Shoulder Taping and Neuromuscular Control

Suzanne J. Snodgrass, PhD, PT, AT Ret*; Scott F. Farrell, PhD, PT*†; Henry Tsao, PhD, MBBS‡; Peter G. Osmotherly, PhD, PT, MMedSci*; Darren A. Rivett, PhD, PT, MAppSci*; Lucy S. Chipchase, PhD, PT, MAppSci§; Siobhan M. Schabrun, PhD, PT§

*School of Health Sciences, University of Newcastle, Callaghan, Australia; †RECOVER Injury Research Centre, Menzies Health Institute Queensland, Griffith University Gold Coast Campus, Southport, Australia; ‡Emergency Department, Caboolture Hospital, Australia; §Brain Rehabilitation and Neuroplasticity Unit, Western Sydney University, Campbelltown, Australia

Context: Scapular taping can offer clinical benefit to some patients with shoulder pain; however, the underlying mechanisms are unclear. Understanding these mechanisms may guide the development of treatment strategies for managing neuromusculoskeletal shoulder conditions.

Objective: To examine the mechanisms underpinning the benefits of scapular taping.

Design: Descriptive laboratory study.

Setting: University laboratory.

Patients or Other Participants: A total of 15 individuals (8 men, 7 women; age = 31.0 ± 12.4 years, height = 170.9 ± 7.6 cm, mass = 73.8 ± 14.4 kg) with no history of shoulder pain.

Intervention(s): Scapular taping.

Main Outcome Measure(s): Surface electromyography (EMG) was used to assess the (1) magnitude and onset of contraction of the upper trapezius (UT), lower trapezius (LT), and serratus anterior relative to the contraction of the middle deltoid during active shoulder flexion and abduction and (2) corticomotor excitability (amplitude of motor-evoked potentials from transcranial magnetic stimulation) of these muscles at rest and during isometric abduction. Active shoulder-flexion and shoulder-abduction range of motion were also evaluated. All outcomes were measured before taping, immediately after taping, 24 hours after taping with the original tape on, and 24 hours after taping with the tape removed.

Results: Onset of contractions occurred earlier immediately after taping than before taping during abduction for the UT (34.18 ± 118.91 milliseconds and 93.95 ± 106.33 milliseconds, respectively, after middle deltoid contraction; $P = .02$) and during flexion for the LT (110.02 ± 109.83 milliseconds and 5.94 ± 92.35 milliseconds, respectively, before middle deltoid contraction; $P = .06$). These changes were not maintained 24 hours after taping. Mean motor-evoked potential onset of the middle deltoid was earlier at 24 hours after taping (tape on = 7.20 ± 4.33 milliseconds) than before taping (8.71 ± 5.24 milliseconds, $P = .008$). We observed no differences in peak root mean square EMG activity or corticomotor excitability of the scapular muscles among any time frames.

Conclusions: Scapular taping was associated with the earlier onset of UT and LT contractions during shoulder abduction and flexion, respectively. Altered corticomotor excitability did not underpin earlier EMG onsets of activity after taping in this sample. Our findings suggested that the optimal time to engage in rehabilitative exercises to facilitate onset of trapezius contractions during shoulder movements may be immediately after tape application.

Key Words: scapula, transcranial magnetic stimulation, electromyography, physical therapy techniques, rehabilitation, shoulder pain, muscle contraction

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Key Points

- Applying therapeutic tape led to the earlier onset of upper and lower trapezius muscle contractions during shoulder-abduction and -flexion tasks, respectively, in a population without shoulder pain.
- Increased shoulder-abduction range of motion immediately after taping may have been related to facilitating upward rotation of the scapula through earlier contraction of the upper trapezius.
- Given that changes in timing and range of motion were not maintained at 24 hours after taping, clinicians should consider combining scapular taping with other interventions to manage shoulder pain.
- The mechanisms underpinning these changes may be related to neuromuscular or noncortical neurologic processes rather than altered corticomotor activity.

Shoulder pain is a common problem, with the estimated 1-month prevalence in the general adult population ranging between 18% and 31%.[1] Impeded neuromuscular control of the scapulothoracic articulation is associated with common musculoskeletal shoulder conditions, such as subacromial rotator cuff impingement and rotator cuff tendinopathy.[2–6] Researchers[7,8] have noted

that the onset of scapular muscle activity occurs before upper extremity movement to stabilize and position the scapula for glenohumeral elevation; however, as Struyf et al[9] observed in their systematic review, individuals with musculoskeletal shoulder conditions demonstrated variations in scapular muscle activation and timing. Therefore, conservative approaches for shoulder conditions usually

include interventions designed to restore normal neuro-muscular control of the scapulothoracic articulation and often incorporate therapeutic exercise and physical modalities, such as therapeutic taping.[10–12] Evidence that scapular kinematics influence shoulder function supports this concept.[13] For example, decreased lower trapezius (LT) activity has been demonstrated after shoulder injury, and altered scapular kinematics have been seen in individuals with a wide range of shoulder conditions.[14,15] Therefore, neuromuscular control is thought to be an important contributor to shoulder and scapular kinematics.[16] However, the mechanisms underpinning interventions intended to alter the neuromuscular control of the scapulothoracic articulation have not been well studied. Understanding these mechanisms would support the development of novel interventions to address neuromuscular control of the scapula and shoulder.

Taping is a modality that athletic trainers, physical therapists, and other health care and sports professionals use for injury prevention and rehabilitation.[17] Clinicians typically apply tape to mechanically restrict undesired joint motion while permitting, or even facilitating, desired movement. A therapeutic benefit related to proprioception through increased tactile input has been proposed as another mechanism of action.[18] Two main variations of tape are available for clinical use: standard athletic tape (rigid adhesive tape applied over a joint to provide biomechanical support[17]) and elastic tape (stretchable adhesive tape, such as Kinesio Tape [Kinesio Holding Corp, Albuquerque, NM] or Dynamic Tape [PosturePals Pty Ltd, Port Vila, Vanuatu][19]).

Therapeutic taping techniques have demonstrated short-term clinical effectiveness in managing some musculoskeletal shoulder conditions, including improved pain[11,20–22] and coordination of scapular muscles.[6,23,24] For example, decreased upper trapezius (UT) and increased LT activity were observed in individuals with shoulder-impingement syndrome after rigid tape was applied perpendicular to the muscle fibers to inhibit the UT.[24] After similar taping using Kinesio Tape, Lin et al[25] demonstrated increased serratus anterior (SA) and decreased UT muscle activity and improved proprioception in healthy individuals. These findings may suggest changes in kinematic variables or neuromuscular control, including centrally mediated changes.[26,27] However, the mechanisms underpinning the benefits of tape are not well understood.[10,11,26,28]

Neuroplastic changes have been shown in individuals with shoulder pain and pathologic conditions. Individuals with rotator cuff conditions have exhibited decreased corticomotor excitability in the infraspinatus muscle.[29] Patients with shoulder instability had a decreased and delayed corticospinal response in the UT.[3] The extent of the contribution of these neuroplastic changes to the kinematic and neuromuscular control of the scapula and shoulder is unknown. If existing interventions aimed at altering neuromuscular control, such as taping, address such changes, this may provide a possible reason for their effectiveness. A better understanding of the kinematic and neuroplastic mechanisms underlying shoulder taping may contribute to improved intervention strategies using tape.

Therefore, the purpose of our study was to investigate the mechanisms underlying the benefits of shoulder taping. Specifically, we aimed to (1) investigate changes in the timing and amplitude of scapular muscle contraction during upper extremity flexion and abduction and (2) determine changes in the corticomotor excitability of the scapular and middle deltoid (MD) muscles after applying tape to the shoulder that is designed to facilitate muscle contractions in the targeted scapular muscles. Given that the taping protocol may have facilitated increased shoulder-flexion and shoulder-abduction joint range of motion (ROM), we also sought to determine whether the taping protocol facilitated or increased ROM for shoulder flexion or abduction. We hypothesized that the onset of scapular muscle contraction would be earlier in relation to the onset of the MD contraction after tape application and that corticomotor excitability (scapular and MD muscles) and joint ROM (shoulder flexion and abduction) would increase.

METHODS

Participants

Fifteen healthy volunteers (8 men, 7 women; age = 31.0 ± 12.4 years, height = 170.9 ± 7.6 cm, mass = 73.8 ± 14.4 kg) participated in this study. All participants self-reported right-hand dominance. Volunteers were eligible for inclusion if they had no history of musculoskeletal shoulder pain or trauma. Using a screening questionnaire devised by Rossi et al,[30,31] we excluded volunteers with any contraindications to single-pulse transcranial magnetic stimulation (TMS). Specifically, recruits were excluded if they had a history of epilepsy or seizures, metal implants in the brain or skull, a cardiac pacemaker, or previous neurosurgery; were pregnant; or were taking medications that could have lowered their seizure threshold. All participants provided written informed consent, and the study was approved by the Human Research Ethics Committee of Western Sydney University (H10184) and the University of Newcastle Human Research Ethics Committee as collaborative research.

Protocol

Electromyography. We used surface electromyography (EMG) to measure the myoelectric activity of the shoulder muscles because it can capture the summation of motor units activated by corticomotor stimulation during TMS, resulting in a smooth motor-evoked potential (MEP) trace that can be easily quantified.[32] Therefore, we also used surface EMG to assess the magnitude and timing of muscle contractions during active movements. After skin preparation, paired Ag/AgCl surface electrodes (dual electrodes no. 272; Noraxon Inc, Scottsdale, AZ) with a diameter of 1 cm and interelectrode distance of 1.75 cm were applied to each participant in the standing position. Electrodes were placed over the muscle bellies of the UT, LT, SA, and MD of the dominant extremity. The location of each muscle was determined through palpating active contractions by 1 researcher (S.J.S.) and verified by another physical therapist researcher (S.F.F.). A ground electrode (Red Dot adult solid-gel soft cloth diaphoretic electrode; 3M Healthcare, St Paul, MN) was placed over the bony prominence of the C7 spinous process. The EMG signals were amplified 2000 times (NL844 4-channel remote pre-amplifier; Digitimer Ltd, Hertfordshire, United Kingdom), band-pass filtered

between 20 and 1000 Hz, and sampled at 2000 Hz using a Micro1401 Data Acquisition System with Signal software (version 5; Cambridge Electronic Design, Cambridge, United Kingdom) and Spike2 software (version 7; Cambridge Electronic Design). After 3 practice repetitions of the test movement, EMG data were collected during 10 repetitions of full-range active shoulder flexion and abduction performed by the participant under the direction of a researcher (S.J.S.) using standardized oral commands.

We imported the EMG data into MATLAB (version R2013b; The MathWorks, Natick, MA) for analysis. All EMG data were full-wave rectified, and the electrocardiogram data were removed from the EMG data using a modified turning-point filter.[13] For muscle responses during active upper extremity movement, *EMG onset* (in milliseconds) was visually identified as the earliest EMG activity discernible from background activity. Visual identification of onsets is valid and is less affected by such factors as increased background activity.[32] We calculated the EMG onset of all shoulder muscles relative to that of the prime-mover MD. *Peak EMG* was defined by the root mean square (RMS) calculated at −0.5 to 0.5 seconds surrounding the point of peak activity. We calculated these data for each of the 10 repetitions of upper extremity movement and used the mean for further analysis.

Transcranial Magnetic Stimulation. Corticomotor excitability was measured using single-pulse TMS (model 200; The Magstim Co, Carmarthenshire, United Kingdom). Each participant was seated for the procedure. Stimulation was undertaken using a 9-cm figure-8 coil applied 4 cm lateral to the vertex of the head on the side contralateral to the shoulder being examined, as described by Alexander et al.[33] We marked this location on the scalp with a pen and remeasured and marked it at the beginning of the second day of testing.

We evaluated corticomotor excitability by constructing a recruitment curve with the amplitude of MEPs (ie, the electrical signals after stimulation of the motor pathways within the brain) measured across stimulation intensities at each 10% interval between 40% and 80% of maximum stimulator output. Five pulses were delivered at each stimulation intensity, with an interstimulus interval of 5 seconds. The TMS was applied at rest and during active shoulder abduction with the upper extremity held isometrically in a static position at 40°. For the active condition, participants remained seated and actively moved the extremity into 40° of abduction. To ensure that participants recognized when they reached 40° of abduction, we positioned a bar that the forearm would touch when it reached 40°. A TMS pulse was delivered while participants held the extremity in this position; participants were then instructed to relax the extremity at their side. We recorded MEPs from the MD, SA, UT, and LT through the electrodes applied for the EMG protocol.

Variables determined from MEPs were (1) *MEP magnitude*, which was defined by the RMS of the EMG signal recorded between onset and offset of the MEP after cortical stimulation and normalized to the peak RMS across all trials at all signal intensities; (2) *onset of the MEP*, which was defined as the time in milliseconds between cortical stimulation and the initial increase in EMG signal; (3) *offset of the MEP*, which was defined as the time in milliseconds from cortical stimulation to the point at which

the EMG signal decreased to the pretaping value or below; and (4) *silent period* (SP), which was defined as the time in milliseconds from the offset of the MEP to the point when background muscle activity resumed. The SP was measured only during the active condition.

To assess these variables, we imported TMS EMG data into MATLAB for analysis. The onset and offset of the MEP and the offset of the SP were identified visually when they were clearly discernible from background EMG activity.[14] To remove any potential for bias, data were presented in random order without reference to the identity of the muscle or trial repetition. The RMS EMG of the MEPs (from onset to offset) was calculated, normalized to the peak response across trials, and plotted as a recruitment curve against the stimulator intensity. The background EMG activity for each trial was calculated as the amplitude of RMS EMG from 55 to 5 milliseconds before stimulation. When no MEP was clearly discernible, the background EMG activity was analyzed in place of MEP RMS data in accordance with Tsao et al.[34] One investigator (S.F.F.) analyzed all EMG data, and another investigator (S.J.S.) repeated the analysis of 2 participants to determine reliability.

Range of Motion. We measured ROM for shoulder flexion and abduction using a 12-in (30.48-cm), plastic, 360° universal goniometer (Baseline, White Plains, NY) with the participant standing. The aim was to determine if the taping protocol facilitated or increased ROM for shoulder flexion or abduction. For flexion, we placed the goniometer axis over the lateral aspect of the center of the humeral head; the stationary goniometer arm parallel to the lateral midline of the trunk, maintaining alignment with the trunk rather than the vertical axis when thoracic extension occurred during shoulder flexion; and the movable arm parallel to the longitudinal axis of the humerus in accordance with Clarkson.[35] For abduction, we placed the goniometer axis at the midpoint of the anterior aspect of the glenohumeral joint, the stationary goniometer arm parallel to the anterior midline of the trunk, and the movable arm parallel to the longitudinal axis of the humerus.[35] Measurements were made by 1 examiner (S.J.S.) for all participants to maximize repeatability.

Experiment. Each participant attended 2 testing sessions approximately 24 hours apart (no less than 20 hours and no more than 26 hours). In each session, the previously described outcomes were measured: surface EMG during active shoulder flexion and abduction, TMS of the motor cortex of the upper limb at rest and during active shoulder abduction, and shoulder-flexion and shoulder-abduction ROM. These outcomes were measured at 4 time points in the study protocol: before application of tape (pretaping), immediately after application of tape (after taping) in the first testing session, and 24 hours after application of tape with the tape on and then with the tape removed in the second testing session.

Rigid athletic tape (Leukotape; BSN Medical, Hamburg, Germany) was applied to the participant's shoulder by an experienced sports physical therapist and former athletic trainer (S.J.S.) using a technique consistent with that described by McConnell and McIntosh[36] and McConnell et al[37] (Figure 1). The skin was prepared with adhesive spray (Tensospray; BSN Medical) and undertape (Fixomull; BSN Medical). The physical therapist applied the tape starting

Table 1. Comparisons of the Onsets of Scapular Muscle to Middle Deltoid Contractions During Active Shoulder Flexion Before and After Taping Extended on Next Page

| | Electromyographic Onset in Relation to Middle Deltoid Contraction Onset, milliseconds, Mean ± SD | | | | Repeated-Measures Analysis of Variance | | |
| | Taping | | 24 h After Taping | | | | |
Muscle	Before	After	Tape On	Tape Removed	F	P	Partial η²
Upper trapezius	−80.24 ± 104.22	−162.70 ± 132.02	−85.66 ± 79.83	−78.11 ± 110.28	4.234	.01	0.232
Lower trapezius	−5.94 ± 92.35	−110.02 ± 109.83	−51.35 ± 86.77	−27.43 ± 102.98	3.935	.02	0.219
Serratus anterior	−130.18 ± 133.07	−139.09 ± 164.93	−153.31 ± 134.49	−153.51 ± 107.84	0.401	.68	0.030

Abbreviation: CI, confidence interval.

ᵃ Positive values for mean differences indicate an earlier relative onset for the muscle compared with before taping.

from the anterior aspect of the humeral head just lateral to the acromion process and exerted manual force to upwardly (laterally) rotate the scapula while securing the other end of the tape over the inferior angle of the scapula. This direction of tension of the tape was applied to retract the humeral head and upwardly rotate the scapula. It aimed to facilitate contraction of the LT and UT and potentially the SA.
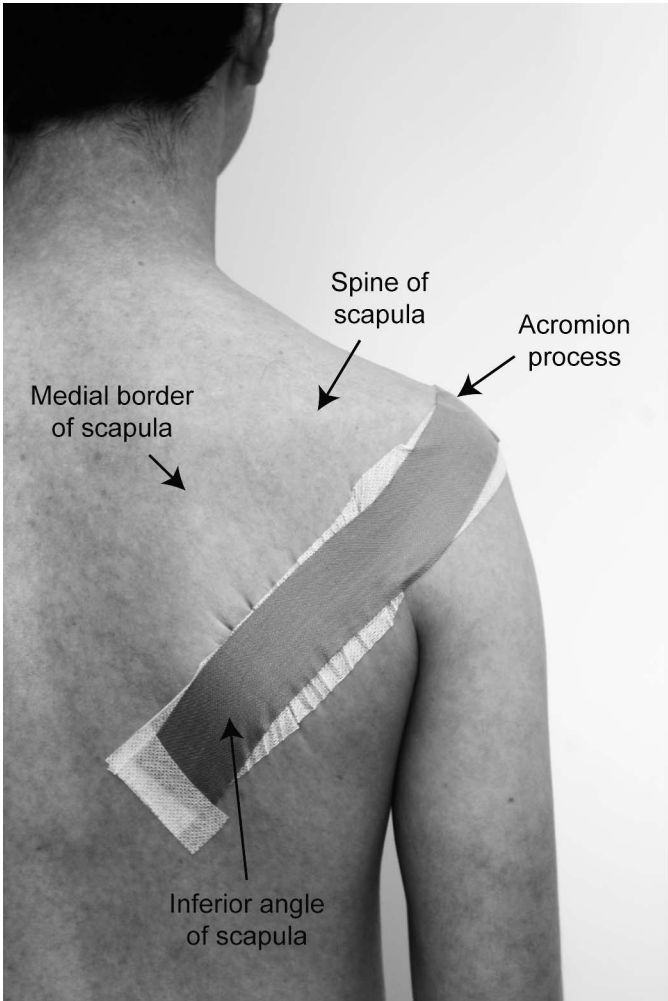

Figure 1. Application of rigid athletic tape to scapula consistent with the technique described by McConnell and McIntosh[36] and McConnell et al.[37]

Statistical Analysis

We used intraclass correlation coefficients (2,1) to determine the interrater reliability of the EMG data analysis for the following outcome measures: EMG onset and peak RMS during active movement and MEP RMS, onset, offset, and SP duration. The EMG, MEP, and ROM measures among times were compared using repeated-measures analyses of variance (ANOVAs) with post hoc Bonferroni corrections for multiple comparisons. The within-subject factor was time (before taping, immediately after taping, 24 hours after taping with tape on, and 24 hours after taping with tape removed). Separate ANOVAs were calculated for each variable (EMG magnitude [peak RMS] and onset during active shoulder movement [flexion and abduction]; MEP measures [RMS, onset, and SP duration]; and goniometric ROM). When the Mauchley test of sphericity was violated, the Greenhouse-Geisser corrected values were reported. Partial η² was provided for each repeated-measures ANOVA to indicate the size of the effects of the differences across times. We supplied the Cohen d for post hoc pairwise comparisons to indicate the effect sizes of the differences among times, which were interpreted as *small* (0.2), *medium* (0.5), and *large* (0.8).[38] We used SPSS (version 22; IBM Corp, Armonk, NY) for statistical analysis. The α level was set at $P \leq .05$.

RESULTS

The reliability of data extraction across all measures for each of the 4 muscles was a median of 0.97 (interquartile range = 0.93–0.97). Technical malfunctions led us to exclude data from the SA from a 26-year-old woman for both TMS and the shoulder-flexion and shoulder-abduction tasks.

Scapular Muscle Activity During Active Shoulder Movement

For the flexion task, we observed an overall effect of time on EMG onset for both the UT ($F_{3,42} = 4.234$, $P = .01$) and LT ($F_{3,42} = 3.935$, $P = .02$; Table 1) muscles. The onset of the UT and LT contractions was earlier immediately after taping than before taping; however, this difference only approached significance for the LT (110.02 ± 109.83 milliseconds and 5.94 ± 92.35 milliseconds, respectively) before the MD contraction onset ($P = .06$; Cohen d = 1.026; Table 1, Figures 2 and 3). We observed no differences in the relative onset of muscle contraction between before

Table 1. Extended From Previous Page

Selected Multiple Comparisons With Bonferroni Correction[a]								
Before Taping to								
After Taping			After Taping With Tape On			After Taping With Tape Off		
Mean Difference (95% CI)	P	Cohen d	Mean Difference (95% CI)	P	Cohen d	Mean Difference (95% CI)	P	Cohen d
82.46 (−25.96, 190.88)	.21	0.693	5.42 (−63.66, 74.51)	>.99	0.058	−2.13 (−83.50, 79.246)	>.99	0.020
104.09 (−1.96, 210.13)	.06	1.026	45.42 (−48.12, 138.95)	.95	0.507	21.49 (−76.96, 119.94)	>.99	0.220
8.92 (−38.34, 56.17)	>.99	0.059	23.13 (−53.54, 99.80)	>.99	0.173	23.33 (−51.24, 97.91)	>.99	0.193

taping and 24 hours after taping (tape on and removed) for the UT and LT or between any times for the SA. No differences were found in peak EMG, as defined by RMS, among times for the flexion task.

For the abduction task, we observed an overall effect of time for both the UT ($F_{3,42} = 5.453$, $P = .01$) and LT ($F_{3,42} = 3.346$, $P = .03$; Table 2) muscles. The onset of the UT and LT contractions was earlier immediately after taping than before taping; it was different for the UT (34.18 ± 118.91 milliseconds and 93.95 ± 106.33 milliseconds, respectively) after MD contraction onset ($P = .02$; Cohen d = 0.530) but not for the LT (Table 2, Figures 2 and 3). No differences were found in the relative onset of muscle contractions between before taping and 24 hours after taping for the UT and LT or among any times for the SA (Table 2). We observed no differences in peak EMG, as defined by RMS, among the different times for the abduction task.

Corticomotor Excitability

Comparisons of MEP variables (RMS, onset, SP) for the UT, LT, SA, and MD across the 4 times for both resting and active TMS conditions are shown in Table 3. For the MD during the active condition, the mean MEP onset was earlier 24 hours after taping with the tape on (7.203 ± 4.327 milliseconds) than before taping (8.709 ± 5.245 milliseconds; mean difference = 1.51 milliseconds; 95% confidence interval = 0.35, 2.66; $P = .008$; Cohen d = 0.313). No other differences were noted among times for the UT, LT, SA, and MD in the other MEP variables in the resting or active condition.

Shoulder-Flexion and Shoulder-Abduction ROM

Comparisons of flexion and abduction ROM goniometer values across the 4 times appear in Table 4. We observed an increase in shoulder abduction immediately after taping.

DISCUSSION

We explored corticomotor excitability as a potential neuromuscular mechanism underpinning a therapeutic taping technique used clinically to manage neuromusculoskeletal shoulder conditions. Our findings suggested that whereas applying tape did not alter the corticomotor
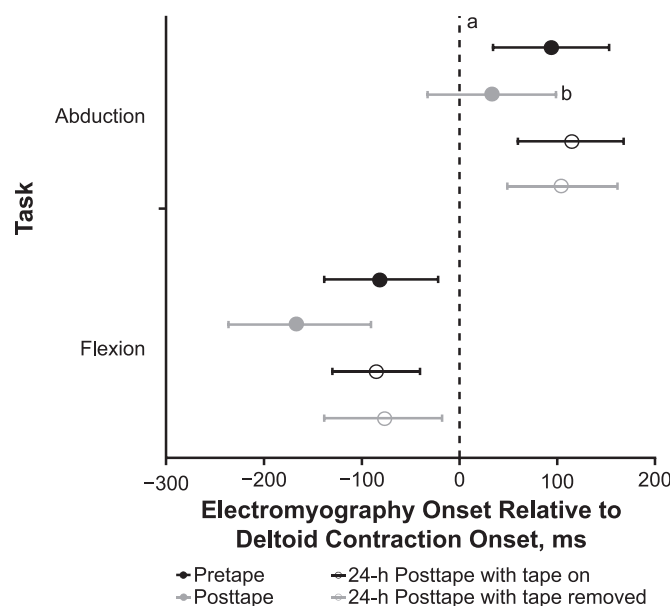
Figure 2. Contraction onset of the upper trapezius muscle relative to that of the middle deltoid during flexion and abduction tasks through all 4 time points of the experiment. [a] Indicates electromyographic onset of the middle deltoid contraction. [b] Indicates difference (P = .02; mean difference = 59.77 milliseconds; 95% confidence interval = 7.34, 112.20 milliseconds).
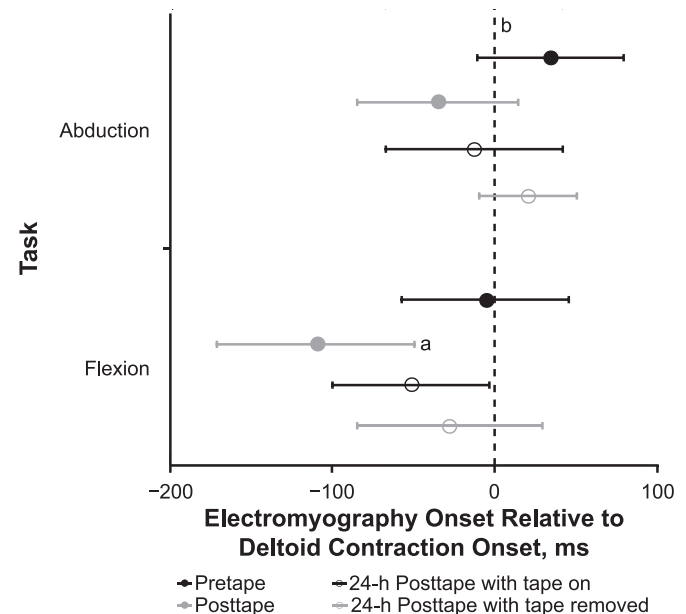
Figure 3. Contraction onset of the lower trapezius muscle relative to that of the middle deltoid in flexion and abduction tasks through all 4 time points of the experiment. [a] Approaches a difference (P = .06; mean difference = 104.09 milliseconds; 95% confidence interval = −1.96, 210.13 milliseconds). [b] Indicates electromyographic onset of the middle deltoid contraction.

Table 2. Comparison of Onsets of Scapular Muscle and Middle Deltoid Contractions During Active Shoulder Abduction Before and After Taping Extended on Next Page

| Muscle | Electromyographic Onset in Relation to Middle Deltoid Contraction Onset, milliseconds, Mean ± SD | | | | Repeated-Measures Analysis of Variance | | |
| | Taping | | 24 h After Taping | | | | |
	Before	After	Tape On	Tape Removed	F	P	Partial η²
Upper trapezius	93.95 ± 106.33	34.18 ± 118.91	114.65 ± 97.43	106.12 ± 101.04	5.453	.01	0.280
Lower trapezius	33.87 ± 81.06	−35.27 ± 89.83	−32.86 ± 119.60	20.58 ± 54.22	3.346	.03	0.193
Serratus anterior	162.16 ± 122.20	130.00 ± 91.48	130.38 ± 93.44	116.93 ± 75.68	1.266	.30	0.089

Abbreviation: CI, confidence interval.

[a] Positive values for mean differences indicate an earlier relative onset for the muscle compared with before taping.

[b] Indicates a difference when the Bonferroni correction for multiple comparisons was used.

excitability of the scapular muscles, it appears to have influenced the timing of the onset of the UT and LT contractions relative to those of the MD muscle; the onset of contractions was earlier in relation to the MD muscle for the UT in abduction immediately after taping and approached a difference ($P = .06$) for the LT in flexion, but these changes were not maintained 24 hours after taping with the tape on. The effect sizes for these differences were medium and large, respectively, as defined by Cohen.[38] These findings suggested that tape may change the relative onset of scapular muscle contractions when applied, but additional intervention would potentially be needed to result in lasting changes or changes in corticomotor excitability.

Altered motor control of the scapular muscles is a feature of neuromusculoskeletal shoulder conditions. Motor-control impairments exist in numerous conditions[13] and include delayed activation of the trapezius and SA with respect to MD contraction onset in individuals with shoulder pain compared with healthy individuals.[39,40] In addition, reduced torque production by the trapezius and SA has been noted in individuals with pain compared with those without pain.[5,13,41,42] Conservative clinical management of patients with shoulder conditions who exhibit such deficits often seeks to correct identified impairments.[13,41,42] Therapeutic taping has been proposed to facilitate this process.[10,24,26]

Consistent with this paradigm, our results suggested that applying tape facilitated earlier contraction onset of the UT

Table 3. Repeated-Measures Analyses of Variance for Motor-Evoked Potential Root Mean Square, Onset, and Silent Periods Across Study Times for All Muscles Tested During Resting and Active Transcranial Magnetic Stimulation Conditions

| Motor-Evoked Potential Variable | Condition | Motor-Evoked Potential Variable, Mean ± SD | | | | Repeated-Measures Analysis of Variance | | |
		Before Taping	After Taping	24 h After Taping With Tape On	24 h After Taping With Tape Removed	F	P	Partial η²
Root mean square[a]								
Upper trapezius	Resting	0.066 ± 0.083	0.077 ± 0.080	0.042 ± 0.024	0.082 ± 0.133	0.792	.51	0.054
	Active	0.613 ± 0.112	0.584 ± 0.265	0.547 ± 0.494	0.592 ± 0.511	0.128	.78	0.009
Lower trapezius	Resting	0.098 ± 0.065	0.232 ± 0.292	0.176 ± 0.264	0.175 ± 0.200	1.404	.26	0.091
	Active	0.738 ± 0.122	0.795 ± 0.306	0.750 ± 0.307	0.827 ± 0.444	0.361	.78	0.025
Middle deltoid	Resting	0.054 ± 0.074	0.033 ± 0.025	0.024 ± 0.012	0.024 ± 0.013	2.131	.16	0.132
	Active	0.742 ± 0.093	0.694 ± 0.189	0.693 ± 0.383	0.686 ± 0.320	0.254	.69	0.018
Serratus anterior	Resting	0.097 ± 0.047	0.090 ± 0.051	0.086 ± 0.050	0.083 ± 0.058	0.611	.61	0.045
	Active	0.725 ± 0.099	0.795 ± 0.216	0.568 ± 0.228	0.539 ± 0.178	6.074	.02	0.318
Onset, milliseconds								
Upper trapezius	Resting	5.709 ± 4.586	6.703 ± 5.207	7.202 ± 4.898	6.739 ± 4.198	1.351	.28	0.145
	Active	5.972 ± 3.639	6.513 ± 3.860	5.689 ± 3.389	6.382 ± 3.988	1.210	.31	0.080
Lower trapezius	Resting	5.431 ± 6.368	6.433 ± 5.141	6.262 ± 4.892	7.324 ± 5.637	0.898	.40	0.101
	Active	7.920 ± 4.532	8.158 ± 4.654	8.061 ± 4.379	7.566 ± 4.433	1.034	.39	0.069
Middle deltoid	Resting	8.577 ± 6.457	9.062 ± 6.780	8.356 ± 6.758	8.507 ± 6.003	0.245	.86	0.026
	Active	8.709 ± 5.245	8.197 ± 4.818	7.203 ± 4.327	7.469 ± 4.537	6.203	<.001[b]	0.307
Serratus anterior	Resting	16.920 ± 4.203	15.283 ± 3.764	14.411 ± 2.018	14.786 ± 4.857	2.395	.26	0.545
	Active	10.669 ± 6.450	11.375 ± 7.618	10.789 ± 6.992	10.520 ± 6.725	0.260	.85	0.020
Silent period, milliseconds								
Upper trapezius	Active	0.073 ± 0.030	0.082 ± 0.036	0.076 ± 0.039	0.083 ± 0.034	0.798	.50	0.068
Lower trapezius	Active	0.054 ± 0.037	0.043 ± 0.017	0.049 ± 0.026	0.049 ± 0.020	0.725	.55	0.075
Middle deltoid	Active	0.044 ± 0.018	0.047 ± 0.018	0.045 ± 0.012	0.048 ± 0.015	0.591	.63	0.047
Serratus anterior	Active	0.061 ± 0.026	0.067 ± 0.033	0.060 ± 0.031	0.049 ± 0.032	1.371	.27	0.103

[a] Root mean square of electromyographic signal of motor-evoked potential normalized for each participant to peak root mean square across all trials at all signal intensities.

[b] Indicates difference when the Bonferroni correction for multiple comparisons was used.

Table 2. Extended From Previous Page

Selected Multiple Comparisons With Bonferroni Correction[a]								
Before Taping to								
After Taping			After Taping With Tape On			After Taping With Tape Off		
Mean Difference (95% CI)	P	Cohen d	Mean Difference (95% CI)	P	Cohen d	Mean Difference (95% CI)	P	Cohen d
59.77 (7.34, 112.20)	.02[b]	0.530	−20.70 (−78.30, 36.90)	>.99	0.203	−12.17 (−84.25, 59.92)	>.99	0.117
69.13 (−23.58, 161.84)	.23	0.808	66.73 (−24.89, 158.35)	.25	0.653	13.29 (−28.35, 54.94)	>.99	0.193
32.17 (−32.90, 97.23)	.89	0.298	31.78 (−51.15, 114.71)	>.99	0.292	45.23 (−56.19, 146.65)	>.99	0.445

and LT fibers relative to the MD muscle immediately after taping. This has not been investigated in other studies[6,23–26] exploring the effects of shoulder taping using EMG, as many researchers have focused on the magnitude of EMG contraction rather than the timing. Consistent with our findings but in the context of the knee, researchers[43,44] studying taping for patellofemoral pain syndrome have noted an earlier contraction onset of the vastus medialis obliquus relative to the vastus lateralis after taping. As such, appropriately applied tape appears to be efficacious for addressing impaired scapular-muscle–firing patterns. In our study, scapular taping did not influence the magnitude of trapezius or SA contractions. This observation is in agreement with the findings of Cools et al[26] but in conflict with those of Smith et al,[6] Hsu et al,[23] Selkowitz et al,[24] and Lin et al.[25] These varied results are likely due to heterogeneity in study designs, namely different participant groups performing different tasks.

Facilitating muscle activation by enhancing cortical motor-neuron output through increased cutaneous afferent input is a mechanism by which scapular taping is theorized to modify neuromuscular control of the shoulder.[10,45,46] Our results, however, suggested that taping did not alter the motor-neuron–pool excitability of the scapular muscles and, as such, do not support this theorized mechanism. Alexander et al[45] used electrically evoked Hoffmann reflexes to examine the effect of taping on motor-neuron–pool excitability in the trapezius and triceps surae[47] in healthy volunteers. They considered the Hoffmann reflex to be an electrophysiologic reflection of motoneuron-pool excitability[45,47] and reported that applying the tape to both the trapezius and triceps surae reduced it. These findings, therefore, are consistent with our results, suggesting that motoneuron excitability does not necessarily underpin the clinical utility of scapular taping.

However, TMS involves activity across 2 synapses: in the motor cortex and the spinal cord.[48] Consequently, detectable variance in the MEPs may involve changes at either or both of these synapses. With respect to our study, changes in neuron excitability at the motor cortex may have been diluted by a lack of change in excitability at the spinal cord, in turn resulting in no differences in TMS variables for the scapular muscles (UT, LT, SA). In future studies, researchers should include measures of peripheral and spinal excitability to conclusively determine whether therapeutic taping alters excitability along the corticomotor pathway.

We observed a decrease in time to MEP onset for the MD during the active TMS condition 24 hours after taping. The MD is the prime mover of abduction, which is undertaken in the active condition, and is not a scapular stabilizer. Therefore, this change in MEP onset may be a consequence of participants repeatedly performing abduction during the experiment (50 repetitions on each measurement occasion), as it did not occur immediately after taping but 24 hours later. Alternatively, the taping technique may have changed the performance of abduction in a manner that influenced the excitability of the MD. Either way, this finding suggested that a change in an active movement repeated over time may affect cortical excitability.

Our findings indicated that the taping technique we used led to an immediate increase in active shoulder-abduction ROM. This may conceivably be due to the taping technique assisting upward rotation of the scapula through the facilitation of the UT contraction, as evidenced by its earlier onset (Figure 2). An earlier onset of the UT contraction could mean that more time is available for greater scapular upward rotation during shoulder abduction, and greater rotation could facilitate increased shoulder abduction.

CLINICAL IMPLICATIONS

Our results suggested that therapeutic taping may be a useful tool in the rehabilitation of patients exhibiting motor-control impairments of the scapular muscles, as taping facilitated earlier onset of trapezial contractions, particularly immediately after taping. Considering the absence of changes in any MEP variable for the scapular muscles (UT, LT, SA), the observed changes in muscle-contraction timing could plausibly be the result of the tape

Table 4. Shoulder-Flexion and Shoulder-Abduction Range of Motion (°) Before and After Taping

Task	Shoulder Range of Motion, Mean ± SD				Repeated-Measures Analysis of Variance		
	Before Taping	After Taping	24 h After Taping With Tape On	24 h After Taping With Tape Removed	F	P	Partial η^2
Flexion	153.07 ± 7.48	155.36 ± 6.99	155.71 ± 7.07	155.64 ± 7.78	2.315	.09	0.151
Abduction	169.07 ± 6.92[a]	173.43 ± 7.45[a]	171.43 ± 8.32	173.43 ± 6.85	3.954	.02	0.233

[a] Indicates difference when Bonferroni correction for multiple comparisons was used.

exhibiting biomechanical influences on the muscles and joints of the shoulder girdle, as demonstrated by Shaheen et al[49] and Hsu et al.[23] Given that the tape was applied to upwardly rotate the scapula, it may facilitate the onset of the UT and LT contractions by improving their length-tension relationships.[10,24] This did not alter the resting activity of the muscles, as evidenced by the absence of differences in background EMG activity before TMS stimulation across the 4 time points, indicating that taping altered contraction onset rather than resting activity.

Taping alone, however, may not change the corticomotor excitability of the muscles. Given the contribution of neuroplastic processes to recovery from neuromusculoskeletal conditions,[50,51] our results suggested that taping is best used as an adjunct to another intervention, such as rehabilitative exercises, if the goal is to improve cortical control of the scapular muscles. In addition, the earlier activation of the UT and LT fibers after taping was not maintained at the 24-hour follow-up. This suggests that immediately after taping may be an optimal time for a patient to perform rehabilitative exercises to achieve corticomotor changes and, in turn, functional improvement or changes in a clinical outcome.

LIMITATIONS AND FUTURE RESEARCH

Given that our participants did not have shoulder pain or a history of shoulder injury, the applicability of these findings to a population with pathologic conditions is not clear because the ability of tape to influence corticomotor control in a healthy shoulder may be limited compared with symptomatic individuals who have motor-control deficits. Researchers, therefore, should explore the effect of taping on cortical excitability in people with shoulder pain, as such work would provide further insight into the neurophysiologic mechanisms contributing to this intervention. If individuals with shoulder pain have altered corticomotor representation of the scapular muscles, the opportunity for change in corticomotor excitability may be greater than in the pain-free participants of our study.

CONCLUSIONS

Our findings suggested that applying therapeutic tape led to an earlier contraction onset of the UT and LT fibers in relation to the MD during shoulder-flexion and -abduction tasks in a pain-free population. An increase in shoulder-abduction ROM was also observed immediately after taping, possibly related to facilitation of upward rotation of the scapula through earlier contraction of the UT and LT relative to the MD, which could be considered the prime mover of shoulder abduction. Changes in timing and ROM were not maintained at 24 hours after taping, indicating that clinicians using scapular taping to manage shoulder pain should consider combining it with other interventions, such as rehabilitative exercises. Taping, however, did not alter the cortical excitability of the scapular muscles, suggesting that the mechanism underpinning the observed changes may be related to neuromuscular or noncortical neurologic processes rather than altered corticomotor activity. Further research is required to determine if a different neurophysiologic response to scapular taping occurs in a population experiencing shoulder pain.

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Address correspondence to Scott F. Farrell, PhD, PT, RECOVER Injury Research Centre, Menzies Health Institute Queensland, Griffith University Gold Coast Campus, Parklands Drive, Southport, Gold Coast, QLD, Australia 4222. Address e-mail to s.farrell@griffith.edu.au.