Excessive Scapular Motion in Individuals Recovering From Painful and Stiff Shoulders: Causes and Treatment Strategies

Background and Purpose. Scapular excursion and the wrist speed were studied before and after instruction and practice designed to achieve symmetrical scapular movement. Subjects. Subjects were 10 female and 6 male patients, aged 44 to 78 years (X=60.3, SD=11.2), with diagnosed shoulder pathologies. Methods. Subjects were videotaped performing a reaching task. Pain status was monitored. The subjects were instructed to make the scapular movement symmetrical. They then repeated the task, while being videotaped, to monitor the effect of instruction. Results. Individuals with asymmetric upper-extremity starting positions had excessive vertical motion of the involved scapula, which they controlled after instruction. Peak wrist speed of the involved upper extremity was lower only after instruction. Conclusion and Discussion. Even in the absence of biomechanical factors or pain, excessive scapular vertical motion appears to occur in the involved upper extremities of individuals recovering from unilateral shoulder problems. Improved scapular control can follow simple verbal instruction and practice, with a slight decrement in wrist speed. [Babyar SR. Excessive scapular motion in individuals recovering from painful and stiff shoulders: causes and treatment strategies. Phys Ther. 1996;76:226–238.]

Key Words: Motion analysis, Movement, Scapula, Shoulder joint.

Suzanne R Babyar

Scapular substitution following unilateral and painful stiff shoulders (UPSS) is often thought to be due to biomechanical factors or pain. In the late stages of recovery from UPSS, however, when range of motion (ROM) and muscle force-generating capacity have been restored, scapular substitutions may represent altered motor control strategies that have become habits. This research was directed first at determining whether scapular substitution patterns exist in individuals recovering from UPSS, and then at analyzing the effect of movement education on the movement patterns and outcomes.

Scapular Substitution Patterns

Normal, pain-free shoulder motion requires adequate mobility in the scapulothoracic, glenohumeral, acromioclavicular, and sternoclavicular joints and appropriate muscle activity. Codman labeled the synergistic interplay of scapular and glenohumeral muscles, resulting in movement at the respective joints, as scapulo/zzcmeral rhythm. Individuals with UPSS resulting from adhesive capsulitis, frozen shoulder syndrome, or diffuse rotator cuff tendinitis limit upper-extremity movement during activities of daily living (ADL). Changes in the soft tissue surrounding the glenohumeral joint may limit the mobility of the joint. Attempts to move may then cause pain and continued dysfunction of the involved upper extremity (UE). The individual may learn to use scapulothoracic, elbow, or trunk motions to substitute for lost glenohumeral motion.

Recovery from UPSS is usually marked by decreased pain and improved ROM and muscle force-generating capacity. Despite this improvement, some individuals appear to be persistent in their use of altered scapulothoracic movement patterns during UE movements.

Scapular substitution patterns are usually thought to exist because of biomechanical abnormalities or an imbalance in strength or length of shoulder muscles. Pain anticipated prior to UE movement or pain experienced during movement could also account for abnormal patterns. Individuals who guard their affected shoulders in the acute stages by limited glenohumeral movement exhibit "pain behavior," which may persist even after the pain subsides. Treatment often focuses on improving joint play and muscle force-generating capacity and on pain reduction, with the further assumption that scapulothoracic rhythm will return automatically.

SR Babyar, PhD, PT, is Assistant Professor, Physical Therapy Program, School of Health Sciences, Hunter College, 425 E 25th St, New York, NY 10010 (USA). She was a doctoral candidate in clinical research, Physical Therapy Department, New York University, when this research was completed in partial fulfillment of her degree requirements.

This study was approved by the New York University Committee on Activities Involving Human Subjects. The rights of human subjects were protected.

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Table 1. Inclusion Criteria

1. History of distal trauma, overuse, immobilization, or idiopathic etiology causing pain and stiffness in the involved shoulder
2. Participation in a physician-prescribed physical therapy or occupational therapy program
3. Pain-free, active shoulder flexion to 90°; minor general shoulder pain or discomfort was accepted
4. Passive glenohumeral flexion to at least 120°; other motions could be restricted
5. Equal force in both upper extremities (UEs), as determined by tests of correlated means, which showed no difference between UEs in dynamometer recordings from isometric contractions of scapular, glenohumeral, and elbow muscles \( t_{(0.5, 18)} > 2.13 \)
6. Ability to hold both UEs in approximately 90° of shoulder flexion without discomfort and without lateral displacement of the scapula from the thorax
7. Ability to hold glenohumeral abduction against submaximal resistance
8. Ability to maintain pain-free, maximal-resisted isometric elbow flexion against the investigator's manual resistance
9. Normal UE sensation to light touch and passive motion sense of glenohumeral flexion
10. Pain-free palpation of the subacromial bursa, the tendon of the long head of the biceps brachii muscle, and supraspinatus tendon insertion

Movement Outcomes
Some researchers\(^{15-15}\) attribute common kinematic features of movements to the execution of learned or innate motor programs. The wrist speed profile, a kinematic feature of the reaching task, gives a measure of the movement outcome and can be used to reflect changes in movement of the UE.\(^{16}\) The profile is a graph of wrist speed versus time.\(^{16}\) Many researchers use the term "wrist velocity profile," but in this report the more appropriate scalar term "wrist speed profile" is used.

For learned reaching tasks such as unrestrained vertical arm movements\(^{17}\) and restrained horizontal arm movements,\(^{18,19}\) the wrist speed profile exhibits a unimodal, bell-shaped curve.\(^{16}\) The smooth, bell-shaped profile represents a coordinative level of central nervous system control that, in theory, results in the most efficient motion possible.\(^{20}\) Characteristics of the reaching task movement outcome seen in the wrist speed profile include the duration of the task, the peak wrist speed, and the percentage of time to peak speed. Relative timing, as measured by time to peak speed, is an important invariant feature of reaching tasks, according to Atkeson and Hollerbach.\(^{17}\) For free vertical arm movements with few accuracy constraints, the time to peak speed generally occurred at 50% of the movement time in studies by Atkeson and Hollerbach,\(^{17}\) Hogan and Flash\(^{20}\) and Hogan\(^{21}\) showed that peak wrist speed occurred before 50% of the movement time if accuracy was required for the reach. If the speed profile was smooth and symmetrical, then the ratio of peak wrist speed to average wrist speed yielded a constant for each successive repetition of the movement.\(^{17,20,21}\) This movement outcome variable represented a measure of relative control.

The data discussed were obtained from persons without any shoulder pathology. Little is known about the characteristics of the wrist speed profile for individuals recovering from shoulder pain and limitation, such as those selected for my study.

When scapulothoracic motion is disproportionate to glenohumeral motion, the potential exists for micro-trauma.\(^{7,22}\) Descriptions of latent scapular substitution patterns and determination of their source may suggest alternatives to current physical therapy practice. If the cause of scapular substitution patterns is identified, clinicians may be able to devise strategies to improve movement patterns of individuals with UPSS earlier in the recovery process.

I examined five research questions:

1. Do individuals recovering from UPSS use abnormal movement patterns despite the apparent restoration of muscle force and ROM and decreased pain of their involved UEs?
2. Are the patterns obligatory results of biomechanical constraints, or can individuals recovering from UPSS restore normal movement patterns after simple verbal instruction, feedback, and practice?
3. Do these individuals exhibit dyscontrol, as noted by a difference between UEs in wrist speed profile, while flexing their arms to a horizontal position?
4. Does correction of abnormal scapular movement during a reaching task favorably influence the wrist speed profile?
5. What inferences can be made about motor control and learning as they relate to scapular substitution patterns?

Method

Subjects
Sixteen adults (10 female, 6 male), aged 44 to 78 years (\( X = 60.3, SD = 11.2 \)), met the inclusion criteria (Tab. 1). All subjects signed informed consent documents.

Participants were recruited from 10 physical therapy and occupational therapy practices. Therapists referred indi-
individuals with UPSS when these individuals could attain at least 90 degrees of pain-free, active shoulder flexion and had equal force-generating capacity of bilateral scapulothoracic, glenohumeral, and elbow musculature. Table 2 presents a frequency distribution of participants' primary and secondary diagnoses classified by gender. Table 3 lists descriptive statistics for participants' demographic information.

During testing sessions, I performed screening procedures to establish whether the participants met the inclusion criteria. Measurement of passive glenohumeral ROM followed the protocol of the American Academy of Orthopaedic Surgeons.\textsuperscript{25} Initial ROM values for the involved UEs obtained by referring therapists and ROM values that I obtained on the day of the experiment are presented in Table 4. I used a Spark hand-held dynamometer\textsuperscript{26} and the protocol of Smidt\textsuperscript{27} to obtain force estimates for midrange isometric contractions for the elbow, glenohumeral, scapulothoracic, and axiohumeral (latissimus dorsi) muscles. Intratester reliability was calculated for the goniometric tests (intraclass correlation coefficient [ICC(3,1)]= .997–.999) and dynamometric tests (ICC(3,1) = .943–.997)\textsuperscript{28} for three repetitions of each test with three pilot study participants and three participants from this study.

The following orthopedic and neurologic tests were performed to rule out related pathologies:

1. To test for bicipital tendinitis, midrange isometric elbow flexion\textsuperscript{29} and palpation of the tendon of the long head of the biceps brachii muscle\textsuperscript{27} were used. If both tests were pain-free, bicipital tendinitis was ruled out.

2. Rotator cuff tears were ruled out if the subject had a negative drop arm test\textsuperscript{28} and had painless and strong, resisted isometric shoulder abduction at 30 degrees.

3. Scapular winging was tested by visual estimate of the symmetry of scapular alignment when the subject performed bilateral isometric shoulder flexion at approximately 90 degrees.

4. To further rule out bicipital tendinitis, rotator cuff tears, and scapular winging, the subject had strong and pain-free isometric force generation against resistance of a hand-held dynamometer.

5. Tenderness in the areas of the subacromial bursa and the insertion of the supraspinatus tendon was ruled out by palpation of the soft tissue around the shoulder joint.

6. Sensation to light touch was tested by lightly stroking along the dermatomes of both UEs with the fingertips. Sensation was determined to be within normal limits if the sensation was intact and symmetrical in both UEs for all dermatomes.

7. Intact passive motion sense of the involved shoulder was determined if the seated participant, with eyes closed, could mirror passive flexion and extension of the involved shoulder with the uninjured UE. These passive movements were performed with manual contact only on bony prominences of the wrist and elbow on the involved side.

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### Table 2

<table>
<thead>
<tr>
<th>Primary Diagnosis</th>
<th>Secondary Diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 (n=8)</td>
<td>Group 2 (n=8)</td>
</tr>
<tr>
<td>Adhesive capsulitis</td>
<td>Frozen shoulder</td>
</tr>
<tr>
<td>Impingement</td>
<td></td>
</tr>
<tr>
<td>Bursitis</td>
<td></td>
</tr>
<tr>
<td>Rotator cuff tear</td>
<td></td>
</tr>
<tr>
<td>Tendinitis</td>
<td></td>
</tr>
<tr>
<td>Radiculitis</td>
<td></td>
</tr>
</tbody>
</table>

*Group 1 (n=8) had glenohumeral arcs that differed by <5° or less and group 2 (n=8) had a >5° difference, either between upper extremities or before or after intervention.*

*Despite the medical diagnosis, examination by the physical therapist ruled out a rotator cuff tear and indicated adhesive capsulitis.

### Table 3

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>X</th>
<th>SD</th>
<th>Median</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>60.3</td>
<td>11.2</td>
<td>65.0</td>
<td>44-78</td>
</tr>
<tr>
<td>Duration of problem (mo)</td>
<td>9.3</td>
<td>5.7</td>
<td>7.5</td>
<td>3-24</td>
</tr>
<tr>
<td>Duration of therapy (wk)</td>
<td>19.0</td>
<td>12.2</td>
<td>17.0</td>
<td>5-47</td>
</tr>
<tr>
<td>Practice time (s)</td>
<td>51.1</td>
<td>37.8</td>
<td>38.5</td>
<td>1-117</td>
</tr>
</tbody>
</table>

*Data for all participants (N=16); see Tab. 2 footnote for explanation of groups.*
Table 4.
Pooled and Group Means, Standard Deviations, and Ranges of Flexion Range of Motion (in Degrees) From Initial Evaluation and of Passive Glenohumeral Range of Motion Performed by the Researcher

<table>
<thead>
<tr>
<th>Movement</th>
<th>Involved Upper Extremity</th>
<th>Uninvolved Upper Extremity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>SD</td>
</tr>
<tr>
<td>Flexion range of motion at initial evaluation&lt;sup&gt;a&lt;/sup&gt;</td>
<td>128.0</td>
<td>19.8</td>
</tr>
<tr>
<td>Group 1</td>
<td>132.9</td>
<td>11.9</td>
</tr>
<tr>
<td>Group 2</td>
<td>123.8</td>
<td>24.9</td>
</tr>
<tr>
<td>Flexion&lt;sup&gt;b&lt;/sup&gt;</td>
<td>141.3</td>
<td>15.3</td>
</tr>
<tr>
<td>Group 1</td>
<td>140.4</td>
<td>16.2</td>
</tr>
<tr>
<td>Group 2</td>
<td>142.1</td>
<td>15.3</td>
</tr>
<tr>
<td>Abduction&lt;sup&gt;b&lt;/sup&gt;</td>
<td>107.4</td>
<td>20.8</td>
</tr>
<tr>
<td>Group 1</td>
<td>115.0</td>
<td>25.6</td>
</tr>
<tr>
<td>Group 2</td>
<td>99.8</td>
<td>11.9</td>
</tr>
<tr>
<td>Lateral (external) rotation&lt;sup&gt;b&lt;/sup&gt;</td>
<td>59.8</td>
<td>16.0</td>
</tr>
<tr>
<td>Group 1</td>
<td>62.1</td>
<td>15.1</td>
</tr>
<tr>
<td>Group 2</td>
<td>57.5</td>
<td>17.5</td>
</tr>
<tr>
<td>Medial (internal) rotation&lt;sup&gt;b&lt;/sup&gt;</td>
<td>39.6</td>
<td>16.9</td>
</tr>
<tr>
<td>Group 1</td>
<td>42.4</td>
<td>15.7</td>
</tr>
<tr>
<td>Group 2</td>
<td>36.8</td>
<td>18.7</td>
</tr>
</tbody>
</table>

<sup>a</sup>Data from initial evaluations in clinic records (n=15); n=7 for group 1 and n=8 for group 2. See Tab. 2 footnote for explanation of groups. 
<sup>b</sup>Data collected by researcher (N=16).

8. Neurological problems were ruled out if sensation and passive motion sense were intact and midrange manual resistance to isometric contractions of the distal muscle revealed no weakness.

Sample size was determined using techniques suggested by Cohen<sup>29</sup> and Zar<sup>30</sup> based on analysis of pilot study data from five individuals who met the selection criteria. The variable used to determine sample size was the sum of the displacement of a point on the acromion during the reaching task in the horizontal (x) and vertical (y) directions.

**Procedure**

Opaque, colored adhesive labels, 1.9 cm in diameter, were secured to the following landmarks on the seated participant: earlobe, greater tuberosity and lateral epicondyle of the humerus, posterior aspect of the wrist, midline of the trunk, brim of the ilium, greater trochanter, and lateral condyle of the femur. A holder consisting of a 9X4.5-cm and a 4.5X4.5-cm PC circuit board, bolted at right angles with two metal L-shaped brackets, was used to hold lighted markers. Two small, 6-V silicone-controlled rectifier lights in lamp holders were each wired, via 90 cm of double-stranded standard bell wire, and secured near the top and base of the 9X4.5-cm circuit board, 7.5 cm apart. This circuit board was covered with black, opaque electrical tape. Wire from each light was connected to a 9-V battery clip on a plastic battery pack holding four 1.5-V AA batteries. The battery packs were wrapped with 2-cm-wide Velcro<sup>®</sup> and held on a 5-cm-wide Velcro<sup>®</sup> belt around the participant’s waist. The 4.5X4.5-cm circuit board of the holder was secured to the acromion with hypoallergenic tape while the 9X4.5-cm portion faced laterally.

Participants were asked whether the holder interfered with normal shoulder movement; if so, the holder was repositioned until participants felt they could move freely. The paper and lighted markers represented points on the limb segment during subsequent kinematic analysis digitizing. The light closest to the acromion was not obscured by the elevating humerus and was secured on the holder that was anchored to the acromion; therefore, this light represented acromial position during the reaching task.

The target, the bottom of the horizontal crossbar of a music stand, was positioned at the height of the seated participant’s involved shoulder and at a distance approximately equal to the participant’s arm length. I assumed that shoulder heights and arm lengths were equal bilaterally; the target remained the same for testing each shoulder. Final height and position settings of the target were made by visual estimate when the participant’s involved humerus achieved a horizontal position as the participant touched the target. Markers taped to the

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<sup>1</sup> Radio Shack, Div of Tandy Corp, 300 One Tandy Center, Fort Worth, TX 76102.

<sup>2</sup> Velcro USA Inc, 466 Brown Ave, PO Box 5218, Manchester, NH 03108.
floor and the stem of the music stand facilitated accurate position replication.

The participant started with the hand of the involved UE resting comfortably on the lap. This preferred starting position allowed clear view of all markers. When given a verbal cue, the participant flexed the arm in a neutral, “thumb-up” orientation and touched the radial border of the metacarpophalangeal joint of the index finger to the bottom of the horizontal crossbar of the music stand (Figure). Accuracy requirements were minimal. The participant was videotaped while performing the movement sequence, which consisted of six repetitions of the task, resting briefly between repetitions. The procedure was repeated for the uninvolved arm. The order of testing was not randomized to allow the participant to spontaneously move the involved UE without prior awareness of the movement pattern of the uninvolved UE. The fourth repetition of the movement sequence was selected for kinematic analysis because this repetition followed a warm-up but preceded potential fatigue.

Verbal instruction and practice for the involved UE followed. All participants were asked to analyze the symmetry of their UE movement patterns by concentrating on scapular movement during a bilateral reach to the target. I made the participant aware of any asymmetry between the movement patterns of the UEs. I also gave guidelines, verbal feedback, and light manual contact on the scapulae during attempts to make the involved UE movement patterns similar to those of the uninvolved UE.

The following instruction guidelines were followed:

1. The participant was asked to repeatedly move both arms simultaneously to the target while noting any differences in scapular movement.

2. I verbally described any asymmetries and appropriate scapulothoracic and glenohumeral motion as it appeared on the uninvolved side.

3. The participant made several attempts to make movements similar to those of the uninvolved side, if necessary.

4. I provided verbal feedback about results of the participant’s efforts and suggested ways to further alter movement, if necessary. For example, if the individual initiated motion with the scapula, I gave instruction to initiate movement with the hand. Minimal manual contact on the superior aspects of the scapulae was used if the participant could not sense scapular movement patterns.

5. Throughout the practice, the participant rested as he or she deemed necessary and asked for feedback. No visual feedback with mirrors was used.

6. As scapular elevation became controlled, I encouraged the participant to move at the same rate as the uninvolved UE for the reaching task. Feedback about the movement rate was provided.

7. Practice ended when the participant said that the involved UE was moving like the uninvolved UE or that no further changes could be made.

Practice and testing conditions were identical to ensure task-specific training. Participants could ask questions or request feedback throughout the practice period. The self-selected practice time allowed for variable need for practice and variability in individual learning styles. Self-determination of goal attainment allowed for the
cognitive aspect of motor learning. Practice time was recorded (Tab. 3). After a 5-minute rest, the subject repeated the movement sequence with the involved UE and then with the uninvolved UE.

Demographic data were attained by open-ended questions on a questionnaire about age, handedness, duration of the problem, duration of therapy, and etiology. Participants documented general shoulder pain and discomfort status (Tab. 5), recalled from the time the problem began, on two sensory-discriminatory dimension of pain, which recorded the magnitude of pain intensity (0=no pain, 10=pain as bad as it could be). The other scale documented the affective or evaluative-emotional dimension of pain, which accounted for the degree of unpleasantness or discomfort associated with the movement (0=no discomfort, 10=the most unpleasant pain imaginable). Participants used another set of VASs to describe any discomfort associated with the movement sequence with the involved UE.

Intratester reliability of digitizing and subsequent estimation of the (x,y) coordinates and wrist speed was performed midway through data collection by digitizing records from each of the four conditions of three subjects, twice each. One set of coordinates from each of the five phases of the movement were used for the reliability study: movement initiation, acceleration phase, peak speed phase, deceleration phase, and movement termination. Intratester reliability in determining (x,y) coordinates was high for the moving points (IC[3,1]=.81-1.00). Likewise, intratester reliability for wrist speed was high (IC[3,1]=.940-.999). Shapiro et al. established the validity of this type of kinematic analysis in calculating angles. Babyar et al. previously established concurrent validity of the KAS during the sit-to-stand activity.

Table 5. Pooled and Group Means, Standard Deviations, Median Values, and Ranges for Sensory and Affective Visual Analogue Scale (VAS) Scores (in Centimeters) for Pain and Discomfort at the Onset of the Problem and on the Day the Study Was Conducted.

<table>
<thead>
<tr>
<th></th>
<th>X</th>
<th>SD</th>
<th>Median</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pain at onsetb</td>
<td>7.4</td>
<td>2.0</td>
<td>7.5</td>
<td>3.3-10.0</td>
</tr>
<tr>
<td>Group 1</td>
<td>7.9</td>
<td>2.3</td>
<td>8.6</td>
<td>3.3-10.0</td>
</tr>
<tr>
<td>Group 2</td>
<td>7.0</td>
<td>1.6</td>
<td>7.3</td>
<td>4.6-9.8</td>
</tr>
<tr>
<td>Discomfort at onsetb</td>
<td>6.9</td>
<td>2.1</td>
<td>7.0</td>
<td>3.3-10.0</td>
</tr>
<tr>
<td>Group 1</td>
<td>7.1</td>
<td>2.0</td>
<td>7.3</td>
<td>4.3-10.0</td>
</tr>
<tr>
<td>Group 2</td>
<td>6.6</td>
<td>2.4</td>
<td>6.2</td>
<td>3.3-10.0</td>
</tr>
<tr>
<td>Current painb</td>
<td>1.3</td>
<td>1.6</td>
<td>1.0</td>
<td>0.0-5.0</td>
</tr>
<tr>
<td>Group 1</td>
<td>1.3</td>
<td>1.7</td>
<td>1.0</td>
<td>0.0-5.0</td>
</tr>
<tr>
<td>Group 2</td>
<td>1.4</td>
<td>1.6</td>
<td>0.9</td>
<td>0.0-4.5</td>
</tr>
<tr>
<td>Current discomfortb</td>
<td>1.7</td>
<td>1.7</td>
<td>1.3</td>
<td>0.0-4.8</td>
</tr>
<tr>
<td>Group 1</td>
<td>2.2</td>
<td>1.8</td>
<td>1.9</td>
<td>0.0-4.8</td>
</tr>
<tr>
<td>Group 2</td>
<td>1.2</td>
<td>1.5</td>
<td>0.9</td>
<td>0.0-4.5</td>
</tr>
</tbody>
</table>

*See Tab. 2 footnote for explanation of groups.

**VAS scores for sensory dimension of pain at onset of shoulder problem.

**VAS scores for affective dimension of pain at onset of shoulder problem.

**VAS scores for sensory dimension of pain on the day the study was conducted.

**VAS scores for affective dimension of pain on the day the study was conducted.

Kinematic Analysis

The Kinematic Analysis Software was used to analyze the movement. During the movement sequence, participants were filmed with a Panasonic S-VHS (Model AG-450) color video cameral from the sagittal view. After the videotaping session, a time code registering to 1/30 of a second was added to the videotape using the Horita Time Code Generator (Model TG50).*

Kinematic analysis with the KAS required two steps: image capture and digitizing. For image capture, the fourth repetition of the reaching task was played on a Panasonic AG-6300 camera videocassette recorder equipped with a Panasonic Digital AV Mixer (Model WJ-MX10). The videotape was paused at every other frame (sampling frequency 15 frames per second) to capture the image using an AT&T Image Capture Board. The captured image was digitized on a SONY Trinitron Color Video Monitor (Model PVM 1910). A Microsoft Mouse was used to position the cursor, a set of cross hairs, over the markers on the image. The KAS assigned Cartesian (x,y) coordinates to each landmark designated by the marker or light, a background reference point, and markers on the ends of a 30.48-cm scale reference. The scale reference was filmed while it was positioned perpendicular to the camera on the seat of the chair after the participant completed each movement sequence. The coordinates for all points in all frames were stored by the KAS. Minimal smoothing of raw data was necessary. The KAS automatically used the least square polynomial moving average smoothing algorithm with a smoothing factor of 1.

Intratester reliability of digitizing and subsequent estimation of the (x,y) coordinates and wrist speed was performed midway through data collection by digitizing records from each of the four conditions of three subjects, twice each. One set of coordinates from each of the five phases of the movement were used for the reliability study: movement initiation, acceleration phase, peak speed phase, deceleration phase, and movement termination. Intratester reliability in determining (x,y) coordinates was high for the moving points (IC[3,1]=.81-1.00). Likewise, intratester reliability for wrist speed was high (IC[3,1]=.940-.999). Shapiro et al. established the validity of this type of kinematic analysis in calculating angles. Babyar et al. previously established concurrent validity of the KAS during the sit-to-stand activity.

10. Sony Corp of America, Communications Products Co, Video Communications Div, SONY Dr, Park Ridge, NJ 07656.
11. Microsoft Corp, 1601 1 NE 36th Way, Box 97018, Redmond, WA 98073.
Data Reduction

The duration of the reaching task was the number of frames in which UE movement occurred, from the starting position to the final position, divided by the sampling rate of 15 frames per second. Starting and final positions were defined from frame-by-frame playback of the captured images and confirmed by examination of the (x,y) data of the moving points. The captured frame before movement of any UE point was observed was the starting position, and the frame where the participant's hand first touched the target was the endpoint. The wrist speed was the linear displacement of a marker on the wrist per unit of time as calculated by the KAS. The peak wrist speed attained during the reaching activity was the maximum value printed on the kinematic analysis report. The average wrist speed was the sum of all wrist speed values divided by the number of frames from the starting position to the final position. A simple ratio was used to compare peak wrist speed and average wrist speed. The percentage of time to peak wrist speed was calculated by dividing the time from the start of the reaching task to the time of peak wrist speed by the duration of the reaching task.

Design

The dependent variables for the movement patterns were the (x) and (y) excursions of the acromial marker. The dependent variables representing movement outcome were duration of the reaching task, peak wrist speed, the ratio of peak wrist speed to average wrist speed, and percentage of time to peak wrist speed. For the first and third research questions, I used a one-factor repeated-measures (within-subject) design. For the second and fourth research questions addressed whether movement patterns or movement outcomes, respectively, differed between UEs before and after motor control instruction. For these analyses, a two-factor repeated-measures (within-subject) design was used. Two within-subject factors and their interactions were analyzed. Side was the first within-subject factor. Time was the second factor to determine whether the difference between before and after instruction was different from zero.

A between-subjects grouping variable was added to each of the designs for statistical reasons. This variable accounted for variability in the arc of the glenohumeral joint during testing without obscuring a treatment effect. The arc of motion was the start position of the glenohumeral joint subtracted from its final position as

<p>| Table 6. Means, Standard Deviations, and Ranges of Starting and Final Positions and Arcs of Glenohumeral Flexion (in Degrees) for Both Upper Extremities (UEs) Before and After Motor Control Instruction |
|-----------------------------------------------|---------------|---------------|---------------|---------------|---------------|
| Involved UEs Before Instruction | Final Position | Starting Position | Arc of Flexion | Involved UEs After Instruction | Final Position | Starting Position | Arc of Flexion |</p>
<table>
<thead>
<tr>
<th>X</th>
<th>SD</th>
<th>Range</th>
<th>X</th>
<th>SD</th>
<th>Range</th>
<th>X</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pooled</td>
<td>26.1</td>
<td>6.4</td>
<td>15.8-35.8</td>
<td>83.0</td>
<td>7.3</td>
<td>77.2-98.4</td>
<td>55.9</td>
<td>8.4</td>
</tr>
<tr>
<td>Group 1</td>
<td>26.2</td>
<td>7.6</td>
<td>11.8-35.8</td>
<td>82.4</td>
<td>8.5</td>
<td>77.2-98.4</td>
<td>55.3</td>
<td>11.1</td>
</tr>
<tr>
<td>Group 2</td>
<td>25.9</td>
<td>5.4</td>
<td>16.0-31.3</td>
<td>83.5</td>
<td>6.5</td>
<td>73.1-95.5</td>
<td>57.6</td>
<td>5.3</td>
</tr>
<tr>
<td>Pooled</td>
<td>25.5</td>
<td>6.4</td>
<td>15.0-30.3</td>
<td>88.0</td>
<td>4.8</td>
<td>73.4-96.6</td>
<td>62.9</td>
<td>11.5</td>
</tr>
<tr>
<td>Group 1</td>
<td>20.2</td>
<td>7.3</td>
<td>10.0-34.0</td>
<td>79.1</td>
<td>3.6</td>
<td>71.9-84.5</td>
<td>58.5</td>
<td>13.6</td>
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<tr>
<td>Group 2</td>
<td>23.9</td>
<td>5.9</td>
<td>4.6-23.3</td>
<td>80.8</td>
<td>6.3</td>
<td>70.4-88.6</td>
<td>68.9</td>
<td>7.7</td>
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</tbody>
</table>

See Table 2 footnote for explanation of groups.
Table 7. Horizontal (x) and Vertical (y) Scapular Excursion Means, Standard Deviations, and Ranges Before and After Motor Control Instruction

<table>
<thead>
<tr>
<th></th>
<th>Before Motor Control Instruction</th>
<th></th>
<th>After Motor Control Instruction</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Involved Side</td>
<td>Uninvolved Side</td>
<td>Involved Side</td>
<td>Uninvolved Side</td>
</tr>
<tr>
<td></td>
<td>X</td>
<td>SD</td>
<td>Range</td>
<td>X</td>
</tr>
<tr>
<td>x displacement (pooled)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1</td>
<td>16.5</td>
<td>12.2</td>
<td>7.0-43.0</td>
<td>21.9</td>
</tr>
<tr>
<td>Group 2</td>
<td>21.6</td>
<td>11.4</td>
<td>10.0-40.0</td>
<td>25.9</td>
</tr>
<tr>
<td>y displacement (pooled)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1</td>
<td>33.1</td>
<td>15.5</td>
<td>11.0-55.0</td>
<td>32.8</td>
</tr>
<tr>
<td>Group 2</td>
<td>45.7</td>
<td>21.7</td>
<td>29.0-89.0</td>
<td>29.6</td>
</tr>
</tbody>
</table>

*See Tab. 2 footnote for explanation of groups.

The person performed shoulder flexion. The treatment effect was secondary to a clinically meaningless, but systematic, mean decrease in arc of 2.5 degrees for both UEs after instruction. The variability in arc was secondary to the participants’ use of preferred starting positions, as determined by post hoc analysis of variance (ANOVA). Not all participants exhibited differences in preferred starting positions. Group 1 (n=8) consisted of individuals whose glenohumeral arcs differed among the four conditions by 5 degrees or less. Group 2 (n=8) had greater than a 5-degree difference, either between UEs or before or after instruction. Table 6 shows descriptive statistics for starting and final glenohumeral positions and resultant shoulder arcs, as measured by the KAS.

Data Analysis

Data were analyzed with SPSS/PC+TM (version 2) software. The multivariate analysis of variance (MANOVA) procedure of SPSS/PC+ was used for the repeated-measures ANOVAs.

The alpha level was set at .05. Post hoc analyses were performed with t tests of correlated means. The Bonferroni inequality was used to set the alpha level for post hoc tests.

Results

Do Scapular Substitution Patterns Exist?

No difference existed between sides for horizontal (x) displacement of the marker on the acromion. Participants used greater (y) displacement with their involved UEs when they attempted to reach the target before they had motor control instruction. Results of the one-factor repeated-measures (within-subject) ANOVA with one factor between subjects for vertical (y) displacement showed a difference only between UEs (F=6.02, P=.028) and for the group×side interaction (F=5.49, P=.034). Table 7 lists descriptive statistics for (x) and (y) displacements before and after motor control instruction. Group 2 participants had the greatest scapular elevation before instruction on their involved sides. Results of post hoc analysis with t tests of correlated means showed that only group 2 had a difference between UEs before instruction (t=3.55, P=.009) that met Bonferroni inequality criteria (P<.025, for two comparisons).

Are Scapular Substitution Patterns Due to Biomechanical Problems?

Verbal instruction helped participants decrease mean scapular vertical (y) displacement for both UEs. Only the involved side of the group 2 participants had a difference before and after instruction (t=3.59, P=.009) that
met the criteria of the Bonferroni inequality \((P<.0125)\) in post hoc tests of correlated means. Results of the two-factor repeated-measures (within-subject) ANOVA with one factor between subjects showed no difference between sides for horizontal \((x)\) displacement after instruction.

**Do Upper Extremities Differ in Movement Outcome Before Instruction?**

Movement outcome variables on the involved side were similar to those of the uninvolved side before instruction, despite the use of greater scapular vertical displacement for the involved UEs. Results of the one-factor (within-subject) repeated-measures ANOVA with one factor between subjects for all movement outcome variables showed no differences between UEs before instruction. Groups did not differ. Table 8 lists descriptive statistics for the speed and duration variables.

**Does Movement Outcome Change After Instruction?**

The involved UEs of participants showed decreased peak wrist speed after instruction in the two-factor (within-subject) repeated-measures ANOVA with one factor between subjects \((F=12.71, P=.003)\). Post hoc analysis with \(t\) tests of correlated means showed that the involved UEs had lower peak wrist speeds after instruction. This difference was due to the lower wrist speed of the involved UEs of group 2 \((t=-9.67, P=.008)\).

Relative timing and control did not change after instruction. Extremities did not differ in percentage of time to peak speed and ratio of peak wrist speed to average wrist speed before and after instruction.

Post hoc analysis with a gender \(x\) group \((2 \times 2)\) ANOVA of the demographic data showed that group 2 participants were younger than their counterparts in group 1. The repeated-measures MANOVA by group and gender for passive glenohumeral ROM values showed that group 2 participants had greater discrepancies between UEs. Other post hoc tests of demographic data, including duration of the problem and duration of physical therapy, revealed no group differences. Groups did not differ in stage of recovery.

**Discussion**

The study verified the common clinical observation that excessive scapular excursion persists for some individuals recovering from UPSS. Because scapular substitution patterns could be eliminated by instruction and feedback, they were not obligatory. Control of the vertical displacement after instruction indicated that these individuals had the biomechanical determinants, muscle force, and joint mobility necessary to complete the task with the involved UEs.
The study gave no evidence that the scapular substitution patterns were pain behaviors as defined by Loeser and Fordyce.11 Self-reports on VASs prior to and after the movement sequence showed that pain was not associated with the movement.

Cailliet described normal coordinated scapulohumeral rhythm as being "programmed for every daily activity and for each athletic activity."7 The need to use the UE for work or recreation may have ingrained the scapular substitution patterns early in recovery until they became motor habits, similar to the habitual posture a person assumes. These habits can be corrected with appropriate instruction and practice.

**The Reaching Task**

When participants performed the reaching task, most of the motion occurred at their glenohumeral joints and their elbows gradually extended. Their hands followed curved paths. Trunk movements were minimal because the target was well within their reach. Soechting and Lacquaniti observed that asymptomatic individuals performed vertical arm movements as described previously. Curved hand paths were also observed with asymptomatic individuals during vertical arm movements.

Individual variations existed for scapular setting, the early positioning of the scapula. I allowed for this variability by subtracting the lowest values from the highest values for the acromial marker in the (x) and (y) directions. This variable scapular setting was also observed with asymptomatic individuals.

**Group Differences**

Examination of Table 6 and post hoc repeated-measures ANOVAs confirmed that differences in starting position were responsible for the variance in glenohumeral arcs of motion. There was no difference between groups in final positions of either UE before or after instruction. The involved UEs of both groups and the uninvolved UEs of group 1 started at approximately the same mean position. Group 2 participants chose to start their uninvolved UEs in less mean shoulder flexion, thus creating a larger mean arc of motion.

The lack of uniformity in starting position and resultant arc of glenohumeral motion should not confound interpretation of these data. Similarities between arcs of motion for involved UEs of both groups allow for adequate comparisons about these UEs. The uninvolved UEs of group 2 participants showed less scapular (y) excursion than their involved UEs before and after instruction, despite the larger arcs of motion. This finding indicates that displacement for a reaching task to 90 degrees of shoulder flexion is not purely a function of the arc of motion. Inman et al. reported that the first 60 degrees of shoulder flexion occurred at the glenohumeral joint, with minimal scapulothoracic contribution. If this finding is true, any excessive scapular elevation of the involved UEs would not be solely dependent on arc of motion and could be attributed to other learned factors.

Not all participants used excessive vertical scapular excursion before instruction. Group 2 subjects had the greatest scapulothoracic excursion for the involved UEs before instruction. They attempted to change the movement pattern, and the process of making the change may have resulted in a slightly longer task duration and lower peak wrist speed for their involved UEs after instruction. Based on post hoc analysis of demographic factors, younger individuals appear to have a greater discrepancy between UE ROMs and might habitually use more scapular elevation to accomplish ADL and overhead sports. This hypothesis warrants further study. Regardless of their ROM status, individuals in group 2 could decrease scapular vertical excursion after instruction and practice. Addition of the grouping variable was a limitation of the study, and future study with a larger sample is warranted.

**Degree of Control Before Instruction**

Participants appeared to have well-learned, efficient movement patterns in both UEs before instruction because wrist speed characteristics were similar in both UEs. Even group 2 participants, who used excessive scapular vertical excursion prior to instruction, showed no difference between UEs in movement outcome. The efficiency was reflected in the same percentage of time to peak wrist speed, in peak wrist speed to average wrist speed ratios similar to those of the uninvolved UE, and in the smoothness of the speed profiles. I believe that this degree of efficiency and control must have been learned throughout the recovery process when individuals with UPSS substituted scapular elevation for glenohumeral motion.

Limitations in glenohumeral motion or pain with movement create a need for individuals with acute UPSS to use other muscle-joint combinations to complete arm elevation. This need is analogous to Bernstein's degrees of freedom principle, whereby a single action can be accomplished by many movement patterns. Free scapulothoracic mobility makes this the obvious choice to substitute for glenohumeral motion. This motor habit was retained by some individuals in the later stages of recovery from UPSS. Participants who used excessive scapular elevation on their involved side exhibited motor equivalence, where different muscle-joint combinations yielded equivalent motor outcome when compared with the uninvolved side. Although some participants used excessive vertical displacement and, presumably,
different muscle activity, they produced smooth, efficient movement when reaching for the target with the involved UE. These participants may have retained scapular substitution patterns because they did not note any decrement in movement outcome.

Participants may have learned scapular substitution patterns as necessary pain behaviors\(^{12,41}\) during the acute phase. Pain was not related to the use of substitution patterns at the time the study was conducted.

**Influence of Improved Scapular Movement on Wrist Speed After Instruction**

Verbal instruction, feedback, and practice influenced the movement pattern of those individuals who used excessive scapular elevation, but the intervention did not change all movement outcome variables. Relative timing and control were preserved even though participants exhibited lower peak wrist speeds on their involved side as they slowed the activity and tried to master scapular control after instruction.

The short practice time probably did not allow time for participants to reach the unconscious, automatic level of motor control as described by Fitts.\(^{52}\) This lack of mastery of the task could have been reflected in the slowing of the performance of the involved UEs and the decrease in peak wrist speed for these individuals. This research was limited to only the immediate effects of instruction and blocked practice. A longer practice session or a distributed practice schedule,\(^{14}\) perhaps for both UEs, could have yielded similar task duration and peak wrist speed.

Another possibility is that involved UEs were influenced by a control factor\(^ {45}\) that facilitated the use of a movement pattern with excessive elevation prior to instruction. Many participants with scapular substitution patterns were not aware that these patterns were present.

**Motor Control Implications**

The motor characteristic that did not vary between UEs before and after instruction was the relative timing of the task, as seen in the percentage of time to peak wrist speed. Participants who used excessive scapular elevation, and thus a different motor output to complete the task, retained relative timing. This finding is consistent with the findings of other studies of asymptomatic individuals in which task variables were manipulated, resulting in differences in motor output. Atkeson and Hollerbach\(^ {17}\) and Ruitenbeek\(^ {46}\) studied the effects of various loads on vertical and horizontal arm movement, respectively. Viviani and Terzuoli\(^ {47}\) manipulated the size of a handwriting task with asymptomatic individuals, thereby requiring them to use differing muscle activity as the scaling changed. These researchers\(^ {17,46,47}\) showed that overall speed may not have been consistent among trials but relative timing was an invariant feature of the tasks.

The invariance of the relative timing, seen in the wrist speed profile despite varying degrees of scapular elevation before and after instruction, showed that participants planned the task according to the movement goal, bringing the hand to the target in an efficient manner,\(^ {48,49}\) rather than according to preplanned muscle activation patterns.\(^ {48}\) They had alternative movement patterns available, which yielded equivalent motor outcomes. Once they were aware of their motor habits, they quickly decreased previously learned scapular vertical displacement, confirming that muscle activation patterns were not obligatory learned scapular vertical displacement, confirming that muscle activation patterns were not obligatory results of a fixed motor program. Electromyographic analysis is needed to support these suppositions.

**Conclusions**

The results of this study suggest that individuals using scapular substitution patterns late in their recovery need therapists to analyze the movements and to deliberately instruct them about improving scapulohumeral rhythm. With simple motor control instruction, the subjects reduced the amount of scapular elevation and retained relative timing and control. Peak wrist speed decreased and movement duration increased slightly after instruction about proper movement patterns.

**Acknowledgments**

I thank Roger Muzii for his editorial review of the manuscripts, Robert Schleihau for assistance in data analysis, Ray Boone for granting the extended use of the kinematic analysis equipment, and the participating therapists for coordinating testing sessions and granting the use of their facilities. Equipment used for this project belonged to the Department of Physical Therapy, Ithaca College.

**References**

vertical arm movements.


