# Sensorimotor Training for Shoulder Injury

## *Literature Review*

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**ABSTRACT**

When the shoulder is injured, a cascade of interrelated events result, including tissue pathology, pain, and sensorimotor alterations. Clinicians use sensorimotor training to address these events. The purpose of this review was to discuss how the sensorimotor system contributes to shoulder function and to review evidence regarding the effectiveness of training to target sensorimotor mechanisms. Review of peer-reviewed literature was performed with both Medline and Cumulative Index to Nursing and Health Literature databases. For studies that involved some component of shoulder sensorimotor training, only those published within the past 10 years were included. The search yielded 23 publications of varying levels of evidence, suggesting the ability of sensorimotor training to result in both acute and chronic adaptations to the sensorimotor system. Although the evidence regarding usage still needs to improve, some data suggest that the sensorimotor system may be trainable.

It is commonly accepted that the joints of the shoulder complex rely heavily on coordinated activation of the muscles that cross each joint for much needed stability and performance of functional activity. The sensorimotor system is primarily responsible for regulating this coordinated muscle activation of the shoulder musculature.[1] When injury to the shoulder occurs, not only do tissue pathology and pain result, but potential alterations to the sensorimotor system can also manifest. As such, clinicians who rehabilitate the shoulder not only have to address the tissue pathology and pain, but also must retrain the sensorimotor mechanisms that are important to shoulder stability and function.

The purpose of this review is to discuss how the sensorimotor system contributes to shoulder function, describe how it is affected with injury, and review evidence regarding the effectiveness of sensorimotor training to target the mechanisms necessary for stability and function of shoulder complex. To complete this review, Internet-based searches of the peer-reviewed literature were performed with both Medline and Cumulative Index to Nursing and Health Literature (CINAHL) databases. Searches were performed with the following keywords (and combinations of keywords): *shoulder*, *scapula*, *sensorimotor*, *proprioception*, *neuromuscular*, *muscle activation*, *electromyography*, *rehabilitation*, and *training*. For the review of evidence, the titles and abstracts of 683 articles were reviewed to identify orthopedic-related articles that either measured change in the sensorimotor system that resulted from some training intervention or measured some sensorimotor characteristic during performance of a sensorimotor training activity. Only studies published within the past 10 years were reviewed. For the intervention studies reviewed, only those that met criteria for inclusion in the Physiotherapy Evidence Database (PEDro) were included. For an intervention to be included in this review (ie, meet PEDro inclusion criteria), the study had to:

- Compare at least 2 interventions (intervention versus control or sham, or 2 interventions).
- Include interventions that are currently part of clinical practice or could become part of clinical practice.

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- Include interventions applied to human subjects who are representative of those to whom the intervention might be applied in the course of clinical practice.
- Involve random allocation or intended-to-be-random allocation of participants to interventions.
- Be published as a full paper in a peer-reviewed journal.

## SENSORIMOTOR CONTRIBUTION AT THE SHOULDER

The sensorimotor system includes sensory, motor, and central integration and processing components involved with maintenance of joint homeostasis during functional activity.[2] The role of the sensorimotor system is to modulate ongoing muscle activation characteristics by using afferent neural input to initiate and adjust efferent neural signal to the desired muscles. This efferent response to a constantly changing afferent signal occurring unconsciously for the purpose of maintaining joint stability is called *neuromuscular control*.[2] Proprioception is one of the afferent neural inputs from the periphery used by the sensorimotor system, conveying information regarding joint movement (kinesthesia), position and orientation, and force applied to or present within a joint.[3] During joint movement, tension and force develop within the tissues (muscles, tendons, fascia, ligaments, and joint capsule) about the shoulder. The result is stimulation of mechanoreceptors, which translates the mechanical change in the tissue (length and tension changes) as a neural signal to the central nervous system (CNS) via afferent neural pathways. Within the CNS, the proprioception information regarding length and tension is integrated with the other peripheral senses, such as tactile sensation, vision, vestibular input, and descending neural signals from spinal cord, brain stem, cerebellum, and cortex.[4] The result is neural signals conveyed through efferent pathways to the motor neurons to produce muscle activation or inhibition and to regulate sensitivity of the mechanoreceptors within the muscle (muscle spindle).[5] Regulation of the sensitivity of muscle spindle through the efferent neural signal, in turn, influences the afferent neural signals sent to the CNS.[5]

Both static joint stability (stability provided by osseous geometry, capsuloligamentous and tenomuscular restraints, and intra-articular pressure) and dynamic joint stability (stability provided by the contractile action by muscles) contribute to functional joint stability. However, the contribution of the dynamic stabilizers outweighs the contribution from the static stabilizers at the glenohumeral joint because of poor glenohumeral joint congruency and laxity of the glenohumeral joint capsule that permit large range of motion.[6-8] The sensorimotor system serves a critical role in providing dynamic joint stability through its control over the activation of muscles that cross the shoulder joint.[4,9] Modulation of tone (and ultimately stiffness) of the muscles surrounding the shoulder by regulation of muscle spindle sensitivity is most likely how the sensorimotor system provides joint stability at the shoulder.[10] When the muscle spindle is highly sensitive, relatively small changes in muscle length and tension triggers afferent neural signals, which results in enhanced muscle tone (muscle activation level) and shorter latency period of the muscle reflexive responses.[11] Increased muscle tone and shorter reflex latency period provide stiffness to the muscle-tendon unit, which makes the shoulder more resistant to perturbing events of the humeral head or scapula. In a recent study, moderate level of muscle activation was shown to result in significant increase in glenohumeral joint stiffness,[12] demonstrating the vital role that muscle activation plays in increasing the joint stiffness and aiding joint stability at the glenohumeral joint. Increased muscle stiffness also improves joint stability by providing tension on the joint capsule, a mechanism referred to as *capsular dynamitization*.[13] The tendons of the rotator cuff muscles and the other muscles that attach onto the proximal humerus (pectoralis major, latissimus dorsi, and teres major) blend into the joint capsule.[14] As result, the glenohumeral joint capsule tightens and stiffens when these muscles are activated.

In addition to regulation of the joint stiffness, sensorimotor system contributes to joint stability by coordinating activities of the muscles surrounding the joint. Coactivation of the rotator cuff muscles is particularly important in producing joint compression to keep the humeral head centered within the glenoid fossa.[15-21] When the 4 rotator cuff muscles coactivate, the muscles collectively produce a resultant joint compressive force, centralizing the humeral head within the glenoid, minimizing translation of the humeral head.[15-22] For example, anterior translation of the humeral head increased by approximately 50%, when the compression force by the rotator cuff muscles decreased by 50%.[23] In addition to the compressive force, coactivation of the deltoid and the rotator cuff muscles allows rotation of the humeral head on glenoid fossa while minimizing superior translation of the humerus during humeral elevation.[24,25]

In addition to the muscles about the glenohumeral joint, precise activation of the muscles controlling scapular movement and stability are also necessary for shoulder stability and function. For example, Moseley et al[26] examined the electromyographic activity of the 3 portions of the trapezius, levator scapula, rhomboids, pectoralis minor, and serratus anterior during different scapular training exercises and noted that majority of the muscles were active during all movement, suggesting that the scapular muscles play important roles during scapular movement. During humeral elevation, the electromyography literature reporting scapular muscle activation suggest that the upper trapezius, lower trapezius, and serratus anterior work in synergy to achieve the upward scapular rotation necessary for humeral elevation to occur.[26-31] Efficient scapular movement is important in positioning and orienting the glenoid fossa in alignment with the humerus so that the line of pull and the length tension relationship of the rotator cuff muscles can be maintained.[32]

### Effect of Injury on Sensorimotor System

Given the important roles the sensorimotor system plays on shoulder stability and function, sensorimotor deficits associated with injury are of great concern clinically and should be addressed following injury. From a review of the literature, it appears that the sensorimotor system can be affected by joint or muscle injuries that cause pain, trauma, or attenuation of the capsuloligamentous and musculotendinous tissues.

The use of experimental pain has allowed the investigators to isolate the effect of pain in absence of mechanical damage to the tissue or the mechanoreceptors.[33-38] Research using experimental pain models have demonstrated changes in sensorimotor system activity simply due to pain.[33-38] Decreased excitability of the cortical and spinal motor neurons in presence of experimental pain demonstrated by one of the studies[38] suggests the existence of central mechanism (ie, inhibition initiated by the motor cortex), resulting in the sensorimotor system alteration. Research has also demonstrated alteration in muscle activation,[33,34,37,39] motor unit firing rate,[35] and maximal force production[36] when pain is present. Alternatively, improvements in muscle activation and scapular movement pattern have also been reported in patients with rotator cuff disease who received anesthetic injection.[40,41]

In addition to the pain that occurs with injury, attenuation and stretching of the capsuloligamentous and musculotendinous structures may also contribute to the sensorimotor function deficits. Alterations in the sensorimotor system, including deficit in proprioception,[42-44] altered muscle activity during upper extremity tasks,[23,45-48] altered reflexive muscle activity,[49] and dysfunctional movement patterns[50] have been reported in patients with anterior and multidirectional instability. Alteration in the proprioception conveyed to the CNS due to reorganization of the length and tension appreciation by the mechanoreceptors and deafferentation of the mechanoreceptors within the tissue or the neural pathways are considered the primary mechanisms for these sensorimotor deficits.[51,52] Because patients with joint instability are typically affected by both joint hyperlaxity and pain,[45,53-55] it is impossible to isolate the effect of joint laxity from that of pain. However, other findings demonstrating decreased sensorimotor function in individuals with asymptomatic joint laxity suggest the laxity itself attributes to sensorimotor deficits in individuals with instability.[56-58] Studies reporting restoration of sensorimotor function in patients with shoulder instability following a surgery to address capsule laxity may also support the influence of joint laxity on sensorimotor system.[42,44,59,60] However, the accompanying decrease in pain that most likely resulted from surgery or the treatment following surgery cannot be overlooked.

Sensorimotor dysfunction has also been demonstrated in patients with varying degrees of rotator cuff tendinopathy (subacromial impingement to rotator cuff tears). The dysfunction found in these patients includes decreased ability to maintain steady force production[61]; decreased activity of the middle deltoid during moderately strenuous external rotation task[62]; increased activation of the biceps brachii[63,64]; alteration of the muscle activity ratio among the upper, middle, and lower portions of the trapezius muscles[46]; disrupted coactivation between the middle trapezius and serratus anterior muscles[35]; suppressed activation and coactivation of the rotator cuff muscles[25,65]; and delayed onset of the muscles around the scapula during elevation tasks.[66] Currently, it is unknown whether these sensorimotor alterations contributed to or result from the tendinopathy.

Although the specific patterns of sensorimotor alterations observed in the studies mentioned above may vary, it is evident that the sensorimotor system is affected by injury and pain. In addition, it seems reasonable to believe that changes in the CNS, as well as damage to the peripheral structures, contribute to the alteration in sen-

TABLE 1

Review Summary of Acute Adaptation (EMG Research Findings) from Shoulder Sensorimotor Training (1998 to Present)[a]

| STUDY | CONTROL PARTICIPANTS | PARTICIPANTS WITH INJURY | TRAINING USED | PERTINENT FINDINGS |
|---|---|---|---|---|
| Decker et al[27] | N | N | OKC, CKC | Identified effective exercises to stimulate the serratus anterior |
| Decker et al[94] | N | N | OKC, CKC | Identified exercises that best stimulate each portion of the subscapularis |
| Ekstrom et al[29] | N | N | OKC | Identified which exercises maximally activated the trapezius and serratus anterior muscles |
| Hintermeister et al[95] | N | N | OKC | Identified exercise that best targets the rotator cuff |
| Kibler et al[93] | Y | Y | OKC | No difference in muscle activation between symptomatic and asymptomatic individuals when performing exercise |
| Kinney et al[101] | N | N | OKC | Demonstrated which position of humeral abduction best isolates the middle and lower portion of the trapezius muscle during prone horizontal abduction exercises |
| Lehman et al[98] | N | N | CKC | Training on an unstable surface (Swiss ball) had no effect on activation of shoulder girdle muscles |
| Lehman et al[99] | N | N | CKC | Training on an unstable surface (Swiss ball) increased muscle activation |
| Lister et al[100] | N | N | OKC, OD | Training using an OD resulted in greater scapular stabilizer activation |
| Ludewig et al[30] | Y | Y | CKC | No difference in serratus anterior and trapezius muscle activation between symptomatic and asymptomatic individuals when performing CKC exercise |
| Myers et al[31] | N | N | OKC | Demonstrated which throwing-related rubber tubing exercises result in the most activation of all muscles of the shoulder girdle |
| Reinold et al[102] | N | N | OKC | Demonstrated which "full can" and "empty can" exercises best isolate the supraspinatus and deltoid (middle and posterior) muscles |
| Reinold et al[103] | N | N | OKC | Demonstrated which external humeral rotation strengthening exercises best activated the rotator cuff and deltoid muscles |
| Uhl et al[97] | N | N | CKC | Exercises that involved progressively increased upper extremity weight bearing resulted in increased shoulder girdle muscle activation |

Abbreviations: EMG, electromyography; OKC, open kinetic chain resistance exercises (eg, cuff weights and elastic bands); CKC, closed kinetic chain exercises performed in an upper extremity weight-bearing position; OD, exercises that involve oscillatory devices (eg, Bodyblade).

[a] None of these articles qualified for a PEDro score assignment

sorimotor system following injury, although the exact neurophysiologic mechanism is still unclear. However, it is important to acknowledge that the sensorimotor function has never been assessed prospectively, and therefore, existence of sensorimotor deficit prior to the occurrence of injury cannot be ignored. Particularly for the shoulder injuries that are chronic in nature, such as rotator cuff tears, chronic instability, or subacromial impingement, it is possible that the sensorimotor deficit may have existed prior to the injury and contributed to the occurrence of the injury. This is a weakness in the current knowledge base regarding risk factors to shoulder injuries. Nonetheless, the studies demonstrating the sensorimotor deficit following injuries discussed thus far clearly indicate the need for training the sensorimotor system following injury.

**TABLE 2**

**Review Summary of Chronic Adaptation from Shoulder Sensorimotor Training (1998 to Present)**

| STUDY | PEDro SCORE | TRAINING USED | VARIABLES MEASURED | PERTINENT FINDINGS |
|---|---|---|---|---|
| Carter et al[104] | 5/10 | Plyo | Strength and throwing velocity | Plyometrics resulted in increased concentric and eccentric strength of the humeral rotators and throwing velocity |
| Ginn and Cohen[111] | 6/10 | CR | Strength, ROM, scapular movement, pain, and function | Demonstrated that a clinical rehabilitation program that includes sensorimotor training is an effective conservative treatment option for shoulder pain |
| Kraemer et al[114] | 6/10 | OKC | Strength and power output, and function (tennis serve velocity) | Demonstrated that sport-specific resistance training that uses multiple sets results in improved strength, power output, and tennis serve velocity in women tennis players |
| Padua et al[108] | 6/10 | OKC, CKC, PNF | Strength, prop, and functional movement | Shoulder strength improved following 5 weeks of OKC and PNF exercise; functional throwing performance improved with PNF |
| Rogol et al[107] | 5/10 | OKC, CKC | Prop | Both OKC and CKC exercises resulted in improved prop |
| Schulte-Edelmann et al[105] | 5/10 | Plyo | Strength | A plyometric program resulted in increased power output by the elbow extensor muscles |
| Swanik et al[106] | 6/10 | Plyo | Prop and strength | Plyometrics resulted in both prop and improved strength characteristics |
| Swanik et al[112] | 6/10 | OKC, CKC | Strength and pain | A 6-week function training program resulted in decreased incidence of shoulder pain in collegiate swimmers, but no strength gains resulted |
| Ubinger et al[110] | 5/10 | CKC | WBS | A CKC training program resulted in improved shoulder stability in a weight-bearing position |

Abbreviations: CKC, closed kinetic chain exercises performed in an upper extremity weight-bearing position; CR, clinical rehabilitation program that involves stretching and various forms of strengthening; OKC, open kinetic chain resistance exercises (eg, cuff weights, elastic bands); Plyo, plyometric exercises; PNF, proprioceptive neuromuscular facilitation exercises; Prop, proprioception; ROM, range of motion; WBS, stability when the upper extremity is placed in a weight-bearing position.

Compounding the influence of injury and pain is the effect of fatigue on the sensorimotor system. Fatigue may also contribute to the sensorimotor deficits demonstrated with pain and injury. Components of the sensorimotor system, including proprioception,[67-75] muscle activation characteristics, [76-81] and movement characteristics and coordination,[76,82-92] appear to be adversely affected by fatigue. The susceptibility of the sensorimotor system to fatigue effects suggests the need for training to improve resistance to fatigability, ultimately decreasing the alterations that manifest with the onset of fatigue.

## EFFICACY OF SHOULDER SENSORIMOTOR TRAINING

Given the important role of sensorimotor mechanisms in shoulder stability and function, clinicians use a variety of training techniques in hopes of restoring these mechanisms that are altered with injury. Sensorimotor training activities are believed to improve activation characteristics and force production by the muscles about the shoulder girdle, alter motor programs, and improve proprioceptive acuity. Specifically, they are believed to stimulate activation and coordination of muscles that might be inhibited or altered following injury, facilitate muscle coactivation vital to the force couple mechanisms, and enhance the reflexive loops associated with joint stability. In addition, it is hoped that by improving the activation characteristics, the proprioceptive feedback from the musculature might be improved as well, through enhanced muscle spindle performance and muscle stiffness. The most common sensorimotor training techniques described in the literature we reviewed included activities that incorporate joint position and movement repositioning, performance of exercise in closed kinetic chain positions, proprioceptive neuromuscular facilitation, plyometrics, joint perturbations, selective activation of specific muscles, or global activation of many muscles about the shoulder girdle. The literature includes research studies that demonstrate acute adaptation to the sensorimotor system from performing specific exercises (Table 1) and chronic adaptation to the sensorimotor system from performing training exercises over a period of time (Table 2).

In our review of the literature, we found 14 studies published in the past 10 years that used electromyography to measure the acute adaptation (activation characteristics) that occurs while performing therapeutic exercises (Table 1). Because these studies do not use intervention research designs that meet PEDro requirements, no score was assigned. Yet the results of these studies do provide some valuable information for clinicians, which warrants a discussion. From the measured activation characteristics, recommendations are often made regarding which exercises best isolate or maximally activate a particular shoulder girdle muscle,[27,93-96] which exercises elicit coactivation or global activation of many of the muscles that are important for shoulder function,[30,31,97] and which mode of exercise (resistance tubing, free weights, oscillatory devices, closed kinetic chain)[29-31,97-103] is most effective in inducing the desired muscle activation. Unfortunately, many of these studies are performed with convenience samples of participants who possess no shoulder injury. Given the demonstrated sensorimotor deficits we see with injury, it is unclear whether these activations patterns reported in healthy study participants can be expected in an injured population as well. However, both Kibler et al[93] and Ludewig et al[30] demonstrated no scapular muscle activation differences between symptomatic and asymptomatic shoulders during performance of scapular stabilization exercises, suggesting that similar patterns of activation may exist in injured individuals such as the healthy convenience sample participants often assessed. In general, the level of efficacy for using sensorimotor training exercises to elicit desired activation patterns might be improved by demonstrating similar patterns in shoulders with injury, through controlled research studies that use both injured and uninjured populations.

In addition to the measured acute adaptations to the sensorimotor system, we found 9 orthopedic or sports-related articles that met the inclusion criteria for PEDro and demonstrated the presence or absences of chronic changes to the sensorimotor system resulting from performing sensorimotor training exercises over an extended period of time (Table 2). A majority of those articles were given a PEDro score of 6 (of 10), with a lack of blinding of participants, therapists, or assessors as the most common reason for deduction of the PEDro score. Of the studies that were not included in this review because they did not meet the 5 criteria necessary for PEDro inclusion, the most common flaws were that the study did not compare at least 2 interventions (ie, 1 intervention compared with a control or sham, or 2 interventions) and the trial did not involve some attempt at random allocation.

Shoulder plyometric exercises have been shown in several studies we reviewed to have benefits for the sensorimotor system, including improved proprioception, strength, power, and functional performance.[104-106] Similarly, traditional weight room exercises have been shown to result in improved proprioception accompanying strength gains.[107] Padua et al[108] examined whether training with different modes of shoulder strengthening exercises (open kinetic chain tubing, closed kinetic chain stability, and proprioceptive neuromuscular facilitation [PNF] diagonal manual resistance exercises) influence proprioception, single-arm dynamic stability, shoulder-rotation strength, and functional throwing performance in healthy individuals. They showed that the shoulder rotation strength was improved with only 5 weeks of training healthy individuals using either open kinetic chain tubing or PNF exercises. The fact that changes in strength occurred in such a short time (only 5 weeks) suggests that these changes were a result of sensorimotor adaptation given that strength adaptations due to muscle hypertrophy tend to take longer periods of training (8-12 weeks) to manifest.[109] Of note, the study by Padua et al[108] was not able to demonstrate proprioceptive improvements but did demonstrate throwing function performance with the proprioceptive neuromuscular facilitation exercise. Ubinger et al[110] demonstrated similar adaptations from performing a 4-week sensorimotor closed kinetic chain training program for the shoulder, showing improvements in shoulder neuromuscular control (as measured through a single arm stability test). These results suggest the sensorimotor system is trainable in a short period of time (4 to 5 weeks).

Ginn and Cohen[111] focused on the influence of neuromuscular training on pain by comparing the effectiveness of exercise therapy aimed at restoring neuromuscular control mechanisms at the shoulder with other conservative interventions for the treatment of chronic shoulder pain with and without accompanying stiffness. Using a randomized control trial, participants either received exercise therapy aimed at restoring dynamic stabilizing mechanisms and muscle coordination at the shoulder, subacromial corticosteroid injection, or a combination of physical modalities and range of motion exercises. At 5 weeks, all participants' pain intensity, functional impairment, active range of motion, isometric muscle force significantly improved with no difference between the treatment groups. The authors concluded that exercise therapy aimed at restoring neuromuscular control, corticosteroid injection, and multiple physical modalities and range of motion exercises are equally effective in the short-term treatment of shoulder pain. Swanik et al[112] used functional training that included elastic tubing, prone dumbbell, and closed kinetic chain exercises to reduce the incidence of shoulder pain in collegiate swimmers. From these results, it appears that sensorimotor training has a positive effect on reducing or preventing shoulder pain.

Although evidence suggests that variables like proprioception, strength, power, pain level, and function can be improved by various forms of sensorimotor training, none of the studies that met the inclusion criteria demonstrated actual changes in muscle activation characteristics (eg, activation patterns, coordination, reflex characteristics) or upper extremity movement patterns. For example, Wang et al[113] reported that scapular movement patterns can be changed with exercise. However, their study was not included in this review because it did not meet the PEDro inclusion criteria due to the lack of a control group. Unfortunately, the current literature base is void of strong intervention studies that specifically demonstrate changes in either muscle activation characteristics or improved movement patterns. Ultimately, the next logical step is to develop and validate sensorimotor training programs that change muscle activation and the resulting movement patterns in patients who would benefit from the training after injury or individuals who are susceptible to sustaining shoulder injury as preventive measures. Demonstration of improvements in sensorimotor function in these population using a well-designed experimental studies would provide higher level of evidence toward the effectiveness of the sensorimotor training in injury intervention. One area that warrants acknowledgement is that a majority of the trials performed to date involved individuals who are currently healthy. We included these trials in the review because the participants tested may benefit from the preventive intervention, given that they are physically active. However, future studies should focus on improving sensorimotor characteristics in participants with injury given that these individuals most likely have sensorimotor deficits, as demonstrated in the literature.

## CONCLUSION

The sensorimotor system contributes to joint stability and function through its control over the muscles that cross the shoulder joint complex. Injury, pain, and fatigue to the shoulder can affect the sensorimotor system both centrally and peripherally due to tissue trauma, pain, and attenuation or stretching of the tissues, resulting in decreased stability and function. Given the important role the sensorimotor system plays in joint stability and function and how the sensorimotor system is affected by the joint injury, training of the sensorimotor system is crucial in treatment following injuries. The current evidence suggests that the sensorimotor system is trainable. As such, clinicians should include sensorimotor training components in their rehabilitation following injury given the deficits that are present with injury and pain or as part of their prevention programs to reduce the effects of fatigue on the sensorimotor system. ■

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