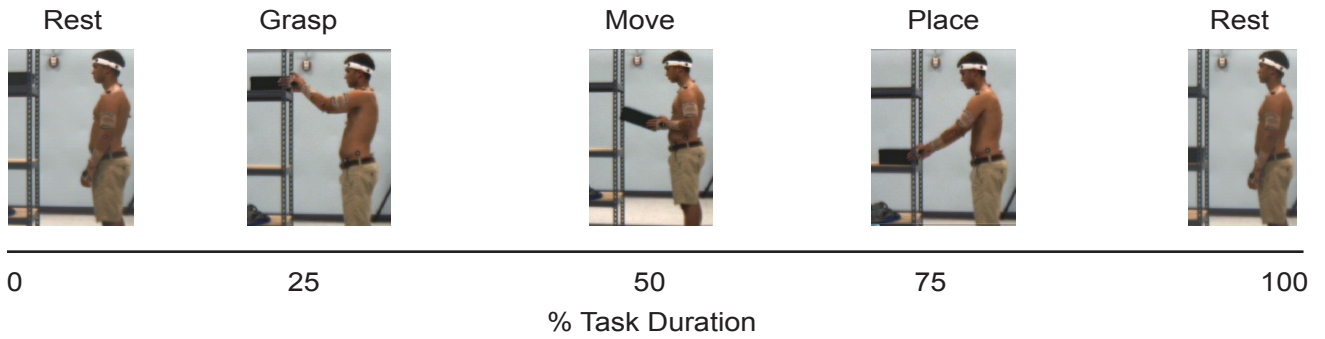
*Suggested citation:* Gates, D. H., Smurr Walters, L., Cowley, J., Wilken, J. M., & Resnik, L. (2016). Brief Report—Range of motion requirements for upper-limb activities of daily living (Suppl. Appendix 1). *American Journal of Occupational Therapy*, 70, 7001350010. <http://dx.doi.org/10.5014.ajot.2016.015487>

# Supplemental Appendix 2. Figures for All Tasks

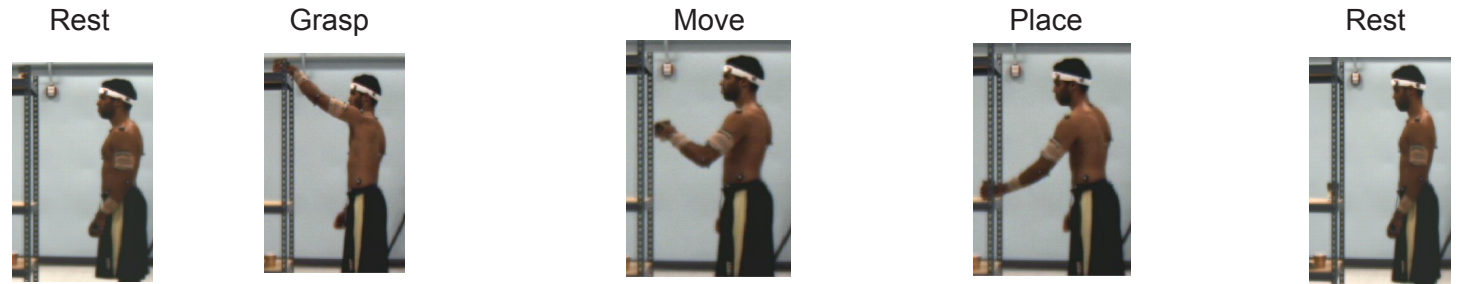
Box off ground task.



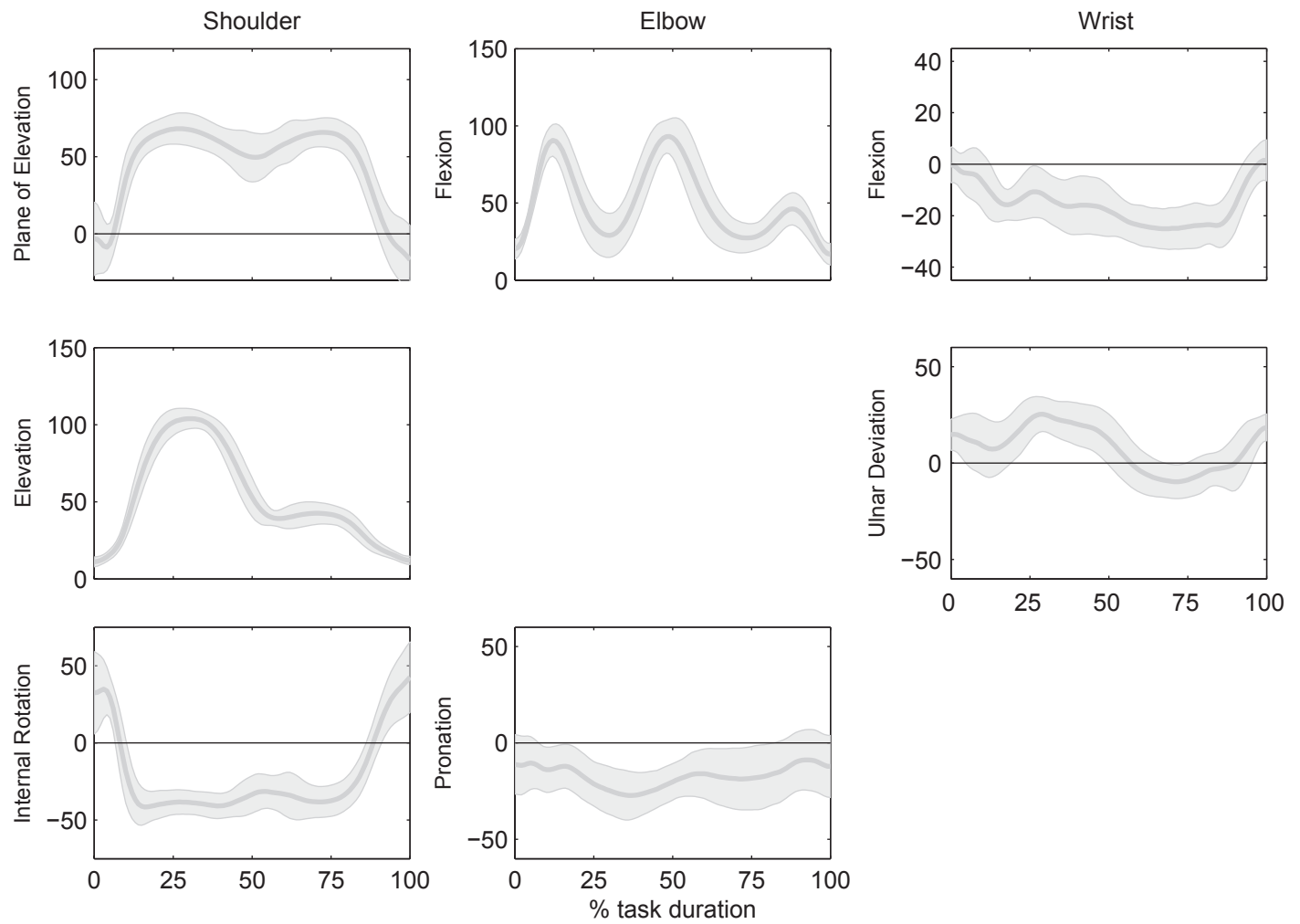
Box off (low) shelf task.



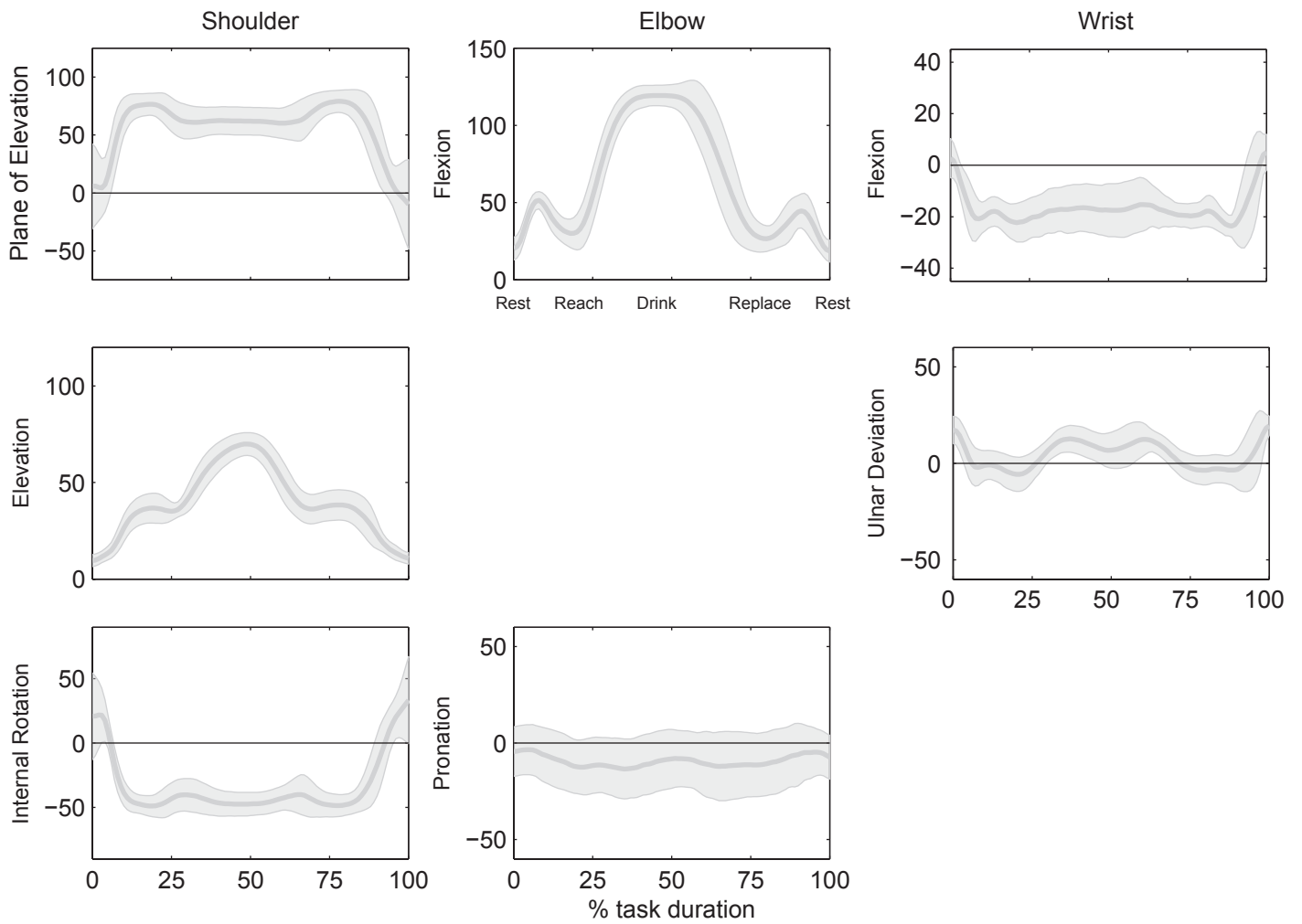
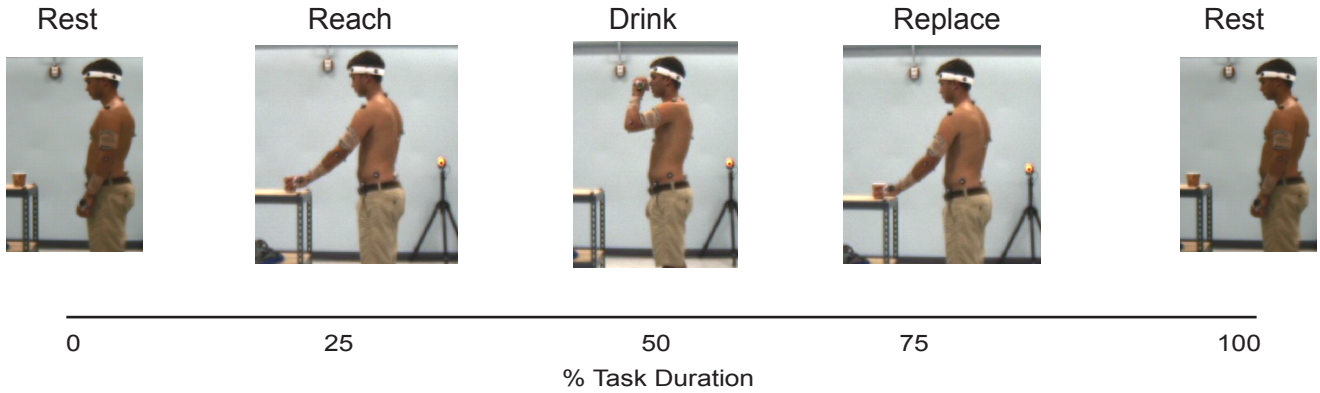
Can off shelf task.



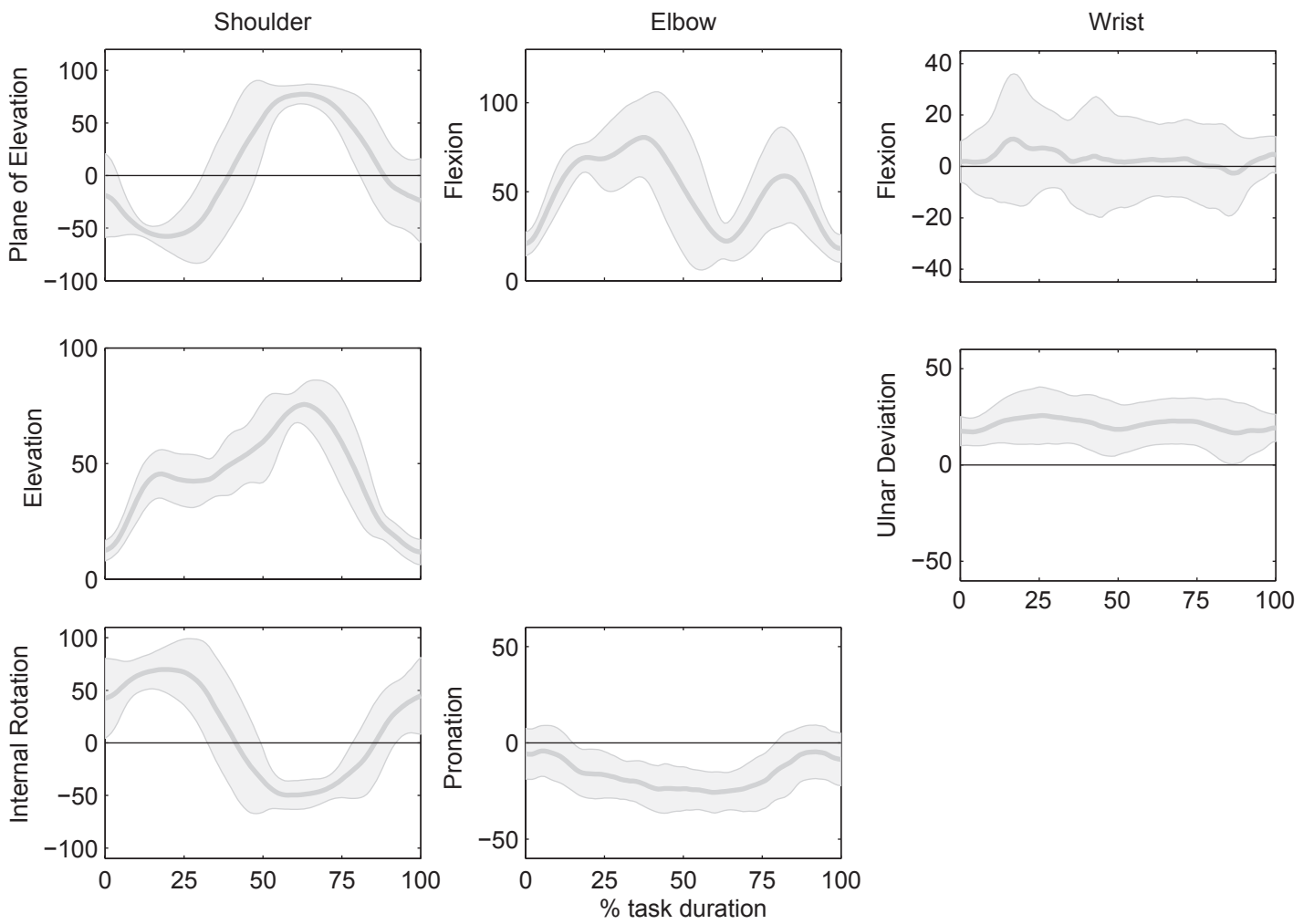
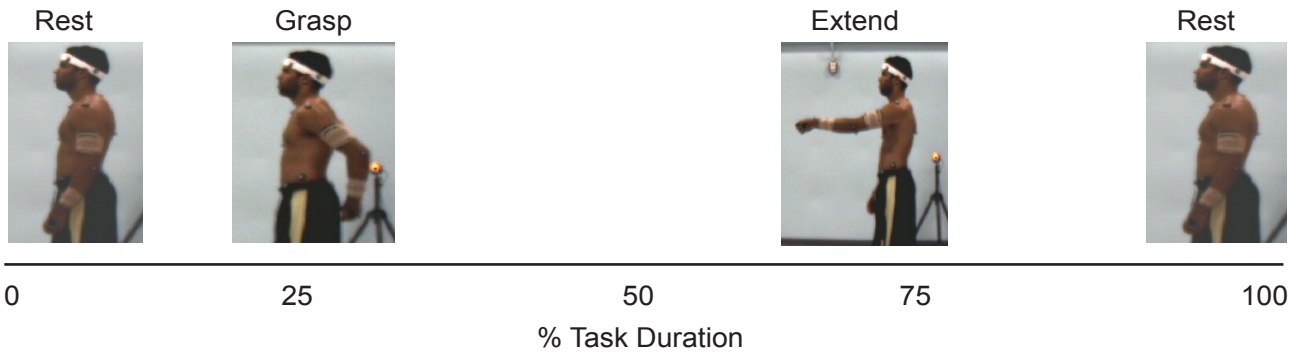
0 25 50 75 100  
% Task Duration



Drinking from a cup.

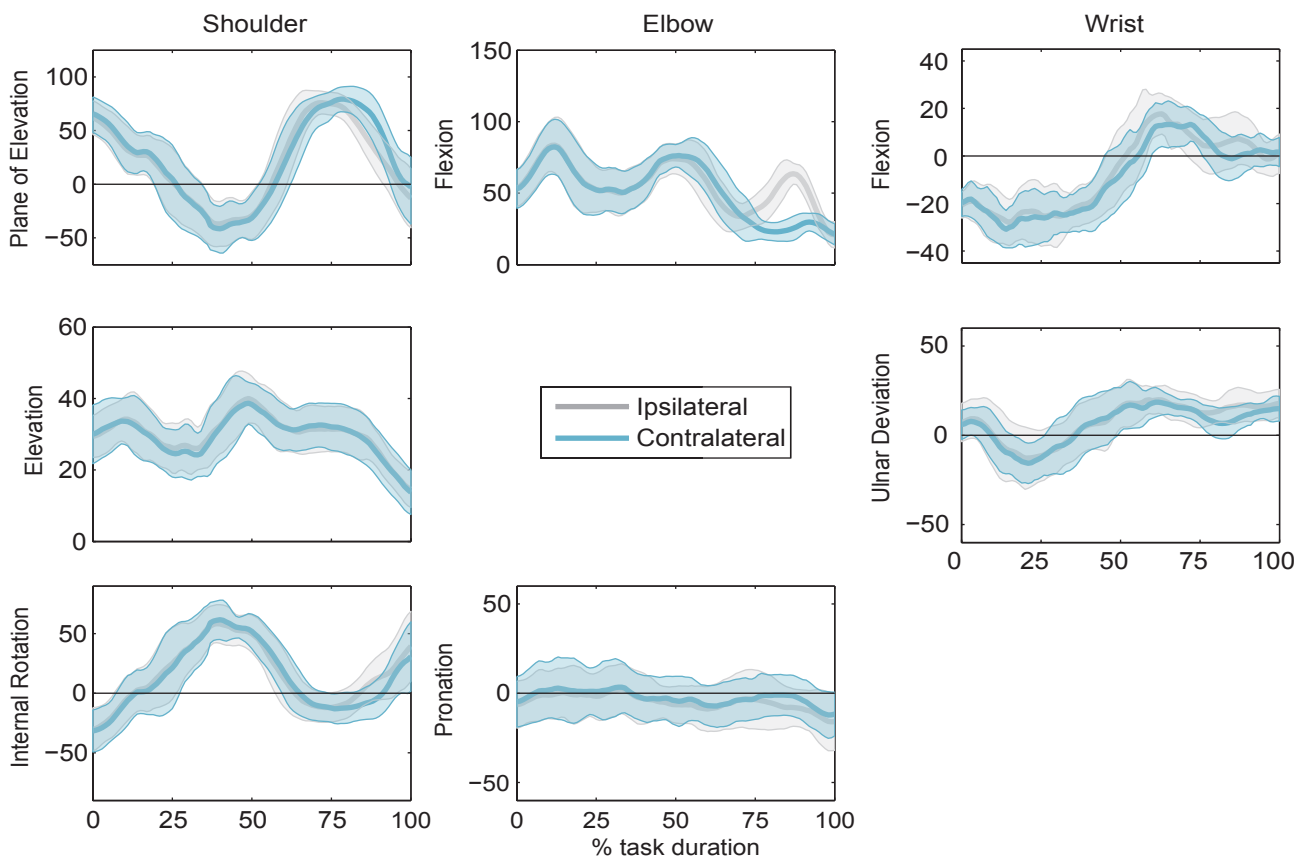
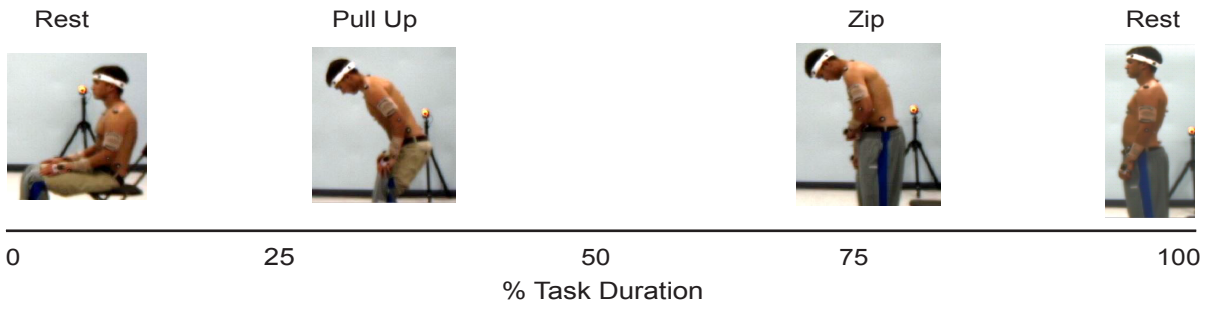


Hand to back pocket.

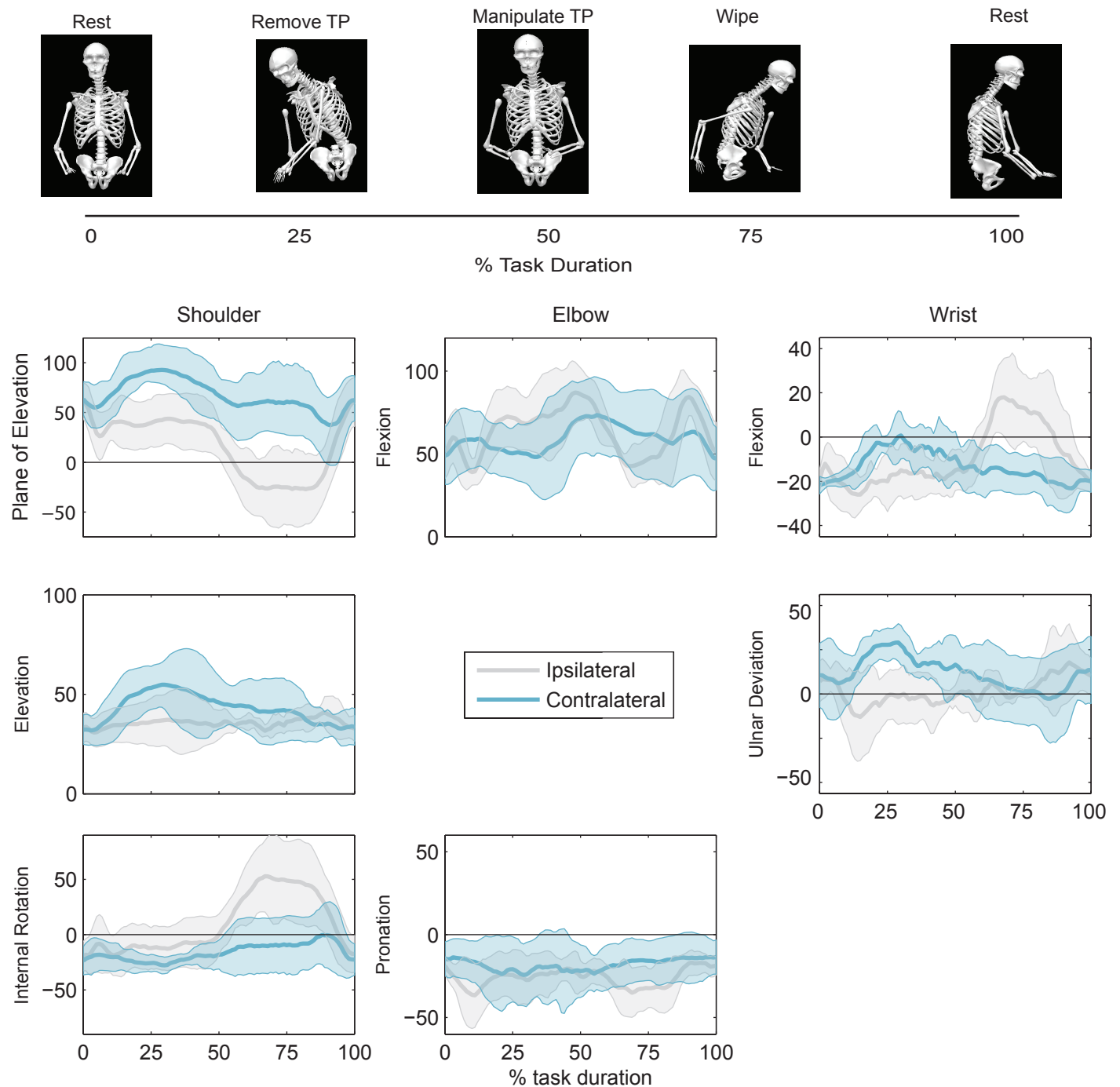




Donning Pants Task.



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

Task Name	N	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

Task Name	N	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 An del 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>