

ORIGINAL RESEARCH

THE EFFECT OF ELECTRICAL STIMULATION VERSUS SHAM CUEING ON SCAPULAR POSITION DURING EXERCISE IN PATIENTS WITH SCAPULAR DYSKINESIS

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ABSTRACT

Background: Conventional therapeutic exercise programs are commonly used to treat patients with scapular dyskinesis. There are no studies that have examined traditional therapeutic exercise programs with the addition of remote triggered electrical stimulation (ES) to affect the position of the scapula (using spine to scapular border distance as a reference point) during the performance of exercises that have lower upper trapezius (UT) to lower trapezius (LT) ratio exercises.

Purpose: The purpose of this pilot study was to compare scapular position after performance of three low UT/LT ratio therapeutic exercises in two conditions, electrical stimulation (ESTherex) and sham electrical stimulation (ShamTherex) in asymptomatic persons who were positive for scapular dyskinesis.

Study Design: Randomized trial, single-blinded

Methods: Eleven asymptomatic university students representing 15 scapulae with a positive Scapular Dyskinesis Test were recruited as subjects. Participants were randomized into exercise and electrical stimulation (ESTherex) or exercise and sham electrical stimulation (ShamTherex). Subjects performed side-lying shoulder external rotation and flexion, and prone horizontal abduction with external rotation in both conditions. Scapular position was assessed during active abduction at four angles before and after performance of these exercises.

Results: There were no significant differences in scapula to spine distance between ESTherex and ShamTherex groups at 0, 45, 90 and 120 degrees of shoulder abduction. A between group difference (ESTherex and ShamTherex) approached significance at 45 degrees ($p = 0.089$, $CI = -.152$ to 1.88 cm) with the post mean measurement of the ShamTherex group (6.44 cm) greater than the post mean measurement of the ESTherex group (5.57 cm). The ESTherex showed a significant pre-to-post mean within group improvement in spine to scapula distance at 120 degrees (mean 2.76 cm, $t = 4.89$, $p = .003$).

Conclusions: Electrical stimulation with exercises for scapular dyskinesis showed improvements in spine to scapula distance at 120 degrees of shoulder abduction.

Level of evidence: Therapy, level 1b

Key words: Electrical stimulation, lower trapezius, scapular dyskinesis,

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BACKGROUND

The scapula and the shoulder are a highly interconnected functional unit with lifetime prevalence estimates of shoulder pain, although imprecise, due to varying degrees of motion loss and symptom duration, that range from 6.7% to 66.7% for the general population.¹ Because the scapula and shoulder function as a unit, a change in normal kinematics of either will result in aberrant shoulder complex mechanics, termed scapular dyskinesis.² Aberrant shoulder complex mechanics result in an increased risk for upper extremity range of motion limitations, upper extremity deficits, or upper quarter pain syndromes.³⁻⁶ For example, over activation of the upper trapezius (UT) in conjunction with delayed activation of the lower trapezius (LT) results in limited posterior tilt of the scapula.^{7,8} Limited posterior scapular tilt has been postulated to lead to a loss of acromial elevation that may predispose an individual to impingement.^{9,10} A systematic review by Kibler et al. links changes in scapular kinematics during arm elevation to a change in glenoid angle that creates an increased risk of shoulder instability.¹¹ Shoulder instability and impingement are two of many potential shoulder pain syndromes that may result from altered scapular kinematics.^{6,12}

Scapular dyskinesis (defined as altered scapular motion and position) can be a precursor to an abnormal relationship between the glenohumeral joint and the scapula during movement, and it is therefore critical that dyskinesia be addressed.¹³ Dyskinesis describes aberrant scapular position at rest, such as winging of the scapula⁶ (excessive prominence of the medial scapular border) and a deviation from normal scapular motion during arm elevation manifesting as a lack of smooth coordinated movement.^{6,9} For example, an individual with observable shoulder shrugging during arm elevation is indicative of lack of coordination between the upper, middle and lower trapezius muscles.¹⁴ Alternatively, Kibler¹⁵ defines a Type II pattern of scapular dyskinesis (Scapular Dyskinesis Classification System) as the presence of a prominent medial scapular border which is most evident during eccentric lowering of the humerus creating rapid downward rotation of the scapula during arm lowering. Excessive shoulder shrugging and rapid downward rotation of the scapula during arm lowering, demonstrate uncoordinated scapular movement, described as scapular dyskinesis.

It is common for physical therapists to treat patients with shoulder pain and scapular dyskinesis. Treatment techniques to address dyskinesis include manual neuromuscular facilitation, tactile cueing, visual feedback, electrical stimulation, supervised exercise, mobilization, strengthening, electromyography, and other interventions.¹⁶

RESEARCH INCONSISTENCIES REGARDING SCAPULAR DYSKINESIS

Studies linking shoulder pathology and scapular dyskinesis have shown contradictory findings. One example is the inconsistent recruitment timing of scapular muscles noted in a systematic review by Struyf et al.¹⁷ In this systematic review electromyographic studies were used for assessment of scapular patterns in patients with impingement and glenohumeral (GH) instability, compared to healthy controls. Regardless of shoulder pathology (impingement or GH instability) findings were conflicting with regard to recruitment of scapular musculature. Of the six studies that assessed EMG in patients with impingement, three reported increased recruitment of the UT,¹⁸⁻²⁰ while three showed no difference in UT activity when compared to healthy controls.²¹⁻²³ Furthermore, of the two studies that compared EMG in the UT of those with and without GH instability, results were also conflicting. One study showed increased UT activity²⁴ while the other study found no difference in UT activity in individuals with instability compared to healthy controls.²⁵ Lack of consensus regarding the combined behavior of muscle recruitment and timing, in the treatment of impingement and glenohumeral instability, leave a gap in the literature that can lead to clinical decisions guided by experience rather than evidence. Based on the findings from the systematic review, Struyf et al., recommend assessing and addressing individual motor pattern deficits.¹⁷

LOWER TRAPEZIUS ROLE IN SCAPULAR DYSKINESIS

One motor pattern deficit noted in scapular dyskinesis is an over active UT combined with an under active LT. Seitz et al. used rehabilitative ultrasound imaging to assess differences in LT muscle thickness in persons with and without scapular dyskinesis.²⁶ Lower trapezius muscle thickness was

increased in persons with scapular dyskinesis compared to individuals without dyskinesis. According to the researchers this change in thickness can be associated with abnormal scapular muscle contractile behavior because of weakness or delayed timing of the muscle. The same trend did not occur when thickness of the serratus anterior muscle was assessed in persons with and without dyskinesis.²⁶

Cools et al.²⁷ used EMG to identify three exercises that address this type of scapular dyskinesis by identifying low UT to high lower and middle trapezius (UT/LT) activation patterns.²⁷ Three exercises were identified: side lying external rotation, side lying shoulder flexion (beginning at 90degrees), and prone horizontal abduction at 90 degrees of abduction. The exercises found to have a low UT/LT ratio address the voluntary muscle recruitment of the LT while minimizing UT firing. These exercises however, do not address the muscle fiber loss from disuse.

MUSCLE BEHAVIOR AND DISUSE ATROPHY RELATED TO LOWER TRAPEZIUS DYSKINESIS

Disuse results in a selective muscle fiber loss.²⁸ When an individual performs voluntary muscle activation, motor fibers are recruited in an asynchronous fixed pattern with the recruitment of slow conducting, slow twitch, fatigue-resistant small muscle fibers (SSFR) before fast conducting, fast twitch, fatigable, large (FFF) muscle fibers. In contrast, when an individual performs high intensity exercise, fast conducting, fast twitch, fatigable muscle fibers are recruited.^{29,30} When electrical stimulation (ES) is coupled with voluntary muscle contraction the result is the recruitment of all muscle fibers synchronously, regardless of muscle fiber size and speed of conduction.³¹ Because of the advantage of this coupled mechanism, electrical stimulation may offer a more comprehensive approach in the treatment of muscles that exhibit alteration in recruitment timing that lead to movement dysfunction.

STUDIES ON THE EFFECT OF ELECTRICAL STIMULATION

Four Cochrane systematic reviews have explored the effect of electrical stimulation in rehabilitation. The reviews differ from the current study in the fol-

lowing ways: one review assessed the effect of ES on central nervous system injuries (CNS)³², while the population in the current study had intact central nervous systems; two reviews assessed the effect of ES on orthopedic shoulder pathologies (rotator cuff disease and adhesive capsulitis),^{33,34} however both of these were applied to address pain and had very different protocols and purposes compared to this study; the final review assessed electrotherapeutics for chronic pain and again, was not applicable to this study.³⁵ To the knowledge of the authors, the application of stimulation in the current study does not appear in the published literature.

Electrical stimulation has resulted in consistent positive outcomes in varied orthopedic and neurologic patient populations.³⁶⁻³⁹ A systematic review assessing the effect of neuromuscular electrical stimulation (NMES) after anterior cruciate ligament reconstruction reported improved quadriceps strength 16 weeks post operatively with an exercise and NMES condition, compared to exercise alone.⁴⁰ Authors suggest that peripheral ES changes motor behavior.^{31,41} Additional examples of the benefit of ES with an exercise program include a study by Scott et al that supported therapeutic ES at the maximum tolerated stimulation intensity for strength improvements in the quadriceps.³⁶ The consistent positive outcomes of ES are also demonstrated in neurologic populations. A 2015 systematic review by Howlett et al. found moderate improvement in walking speed when ES was compared to no intervention and training alone for functional activity improvement following stroke.³⁷ These studies lend support for underlying mechanisms of ES as a treatment, however no studies directly use ES in the manner being explored in the current study.

RESEARCH DEFINING THE PHYSIOLOGICAL EFFECTS OF ELECTRICAL STIMULATION

Although all the effects that ES has on the body are not completely understood, there is clear support for proposed mechanisms. These mechanisms include the following: 1) the effect on central nervous system (CNS) generated frequency pattern⁴¹, 2) excitation of potential selective fiber types⁴², and 3) dose repeatability (e.g. the same motor response

every time with the same ES set up and parameters, regardless of voluntary patient input). Scapular dyskinesis, which has an involuntary component that may require new CNS input and, which may respond to selective fiber recruitment to correct, could respond to ES as an additional intervention. ES may allow for an individual to internalize proper scapular position more quickly as compared to other contemporary treatments

THE EFFECT ON CENTRAL NERVOUS SYSTEM (CNS) GENERATED FREQUENCY PATTERN

With regard to CNS generated frequency patterns, electrical stimulation is known to modulate ascending and descending input to motor systems. Sugawara et al. found increased primary motor cortex motor evoked potentials (MEPs) in the extensor carpi radialis (ECR) when ES was combined with voluntary muscle contraction compared to ES or voluntary contraction alone. The combination of ES and voluntary muscle contraction of the ECR also resulted in decreased MEPs of the flexor carpi radialis when compared to the condition of ES or voluntary contraction alone.³¹

In addition to increased primary motor cortex excitability of the electrically stimulated muscle groups, ES recruits (whether the individual chooses to or not) muscle fibers that the patient often does not know how to recruit, or is not able to recruit with his or her voluntary muscle contraction alone. These are also the same muscles that therapists spend a lot of time in treatment trying to get the patient to recruit. Therapist facilitation methods not employing ES do not have the same physiological effects as those using ES. Henderson et al. speculate that there is no difference in motor unit recruitment order based on conduction time in response to ES, but that variability of motor unit pool recruitment is dependent upon the stimulation threshold of the peripheral nerve, the location of axon within the nerve and various other axon characteristics such as hyperpolarization following ES.⁴² Electrical stimulation that assists in repositioning of the scapula may have the potential to address dyskinesis related disuse as could be associated with an elongated and or weakened lower or middle trapezius. For example,

Cools et al. report “abnormal recruitment timing” in the middle and lower trapezius in overhead athletes with impingement.¹⁴ If a delay in the onset of muscle recruitment is a reflection of stretch weakness⁴³ and the stretch weakness persists, and it leads to atrophy (as occurs in innervated skeletal muscle with an intact but unused alpha motor neuron),⁴³ and ES may address this weakness peripherally.

SELECTIVE FIBER TYPE ACTIVATION WITH ELECTRICAL STIMULATION

A motor unit refers to a motor neuron and the associated skeletal muscle fibers,⁴⁴ a shift in fiber type as result of disuse from dyskinesis, may respond more rapidly to ES combined with voluntary contraction than ES or exercise alone. Specifically, SSFR fibers may be more susceptible to disuse atrophic signaling resulting in a shift in muscle fiber ratios.^{28,45} When there has been a shift in muscle fiber type, as a result of disuse, aging, and/or disease,²⁸ voluntary muscle contraction may be inadequate to address motor pattern deficits. Efficacious treatments for these patient populations are critically important in a fast-paced payer driven healthcare environment.

The upper and lower trapezius are made up of different muscle fiber types, which allows for the various functional roles of the trapezius.⁴⁶ The lower trapezius is predominantly SSFR (Type I) muscle fiber whereas the upper trapezius is comprised of more FFF (Type II) muscle fiber possibly making the entire muscle complex at risk for shifts in muscle fiber type from disuse.⁴⁷ However, this same varied fiber composition of the upper and lower trapezius make the trapezius a prime candidate for ES to address ill effects of disuse related muscle atrophy.

ELECTRICAL STIMULATION DOSE REPEATABILITY

The introduction of ES to comprehensively address motor pattern deficits, results in electrically induced muscle contractions, which produce a predictable muscle fiber recruitment that is impossible to achieve with therapist facilitated motor cueing or voluntary muscle contraction alone. Because the training effect is consistently replicable, void of therapist expertise, or void of patient motivation, it may be an optimal training condition. In short, ES adds

consistent training conditions (reproducible intervention, recruitment of all muscle fiber types, and regulation at supraspinal levels). When applied to the dyskinetic scapula it provides a non-volitional, repositioning of the scapula, prior, to the patient performing targeted exercise.

The purpose of this pilot study was to compare scapular position after performance of three low UT/LT ratio therapeutic exercises in two conditions, electrical stimulation (ESTherex) and sham electrical stimulation (ShamTherex) in asymptomatic persons who were positive for scapular dyskinesis.

It was hypothesized that the addition of electrical stimulation to the lower trapezius during low UT/LT ratio therapeutic exercise would produce a greater change in scapular to spine measurements compared to sham electrical stimulation condition during the same low UT/LT ratio exercises.

METHODS

Subjects

Subjects were recruited from a sample of convenience comprised of student volunteers recruited from the Department of Physical Therapy at Fresno State University. Subject recruitment included students with any of the following: scapular winging, excessive scapular motion or prominent scapulae. Inclusion criteria included: aged 18 to 35 years with a positive Scapular Dyskinesis Test (SDT). Positive SDT tests were noted by winging or medial border prominence noted visually at rest, lack of smooth coordinated movement (early scapular elevation or shrugging while raising the arm into forward flexion, and/or rapid downward scapular rotation during arm lowering from full flexion). The motion was characterized as dyskinesis as “yes” (presence of deviation or dysrhythmia/asymmetry) or “no” (no dyskinesis)⁴⁷ by an orthopedic certified specialist physical therapist with twenty-six years of clinical experience. The subjects were assessed for visual winging of the scapula at rest and during active flexion and abduction following completion of an intake questionnaire.

Subjects meeting any of the following criteria were excluded: non-intact skin or rash in the electrode area, impaired sensation, impaired cognition, ballistic movements, spastic movements, rheumatoid

arthritis, osteoporosis, osteoarthritis, fever, flu-like symptoms, current infection, pregnancy, scoliosis, cancer, thoracic outlet syndrome, myelopathy, diagnosis of fibromyalgia, evidence of any upper quadrant orthopedic cervical disorder or pathology, central nervous system involvement, cervical stenosis, cervical thoracic surgery, chronic migraines, fracture, past or current use of corticosteroids. Exclusion criteria were based on an interview and intake questionnaire review by principal investigators. All subjects provided informed consent before participation. The Department Review Board of Fresno State University in Fresno California approved the study. Eleven subjects representing fifteen scapulae were randomized into ESTherex or ShamTherex group.

Measurement Procedures

Thoracic spinous process (between T7-T10)⁴⁸ to inferior scapular angle distance was measured with the arm positioned at varying degrees of shoulder abduction, (0, 45, 90, and 120), in standing. Pre-data collection, intra-rater reliability for the manual measures was established ($r = .60$).

During the manual measurement, the patient stood facing a wall mounted large diagrammed goniometer. A surgical marker was used to mark the center of rotation at the glenohumeral joint as assessed by two physical therapists. The blinded physical therapist (OCS with 26 years of experience) provided palpation of bony landmarks (kneeling/head down position) while a second physical therapist passively placed the subjects arm in the correct position (abduction with external rotation) so that it was aligned with either the 45, 90, or 120 degree marking on the wall goniometer and the subject actively held the arm once aligned correctly with corresponding angle on the wall goniometer. A trained Doctor of Physical Therapy (DPT) student recorded the tape measured SSD distance. The measurement readings were unknown to the orthopedic certified specialist physical therapist who palpated the bony landmarks. Measurements were taken at the beginning of week 1, and the end of weeks 2 and 3.

Exercise: Protocol and Subject Education

The number of treatments, in addition to repetitions and sets of exercises chosen, are those seen in

usual care outpatient physical therapy settings (2x per week, 3-week duration). Three exercises were selected. The exercises included side lying external rotation at 90 degrees (with a towel roll under the distal humerus), side lying forward flexion from 90 degrees to nose-level (at 120-130 degrees of flexion), prone horizontal abduction with external rotation at 90 degrees abduction (Figures 1-3).

The ESTherex group received ES to the lower trapezius triggered by a second physical therapist (with 20 years of experience teaching electrotherapeutics at Fresno State University), using a remote trigger switch to coordinate the ES immediately prior to the patient initiated movement. In order to ascer-



Figure 3. *Prone horizontal abduction with electrical stimulation to the lower trapezius*

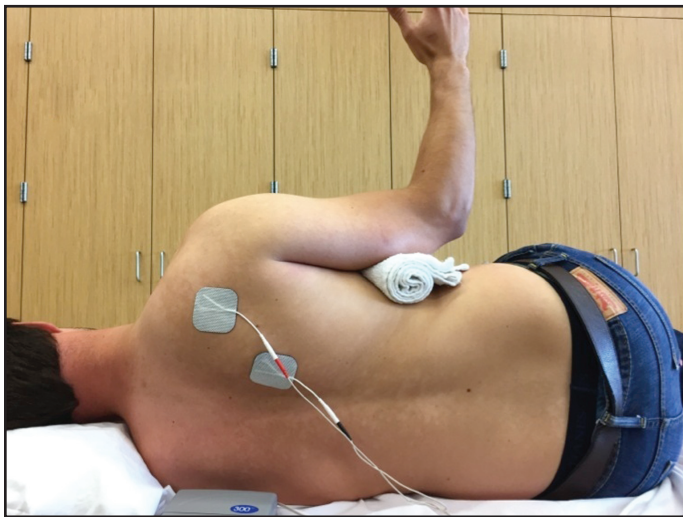


Figure 1. *Sidelying shoulder external rotation with electrical stimulation to the lower trapezius*



Figure 2. *Sidelying shoulder flexion with electrical stimulation to the lower trapezius*

tain optimal scapular retraction and depression from electrical stimulation, the subject's arm was placed in a manual muscle test position for the LT and given slight resistance so lower trapezius fibers were visualized for proper electrode placement.⁴⁹ The electrode placement was slightly adjusted until the optimal scapular retraction and depression was obtained. Once the desired electrode placement was established, the electrode was outlined with a surgical marker for reproducibility between exercise sessions. The frequency and pulse width were 30pps and 250usec respectively. A pulse with of 250usec was used to guarantee a fused muscle contraction (however not a strengthening contraction). Rates greater than 30pps were not used to avoid any signs of muscle fatigability. The intensity was set high enough to produce visible scapular pull with appropriate scapular retraction and depression combined. Once set, the intensity was not changed between treatment sessions. The intensity within the intervention group varied between 23 milliamps (mA) and 29 mA. Stimulation intensity was recorded and reproduced on each subsequent treatment session. The comfort of all contractions was confirmed by the subject's verbal approval. The ESTherex group performed the three exercises with ES. Each exercise was performed three sets of 15 repetitions with a one-minute rest between exercise repetitions. The electrical stimulation was used during clinic exercise sessions only. A biphasic-pulsatile current was used.

The ShamTherex groups received no ES. The machine was turned on only to show the lights change when the remote trigger was pressed. As with the intervention group, the ShamTherex group also received sham ES via remote trigger application by a physical therapist, beginning just prior to patient initiated movement and stopping with cessation of patient voluntary movement.

One educational session, for exercise program instruction and practice, was provided to both groups, prior to beginning the exercise protocol. Participants received home exercise program (HEP) handouts that included pictures of the three exercises and written instructions. Participants also received HEP logs to record HEP compliance. Participants were instructed to perform all exercises at home in the same manner as performed during the intervention sessions (3x15) without the addition of resistance. Both groups were seen for two treatments per week for three weeks after the initial assessment and set-up visit, for a total of 7 sessions. Participants completed exercise logs during the 3-week treatment duration, and provided a self-report of exercise compliance. All participants reported compliance with the HEP (performed 2 additional days outside of the treatment sessions). All but two HEP logs were maintained by participants, and turned in at the end of the treatment trial. The missing two HEP logs were from participants in the ShamTherex group. Two physical therapists performed all interventions with one DPT student to assist set-up and recording of data.

RESULTS

With regard to between group comparisons, spine to scapula distance was assessed in 15 scapulae to compare ESTherex to ShamTherex. Independent t-tests indicated no significant differences in spine to scapula distance between ESTherex and ShamTherex at 0, 45, 90 and 120 degrees of standing shoulder abduction at the end of the six treatment sessions (Table 1). Independent t-tests comparing post-mean differences (ESTherex and ShamTherex) approached a statistically significant difference at 45 ($p = .089$, $CI = -.152$ to 1.88 cm) with the post mean measurement of the ShamTherex group (6.44 cm) greater than the post mean measurement of the ESTherex group (5.57 cm) (Table 2).

Table 1. Group Statistics: ShamTherex and ESTherex

Shoulder Abduction Angle	Group	N	Mean (cm) ^a
Pre0	ShamTherex	8	6.1375
	ESTherex	7	5.4714
Post0	ShamTherex	8	6.2500
	ESTherex	7	5.5.000
Pre45	ShamTherex	8	6.3875
	ESTherex	7	5.4857
Post45	ShamTherex	8	6.4375
	ESTherex	7	5.5714
Pre90	ShamTherex	8	7.6625
	ESTherex	7	7.1429
Post90	ShamTherex	8	6.4125
	ESTherex	7	6.9286
Pre120	ShamTherex	8	8.4375
	ESTherex	7	10.171
Post120	ShamTherex	8	6.9625
	ESTherex	7	7.4143
^a Inferior medial scapular angle to spine distance (at T7-T10) in centimeters			

For purposes of a learning effect, within group differences were also analyzed. A trend was noted within the ShamTherex and ESTherex groups at 0 and 45 degrees when compared to trends seen within each group at 90 and 120 degrees. In other words, the higher abduction angles (90 and 120) showed closer mean spine to scapula distance compared to the lower angles (0 and 45). At 0 and 45 degrees both the ShamTherex and ESTherex spine to scapula mean SSD scores were larger (further from the spine). A similar trend was noted in the mean scores within the ShamTherex group and the ESTherex group at 90 and 120 with the mean score differences being lower in both conditions at the greater abduction angle. Of significance is the pre-post within group difference of the ESTherex group at 120 degrees of abduction. At 120 degrees of abduction, despite the small sample size, there was a statistically significant decrease in means pre-measurement to post-measurement at 120 for the ESTherex group (mean 2.76 cm, $t = 4.89$, $p = .003$) (Table 3). This is even more important to note because the ShamTherex group started with 1.73 cm less spine to scapula distance (better positioning) than the ESTherex group at 120 degrees (ShamTherex 8.44 cm and 6.96 cm, ESTherex 10.17 cm and 7.41 cm) (Tables 3 and 4). Although there was not a significant difference in between group, post-test measures, the within group pre-to-post mean changes of the ESTherex group (measured by SSD distances, as an

Table 2. *Independent Samples Test ESTherex and ShamTherex Post Mean Differences*

<u>Shoulder Angle</u>	t-test for Equality of Means^a				95% Confidence Interval of the Difference	
	t	2 –tailed	Mean Difference	Std. Error	Lower	Upper
Pre0	1.034	.320	.66607	.64439	-.7270	2.058
Post 0	1.517	.153	.75000	.49434	-.3179	1.812
Pre 45	1.289	.220	.90179	.69935	-.6091	2.413
Post 45	1.838	.089	.86607	.47114	-.1518	1.884
Pre 90	.639	.534	.51964	.81271	-1.236	2.275
Post 90	-.902	.383	-.51607	.57207	-1.752	.7198
Pre 120	-1.451	.171	-1.7339	1.1951	-4.316	.8478
Post 120	-.625	.543	-.45179	.72239	-2.012	1.109

^a Inferior medial scapular angle to spine distance (T7-T10) in centimeters
 Note: No statistically significant difference between ESTherex (intervention) & ShamTherex (control) group scapula to spine distance (SSD) in centimeters.

Table 3. *Paired Samples T Test ESTherex (post mean scores)*

Pair No.	Pair angle	Mean	95% Confidence Interval of the Difference		t	Sig (t-tailed)
Pair 1	pre0-post0	-.0286	-1.115	1.057	-.064	.951
Pair 2	pre45-post45	-.0857	-1.003	.8321	-.229	.827
Pair 3	pre90-post90	.2143	-.9475	1.376	.451	.668
Pair 4	pre120-post120	2.757	1.376	4.138	4.88	.003*

*Statistically significant difference in pre-measurement to post-measurement within group SSD means

Table 4. *Paired Samples T Test ShamTherex (post mean scores)*

Pair No.	Pair angle	Mean	t	Sig (t-tailed)
Pair 1	Pre0-post0	-.11250	-.348	.738
Pair 2	Pre45-post45	-.05000	-.101	.922
Pair 3	Pre90-post90	1.2500	1.754	.123
Pair 4	Pre120-post120	1.4750	2.220	.062

indicator of greater scapular excursion) exceeded that of the ShamTherex group. Although the ESTherex group initially started with more scapular excursion compared to the ShamTherex group at the same angle, their within group change was significant even though their scapular position started with more excursion than the ShamTherex group at 120.

DISCUSSION

No statistically significant between group difference was found between the ESTherex and ShamTherex group in SSD at different degrees of standing shoulder abduction. There was significant spine to scapula change in distance in the ESTherex group at 120 pre-measurement to final post-treatment measurement. Of note, the pre-measurement of 120,

the ESTherex scapula to spine distance was further from the spine in comparison to the ShamTherex group, although the difference was not statistically significant. The significant within group effect for the ESTherex group demonstrates a sustained scapular reposition (measurements taken after ES completed). This finding may reflect the improvement in resting muscle state associated with the addition of electrical stimulation to voluntary drive.^{49,50} The same within group effect was not seen in the ShamTherex group. In order to understand the meaning of this within group effect, it will be necessary in subsequent studies to not only look at SSD change but to add clinical measures for pain and function in clients with shoulder pain in the presence of dyskinesia, in order to truly understand

the implication of a SSD change. However, because these subjects were positive for dyskinesia but not symptomatic for pain, this could not be assessed during this pilot study.

The absence of a between group effect may be explained by low power in this small pilot sample. Because the intervention specifically addressed LT activation via the addition of ES, the finding that the ESTherex group showed the most improvement at 120 degrees (when the lower trapezius would be most active) may indicate a change in motor pattern. However, this cannot be construed from the one significant outcome of this limited sample population. While both groups (ESTherex and ShamTherex) did not show improvements at 0 and 45, within group changes in SSD were observed from initial to final measurement at 90 and 120; although the finding at 90 degrees was not statistically significant. This is consistent with typical firing patterns seen in the lower trapezius.

The other finding that may be notable and will require further research, is the between group statistic at 45 degrees of abduction ($p = 0.089$). This finding at 45 degrees abduction, although not significant, in spite of the small sample size, may suggest an improvement in the starting position of the scapula for the ESTherex group. Borsa et al. reported that the scapula downwardly rotates prior to humeral elevation 0 to 30 degrees.⁵¹ Since all scapulae in the study were dyskinetic, a larger sample may change this non-significant observation and answer the question regarding scapular set position prior to elevation in dyskinetic scapulae.

Another important consideration is firing behavior of the LT. Lower trapezius firing is greatest between humeral elevation angles 90 and 120 degrees, with the largest demand at 120 of elevation.⁵² In fact, that is what is noted for the within groups' mean changes observed at 90 and 120, when increased LT activation would start to affect scapular excursion. The greatest mean difference was seen in the ESTherex group at 120. Based on this, a few things may be occurring. At the most demanding LT position (120), the scapula showed the greatest gains in excursion differences with the addition of ES cueing. This was not the case again, for the ShamTherex group (ESTherex 2.76 cm, ShamTherex -1.51 cm). In the case of scapular dyski-

nesis, as a result of the dis-coordinated recruitment of UT to LT firing, the addition of ES to a targeted exercise program may result in less LT hypoactivity. Although it is important to note that at this time, this idea is only conjecture.

The benefit of adding ES to the LT as an adjunct to three low UT/LT exercises may be multifaceted. Electrical stimulation assists in repositioning of the scapula, ES non-selectively recruits all muscle fiber subtypes,⁴⁴ and ES demonstrates positive effects on M1 cortical levels when combined with voluntary muscle contraction.⁴¹

In this study, investigators observed repositioning of the scapula (increased retraction and depression) as a result of ES cueing. Repositioning of the scapula creates a change in length of the scapular muscles that more closely resembles a non-dyskinetic scapula. This repositioning effect would be applicable for example, in cases such as an elongated LT combined with a shortened pectoralis minor muscle as is seen in scapular protraction. Electrical stimulation facilitated repositioning of the scapula (improved retraction and depression) places the LT and pectoralis minor in a position that more closely approximates non-dyskinetic scapula (in the absence of contraction), compared to scapular protraction alone. This change in position may artificially restore the normal length tension relationships of adjacent soft tissues. Normal length of the scapular muscles can improve the timing of muscle firing, resulting in improved quality of movement, and addresses one aspect of the Scapular Algorithm as proposed by Cools et al,⁵³ in the treatment of scapular dyskinesis. Additionally, scapular repositioning can create a change in the position of the glenohumeral joint.¹¹ A change in glenohumeral position will change the soft tissue relationships of the peri-glenoid muscles and ligaments, and in addition, positively affect the scapular muscles.

Electrical stimulation provides a non-selective, synchronous recruitment of muscle fibers that recruits a greater number of muscle fibers than voluntary muscle contraction alone.^{30,31,42} Electrical stimulation recruits all muscle fiber subtypes (type I, IIa, IIx/d, IIb)^{44,49} including oxidative Type I muscle fibers (SSFR) normally recruited in activities of daily

living. If in the case of disuse related dyskinesia, it is the oxidative subtype of muscle fiber that is atrophied, then hypothetically exercise alone should adequately address the muscle fiber imbalance. However, selectivity for muscle atrophy remains a mystery^{28,44} therefore in the absence of understanding the etiology of the disuse, ES may be an essential addition to a comprehensive rehabilitation program.

In addition to possibly reestablishing muscle fiber balance between SSFR fibers and FFF fibers, ES provides input to Type II (FFF) fibers in a standardized and reproducible manner. This type of facilitation is unattainable by conventional physical therapy facilitation techniques alone. When disuse atrophy from aging or disease results in the loss of FFF fibers, ES can assist with the restoration of muscle fiber loss without requiring high levels of exercise or ES induced maximal muscle contractions that can be painful and are likely unachievable in some patients. Not only does ES provide a more complete muscle fiber recruitment; it minimizes practitioner imposed variability by providing a consistent replicable cue. Electrical stimulation produces a highly reproducible positional change of the scapula (with respect to spine to scapular border distance) as a new reference point, which may facilitate improved coordination of upper, middle, and lower trapezius muscle recruitment.

Lower trapezius firing at humeral elevation angles less than 30 degrees of abduction is minimal.² In the case of dyskinesia, the potential exists for LT firing at angles less than 30 degrees when setting of the scapula should occur. Premature muscle firing may represent a premature activation of adjacent scapular muscles. Electrical stimulation to the LT at the initiation of shoulder flexion at 90 degrees in sidelying and prone, provides a correctly timed motor cue to the LT to facilitate accurate muscle firing. It is likely that this could carry over into functional positions. Of note, all subjects in the intervention group stated that their scapula felt different after electrical stimulation. No subjects in the control group reported a different feeling in the scapula at any time during the treatment protocol. The participant descriptor word, "different", was in response to the question posed to all participants at the beginning of each treatment session, "how do you feel?" (asked at the same time HEP logs were checked). Premature firing of the LT (during

the scapula setting phase) in dyskinetic scapulae may provide one plausible explanation for the approaching significance between groups at 45 degrees abduction.

Visual inspection of the scapula is a clinically relevant method for assessing scapular dyskinesia.^{8,47,54,55} Interestingly however, consistent assessment of the scapula for dyskinesia may not be incorporated into typical physical therapy assessment of the upper quarter. Screening for dyskinesia requires no equipment and can be performed in less than one minute.

LIMITATIONS

The following limitations are noted in this research. This pilot addresses only scapular position as affected by ES of the LT in patients with scapular dyskinesia. It is the recommendation of the authors that continued ES studies should also explore serratus anterior recruitment and/or timing deficits. Second, the use of inferior medial scapular angle to thoracic spinous process distance (SSD), as a predictor of scapular dyskinesia, is an imprecise and overly simplified psychometric that utilizes frontal plane distance to describe impairments that occur in three planes. It is an overly simplified, but clinically useful psychometric to describe static and dynamic positioning of the scapula. SSD was chosen in an attempt to incorporate a tool that is accessible and efficient to administer in busy outpatient settings. The investigators made the assumption that decreased scapula-spine distance indicates less scapular dyskinesia. In the presence of shortened middle trapezius, rhomboid, or levator scapulae muscles, the inferior angle to spinous process distance may also be decreased. Of additional consideration was the limited number of scapulae assessed in this pilot study. Further research with larger and more diverse samples is indicated.

CONCLUSIONS

No statistically significant between group difference was found between the ESTherex and ShamTherex group in SSD at various degrees of shoulder abduction. The significant within group SSD change pre to final post treatment measurement in the ESTherex group at 120 degrees is promising. This finding supports the continued exploration of the effect of ES to the LT combined with low UT/LT ratio exercises in persons with scapular dyskinesia and an increased SSD.

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