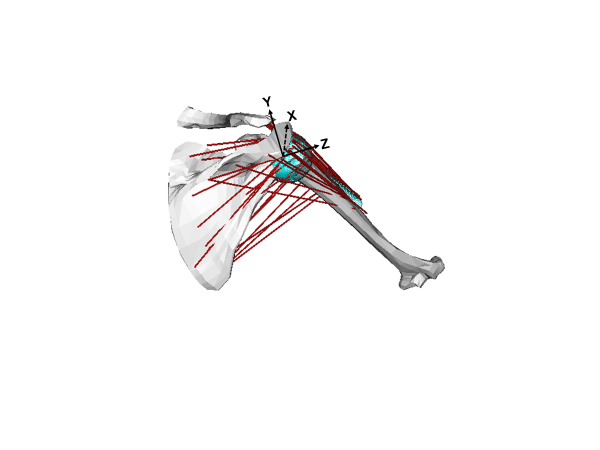
**Supplementary Material: Model coordinate system (Figure A.1), Horizontal Adduction/Abduction (Figure A.2; Table A.1) and Internal/External Rotation (Figure A.3; Table A.2) Moment Arm Results**



**Figure A.1:** The modified Delft Shoulder and Elbow Model (DSEM) with the scapulohumeral muscles and humeral head/shaft wrapping objects visible (van der Helm, 1994a,b; Blana et al., 2008). Scapula coordinate system is shown, with the positive X-, Y-, and Z-axis referring to the anterior, superior, and lateral directions. Muscle lines of action are expressed as the clockwise angle from the Z-axis for the YZ plane (superior-inferior line of action) and XZ plane (anterior-posterior line of action).



**Figure A.2:** Model-predicted humeral horizontal adduction/abduction moment arms with varying attachment locations. All simulations (1000 iterations for each muscle element) are plotted as thin lines. Thick, dark bands represent mean values for each muscle. Darker shades for the infraspinatus/subscapularis and supraspinatus represent superior and anterior regions, respectively. Positive (negative) values indicate humeral horizontal adduction (horizontal abduction).

**Table A.1:** Regression models predicting humeral horizontal adduction/abduction moment arms (mm) for each scapulohumeral muscle. Independent variables include attachment changes at the scapula (Sx, Sy, Sz) and humerus (Hx, Hy, Hz) in each axis. For the anterior deltoid, the attachment locations were changed at the clavicle (Cx, Cy, Cz) (denoted with an asterisk\*). All attachment changes were centered relative to the mean and divided by the standard deviation. Humeral elevation angle relative to the thorax (HT) and its quadratic (HT2) and cubic (HT3) terms were added as covariates. Values represent unstandardized beta coefficients.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Muscle** | **B0** | **Sx or \*Cx** | **Sy or \*Cy** | **Sz or \*Cz** | **Hx** | **Hy** | **Hz** | **HT** | **HT2** | **HT3** | **R2** |
| S. Infraspinatus | -14.9 | -0.2 | -0.1 | 0.1 | 2.6 | -0.9 | -2.8 | -6.0E-02 | -4.0E-04 | 2.8E-06 | 0.94 |
| I. Infraspinatus | -21.3 | -0.3 | -1.0 | 0.8 | 2.5 | -0.6 | -2.9 | 8.4E-02 | -1.3E-03 | 4.6E-06 | 0.98 |
| A. Supraspinatus | 14.3 | 0.2 | 0.0 | -0.1 | 2.3 | -0.4 | -1.1 | -3.5E-01 | 2.2E-03 | -9.4E-06 | 0.98 |
| P. Supraspinatus | -12.5 | 0.5 | 0.7 | 0.0 | 1.9 | -0.2 | -1.6 | -1.7E-01 | 1.4E-03 | -5.9E-06 | 0.97 |
| S. Subscapularis | 19.6 | 0.5 | -0.5 | 2.3 | 0.0 | 0.3 | -0.1 | 5.7E-02 | -1.3E-03 | 5.6E-06 | 0.80 |
| M. Subscapularis | 23.0 | 0.0 | 0.1 | -0.1 | 2.1 | -0.9 | -0.7 | 1.4E-01 | -4.5E-03 | 2.0E-05 | 0.95 |
| I. Subscapularis (L) | 19.9 | -0.2 | 1.2 | -0.8 | 2.1 | -0.5 | -0.5 | 3.5E-02 | -8.1E-05 | -4.6E-06 | 0.83 |
| I. Subscapularis (S) | 15.9 | 0.9 | 0.9 | -1.7 | 2.4 | -0.4 | -0.9 | -1.1E-01 | 1.7E-03 | -4.5E-06 | 0.93 |
| Teres Minor | -18.4 | 0.5 | -2.7 | 0.9 | 0.7 | -0.1 | -4.5 | -1.7E-01 | 1.9E-03 | -7.6E-06 | 0.98 |
| Teres Major | 9.3 | 1.4 | 0.1 | -1.4 | 0.9 | -0.8 | -0.9 | 1.3E-01 | -8.5E-04 | 6.8E-07 | 0.88 |
| A. Deltoid (1)\* | 4.5 | 0.0 | -0.7 | -1.2 | 0.0 | 0.1 | 0.3 | 9.3E-02 | 1.7E-05 | 1.5E-06 | 0.96 |
| A. Deltoid (2)\* | 2.1 | 0.3 | -0.8 | -1.6 | 0.2 | -0.1 | 0.4 | 2.4E-01 | 1.3E-03 | -7.4E-06 | 0.99 |
| M. Deltoid (1) | -0.7 | 1.9 | 0.3 | -0.8 | -0.3 | 0.0 | -0.4 | -2.8E-01 | 3.0E-04 | 2.1E-06 | 0.99 |
| M. Deltoid (2) | 0.2 | 4.6 | 0.2 | -0.5 | -0.2 | 0.0 | 0.0 | -2.4E-01 | 1.6E-03 | -5.4E-06 | 0.92 |
| P. Deltoid | -8.8 | 1.5 | -0.8 | -5.0 | -0.4 | -1.0 | -0.9 | 1.4E-01 | -4.4E-03 | 2.1E-05 | 0.74 |
| Coracobrachialis | -4.8 | 1.4 | -0.3 | -3.2 | 0.3 | -0.1 | 0.3 | 4.0E-01 | 3.8E-04 | -7.9E-06 | 0.98 |



**Figure A.3:** Model-predicted humeral rotational moment arms with varying attachment locations. All simulations (1000 iterations for each muscle element) are plotted as thin lines. Thick, dark bands represent mean values for each muscle. Darker shades for the infraspinatus/subscapularis and supraspinatus represent superior and anterior regions, respectively. Positive (negative) values indicate humeral internal (external) rotation.

**Table A.2:** Regression models predicting humeral rotational (i.e. internal/external rotation) moment arms (mm) for each scapulohumeral muscle. Independent variables include attachment changes at the scapula (Sx, Sy, Sz) and humerus (Hx, Hy, Hz) in each axis. For the anterior deltoid, the attachment locations were changed at the clavicle (Cx, Cy, Cz) (denoted with an asterisk\*). All attachment changes were centered relative to the mean and divided by the standard deviation. Humeral elevation angle relative to the thorax (HT) and its quadratic (HT2) and cubic (HT3) terms were added as covariates. Values represent unstandardized beta coefficients.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Muscle** | **B0** | **Sx or \*Cx** | **Sy or \*Cy** | **Sz or \*Cz** | **Hx** | **Hy** | **Hz** | **HT** | **HT2** | **HT3** | **R2** |
| S. Infraspinatus | -14.9 | 0.1 | 2.2 | -0.1 | 2.2 | -0.1 | -1.7 | -6.7E-02 | 1.7E-03 | -2.7E-06 | 0.89 |
| I. Infraspinatus | -20.5 | 0.2 | 1.2 | -0.8 | 2.6 | 0.0 | -2.7 | -1.1E-02 | 4.7E-04 | 2.0E-06 | 0.95 |
| A. Supraspinatus | 13.9 | 1.4 | 0.0 | -0.2 | 1.8 | 0.1 | 0.0 | -3.2E-01 | 4.4E-03 | -1.7E-05 | 0.88 |
| P. Supraspinatus | -13.0 | 1.2 | 1.6 | 0.1 | 1.2 | 0.0 | -0.6 | -1.2E-01 | 3.7E-03 | -1.2E-05 | 0.97 |
| S. Subscapularis | 19.0 | 0.2 | -2.8 | 0.2 | -0.1 | 0.5 | -0.1 | 1.2E-01 | -3.2E-03 | 8.9E-06 | 0.94 |
| M. Subscapularis | 21.7 | 0.5 | -1.0 | -0.2 | 2.3 | -0.5 | -0.4 | 2.8E-01 | -5.7E-03 | 2.3E-05 | 0.95 |
| I. Subscapularis (L) | 18.5 | 0.3 | -0.1 | -0.2 | 2.5 | -0.1 | -0.5 | 1.9E-01 | -9.3E-04 | -5.8E-06 | 0.85 |
| I. Subscapularis (S) | 15.6 | 0.2 | -0.1 | -0.2 | 2.6 | 0.0 | -1.0 | -6.6E-02 | 1.2E-03 | -6.4E-06 | 0.94 |
| Teres Minor | -15.9 | 0.0 | 0.5 | -0.2 | 0.8 | 0.1 | -4.6 | -4.1E-01 | 4.4E-03 | -9.3E-06 | 0.92 |
| Teres Major | 10.9 | 0.2 | -0.2 | -0.1 | 1.2 | 0.3 | -1.0 | -1.4E-02 | -3.4E-04 | 7.2E-07 | 0.98 |
| A. Deltoid (1)\* | 5.0 | 0.1 | 0.2 | -0.3 | 0.0 | 0.3 | 0.8 | -5.5E-02 | 1.3E-03 | -5.6E-06 | 0.92 |
| A. Deltoid (2)\* | 4.3 | 0.1 | 0.1 | -0.3 | 0.1 | 0.5 | 0.8 | -6.3E-04 | 7.0E-04 | -3.7E-06 | 0.94 |
| M. Deltoid (1) | -4.8 | 0.5 | 0.2 | 0.2 | -0.6 | -0.1 | -0.2 | 1.0E-01 | -6.2E-04 | 2.2E-06 | 0.97 |
| M. Deltoid (2) | -3.1 | 1.3 | 0.1 | -0.1 | -0.4 | 0.0 | 0.2 | 9.5E-02 | -8.2E-04 | 3.0E-06 | 0.96 |
| P. Deltoid | -7.0 | 0.3 | 0.5 | 1.4 | 0.1 | -0.2 | -0.5 | 4.2E-02 | 2.2E-04 | -1.8E-07 | 0.93 |
| Coracobrachialis | -1.0 | 0.0 | -0.1 | -0.3 | 0.4 | 0.0 | 0.5 | 2.3E-02 | -3.0E-04 | 1.4E-06 | 0.95 |