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**Scapular and humeral movement patterns of people with stroke  
during range of motion exercises**

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**Background and Purpose:** Range-of-motion (ROM) exercises may contribute to hemiparetic shoulder pain, but the mechanisms behind this are unknown. This study examined scapular and humeral movement patterns in people with hemiparesis post stroke as they performed commonly prescribed ROM exercises.

**Methods:** Using kinematic techniques, we studied 13 people with hemiparesis, both with and without pain, as they performed three commonly prescribed ROM exercises: person-assisted ROM, self-assisted ROM, and cane-assisted ROM. Their data were compared to 12 matched controls performing scapular plane shoulder elevation using mixed model ANOVAs.

Correlation analyses were used to examine relationships between subjects' ratings of pain and kinematic data.

**Results:** The hemiparetic group had mild pain at rest that increased during the performance of the exercises. Humeral external rotation in the hemiparetic group was decreased in all three ROM exercises compared to shoulder elevation in the control group. Scapular upward rotation in the hemiparetic group was decreased for the person-assisted ROM exercise only. No differences in scapular tilt were found between groups. The extent of movement abnormalities was not related to pain severity.

**Discussion and Conclusions:** People with hemiparesis had altered scapular and humeral movement patterns and increased shoulder pain when performing the ROM exercises. These data can assist clinicians in making decisions regarding which exercises to prescribe to preserve shoulder motion and prevent contractures in this population.

## Background and Purpose

Hemiparesis or hemiplegia, i.e. the loss of some or all voluntary muscle activation on one side of the body, is a common impairment following stroke. The reduced ability to move leads to prolonged periods of time spent immobile.<sup>1-3</sup> A major concern for rehabilitation clinicians is the time spent with the upper extremity resting in the lap; shoulder and arm muscles, particularly shoulder internal rotators and extenders, and elbow flexors, are held in shortened positions, potentially leading to loss of available motion and contractures.<sup>4</sup> To address this concern, people with hemiparesis or hemiplegia are often prescribed range-of-motion (ROM) exercises. Data supporting the effectiveness of ROM and stretching exercise in preventing loss of motion and contractures after stroke are inconclusive.<sup>4-7</sup>

A related concern for rehabilitation clinicians is whether or not performing ROM exercises contributes to hemiparetic shoulder pain.<sup>8,9</sup> Hemiparetic shoulder pain is a disabling condition with many possible etiologies<sup>10-12</sup>, affecting up to 72% of patients with hemiparesis.<sup>11,13,14</sup> ROM exercises could be one contributing factor to shoulder pain secondary to altered scapular and humeral movement patterns. Precise scapulohumeral coupling is needed to preserve the suprahumeral space and prevent impingement of the rotator cuff tendons. Proper coupling includes upward rotation and posterior tilting of the scapula<sup>15-18</sup> and external rotation of the humerus.<sup>15,16</sup> Reduced voluntary neural drive from the stroke may disrupt the timing and activation of scapulothoracic and rotator cuff muscles.<sup>19</sup> As the arm is moved during an exercise, the exercise may push the humerus into elevation angles higher than the subject can actively produce without assistance. As a clinician, one needs to be concerned about prescribing ROM exercise to preserve movement and avoid contractures while simultaneously avoiding exercises that could contribute to the development or persistence of hemiparetic shoulder pain.

The purpose of this study was to examine the scapular and humeral movement patterns in people with hemiparesis post stroke performing commonly prescribed ROM exercises: person-assisted ROM, self-assisted ROM, and cane-assisted ROM. Their scapular and humeral movement patterns during the exercises were compared to a group of neurologically intact healthy controls performing scapular plane shoulder elevation, which was our best proxy for normal shoulder motion. We hypothesized that people with hemiparesis would have abnormal scapular and humeral movement patterns when performing the selected exercises. Additionally, we hypothesized that the extent of movement abnormality would be related to the severity of reported pain during that movement. A better understanding of the scapular and humeral movement patterns associated with commonly prescribed ROM exercises may help clinicians identify which exercises are to be avoided and how exercises may be modified to better replicate the scapular and humeral movement patterns of normal shoulder motion.

## **Methods**

### ***Participants***

This was a pilot sample of convenience. Thirteen subjects with hemiparesis were recruited from a local rehabilitation hospital. Subjects with hemiparesis were included if they 1) had a diagnosis of stroke, 2) onset of unilateral upper extremity weakness following stroke. Subjects were excluded if they 1) had a history of shoulder pain and pathology prior to stroke, 2) were unable to follow 2-step commands, 3) showed signs of hemi-neglect, 4) showed symptoms consistent with referral from cervical or thoracic spine, 5) had any serious medical complications that would prevent them from participating, and/or 6) were unable to provide informed consent.

Twelve healthy subjects were recruited from the community. The age and gender composition of the control group was selected to match the age and gender composition of the hemiparetic group. Control subjects were excluded if they 1) had a history of stroke, 2) history or current complaints of shoulder pain or history of diagnosed shoulder pathology, 3) if they had any serious medical conditions that would prevent them from participating, and/or 4) if they failed to provide informed consent. The study was approved by the Washington University Human Research Protection Office prior to recruitment and testing. All subjects signed informed consent documents prior to participating.

### ***Kinematic Measurements***

Computer-based kinematic techniques were used to quantify movement of the contralesional, more-involved shoulder, arm, and thorax.<sup>20</sup> Three-dimensional movements of the upper extremity were captured using an electromagnetic tracking system (Motion Monitor built around Flock of Birds, Innovative Sports Training Inc., Chicago IL). Four sensors were attached to the 1) trunk: mid-sternum, 2) the arm: proximal to the lateral epicondyle, bisecting the arm mass, 3) the forearm: proximal to the mid-point between the radial and ulnar styloids on the dorsum of the forearm, and 4) the scapula: distal flat aspect of the acromion (Figure 1).<sup>21</sup> The forearm sensor was initially included to monitor if subjects were moving with a flexed elbow; since this did not occur, elbow sensor data are not included in this report. All sensors and trailing wires were taped down and secured with Coban (3M, St. Paul MN) to prevent slippage and arbitrary sensor movement. The hardware manufacturer reports a root mean square accuracy of 0.5° for orientation and 1.8 mm for position for the sensors used. With arms relaxed, bony landmarks on the thorax, scapula, and humerus were digitized with a custom probe to permit

transformation of sensor data into local segment coordinates using the accepted order of internal/external rotation, upward/downward rotation, and posterior/anterior tilting, according to the protocol recommended by the International Society of Biomechanics, Shoulder Group.<sup>20</sup>

Glenohumeral joint center was estimated using a least squares algorithm to find the point on the humerus that moved least in respect to the scapula as it was moved through short arcs.

<<Insert Figure 1>>

Kinematic data were low-pass filtered at 6 Hz using a second-order Butterworth filter. Motion Monitor software was used to calculate and extract segmental position and angle data from the sensor data using standard rigid body methodology.<sup>20</sup> The scapulothoracic angular data extracted were scapular upward rotation and scapular tilt, and the glenohumeral angular data were humeral elevation and humeral external rotation (Figure 2). Scapular internal/external rotation data were also extracted but are not included in this report due to lack of consensus what constitutes normal scapular internal and external rotation during humeral elevation with some studies reporting scapular external rotation as the arm is elevated<sup>18,22,23</sup> and some studies demonstrating scapular internal rotation as the arm is elevated.<sup>24-26</sup> Anatomical variations in the shape and size of the thorax and ribs could also impact the relative internal and external rotation of the scapula as it slides along the thorax. The plane of elevation for humeral elevation depended on the exercise, but generally this elevation occurred between the sagittal plane and the scapular plane (approximately 30° anterior to the frontal plane by visual estimation). Scapular upward rotation was rotation of the scapula in frontal plane about an anterior-posterior axis in which the inferior angle moves laterally. Scapular posterior tilt was rotation of the scapula in the sagittal plane about a lateral axis in which the superior border of the scapula moves posteriorly. Humeral external rotation was the spinning of the humerus on the glenoid laterally. All angular

data were calculated according to the recommended protocol.<sup>20</sup> For ease of communication, increasing the data for humeral external rotation and scapular upward rotation were multiplied by -1. Custom-written software in MATLAB (The Mathworks Inc., Natick MA) was used for subsequent analysis to find the above angles at the start of movement and at, 30°, 60°, 90°, and 120° of humeral elevation.

<<Insert Figure 2>>

### ***Protocol***

Testing began with subjects seated in a wooden chair with the upper limb dependent. Care was taken to ensure that the tested upper extremity and scapula did not contact or were otherwise obstructed by the chair. Subjects performed 3 trials of each exercise at a self-selected pace and were given rest breaks as needed. All subjects were able to perform the exercise as instructed, although some required several practice trials before movements were recorded. Controls were tested using the same self-selected speed protocol as subjects. One examiner did all the testing and digitizing.

The 3 commonly prescribed ROM exercises were: person-assisted ROM, self-assisted ROM, and cane-assisted ROM. (Figure 3) They were all performed as active-assisted ROM, in that the subject used their more-involved extremity as much as possible, and the assistance provided further ROM beyond what they could do unassisted. Person-assisted ROM (Figure 3A) was performed by a single tester. Assistance was given by another person under the middle portion of the arm and under the mid-forearm as the subject performed humeral elevation.<sup>7</sup> Self-assisted ROM (Figure 3B) was performed with the subject supporting the elbow of the more-involved extremity with the less-involved extremity as he or she performed humeral

elevation.<sup>6</sup> Person-assisted and self-assisted ROM occurred near the plane of flexion. Cane-assisted ROM (Figure 3C) was performed using a plastic pipe that approximated the diameter and length of a standard cane. The subject gripped the cane with an overhand grip with hands slightly wider than shoulder width apart. They performed bilateral shoulder elevation, providing assistance from the less-involved extremity through the cane to assist the more-involved extremity. Cane-assisted ROM occurred in the scapular plane. As done clinically, the examiner provided assistance with grasping the cane if needed. Once grasped, all subjects could produce at least minimal forces to grip the cane.

<<Insert Figure 3>>

All exercises were compared to controls performing scapular plane shoulder elevation because it represents the best proxy for normal scapular and humeral motion and it is often used to examine shoulder motion in healthy controls and patient populations.<sup>18,21,23,27,28</sup> We did not compare scapular and humeral movements of the more-involved shoulder to the less-involved shoulder because the less-involved shoulder has been found to have kinematic alterations<sup>29</sup> and because the less-involved shoulder was assisting with 2 of 3 exercises. Comparisons were also not made to controls performing the exercises because that would be a contrived situation, i.e. people with healthy shoulders would not perform these exercises.

### ***Clinical Measures***

Shoulder pain at rest and during movement trials was recorded using a numeric pain rating scale (0-10 points). Subjects rated their pain prior to testing and after each trial. This scale has been shown to be a reliable and sensitive pain scale for use in older populations.<sup>30</sup> It has good reliability in subjects with orthopedic shoulder conditions<sup>31</sup> as well as subjects with

hemiparesis.<sup>32</sup> The Stroke Impact Scale, Hand Function subscale was used to capture upper extremity functional deficits in the sample.<sup>33</sup> This reliable, valid, and quick measure agrees well with the more time-consuming Fugl-Meyer Upper Extremity Motor subscale.<sup>34</sup> Muscle tone at the elbow and shoulder was assessed using the Modified Ashworth Scale.<sup>35</sup>

### ***Data analysis***

Statistica (StatSoft Inc., Tulsa OK) was used for statistical analyses and the criterion for statistical significance was set at  $p < 0.05$ . A repeated measures ANOVA and post hoc t tests were used to compare pain at rest (prior to performing any movement) and pain during each exercise, quantified by the average of numeric pain rating given during the 3 trials. Mixed-model, repeated measures ANOVAs were used to test for significant differences in humeral external rotation, scapular upward rotation, and scapular tilt between the hemiparetic group performing each exercise and control group performing scapular plane shoulder elevation at start of movement, 30°, 60° and 90° of humeral elevation. Averages of the three trials for each subject were entered into the ANOVAs. Because we used a single control condition (control group scapular plane shoulder elevation), we ran separate ANOVAs for each exercise vs. the control condition. Post hoc comparisons using Fishers Least Significant Difference were used when significant main or interaction effects were found. Protected t-tests with a more stringent criterion of  $p < 0.01$  were used to assess differences at 120° since many hemiparetic subjects did not achieve these angles. This analysis strategy permitted the inclusion of all subjects in the ANOVAs yet still examined the higher humeral elevation angles.

Since some of our subjects had shoulder pain and others did not, we used Spearman Rho correlations to test if severity of pain during performance of each specific exercise was related to

scapular and humeral movement at various humeral angles during that same exercise. This would provide an indication as to how pain might have influenced the recorded movements.

## **Results**

Characteristics of the 13 subjects with hemiparesis and 12 controls are provided in the Table. Time since stroke for the hemiparetic subjects was variable, ranging from 1 month to 2 years. As expected, upper extremity function was decreased and average spasticity levels were mild, as indicated by the Hand Function subscale of the Stroke Impact Scale and the Modified Ashworth Scale, respectively.

<<Insert Table 1>>

## ***Pain***

Five hemiparetic subjects reported pain in their involved shoulder prior to testing. Of the eight hemiparetic subjects who did not report pain prior to testing, four experienced some shoulder pain during various exercises. On average, the hemiparetic group reported mild pain at rest which increased during performance of the exercises (bottom of Table). Pain was increased during the performance of the exercises compared to rest (within subjects main effect,  $F_{3,36} = 4.01$ ,  $p = 0.015$ ). Post hoc t-tests indicated that pain during the performance of person-assisted ROM and self-assisted ROM were greater than pain at rest ( $p = 0.03$ ,  $p = 0.02$  respectively), and pain during the performance of cane-assisted ROM showed a trend towards greater pain than pain at rest, but did not reach significance ( $p = 0.08$ ).

## ***Scapular and humeral movement during the 3 exercises***

Scapular and humeral movement data from the 3 exercises in the hemiparetic group and from scapular plane shoulder elevation in the control group are shown in Figure 4. Here we report the relevant main effects of group and group by angle interactions as they pertain to our hypotheses. For the post hoc testing of group by angle interactions, we indicate the comparisons where significant differences were not found. As expected, there were main effects of angle for each exercise across the examined motions ( $p$  values  $< 0.05$ ).

In the person-assisted ROM exercise (Figure 4, top row), the hemiparetic group had decreased humeral external rotation (main effect of group,  $F_{1,23} = 14.2$ ,  $p < 0.001$ ; group x angle interaction,  $F_{3,72} = 10.2$ ,  $p < 0.001$ ; post hoc testing yielded no significant difference at  $0^\circ$ ,  $p = 0.30$ ) and decreased scapular upward rotation (main effect of group,  $F_{1,23} = 4.4$ ,  $p < 0.05$ ; group x angle interaction,  $F_{3,72} = 4.5$ ,  $p < 0.006$ ; post-hoc testing yielded no significant difference at  $0^\circ$ ,  $p = 0.70$ ) compared to controls performing scapular plane shoulder elevation. Protected t-tests at  $120^\circ$  demonstrated decreased humeral external rotation ( $p < 0.01$ ), but no difference in scapular upward rotation ( $p = 0.42$ ) in the hemiparetic group compared to controls. Scapular tilt was not different between groups (main effect of group,  $F_{1,23} = 1.1$ ,  $p = 0.32$ ; at  $120^\circ$  protected t-test,  $p = 0.44$ ).

In the self-assisted ROM exercise (Figure 4, middle row), the hemiparetic group had decreased humeral external rotation (main effect of group,  $F_{1,23} = 29.4$ ,  $p < 0.001$ ; group x angle interaction,  $F_{3,72} = 19.3$ ,  $p < 0.001$ ; post hoc testing yielded no significant difference at  $0^\circ$ ,  $p = 0.86$ ) compared to controls performing scapular plane shoulder elevation. Protected t-tests at  $120^\circ$  demonstrated decreased humeral external rotation ( $p < 0.001$ ) in the hemiparetic group compared to controls. Scapular upward rotation was not different between groups (main effect of group,  $F_{1,23} = 1.9$ ,  $p = 0.18$ ), but showed a group x angle interaction ( $F_{3,72} = 5.1$ ,  $p < .003$ ; post

hoc testing yielded no significant difference at 0°,  $p = 0.90$ ). Scapular upward rotation was not different at 120° (protected t-test,  $p = 0.57$ ). Scapular tilt was not different between groups (main effect of group,  $F_{1,23} = 0.5$ ,  $p = 0.49$ ; at 120° protected t-test,  $p = 0.75$ ).

In the cane-assisted ROM exercise (Figure 4, bottom row) the hemiparetic group had decreased humeral external rotation (main effect of group,  $F_{1,23} = 15.5$ ,  $p < 0.001$ ; group x angle interaction,  $F_{3,72} = 15.9$ ,  $p < 0.001$ ; post hoc testing yielded no significant difference at 0°,  $p = 0.31$ ) compared to controls performing scapular plane shoulder elevation. Protected t-tests at 120° demonstrated decreased humeral external rotation ( $p < 0.001$ ) in the hemiparetic group compared to controls. No differences between groups were found for scapular upward rotation (main effect of group,  $F_{1,23} < 0.01$ ,  $p = 0.95$ ; at 120° protected t-test  $p = 0.65$ ) or scapular tilt (main effect of group,  $F_{1,23} = 1.6$ ,  $p = 0.22$ ; at 120° protected t-test  $p = 0.73$ ).

<<Insert Figure 4>>

### ***Relationships between pain and movement***

No relationships were found between reported pain during the performance of each exercise and the scapular and humeral movement data. Spearman rho values ranged from -0.46 to + 0.36 (all  $p$  values  $> 0.05$ ).

### **Discussion**

The hemiparetic group had altered movement patterns during performance of the ROM exercises compared to our proxy of normal shoulder motion. On average, the hemiparetic group had mild pain at rest which increased during the performance of the exercises. Severity of pain was not associated with scapular or humeral movement patterns during the exercises.

Our primary hypothesis was supported: people with hemiparesis had abnormal scapular and humeral movement patterns when performing the tested exercises. The performance of stretching and ROM exercises have been previously associated with shoulder pain in people with hemiparesis.<sup>8,9</sup> Our data build on these reports by describing abnormal scapular and humeral movements that occurred during the performance of shoulder ROM exercises. Data from the present study provide a biomechanical mechanism for how performing these exercises may contribute to the development of shoulder pain post stroke.

The most salient finding during the performance of all three exercises was the decrease in humeral external rotation. The lack of dynamic humeral external rotation found here is compatible with literature showing an association between reduced passive humeral external rotation and hemiparetic shoulder pain.<sup>32,36-38</sup> Conditions that decrease humeral external rotation increase rotator cuff compression particularly against the greater tuberosity; the compression increases as the humerus is elevated.<sup>39-41</sup> We speculate that performing these ROM exercises as described could contribute to, or exacerbate, hemiparetic shoulder pain by repeatedly compressing the rotator cuff tendons.

It is worth noting that the etiology and contributing factors of shoulder pain following are multifactorial and poorly understood.<sup>11,12,36,42 43,44</sup> It is likely that more than one factor plays is responsible. These factors may overlap extensively and no single factor may be responsible for pain in individual patients. These factors include shoulder subluxation, reflex sympathetic dystrophy, and adhesive capsulitis. The resultant disruptions in movement patterns, regardless of diagnosis, can lead to strain and tearing of rotator cuff muscles as well as impingement of the rotator cuff tendons. It appears that performing ROM exercises as described may be promoting

these abnormal movement patterns and thus should be modified or avoided in this population regardless of diagnosis.

Our secondary hypothesis was not supported: the extent of movement abnormalities were not related to the extent of pain during the selected exercise. There are three possible explanations for this. First, it is possible that severity of pain is not related to the extent of movement abnormalities as seen in this sample. This possibility is consistent with the understanding that feelings of pain are influenced by many factors.<sup>45-47</sup> The extent of scapular and humeral movement abnormalities might therefore be only one of many contributing factors. Alternatively, it is possible that the relationship between pain and extent of movement abnormalities is affected by time, i.e. performing many repetitions of these exercises over a long period would create an association between pain severity and abnormal movement. In this alternative scenario, rotator cuff compression incurred while performing these exercises would accumulate. The eventual result might be microtrauma and pain, which in turn could lead to more abnormal movement patterns.<sup>48</sup> Since we did not investigate other factors that may have contributed to the reported pain and we only tested three repetitions of each exercise, our data do not permit us to distinguish between these possibilities. A third possibility for the lack of relationship is the small sample size of this study (see suggestions for future studies under Limitations below).

### ***Clinical considerations for when prescribing specific exercises post stroke***

Of the three exercises evaluated, person-assisted ROM of the hemiparetic shoulder had the most differences in scapular and humeral motion compared to active ROM of the normal shoulder. These differences, decreased humeral external rotation and scapular upward rotation,

may be attributed to the fact that the scapula and humerus were not monitored or controlled during performance of this exercise. A skilled therapist performing this same exercise may be much more likely to monitor and control these motions. It is often the case however, that a therapist provides the initial instruction, and then this exercise is performed repeatedly with assistance from a non-skilled caregiver. We sought to replicate this common method of performance. The results of this study therefore highlight the importance of education to caregivers who may be performing this person-assisted ROM exercise on people with hemiparesis. Specific education on how to externally rotate the humerus and manually assist the scapula into upward rotation may be needed to perform this exercise with more normalized shoulder motions.

The self-assisted ROM exercise resulted in decreased humeral external rotation compared to normal shoulder motion. Using the less-involved upper extremity to assist their more-involved upper extremity naturally puts both arms into horizontal adduction and internal rotation; this is particularly true for larger individuals with wide trunks. Based on these mechanical constraints, therapists may want to avoid the self-assisted ROM exercise when considering options to preserve movement and prevent contractures in people with hemiparesis post stroke.

The cane-assisted ROM exercise also resulted in decreased humeral external rotation compared to normal shoulder motion. An overhand grip was used to grip the cane in the present study. The overhand grip placed the forearm in pronation and likely contributed to a less externally rotated humerus. One way to modify this exercise would be to switch to an underhand grip. The underhand grip would position the forearm in supination and may help to promote humeral external rotation. A challenge to making this modification is that people with stroke might have more trouble maintaining an underhand grip than an overhand grip with the paretic

hand. This could be addressed with a strap or other individualized modification. We speculate that, if modified to employ an underhand grip, the cane-assisted ROM exercise may be an acceptable choice for preserving shoulder movement and preventing contractures in people with hemiparesis post stroke. It should be noted however, that the clinical premise that contractures can be prevent through ROM exercises is not fully supported by data at this time.<sup>49</sup>

### ***Limitations***

Three main limitations should be taken into account when interpreting the results of this study. First, the sample size was small, limiting the ability to detect differences between groups and relationships to pain and the ability to generalize our findings. Second, we studied only three ROM exercises, each performed according to specific instructions. Other exercises and their variations may have different effects on the movement patterns of the humerus and scapula. Finally, our sample included people with hemiparesis both with and without shoulder pain. While people with and without pain are prescribed ROM exercises during their rehabilitation, grouping them together could have masked unique findings in one subgroup or the other. Future longitudinal studies on this topic with larger sample sizes, more variations of exercises, and grouping of subjects into subpopulations with respect to pain would greatly improve therapist decision-making when choosing exercises.

### **Conclusions**

Reduced humeral external rotation was the most common movement abnormality observed during the performance of three commonly-prescribed shoulder ROM exercises by people with hemiparesis post stroke. Our data can assist clinicians in making decisions

regarding which exercises to prescribe to preserve shoulder motion and prevent contractures in this population.

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**Table 1.** Subject characteristics. All values are means (range) unless otherwise noted.

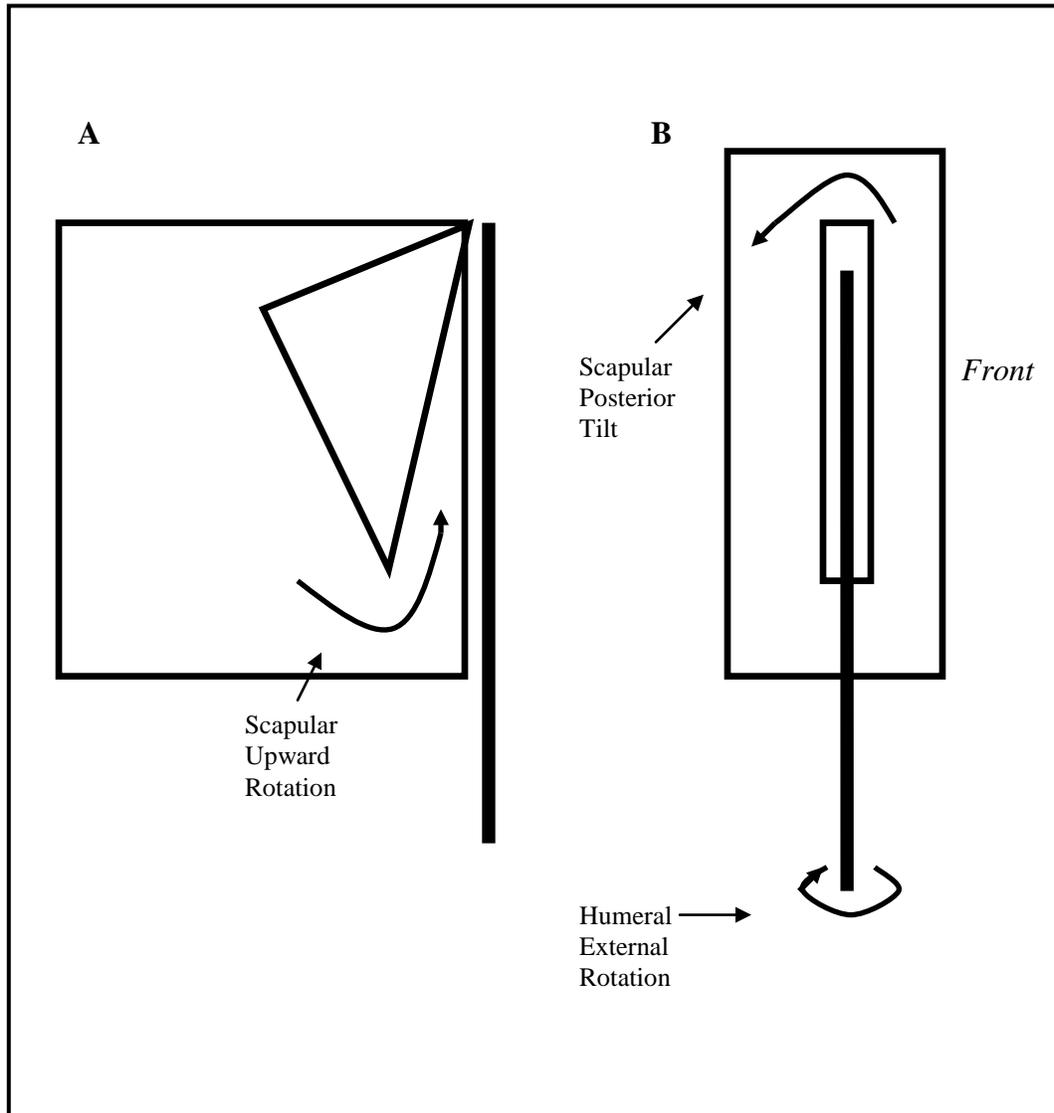
|   | Hemiparetic Subjects<br>N=13 | Control Subjects<br>N=12 |
|---|------------------------------|--------------------------|
| Age, in years                                     | 56 (49-64)                   | 54 (40 - 72)             |
| Gender  | 8 male, 5 female             | 7 male, 5 female         |
| Time since stroke in months                       | 5 (1 - 24)                   |                          |
| Stroke Impact Scale Hand Function Subscale*       | 29.2 (5-90)                  |                          |
| Modified Ashworth Scale – elbow as median (range) | 0 (0 - 3)                    |                          |
|   |                              |                          |
| Pain at rest                                      | 1.5 (0 – 6)                  |                          |
| Pain with Person-assisted                         | 3.9 (0 – 7.7)†               |                          |
| Pain with Self-assisted                           | 4.2 (0 – 8.5)†               |                          |
| Pain with Cane-assisted                           | 3.4 (0 – 8.25)               |                          |

\*Self reported measure of upper extremity, scores range from 0 to 100, with 100 representing full hand function.

†Significantly different than pain at rest,  $p < 0.05$ .



**Figure 1.** Sensor placement for testing. Note that although not shown in picture, sensors and trailing wires were secured with tape and Coban to prevent slippage and arbitrary sensor movement.



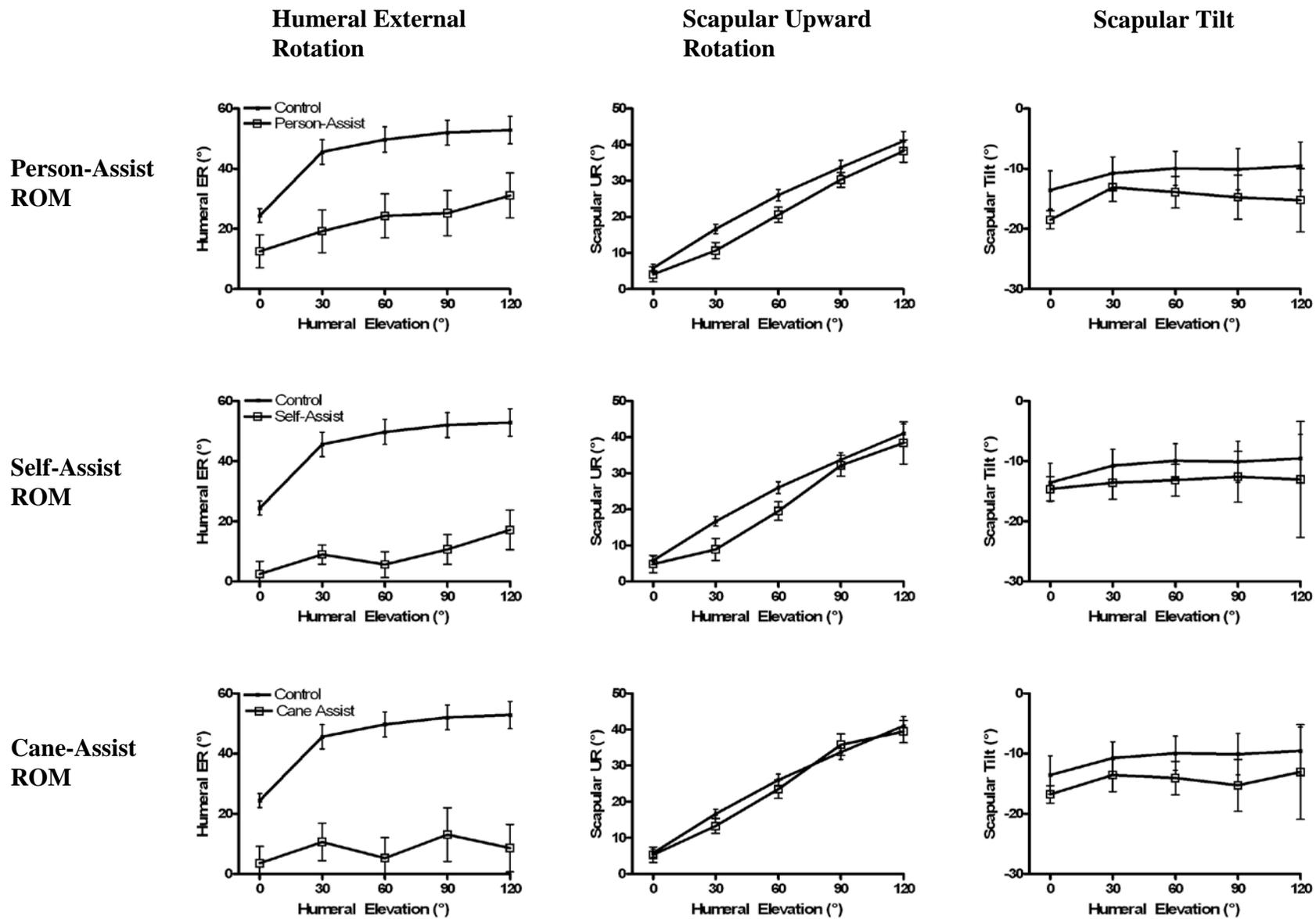
**Figure 2.** Schematic illustration of rotations shown on a right sided scapula.

A: The triangle represents the scapula and the bar represents the humerus as looking at it from behind the subject. Scapular upward rotation occurs when the inferior angle moves laterally as shown by the arrow.

B: The small rectangle represents the scapula and the bar represents the humerus as looking at the subject from the side. Scapular posterior tilt occurs when the superior border of the scapula rotates posterior. Humeral external rotation occurs when the humerus spins on its long axis laterally.



**Figure 3.** Photographs illustrating exercise performance.  
A: Person-assisted ROM; B: Self-assisted ROM; C: Cane-assisted ROM.



**Figure 4.** Group data. Values are means  $\pm$  SEs of each data point.