

# Subacromial Anesthetics Increase Proprioceptive Deficit in the Shoulder and Elbow in Patients With Subacromial Impingement Syndrome

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**ABSTRACT:** Shoulder proprioception gives information regarding arm joint position and movement direction. Several studies have investigated shoulder proprioceptive acuity in patients with subacromial impingement syndrome (SIS); however, differences in protocols and between-subjects designs have limited scientific inferences regarding proprioception and SIS. We aimed to determine within-subject differences in shoulder and elbow proprioceptive acuity in 17 patients with stage 2 SIS following treatment of a local anesthetic injection. In addition, we used 17 healthy, age-, sex-, and arm dominance-matched controls to determine the magnitude of differences after treatment. Joint position sense (JPS) was measured before and after treatment in both groups in the sagittal plane for the shoulder and elbow. Our results indicate that patients with SIS have less sensitivity to angular position and tended to overshoot their targets with greater variability during angle-matching tasks for the shoulder (1.8° difference,  $P = .042$ ) and elbow (5.6° difference,  $P = .001$ ) than controls. The disparities in JPS found in patients with SIS were not resolved following subacromial injection; in fact, the magnitude of the errors increased after treatment where postinjection errors were significantly greater ( $P = .046$ ) than controls, with an average difference of 2.4°. These findings suggest that patients with SIS have decrements in either the signaling or processing of proprioceptive information and may use pain to reduce these inequalities.

**KEYWORDS:** Anesthetic Injections, proprioception, Subacromial Impingement Syndrome, shoulder joint position sense

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## Introduction

Subacromial impingement syndrome (SIS) is one of the most commonly reported musculoskeletal complaints, typically affecting older adults between the ages of 45 and 65 years.<sup>1</sup> Clinically, patients with SIS typically present with loss of arm function and pain, which is intensified with elevation of the arm.<sup>2</sup> Other symptoms of SIS include altered scapular kinematics and scapular muscle recruitment during arm elevation.<sup>3–9</sup> It is possible that patients with SIS have proprioceptive deficits and these deficits influence muscle behavior and kinematic movement patterns of the shoulder.<sup>10–15</sup> Neuromuscular control of the shoulder joint is vital for maintaining shoulder stability and overall shoulder function.<sup>16–19</sup>

Experimental pain has been shown to inhibit the primary motor cortex<sup>20</sup> as well as spinal neurons.<sup>21</sup> This phenomenon may serve as an evolutionary mechanism to protect painful anatomic structures from further damage.<sup>22</sup> However, as pain is sensory information, it is unclear whether noxious afferents assist or reduce proprioception in the shoulder. In a study conducted by Sole et al,<sup>23</sup> moderate subacromial pain was elicited using a hypertonic saline injection. Findings from that study demonstrate that movement sense is heightened in the presence of pain, whereas passive position sense is unaffected.<sup>23</sup> Subacromial anesthetic injections are an effective means of reducing noxious stimuli in the shoulders of patients with

SIS<sup>24</sup>; however, the effects of these injections on healthy shoulders have no influence on proprioceptive acuity.<sup>25</sup> Although a subacromial injection removes all afferent signaling from the subacromial space, it is likely that afferent feedback from mechanoreceptors of the shoulder is uninfluenced by localized subacromial anesthetics.<sup>25</sup>

From a recent systematic review and meta-analysis (and one additional study conducted after the meta-analysis), studies including SIS and chronic rotator cuff pain syndrome demonstrate strong evidence for a joint position sense (JPS) deficit in flexion when compared with controls.<sup>26,27</sup> Furthermore, studies demonstrate JPS improvements following decompression surgery, suggesting that the deficit may be absolved with relief of symptoms.<sup>14,28</sup> Joint position sense measurements have consistently been the most accurate when the joint approaches 90° of flexion in healthy controls<sup>29–33</sup> but does not appear to be the most accurate in patients with SIS and may in fact be less accurate at higher elevation angles due to increased symptoms at higher angles.<sup>10</sup> It is possible that the proprioceptive mechanisms that make 90° of elevation the most accurate are diminished with increased pain associated with elevation of the arm in patients with SIS. It is unknown whether patients with SIS are sensitive to the influences of arm elevation angle on shoulder and elbow JPS. Furthermore, it is unknown whether



patients with SIS will demonstrate proprioceptive deficits at the elbow joint, which may be an indicator of systemic proprioceptive insufficiency.

To date, no study has investigated the influence of subacromial pain reduction on shoulder JPS. Furthermore, no study has investigated proprioceptive acuity in adjacent joints following a reduction in pain. Therefore, the aims of the study were two-fold: to determine whether proprioceptive errors in the shoulder are associated with subacromial pain and to determine whether proprioceptive errors are systemic (found in multiple joints) in patients with SIS. We hypothesize that joint position errors will be greater in magnitude for the patient population versus controls and that patients will be less sensitive to changes in arm angle than controls. After anesthetic injection, we hypothesize that the magnitude of errors will decrease with respect to the preinjection errors; furthermore, patients will be more accurate with respect to target angle, with a higher accuracy bias for elevated target positions. For the elbow, we hypothesize that no differences in error will be detected by group or condition (injection).

## Methods

*Design:* Case controlled, experimental.

*Level of evidence:* III

### Subjects

In total, 17 patients with SIS and 17 healthy control subjects were recruited for this study. Patients had an average age of 50 ( $\pm 11$ ) years. Healthy controls participants had an average age of 52 ( $\pm 10$ ) years. Control subjects were matched within 5 years of age to a patient of the same sex and arm dominance. An orthopedic surgeon (second coauthor) performed all clinical tests described. Control subjects were excluded from the study with a positive diagnostic test of their shoulder; the same tests were used for the inclusion of the patient population. Our symptomatic group inclusion criteria were a positive sign for at least 3 of the following 5 tests: Hawkins-Kennedy test, Neer test, painful arc test, empty can test, and painful external rotation test.<sup>34</sup> Patients having had shoulder surgery on the symptomatic side, a positive Spurling test, traumatic shoulder dislocation or instability in the past 3 months, reproduction of shoulder pain with active or passive cervical range of motion, or signs of a rotator cuff tear (drop-arm test, lag signs, gross external rotation weakness assessed by a manual muscle test, or positive image findings) were excluded from this study. Radiographs were taken for all patients as part of their treatment, and patients were excluded if the results of their image test indicated calcific bursitis or any other pathology inconsistent with stage 2 SIS. The experimental protocol was approved by the Institutional Review Board of the University of Oregon. Written and verbal instructions of testing procedures were provided, and written consent was obtained from each subject

prior to testing. From the orthopedic evaluation, patients were asked to indicate their shoulder pain level on a visual analog pain scale (VAS).

### Instrumentation

A Fastrak magnetic tracking device (Polhemus, Colchester, VT) was used for collecting 3-dimensional kinematics of the shoulder and elbow. The unit consists of a transmitter, 3 custom removable sensors, and a digitizer, all wired to a system electronics unit, which determines the relative orientation and position of the sensors in space. Removable sensors were used to move the patients from the data collection room to the treatment room without disruption of the calibration of our equipment. The transmitter served as a global reference frame and was fixed to a rigid plastic base and oriented such that its coordinate axes aligned with the cardinal planes of the human body. The digitizer sensor was used to identify anatomical landmarks with respect to the global reference frame. After digitization, the arbitrary coordinate systems defined by the magnetic tracking device were converted to anatomically appropriate coordinate systems. The anatomical coordinate systems were defined following the recommendations of the International Society of Biomechanics Committee for Standardization and Terminology.<sup>35</sup> Forearm calibration followed protocols described by Lin and Karduna.<sup>36</sup> Furthermore, we constrained motion to one joint at a time, eg, subjects were instructed to perform flexion of only elbow or shoulder per trial; however, we did not fix the neighboring joint with casts or joint braces.

Three receivers were placed on anatomical segments for the duration of the study, and each receiver was detached from its cable during the treatment phase. The first receiver was placed on the sternum at the level of the manubrium. The receiver was taped into place using double-sided adhesive tape, with an additional layer of tape on top of the receiver which helped secure the device to the skin. The second receiver was placed on the dorsum of the wrist using double-sided tape and elastic tape. The third receiver was placed over the scapula with adhesives after mounting it on a custom scapular tracking device machined from plastic.<sup>37</sup> All kinematic data were represented using standard Euler angle sequences for plane, elevation and external rotation for the humerus, and flexion, supination, and carrying angle for the elbow.<sup>35</sup> For digitization and testing, subjects sat on a stool to help stabilize their thoracic posture.

### Protocol

After digitization, subjects were outfitted with a head-mounted display (Z800, eMagine, Bellevue, WA), which allowed the subjects to see a virtual representation of the target position while preventing visual feedback from their hand or the outside environment (Figure 1). The predetermined target angles were 50°, 70°, and 90° for either elbow flexion or shoulder elevation in the sagittal plane.<sup>29,30</sup> All targets were repeated 4 times and were



**Figure 1.** Virtual representation of the arm (red line) with respect to the target position (space between the white lines). Left figure (A), demonstrates the arm moving towards the target, and the right figure (B), represents the arm within the target field.

presented in random order. Due to time constraints on the patient and physician, we report two instances of patients failing to complete four trials at a given target angle. In these cases of missing data, we used three trials at a given target location and included these data in our analysis. The order of joint testing (shoulder and elbow) was randomized. Between each trial, subjects were given a five-second rest. Practice trials were completed prior to testing until participants demonstrated competency with the protocol. No feedback regarding proprioceptive accuracy was given to the subjects at any time. Subjects were guided to each target angle using a custom LabVIEW program (National Instruments, Austin, TX). The center of the head-mounted display contained two fixed, parallel white lines that represented a  $\pm 1^\circ$  boundary with respect to the target. Subjects elevated their arm or flexed their elbow with their thumb pointed upward and their arm in the sagittal plane until a red line, which represented real-time feedback of their limb, appeared on the screen. Subjects placed the red line between the two fixed white lines, indicating target acquisition (Figure 1). Once in this position, subjects were instructed to memorize the location of their hand in space for three seconds. The virtual representation then disappeared (so that the screen turned black) and the subject was then instructed to relax their arm by their side. After five seconds with their arm by their side, the computer program instructed the subject to “find target.” After the subject returned to where they thought their joint had previously been, they indicated to the researcher by saying “here,” and the researcher then marked this position for later analysis. The subjects then return their arm to their side and waited for the next trial.

To evaluate the accuracy and precision of the JPS task, the angular difference between the positioned and repositioned arm location was calculated for each target. The constant error was calculated from the average of the angular deviations for each group of targets at three levels:  $50^\circ$ ,  $70^\circ$ , and  $90^\circ$ . This constant error represents the angular accuracy and directional bias and the variable error (precision) represents the individual’s consistency during the angle-matching task.<sup>38</sup> Constant and variable errors are used in concert to give a representation of JPS.<sup>29</sup>

#### *Clinical treatment*

After the study protocol, patients received a subacromial injection of anesthetic (6 mL of 0.5% bupivacaine with

epinephrine and 3 mL of lidocaine with epinephrine) and corticosteroid (1 mL of 40 mg methylprednisolone acetate) as part of their normal treatment. The procedure was completed by one of the coauthors (M.S.) who is an orthopedic surgeon. Patients were then given a 15-minute adjustment period and were asked to move their arm to disperse the drug within the subacromial bursa. The diagnostic special tests were repeated by the same physician and patients were again asked to report the worst shoulder pain level during the clinical tests on a VAS. Patients were blinded from their previous VAS submission. Following the adjustment period, patients were asked to repeat the study protocol. No sensors were removed for the injection, and the same calibration data were used from the previous study protocol.

#### *Statistical analysis*

SPSS version 21.0 (IBM, Chicago, IL) was used for statistical analysis. For differences in VAS pain scores, a dependent-samples *t* test was run on pre- and postinjection pain scores. To test the hypothesis that patients with SIS would not demonstrate an accuracy bias with respect to target elevation angle; six one-way analyses of variance (ANOVAs) were run using a priori linear contrasts, where each condition (preinjection, postinjection, and controls) yielded a slope based off the three target locations ( $50^\circ$ ,  $70^\circ$ , and  $90^\circ$  targets) for shoulder and elbow. To test the hypothesis that joint position errors would be greater in magnitude for the patient population than controls, data were collapsed (averaged) across target angle, and independent-samples *t* tests were run for both the shoulder and elbow. To test the hypothesis that joint position errors would decrease in magnitude following a subacromial injection, data were collapsed (averaged) across target angle and dependent-samples *t* tests were run for both the shoulder and elbow.

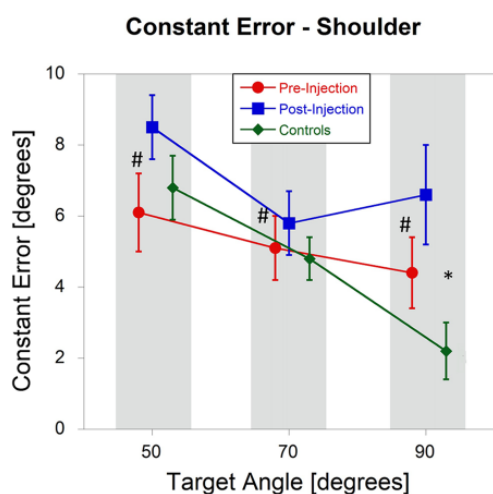
To test for consistency in target matching, we performed 2-way repeated-measures ANOVAs with variable error as the dependent variables for the shoulder and elbow. Target angle ( $50^\circ$ ,  $70^\circ$ , and  $90^\circ$ ) and condition (pre- and postinjection) were the independent variables. In addition, we performed 2-way mixed-effects ANOVAs to compare postinjection versus control group for variable errors as the dependent variables for the shoulder and elbow. Target angle ( $50^\circ$ ,  $70^\circ$ , and  $90^\circ$ ) and group (postinjection versus controls) were the independent variables. For all statistical tests,  $\alpha$  was set to 0.05. Pairwise comparisons

were performed where significant interactions and main effects were found using the least significant difference test.

## Results

All subjects tolerated the procedure without incident. Before treatment, VAS scores were on average 57.4 ( $\pm 20.3$ ) and were reduced to 14.8 ( $\pm 17.0$ ) after treatment, which marked a 72% reduction ( $P < .001$ ) in VAS pain after injection.

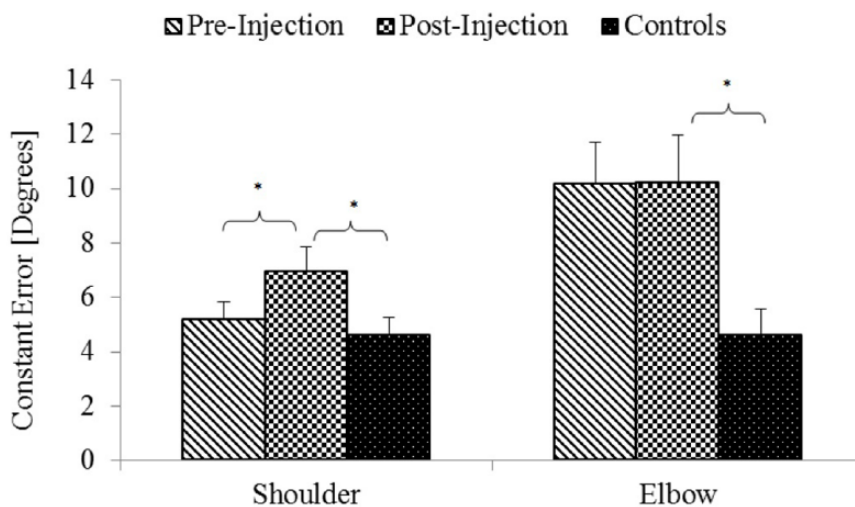
For constant errors at the shoulder prior to injection, patients with SIS were not sensitive to angle ( $P = .07$ ), nor are they sensitive to angle following a subacromial injection ( $P = .128$ ). However, controls were sensitive to angle ( $P < .001$ ) with errors decreasing as elevation targets increased (Figure 2). For the magnitude of errors of the shoulder between patients postinjection and controls, results indicate that postinjection



**Figure 2.** Constant errors for the shoulder during shoulder flexion task with targets of 50-70-90 degrees. Pre (red) and post (blue) injection data are plotted for the patient population versus controls (green).

#Significant within-subjects comparisons,

\*Significant between-subjects comparisons.



**Figure 3.** Magnitude of constant errors for the shoulder and elbow pre-injection, post-injection and for controls. Errors are represented with the standard error of the mean. \*Significance, where  $p < 0.05$ .

errors were significantly greater ( $P = .046$ ) than controls, with an average difference of  $2.4^\circ$  (Figure 3). For the magnitude of shoulder errors between pre- and postinjection (averaged across target angle), results indicated that postinjection errors were significantly greater ( $P = .042$ ) than preinjection errors, with an average difference of  $1.8^\circ$  (Figure 3).

For the constant errors at the elbow, our tests indicated that prior to the injection, patients were sensitive to elevation angles ( $P = .02$ ) with errors reducing linearly (Figure 4). Following the subacromial injection, elbow errors were reduced linearly ( $P < .001$ ), where errors decreased from  $12.5^\circ$  at the  $50^\circ$  target to  $5.8^\circ$  at the  $90^\circ$  target (Figure 4). For controls, errors were linearly reduced by elevation of the elbow ( $P < .001$ ) (Figure 4). For the magnitudes of errors (averaged by target angle) postinjection versus controls, results indicate that for the elbow, errors were on average  $5.6^\circ$  greater in the patient group than in the control group ( $P = .01$ ); however, no significant differences ( $P = .99$ ) were noted for the magnitude of errors of the elbow as a result of subacromial injection (Figure 3).

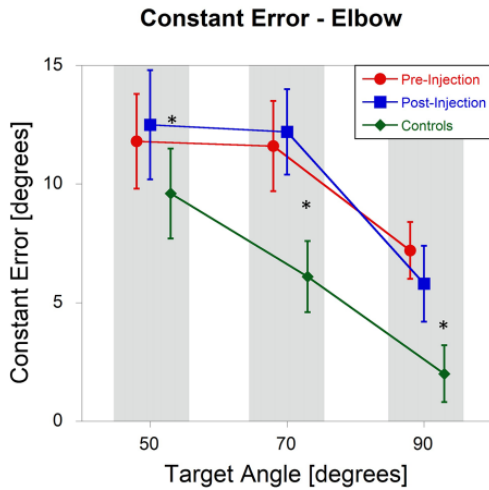
For variable errors at the shoulder, there were no significant interactions ( $P = .211$ ) or main effects of injection ( $P = .859$ ), nor were there any significant influences of target angle ( $P = .724$ ). When compared with controls, postinjection variable errors were on average  $2.7^\circ$  greater for all angles ( $P < .001$ ) (Figure 5).

For variable errors at the elbow, there were no significant interactions ( $P = .276$ ) or main effects of injection ( $P = .069$ ), nor were there any significant influences of target angle ( $P = .106$ ). When compared with controls, postinjection variable errors were on average  $3.6^\circ$  greater for all angles ( $P < .001$ ) (Figure 6).

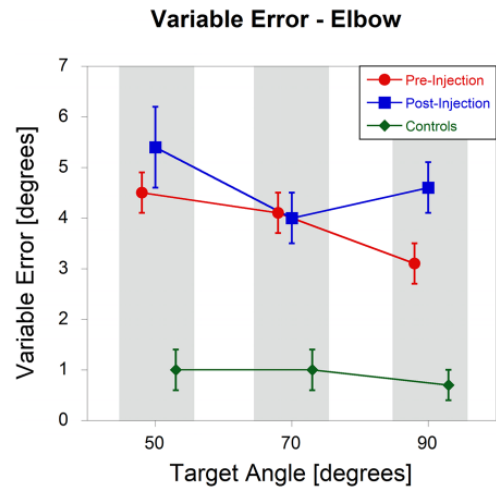
## Discussion

There were three goals for this study. First, we examined whether shoulder proprioceptive acuity was altered after the removal of chronic pain in patients with SIS. Second, we assessed whether patients with impingement demonstrated

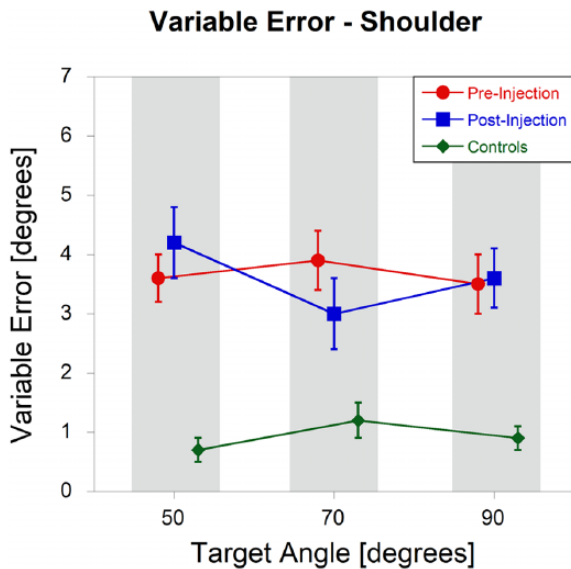




**Figure 4.** Constant errors for the elbow during elbow flexion task with targets of 50-70-90. Pre (red) and post-(blue) injection data are plotted for the patient population versus controls (green).  
\*Significant between-subjects comparisons.



**Figure 6.** Variable errors for the elbow during elbow flexion task with targets of 50-70-90. Pre (red) and post-(blue) injection data are plotted for the patient population versus controls (green).



**Figure 5.** Variable errors for the shoulder during shoulder flexion task with targets of 50-70-90. Pre (red) and post-(blue) injection data are plotted for the patient population versus controls (green).

proprioceptive deficits in the elbow joint as well as in the shoulder. Third, we were interested in determining whether patients with SIS demonstrated better JPS of the shoulder and elbow as joint angles approached 90° of flexion in the sagittal plane, as this relationship has been well established in the literature with respect to healthy shoulders.<sup>29-31,33</sup> Each of our hypotheses and corresponding results are discussed below.

Our results did not support our first hypothesis because patients were not different than controls preinjection and had greater overshooting errors postinjection (Figure 2). It is possible that patients were using pain to help guide their arm to the target positions and were unable to use this sensory feedback once the subacromial bursa was anesthetized,

thus resulting in poorer accuracy. Hassan et al<sup>39</sup> showed similar results (diminished proprioceptive acuity) after anesthetic injections in patients with chronic knee pain (osteoarthritis). In a recent study conducted by Sole et al,<sup>23</sup> painful hypotonic saline injections to the subacromial bursa resulted in a 30% reduced threshold to detection of passive movement direction in healthy shoulders. Findings from that study suggest that pain may increase kinesthetic sense in healthy individuals; however, pain did not have an effect on proprioceptive accuracy during passive joint replication tasks in that study.<sup>23</sup> Several studies have demonstrated that subacromial injections alter scapular kinematics; specifically resulting in increased scapular anterior tilting during unconstrained reaching tasks in the patient population.<sup>9,40</sup> It is possible that the scapular dyskinesia found in these studies was augmented due to a reduction in proprioceptive awareness and reduction in subacromial pain. Interestingly, patients with SIS who have received shoulder surgery and rehabilitation are reported to have resolved proprioceptive deficits.<sup>14</sup> Taken together, these data point to a conclusion that patients with chronic joint pain adapt to painful stimuli and rely on nociceptive afferents to establish proprioceptive awareness of limb position.

Our results indicate that anesthetic injections acutely disrupted proprioceptive acuity, presumably due to diminished nociceptive feedback. It is unlikely that the subacromial anesthetic injection directly affected mechanoreceptors as the subacromial injection is localized to the subacromial bursa and contains vasoconstricting epinephrine. In a cadaveric study, subacromial injections were successfully placed 83% of the time and injection fluid extravasated into surrounding tissues less often than not.<sup>41</sup> Previous work has demonstrated that subacromial anesthetic injections have no influence on proprioceptive acuity and JPS in healthy shoulders.<sup>25</sup> In other sensory systems, the manipulation of sensory information may result in

periods of adjustment where changes in the processing of sensory information are exposure dependent.<sup>42</sup> Prism goggle studies, for example, are commonly used to examine the influence of visual manipulation on motor system adaptations and proprioception.<sup>42–44</sup> Results from these studies indicate that manipulation of the visual field results in motor adaptations of the arm in space, which occur even after the prism goggles are removed (after-effect).<sup>42–44</sup> In this analogy, pain could be similar to the prism goggles, and the removal of pain is analogous to the after-effects associated with the removal of the prism goggles. Therefore, it is possible that patients will improve proprioceptive acuity once the after-effects of the injection subside. To determine the influence of an after-effect, studies should examine proprioceptive acuity in patients with SIS longitudinally after receiving subacromial injections.

For accuracy at the elbow joint, we hypothesized that there would be no differences between patients with SIS versus healthy controls, nor would there be differences following the subacromial injection. Our results indicate that unlike the shoulder joint, patients demonstrated a linear increase in accuracy for the elbow as predicted (Figure 4). However, the magnitude of errors in patients were greater than the magnitude of the error in healthy controls (Figure 3). This discrepancy in proprioceptive acuity of the elbow was independent of our manipulation of nociceptive feedback of the shoulder, meaning patients with SIS demonstrated greater proprioceptive deficits of the elbow before and after the subacromial injection when compared with controls (Figure 4). This finding leads to a “chicken or the egg” conundrum, where it is unknown whether proprioceptive differences between patients and controls are the result of the SIS or precede the injury. Decrements in proprioceptive acuity at the elbow in patients with shoulder SIS could be related to disruptions in the processing of proprioceptive information centrally but are not likely to be due to the mechanical irritation or pain from the shoulder joint as the subacromial injection had no influence on proprioceptive acuity in the elbow (Figure 4).

Our hypothesis that the angular bias between accuracy and elevation of target would be disrupted in patients with SIS and would be restored following an anesthetic subacromial injection was partially supported. Our results indicate that patients with SIS were not sensitive to the influence of elevation angle on joint position accuracy for the shoulder or elbow, either before or after the injection (Figures 2 and 4). For healthy control subjects, our findings agree with the literature that for the shoulder and elbow, healthy individuals demonstrate a decrease in constant errors as joint angles approach 90° of flexion in the sagittal plane.<sup>10,25,29–31,45</sup> As the arm approaches 90° of flexion in the sagittal plane, external torque demand peaks, thus requiring greater muscle recruitment. Previous studies have confirmed that proprioceptive acuity and JPS increase with external loads.<sup>32</sup> Patients with rotator cuff pathology tend to have

atrophy of shoulder musculature<sup>46</sup> which may ultimately result in weakness, especially as the arm approaches 90° of flexion in the sagittal plane. It is possible that patients with SIS also experience some muscular atrophy of the shoulder which could be partially responsible for decrements in JPS accuracy of the shoulder and may help to explain the lack of sensitivity to elevation of the arm.

For constant and absolute errors, the linear influence of angle in healthy subjects has been repeated in multiple studies.<sup>10,25,29,31,45</sup> However, this trend does not extend to variable errors (precision).<sup>10,25,29,30</sup> We hypothesized that variable errors in patients with SIS would be greater than controls but would improve following a subacromial injection. Results from our study partially support our hypothesis, where patients with SIS had greater variable error when repositioning their arm to targets than controls for both shoulder and elbow; however, following treatment, there were no significant changes in precision (Figures 5 and 6). This finding suggests that SIS is associated with a decrement in the ability to consistently determine where one’s arm is located in space and may be independent from pain. It is possible that other symptoms associated with SIS, such as rotator cuff deterioration, tendon thickening, and changes to the subacromial bursa, may influence the ability to consistently identify targets in space.

### Limitations

We did not include a treatment condition for our control individuals. Due to the lack of randomization, which was constrained by our clinical design, it is possible that learning effects and familiarization to the protocols could affect the results after injection. Furthermore, it is possible that the magnitude of the differences were minimized after injection due to a learning bias, future studies should account for injury duration, in terms of how long a patient has had SIS and how long they have had to alter their behavior in their analysis.

### Author Contributions

All authors contributed to the research design, collection, and writing of this manuscript being submitted to *Clinical Medical Insights: Arthritis and Musculoskeletal Disorders*.

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