Fine-Wire Intramuscular Insertion to the Lumbar Paraspinal Muscles does not Affect Muscle Activation and Performance During High Exertion Spinal Extension Muscle Contractions

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FINE-WIRE INTRAMUSCULAR INSERTION TO THE LUMBAR PARASPINAL MUSCLES DOES NOT AFFECT MUSCLE ACTIVATION AND PERFORMANCE DURING HIGH EXERTION SPINAL EXTENSION MUSCLE CONTRACTIONS

By
James DiMascio
Rebeka Hicks
Matthew Kimber

A doctoral project submitted in partial fulfillment of the requirements for the

Doctor of Physical Therapy

Department of Physical Therapy
School of Allied Health Sciences
Division of Health Sciences
The Graduate College

University of Nevada, Las Vegas
May 2017
We recommend the doctoral protect prepared under our supervision by

James DiMascio, Rebeka Hicks, Mathew Kimber, and Kelsey Snyder

ettitled

Fine-Wire Intramuscular Insertion to the Lumbar Paraspinal Muscles Does Not Affect Muscle Activation and Performance During High Exertion Spinal Extension Muscle Contractions

is approved in partial fulfillment of the requirements for the degree of

Doctor of Physical Therapy
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ABSTRACT

**Background and Purpose:** Low back pain (LBP) is associated with paraspinal muscle dysfunctions. A method to study the deep lumbar paraspinal muscle activation is with intramuscular electromyography (EMG). However, it is currently unknown how paraspinal muscle performance is affected by the invasive intramuscular insertion and the presence of the fine-wire electrode in the muscle. The purpose of this study was to analyze how insertion of fine-wire EMG into lumbar paraspinal muscle affects the lumbar paraspinal muscle fatigue, endurance, activation, and peak extention torque during high exertion spinal extension exercises.

**Participants:** 20 individuals between the ages of 18-40 participated. The participants were healthy with no history of LBP within the last 6 months that required activity modification or medical care.

**Methods:** Data was obtained during 3 separate testing sessions, spaced 5 to 10 days apart. The first session obtained baseline outcome measures without intramuscular insertion (BL), with subsequent sessions utilizing a random order of insertion followed by leaving the intramuscular electrode fine-wire in (WI) or out (WO) of the muscle. Lumbar paraspinal peak extension torque was assessed with isokinetic dynamometry. Lumbar paraspinal edurance was evaluated using the Sorensen test. Paraspinal muscle fatigue was assessed using the rate of change (slope) of the median frequency during the endurance test. Percent of muscle activation was calculated by using the average muscle activation level during the endurance task. Pain and discomfort levels were recorded using the Visual Analog Scale (VAS) at specific times during the test sessions. All outcome measures were compared across the 3 conditions using one-way repeated measures ANOVAs and post-hoc analyses when indicated.

**Results:** Our results showed no significant difference in peak torque (p = 0.196) between the BL, WI, and WO conditions. A significant difference in lumbar paraspinal endurance was found between the 3 conditions (p = 0.025). Post-hoc analysis showed that the muscle endurance in the WO condition was significantly longer than the BL condition (161.30 ± 58.267 sec vs. 142.05 ± 48.159 sec; p = 0.037). Percent of muscle activation during the endurance testing was not significantly different between the 3 conditions (p = 0.120). Pain scores reported during the 3 conditions were minimal (ranged 0-4/10). No
pain was reported on the first day of testing (BL). No significant difference in pain scores was found between the WI and WO conditions: during each of the the three MVIC trials, after the MVIC trials, during the Sorensen test, or after the Sorensen test (p = 0.104, p = 0.186, p = 0.214, p = 0.330, p = 0.527, p = 0.481, respectively).

**Discussion:** Our findings suggested that the insertion and presence of fine-wire EMG in the lumbar paraspinal muscles had no significant impact on lumbar paraspinal muscle peak extension torque, activation or fatigue and induced minimal pain. However, the results did suggest that the insertion and subsequent removal of the fine-wire did have an affect on lumbar paraspinal endurance. This study provides empirical evidence to validate the use of fine-wire EMG for studying lumbar paraspinal muscles during activities that require high muscular exertion.
ACKNOWLEDGMENTS

This research study was made possible by the 2015 University of Nevada, Las Vegas Physical Therapy Student Opportunity Research Grant. The authors would like to thank Szu-Ping Lee, PT, PhD for his excellent guidance as principle investigator of this study and Emilio Puementura, PT, DPT, PhD, OCS, FAAOMPT for his help and guidance as the Co-principal investigator of this study. The authors would also like to thank Dr. Jo Armour. Smith, PhD, PT, OCS for her contribution to the study.
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INTRODUCTION:

It is predicted that 60-80% of the population will experience an episode of low back pain (LBP) at some point in their lifetime.\textsuperscript{1,2} Many potential causes of LBP have been identified, and likely it is a multifactorial problem. One theoretical cause of LBP is spinal instability. Panjabi described spinal stability consisting of 3 subsystems: the passive subsystem (bones, ligaments, facet joints), the active subsystem (muscles and tendons), and the neural control subsystem (golgi tendon organs, muscle spindles, reflex pathways).\textsuperscript{3} If one or more of the subsystems is disrupted, the entire stabilizing system can be affected and lead to LBP. Crisco et al. demonstrated that a cadaveric neutral spine with all muscles removed, will buckle under only 20 pounds, which is well below normal physiological loads.\textsuperscript{4} This indicates that the passive subsystem may not provide as much spinal stability as the active subsystem, which is the reason why the paraspinal musculature is often the focal point of current research on LBP.

In the lower back, the lumbar paraspinal muscles are composed of the erector spinae (longissimus and iliocostalis) and the multifidus muscles. However, the deep lumbar paraspinal muscles, especially the lumbar multifidus, are more commonly targeted in research due to their role in lumbar intervertebral stabilization and their link to LBP. The deepest portion of the lumbar multifidus is made up of fibers short fibers that cross 1-2 spinal segments. This allows these muscles to control intersegmental motion of the spine and resist shear forces and thus protects ligaments, intervertebral discs, and other articular structures from increased stress.\textsuperscript{5} This also means that endurance of the lumbar multifidus is more important than strength due to its role in lumbar stability.\textsuperscript{6} Global muscles, such as the erector spinae, span multiple vertebral levels and are more suited for movements involving entire spinal regions (lumbar flexion and extension) and are not capable of controlling shear forces of individual vertebral segments.\textsuperscript{5} The lumbar paraspinal muscles work in conjunction with the other muscles of the trunk to provide strength and stability to the lumbar spine.\textsuperscript{7} For example, the multifidus co-contracts with the transversus abdominis muscle (connected to the lumbar spine via the thoracolumbar fascia), which increases intrabdominal pressure, further adding stiffness and stability to the lumbar spinal segments.\textsuperscript{5}
Due to the importance of paraspinal muscles in providing spinal stability, activation patterns of this muscle group have been an active area of research. Hodges has performed several studies related to spinal stability.\textsuperscript{8,9} He has found that in healthy controls without LBP, perturbations to the spine, such as limb movements, result in anticipatory contraction of the transverse abdominus, regardless of the direction of limb movement.\textsuperscript{9} Contraction of other spinal muscles including the lumbar multifidus occur after activation of the prime movers of the limb.\textsuperscript{9} However, the lumbar musculature has been shown to act differently in individuals with LBP.\textsuperscript{9} It has been shown that the deep trunk stabilizers (especially the lumbar multifidus) react to perturbations significantly later compared to healthy controls.\textsuperscript{10,11} Many studies have also found that individuals with LBP have decreased endurance of the lumbar spine extensors and lumbar multifidus. Furthermore, Kjaer et al found that atrophy of the lumbar multifidus muscle and resultant fatty infiltration is significantly related to LBP but has no relation to an individual’s body mass index (BMI).\textsuperscript{9}

A common method used to assess muscle activation is electromyography (EMG).\textsuperscript{10} There are two types of EMG used in clinical research: surface electrode EMG and fine-wire intramuscular EMG. Surface electrodes can pick up signals from other muscles (cross-talk) in the area that could be contracting concurrently or have a different functional role than the muscle being studied.\textsuperscript{10} It has been shown that surface EMG electrodes are less specific to the multifidus muscle and more specific to the overlying longissimus muscle, suggesting that accurate measurement of multifidus muscle activation requires intramuscular EMG electrodes.\textsuperscript{11} The intramuscular EMG can target a specific muscle by inserting the fine-wire directly into the muscle belly using guidance of ultrasound imaging. This allows for direct measurement of the activity of the paraspinal musculature that is not clearly accessible by surface electrodes.\textsuperscript{10}

Although intramuscular EMG is better able to assess activation of specific muscles, it has the potential disadvantage of altering motor behavior due to the pain/discomfort associated with the insertion and presence of the intramuscular fire-wires during high exertion muscle contractions. There has been some research that suggests the presence of the EMG wire may alter muscle activity in the paraspinals.\textsuperscript{12}
While this procedure has been proven to be safe, it is currently unknown whether this invasive procedure and the associated pain/discomfort would alter the activation, peak torque, fatigue, and endurance of the lumbar paraspinals during high exertion spinal extension exercises.

Musculoskeletal pain is associated with multiple changes in muscle performance. When a muscle is in a painful state there is a reduction in its maximal voluntary contraction (MVC). One of the leading theories that explains why muscles in pain move differently is the pain adaptation theory. According to this theory, when a muscle is in pain there is an adaptation that causes it to have a reduction in amplitude and velocity during movement, thereby reducing its maximal force, whereas at the same time the opposing antagonistic muscles will have an increase in activity. Several studies have shown this to be true by causing experimentally induced pain with saline injected into the muscle. Muscles in a state of experimentally induced pain show a decrease in motor unit discharge rates during isometric contractions, as well as a change in motor unit recruitment strategies. Graven-Nielsen et al. demonstrated that muscles experiencing a painful (nociceptive) stimuli from injection of the saline solution did not produce the same torque levels as compared to the pre-pain condition. A study by Descarreaux et al showed that experimentally induced cutaneous pain to the lumbar region altered isometric trunk forces. Smith et al sought to determine whether the presence of intramuscular EMG electrodes could alter muscle performance. However their study investigated muscle performance only during submaximal strength conditions. Smith et al required test participants to complete steady-state locomotion and walking turns which reportedly demand paraspinal activation that is less than 20% of maximum voluntary contraction.

The purpose of this study was to investigate the effects of intramuscular EMG electrode insertion on peak extension torque production, endurance, fatigue, and activation of the lumbar paraspinal muscles specifically during high exertion lumbar extension tasks. Our study attempted to determine if the insertion of the needle and/or the presence of the EMG fine-wire caused a change in torque production and pain similar to the changes seen with a saline injection. We hypothesized that insertion and the presence of intramuscular fine-wire electrodes would lead to pain and reduced paraspinal muscle activation, peak torque production, and endurance as well as and increasing paraspinal muscle fatigue. The findings of this
study provided invaluable information for the future research of lumbar paraspinal muscle performance and low back dysfunction.

**METHODS**

**Participants**

Our participants were 20 healthy individuals (Descriptive statistics in Table 1) that were between 18-40 years of age, had no history of chronic LBP, and no history of back pain in the last 6 months that required activity modification or medical care. The exclusion criteria included having any current lower back dysfunctions, risk of bleeding and infection, or fear of needles (detailed list in Table 2). Student researchers recruited participants by posting flyers throughout the University of Nevada Las Vegas campus that advertised the need for research participants. Research participants were recruited through announcements in undergraduate health science classes and to students in the Doctor of Physical Therapy program and the Kinesiology graduate program.

<table>
<thead>
<tr>
<th>Number (n)</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Age (years)</td>
<td>25.70 ± 3.47</td>
</tr>
<tr>
<td>Mean Height (m)</td>
<td>1.73 ± 0.09</td>
</tr>
<tr>
<td>Mean Weight (kg)</td>
<td>74.3 ± 14.3</td>
</tr>
</tbody>
</table>

Table 1: Descriptive statistics of participants
## Exclusion Criteria

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>1.</td>
<td>Diabetes mellitus</td>
</tr>
<tr>
<td>2.</td>
<td>Rheumatic joint disease</td>
</tr>
<tr>
<td>3.</td>
<td>Clotting disorder</td>
</tr>
<tr>
<td>4.</td>
<td>Polyneuropathy</td>
</tr>
<tr>
<td>5.</td>
<td>Lower back surgery</td>
</tr>
<tr>
<td>6.</td>
<td>Bilateral leg pain</td>
</tr>
<tr>
<td>7.</td>
<td>Radiological/clinical diagnosis of spinal stenosis</td>
</tr>
<tr>
<td>8.</td>
<td>Radiological/clinical diagnosis of structural scoliosis</td>
</tr>
<tr>
<td>9.</td>
<td>Spinal malignancy</td>
</tr>
<tr>
<td>10.</td>
<td>Spinal infection</td>
</tr>
<tr>
<td>11.</td>
<td>Lumbar radiculopathy</td>
</tr>
<tr>
<td>12.</td>
<td>Pregnancy</td>
</tr>
<tr>
<td>13.</td>
<td>Fear of needles</td>
</tr>
<tr>
<td>14.</td>
<td>Any bleeding disorder</td>
</tr>
</tbody>
</table>

**Table 2:** Exclusion criteria

**Procedure**

Participants were asked to attend 3 separate days of testing which were scheduled 5-10 days apart to allow for full muscle recovery from the previous testing session. Participants were instructed to wear exercise clothing that would permit freedom of movement during the tests of lumbar muscle performance. Participants were asked to refrain from exercise the day of their testing sessions, and also to avoid strenuous exercise/activity less than 2 days before their testing sessions. Each day the participant went through a small warm-up that included walking, lumbar rotations, lumbar extensions, and a lumbar flexion stretch, which lasted about 10 minutes. The first day of testing involved surface EMG electrode placement over the right lumbar paraspinals at the L4 spinal level and the completion of baseline (BL) muscle performance testing. During muscle performance testing, the participant underwent lumbar
extension isometric strength testing using the isokinetic dynamometer in order to assess peak muscle torque. Then, a 5-minute rest-break was given to allow for muscle recovery. The participant then performed the Sorensen Test in order to assess lumbar extension muscle endurance as well as lumbar paraspinal muscle fatigue and activation. The surface EMG was then removed and day 1 was concluded.

Day 2 began with the same warm-up protocol as day 1. After the warm-up, the surface EMG electrode was placed on the participant’s right lumbar paraspinal muscles at the L4 spinal level. Next, the fine-wire EMG electrode was inserted into the deep fibers of the participant’s left lumbar multifidus muscle guided by ultrasound imaging. Then, one of two conditions occurred: The guide needle was removed while leaving the fine-wires implanted in the lumbar multifidus muscle [Wire In (WI) condition] or the fine-wires were removed immediately along with the guide needle [Wire Out (WO) condition]. Test condition of day 2 (WI or WO) was randomized for each participant and participants were blinded to which condition occurred each day (Figure 1). The participant was asked to limit the amount of lumbar flexion for the remainder of the session in order to prevent dislodgement of the fine-wire EMG from the deep fibers of the lumbar multifidus. The participant then underwent the same muscle performance testing protocol as day 1. Equipment (surface EMG electrode, fine-wires, fine-wire electrode) was then removed from the participant’s body and day 2 was concluded.

Day 3 protocol was the same as day 2 with the exception of the test condition. Depending on the test condition the participant received on day 2 (WI or WO), the opposite condition was given on day 3 so that every participant underwent a BL, WI, and WO condition (Figure 1). After insertion, the participant completed the same muscle performance testing as the previous days. Equipment was then removed and day 3 was concluded.
Figure 1: Flow chart of fine-wire insertion/removal protocol

**Instrumentation**

**EMG Preparation**

The participant was asked to lie prone on the treatment table with their lower back exposed. The skin over the lumbar spine and adjacent musculature was sterilized with alcohol wipes and a surface EMG electrode was placed over the right lumbar paraspinal muscles at the L4 spinal level. During sagittal plane motions of the lumbar spine (flexion/extension), the L4 vertebra has been shown to have the most A-P translation of the lumbar spine.\(^\text{15}\) The deep lumbar paraspinal muscles, especially the multifidus, resist translatory movements, the muscles in this area are expected to have high levels of activity. One of the lead researchers, either Dr. Lee or Dr. Puentedura, used a General Electric NextGen LOGIQe scanner (GE Healthcare, Milwaukee, WI, USA) diagnostic ultrasound imaging unit to view the left lumbar paraspinal muscles at the L4 spinal level and locate the deep fibers of the lumbar multifidus muscle. Left lumbar paraspinal muscles were chosen for ease of access with current lab equipment set-up. The researcher then inserted the guide needle containing the EMG fine-wires into the previously identified muscle fibers with continued visualization using the ultrasound imaging (Figure 2). The wires were inserted into the deep fibers of the lumbar multifidus muscle and the needle was removed. The fine-wires were either left in the lumbar multifidus (WI condition) or were immediately removed along with the guide needle (WO...
condition). The participants were blinded to which condition they were receiving on each testing day. During the WI and WO conditions, participants were told that they may or may not feel the presence of the fine wire electrode. During the WO condition the wire electrode was inserted and immediately removed with the removal of the guide needle without participant acknowledgement. The participant was then asked to perform a lumbar extensor contraction in order to set the EMG fine-wires in the muscle fibers of the deep lumbar multifidus. If the participant completed a WO condition on day 2 of testing a sham fine-wire removal was performed at the end of their muscle testing session.

Figure 2: Axial ultrasound image demonstrating insertion of the fine-wire EMG (and guide needle)

Isokinetic Dynamometer

Isokinetic dynamometers are commonly used to measure muscle strength in the form of torque production. During testing the dynamometer lever arm was held in static position to read peak isometric contraction strength. Trunk flexor and extensor torque production during dynamometer testing has been shown to be significantly correlated with its respective EMG data. During testing of the lumbar paraspinal peak extension torque, the axis of rotation of the dynamometer was aligned with the
participant’s L4 vertebral body. Prior studies have found that the instantaneous axis of rotation (IAR) during lumbar flexion/extension is located at the L4-L5 level.\textsuperscript{16}

**Muscle Performance Tests**

**Assessment of Peak Isometric Lumbar Extension Torque**

For the spinal extension peak torque production assessment the participant was asked to lie in the prone position on the dynamometer with their hands placed behind their head. The lever arm of the dynamometer was set to a length so that the center of the pad of the lever arm was across the participant’s upper back in line with the spines of their scapulae. The distal lower legs were secured to the table. Our dynamometer testing protocol consisted of multiple 5-second maximal isometric voluntary contractions (MVIC) of lumbar extension. The first was a 5-second practice trial in order to familiarize the subject with the test. This was followed by a 5-second break. The next 3 MVIC trials were recorded and were separated by 1-minute rest breaks. After the MVIC trials, the participant was given a rest break of 5 minutes prior to starting the muscle endurance testing.

**Assessment of Lumbar Paraspinal Muscle Extension Endurance (Sorensen Test)**

The participant performed the Sorensen test to assess lumbar paraspinal extension endurance.\textsuperscript{1} Studies have established that the Sorensen Test assesses isometric muscle endurance and it is has been found that reproducibility of this test was satisfactory (intraclass coefficient of correlation > 0.75) in both healthy individuals and in those who are experiencing low back pain.\textsuperscript{1} In the current study the participant laid prone on the table with both anterior superior iliac spines (ASIS) aligned with the edge of the table and their upper body hanging off the edge. A small bench was located under their upper body for their arms to support them until the start of the test. A small chain was placed around their neck which had a bobber attached to the end of it. This chain was adjusted so that the bobber hung approximately 1-inch above the small bench below their body, which is shown in Figure 3. The participant’s distal lower legs were strapped to the table to prevent the participant from falling forward. A researcher held the
participant’s ankles to the table to further prevent any forward falling of the participant. Once the test began, the participant placed their arms across their chest and held their body parallel to the ground so that the bobber maintained a height of approximately 1-inch above the bench. They were instructed to hold this position for as long as possible. Termination of the test was determined by the bobber coming into contact with the bench or the participant voluntarily terminating the test by grabbing the bench. The time elapsed during the participant’s Sorensen test was recorded in seconds.

**Pain Assessment**

Pain data was collected from each testing subject using a 11-point visual analog scale (VAS) on five separate occasions throughout each day of testing. The VAS was chosen to assess pain as it has been shown to have a reliability as high as ninety percent for acute pain measurements (ICC 0.97, 95% CI 0.96 to 0.98). Study participants were asked to rate their pain level prior to EMG insertion, immediately after fine wire EMG insertion, prior to peak isometric extension testing, immediately after peak isometric extension testing, and immediately after the conclusion of the endurance testing.

![Figure 3: Sorensen Test for the assessment of lumbar paraspinal muscle extension endurance](image-url)
Data Analysis

Peak isometric back extension torque was obtained as the single maximal spinal extension torque obtained during the 3 MVIC trials. The unit of torque is Newton-meter (N•m). Muscle endurance was measured as duration of time in seconds during the Sorensen test. Levels of discomfort/pain during testing procedures were recorded using a 11-point VAS.

Muscle activation and fatigue were analyzed using the surface EMG data over the contralateral lumbar paraspinal group to determine the global activation and fatigue of the paraspinal muscles. EMG data were filtered (10-450 Hz bandpass) and then full-wave rectified. The maximal muscle activation level was determined as the highest 1-second amplitude during the MVIC trials. For EMG data obtained during the lumbar paraspinal endurance test, median frequency analysis was performed to assess the rate of change of muscle activation frequency over the duration of the trial. A power spectral analysis was performed from each second of data using a fast Fourier transformation to determine the median frequency for each second of two 30 second segments of the endurance test. The first of these 30 second segments being analyzed began ten seconds after the initiation of the endurance test. The last 30 second segment being analyzed concluded ten seconds before termination of the endurance test. The median frequency values obtained were plotted over time and a regression analysis was used to determine the slope of a best-fit line between these points. Additionally, we wanted to determine the percentage of peak muscle activation the participants were using during the endurance task. In order to do this, we first looked at the highest one second average of muscle activation during their MVIC trials (peak muscle activation). We then compared this highest one second average from the MVIC trials to the highest one second average of muscle activation from the first thirty seconds and the last thirty seconds of the endurance task. All EMG data analysis was conducted using a customized program (MATLAB® version R2013a, The MathWorks, Inc., MA, USA).
Statistical Analysis

Statistical analyses were conducted using IBM SPSS version 22.0 software. One-way repeated measures ANOVA was used to compare peak isometric back extension torque, muscle endurance time, pain level, percent muscle activation, and median frequency slopes between the baseline (BL), wire in (WI), and wire out (WO) conditions. The assumption of homogeneity of variance (sphericity) was tested with Mauchly’s Test of Sphericity. Where this was significant, Greenhouse-Geisser adjusted statistics were utilized. Where main effects were apparent, post-hoc tests were conducted utilizing a Bonferroni correction. A paired T-Test was utilized to compare pain scores between the three conditions (BL, WI, and WO) during each muscle performance task. Significance level was set at 0.05 for all statistical analyses.

RESULTS

There was no significant difference in peak torque (MVIC) between the BL, WI, WO trials (p = 0.196) (Table 3). When comparing muscle endurance times between the three sessions, Mauchly’s Test of Sphericity was significant (p = 0.001); Greenhouse-Geisser adjusted statistics showed a significant difference in muscle endurance times between the three sessions (p = 0.025, Greenhouse-Geisser adjusted F = 5.103). Bonferroni post-hoc comparison showed that the muscle endurance time from the WO trial was significantly longer than in the BL condition (p = 0.037) (Table 4). Post-hoc comparison also showed no significant difference in endurance times between the BL and WI trials, or the WI and WO trials (p = 0.238, p = 0.380, respectively) (Table 4).
Our results showed no significant difference in median frequency slopes during the entirety of the endurance tasks between the BL, WI, and WO trials (p = 0.120) (Table 3). There was also no significant difference in the median frequency slope during the first 30 seconds of the endurance task between the BL, WI, and WO trials (p = 0.982), nor was there a significant difference in the median frequency slope during the last 30 seconds of the endurance task between the BL, WI, and WO trials (p = 0.578) (Table 3).

There was no significant difference in percent activation during the first 30 seconds of the endurance task between the BL, WI, and WO trials (p = 0.676) (Table 3). There was also no significant difference in percent activation during the last 30 seconds of the endurance task between the BL, WI, and WO trials (p = 0.154).

Pain was rarely reported during the 3 days of testing. The highest report of pain was a 4/10 and the lowest was a 0/10 (Table 5). None of the participants reported any pain at any point on day 1 (BL) of

### Table 3: Data results from muscle performance tasks between all three trials

<table>
<thead>
<tr>
<th></th>
<th>Baseline (BL)</th>
<th>Wire In (WI)</th>
<th>Wire Out (WO)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Peak Torque (N*m)</strong></td>
<td>116.20 ± 37.317</td>
<td>120.65 ± 38.270</td>
<td>118.40 ± 34.861</td>
<td>0.196</td>
</tr>
<tr>
<td><strong>Sorensen Test Time (s)</strong></td>
<td>142.05 ± 48.159</td>
<td>155.95 ± 58.497</td>
<td>161.30 ± 58.497</td>
<td>0.025*</td>
</tr>
<tr>
<td><strong>Median Frequency Slope (Total)</strong></td>
<td>-0.4004 ± 0.1579</td>
<td>-0.4414 ± 0.2026</td>
<td>-0.4219 ± 0.1762</td>
<td>0.120</td>
</tr>
<tr>
<td><strong>Median Frequency Slope (First 30 seconds)</strong></td>
<td>-0.2561 ± 0.6743</td>
<td>0.6610 ± 0.4636</td>
<td>-0.4699 ± 0.5361</td>
<td>0.982</td>
</tr>
<tr>
<td><strong>Median Frequency Slope (Last 30 seconds)</strong></td>
<td>-0.5148 ± 0.4082</td>
<td>-0.3825 ± 0.5117</td>
<td>-0.5476 ± 0.4527</td>
<td>0.578</td>
</tr>
<tr>
<td><strong>Percent of peak muscle activation (first 30 seconds)</strong></td>
<td>50.30 ± 13.04%</td>
<td>53.23 ± 17.63%</td>
<td>49.47 ± 13.67%</td>
<td>0.676</td>
</tr>
<tr>
<td><strong>Percent of peak muscle activation (last 30 seconds)</strong></td>
<td>60.29 ± 13.94%</td>
<td>56.96 ± 16.51%</td>
<td>55.62 ± 19.38%</td>
<td>0.154</td>
</tr>
</tbody>
</table>

*indicates a significant p-value

### Table 4: Bonferroni post-hoc comparison of Sorensen Test Times between all three trials

<table>
<thead>
<tr>
<th></th>
<th>Condition</th>
<th>Condition</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sorensen Test Time (s)</strong></td>
<td>Baseline (BL)</td>
<td>Wire In (WI)</td>
<td>0.238</td>
</tr>
<tr>
<td></td>
<td>142.05 ± 48.159</td>
<td>155.95 ± 58.497</td>
<td></td>
</tr>
<tr>
<td><strong>Sorensen Test Time (s)</strong></td>
<td>Baseline (BL)</td>
<td>Wire Out (WO)</td>
<td>0.037*</td>
</tr>
<tr>
<td></td>
<td>142.05 ± 48.159</td>
<td>161.30 ± 58.497</td>
<td></td>
</tr>
<tr>
<td><strong>Sorensen Test Time (s)</strong></td>
<td>Wire In</td>
<td>Wire Out (WO)</td>
<td>0.380</td>
</tr>
<tr>
<td></td>
<td>155.95 ± 58.497</td>
<td>161.30 ± 58.497</td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Data results from muscle performance tasks between all three trials

Table 4: Bonferroni post-hoc comparison of Sorensen Test Times between all three trials
testing; therefore, a paired t-test was utilized to determine if there was a difference in reported pain scores between the WI and WO groups. Days 2 and 3 (WI and WO) yielded reports of pain, but no significant difference in pain scores was found between the WI and WO trials during each of the three MVIC trials, after the MVIC trials, during the Sorensen Test, or after the Sorensen Test (p = 0.104, p = 0.186, p = 0.214, p = 0.330, p = 0.527, p = 0.481, respectively) (Table 6). At no point during the study did pain prevent a participant from performing with maximal effort or cause termination of the muscle performance tests.

![Table 5: Pain scores during muscle performance tests from participants that reported pain during testing](image)

*Highest pain value reported (Mean value of all 3 MVIC trials)

<table>
<thead>
<tr>
<th></th>
<th>MVIC</th>
<th>Sorensen Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WI</td>
<td>WO</td>
</tr>
<tr>
<td><strong>Subject 1</strong></td>
<td>3 (2.3)*</td>
<td>0</td>
</tr>
<tr>
<td><strong>Subject 2</strong></td>
<td>1 (1)*</td>
<td>0</td>
</tr>
<tr>
<td><strong>Subject 9</strong></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Subject 10</strong></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Subject 18</strong></td>
<td>1 (0.67)*</td>
<td>0</td>
</tr>
<tr>
<td><strong>Subject 20</strong></td>
<td>1 (0.33)*</td>
<td>0</td>
</tr>
</tbody>
</table>

**Table 6**: Paired T-Test results comparing pain scores between the WI and WO conditions during muscle performance testing

<table>
<thead>
<tr>
<th></th>
<th>Mean Pain Score</th>
<th>Standard Deviation</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MVIC Trial 1</strong></td>
<td>WI 0.200</td>
<td>0.523</td>
<td>0.104</td>
</tr>
<tr>
<td></td>
<td>WO 0.000</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td><strong>MVIC Trial 2</strong></td>
<td>WI 0.150</td>
<td>0.489</td>
<td>0.186</td>
</tr>
<tr>
<td></td>
<td>WO 0.000</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td><strong>MVIC Trial 3</strong></td>
<td>WI 0.200</td>
<td>0.696</td>
<td>0.214</td>
</tr>
<tr>
<td></td>
<td>WO 0.000</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td><strong>After MVIC Trials</strong></td>
<td>WI 0.050</td>
<td>0.224</td>
<td>0.330</td>
</tr>
<tr>
<td></td>
<td>WO 0.000</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td><strong>During Sorensen Test</strong></td>
<td>WI 0.250</td>
<td>0.910</td>
<td>0.527</td>
</tr>
<tr>
<td></td>
<td>WO 0.100</td>
<td>0.447</td>
<td></td>
</tr>
<tr>
<td><strong>After Sorensen Test</strong></td>
<td>WI 0.100</td>
<td>0.308</td>
<td>0.481</td>
</tr>
<tr>
<td></td>
<td>WO 0.250</td>
<td>0.910</td>
<td></td>
</tr>
</tbody>
</table>
DISCUSSION

This study compared the peak isometric back extension torque, endurance, fatigue, percent activation of the lumbar paraspinal musculature, and pain in healthy participants during maximal isometric tasks with and without the insertion of intramuscular EMG electrodes into the lumbar paraspinals. Our hypothesis was that the presence of the fine-wire EMG in the lumbar paraspinal muscles would induce pain into the lumbar paraspinal musculature and subsequently reduce lumbar paraspinal muscle performance in the form of endurance, peak isometric back extension torque, and percent activation, as well as increase paraspinal muscle fatigue. Our results showed that the presence of the EMG fine-wire did not affect any of these factors during the high exertion isometric tasks.

Intramuscular EMG electrodes are widely utilized in studies of deeper musculature, however, there is currently no conclusive evidence as to whether or not their insertion alters muscle behavior. To date, there have been few studies reporting changes in muscle performance due to experimentally induced muscular pain. Many of the current studies look at the function of the paraspinals during experimentally induced pain procedures such as saline solution injection or electrical stimulation. Moseley et al., for example, found that experimentally induced pain alters trunk muscle activation and postural strategy. However, in their study participants were also told to expect a painful stimulus and thus it is possible that they reacted in response to the anticipation of LBP. In our study, the participants reported no pain on the first day of testing (BL) and low pain levels during days 2 and 3 of testing (WO, WI). This leads us to believe that the insertion of the intramuscular EMG does not create the same level of pain and discomfort that is produced during experimentally induced pain studies that utilizes saline injections or electrical stimulation. There have been other studies that also confirm participants experience only minor discomfort due to the insertion of the fine-wire EMG.

Although there has not been previous research on the static performance (torque, endurance, fatigue, percent activation) of the lumbar musculature post EMG insertion, there has been previous research on the effects of intramuscular EMG insertion on thoracolumbar and lumbopelvic kinematics. This research performed by Smith et al found that participants showed no significant difference in
thoracolumbar motion or lumbopelvic motion in the transverse and frontal planes during a dynamic walking task post-intramuscular EMG insertion. These findings, as well as the findings of the current study, indicate that the fine-wire EMG insertion does not affect muscular performance or lumbopelvic kinematics. These results further support the use of intramuscular EMG insertion to assess muscular activity without needing to account for the needle insertion/presence affecting muscular behavior or kinematics.

In the current study, it was seen that there was a significant difference in muscle endurance between the WO and the BL condition. We attributed this increase in endurance to motor learning of the task from practice during the BL session as well as being due to the participants self-efficacy to improve their endurance times in comparison to previous attempts. Interestingly, the increase in endurance was only seen in the WO trials even though WO and WI trial days were randomized. Because of the randomization of WI/WO days the learning effect and/or self efficacy would, in theory, also be controlled for. This does leave the possibility that the presence of the wire during WI trials had some effect on muscle endurance.

However, this difference in endurance could also be explained by one of the possible limitations of our study. Subjects were asked to return for WI and WO testing procedures at a similar time of day as their original baseline testing. They were also instructed on the same warm-up protocol prior to each testing day. Participants were also instructed to refrain from exercise the day of their testing sessions, and to avoid strenuous exercise/activity less than 2 days before their testing sessions. However, subjects were not questioned on activity levels prior to each testing session and differences in their activity levels could have altered muscle function. For example, it is possible that a participant could have spent time before the baseline test resting in anticipation for the baseline testing protocol and then increased/decreased physical activity based on daily life demands in the time just prior to WI/WO trials.

Perceived or anticipated pain can also alter movement. Previous research has found that anticipated pain, more so than actual pain, correlated with altered movement. Unlike the current study, Smith et al assessed trunk mechanics during walking tasks following insertion of fine-wire EMG.
various time points in Smith’s experiment, participants reported their current pain level as well as the pain level they anticipated feeling after needle insertion or after walking tasks. Low pain levels were reported throughout for both current and anticipated pain. It is possible that our participants also anticipated pain and may have altered the biomechanics of their lumbar spine during muscle performance tasks, which is something we could not control for. Smith et al hypothesized that because all participants were made aware of the testing procedure, including the intramuscular EMG procedures, those that were fearful and would have likely had higher anticipated pain opted to not participate. Though we did not ask our participants to report their anticipated pain, we did inform all potential participants about the invasive procedures necessary for placement of the intramuscular EMG devices. Similar to Smith et al, therefore, we may assume that participants that were apprehensive of this process would have chosen not to participate in our study. Therefore the individuals that did participate likely had low levels of anticipated pain which is reflective of the pain reports they provided during muscle performance testing.

One of the primary limitations of this study is that the tasks used to assess lumbar paraspinal function were static, isometric tasks. Our results showed that the insertion of the EMG wire did not significantly change muscle function during tasks that require minimal spinal excursion. However, during everyday life, the lumbar paraspinals do not only function to create spinal stability during isometric tasks, but they also play an important role during tasks that require larger degrees of movement through the spine. For example, they help to create the motions of spinal extension and rotation as well as working eccentrically against gravity when the trunk is moving into flexion.

With this in mind, it is unclear whether or not the EMG insertion would cause enough pain to alter the paraspinal function during more dynamic tasks that do require increased spinal excursion rather than simple isometric tasks. A study completed by Zedka et al attempted to look at how the paraspinal muscles functioned during tasks with greater spinal excursion under painful and non-painful conditions. In their study, they used saline solution injection into the erector spinae muscle to create LBP. Once saline solution had been injected, function of the erector spinae was analysed using surface EMGs placed cutaneously over the muscle. The participants where then instructed to perform a series of maximal spinal
flexion and extension tasks. The results of this study showed that the painful stimuli decreased the velocity and range of trunk motion (flexion and extension in standing) similar to the finding of Smith et al.20,26 The study also found that the mean EMG amplitude of the lumbar paraspinals was significantly decreased during active back extension from a fully flexed position.26

The results of Zedka et al study show that LBP can significantly alter erector spinae function during tasks that require higher levels of spinal excursion. However, these findings cannot be directly translated to the use of intramuscular EMG because the pain ratings reported in the Zedka et al study were much higher (5-6/10 on average) than those reported in the current study. Because the participants in the current study did not report similar pain levels to those in the Zedka et al. study we cannot directly say that the insertion of the EMG wire would similarly cause altered function of the lumbar paraspinals during activities that require more spinal excursion. Although we can speculate that the insertion of the intramuscular EMG would not alter muscle performance in movements that require greater spinal excursion, there is no definitive answer as to what the effects on muscle performance will be. This leaves room for future research to investigate the effects that the presence of the fine-wire EMG has on lumbar paraspinal muscle function during more dynamic tasks.

CONCLUSION

This study provides empirical evidence to validate the use of fine-wire EMG for studying lumbar paraspinal muscle strength, activation and endurance during isometric tasks. Future and past studies using fine-wire EMG for muscle testing procedures do not need to take into consideration the effect that the presence of intramuscular EMG has upon muscle activation, strength, and endurance during isometric tasks.
APPENDIX A

| Number (n) | 20 |
| Mean Age (years) | 25.700 |
| Mean Height (m) | 1.7330 |
| Mean Weight (kg) | 74.255 |

Table 1: Descriptive Statistics of participants

<table>
<thead>
<tr>
<th>Exclusion Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Diabetes mellitus</td>
</tr>
<tr>
<td>2. Rheumatic joint disease</td>
</tr>
<tr>
<td>3. Clotting disorder</td>
</tr>
<tr>
<td>4. Polyneuropathy</td>
</tr>
<tr>
<td>5. Lower back surgery</td>
</tr>
<tr>
<td>6. Bilateral leg pain</td>
</tr>
<tr>
<td>7. Radiological/clinical diagnosis of spinal stenosis</td>
</tr>
<tr>
<td>8. Radiological/clinical diagnosis of structural scoliosis</td>
</tr>
<tr>
<td>9. Spinal malignancy</td>
</tr>
<tr>
<td>10. Spinal infection</td>
</tr>
<tr>
<td>11. Lumbar radiculopathy</td>
</tr>
<tr>
<td>12. Pregnancy</td>
</tr>
<tr>
<td>13. Fear of needles</td>
</tr>
<tr>
<td>14. Any bleeding problems</td>
</tr>
</tbody>
</table>

Table 2: Exclusion Criteria

<table>
<thead>
<tr>
<th></th>
<th>Baseline (BL)</th>
<th>Wire In (WI)</th>
<th>Wire Out (WO)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Torque (N*m)</td>
<td>116.20 ± 37.317</td>
<td>120.65 ± 38.270</td>
<td>118.40 ± 34.861</td>
<td>0.196</td>
</tr>
<tr>
<td>Sorensen Test Time (s)</td>
<td>142.05 ± 48.159</td>
<td>155.95 ± 58.497</td>
<td>161.30 ± 58.497</td>
<td>0.025*</td>
</tr>
<tr>
<td>Median Frequency Slope (Total)</td>
<td>-0.4004 ± 0.1579</td>
<td>-0.4414 ± 0.2026</td>
<td>-0.4219 ± 0.1762</td>
<td>0.120</td>
</tr>
<tr>
<td>Median Frequency Slope (First 30 seconds)</td>
<td>-0.2561 ± 0.6743</td>
<td>0.6610 ± 0.4636</td>
<td>-0.4699 ± 0.5361</td>
<td>0.982</td>
</tr>
<tr>
<td>Median Frequency Slope (Last 30 seconds)</td>
<td>-0.5148 ± 0.4082</td>
<td>-0.3825 ± 0.5117</td>
<td>-0.5476 ± 0.4527</td>
<td>0.578</td>
</tr>
<tr>
<td>Percent of peak muscle activation (first 30 seconds)</td>
<td>50.30 ± 13.04%</td>
<td>53.23 ± 17.63%</td>
<td>49.47 ± 13.67%</td>
<td>0.676</td>
</tr>
<tr>
<td>Percent of peak muscle activation (last 30 seconds)</td>
<td>60.29 ± 13.94%</td>
<td>56.96 ± 16.51%</td>
<td>55.62 ± 19.38%</td>
<td>0.154</td>
</tr>
</tbody>
</table>

Table 3: Data results from muscle performance tasks between all three trials
* indicates a significant p-value
Table 4: Bonferroni post-hoc comparison of Sorensen Test times, * indicates a significant p-value

<table>
<thead>
<tr>
<th>Sorensen Test Time (s)</th>
<th>Condition</th>
<th>Condition</th>
<th>p-value</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Baseline (BL)</td>
<td>Wire In (WI)</td>
<td>0.238</td>
</tr>
<tr>
<td></td>
<td>142.05 ± 48.159</td>
<td>155.95 ± 58.497</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wire Out (WO)</td>
<td>Wire Out (WO)</td>
<td>0.037*</td>
</tr>
<tr>
<td></td>
<td>161.30 ± 58.497</td>
<td>161.30 ± 58.497</td>
<td></td>
</tr>
</tbody>
</table>

Table 5: Pain scores during muscle performance tests from participants that reported pain during testing. *Highest pain value reported (Mean value across trials)

<table>
<thead>
<tr>
<th></th>
<th>Mean Pain Score</th>
<th>Standard Deviation</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MVIC</td>
<td>WI</td>
<td>0.200</td>
<td>0.523</td>
</tr>
<tr>
<td></td>
<td>WO</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>MVIC</td>
<td>WI</td>
<td>0.150</td>
<td>0.489</td>
</tr>
<tr>
<td></td>
<td>WO</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>MVIC</td>
<td>WI</td>
<td>0.200</td>
<td>0.696</td>
</tr>
<tr>
<td></td>
<td>WO</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>After MVIC Trials</td>
<td>WI</td>
<td>0.050</td>
<td>0.224</td>
</tr>
<tr>
<td></td>
<td>WO</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>During Sorensen Test</td>
<td>WI</td>
<td>0.250</td>
<td>0.910</td>
</tr>
<tr>
<td></td>
<td>WO</td>
<td>0.100</td>
<td>0.447</td>
</tr>
<tr>
<td>After Sorensen Test</td>
<td>WI</td>
<td>0.100</td>
<td>0.308</td>
</tr>
<tr>
<td></td>
<td>WO</td>
<td>0.250</td>
<td>0.910</td>
</tr>
</tbody>
</table>

Table 6: Paired T-Test results comparing pain scores between the WI and WO conditions during muscle performance testing.
APPENDIX B

Figure 1: Flow chart of fine-wire insertion/removal protocol.

Figure 2: Axial ultrasound image demonstrating insertion of the EMG (and guide needle).
Figure 3: The Sorensen Test for the assessment of lumbar paraspinal muscle extension endurance
REFERENCES


CURRICULUM VITAE

James DiMascio

Education

- University of Nevada, Las Vegas: Las Vegas, Nevada
  - Doctor of Physical Therapy. Expected Degree: May 2017
- University of Nevada, Las Vegas: Las Vegas, Nevada
  - Bachelor of Science in Kinesiology - Allied Health. May 2012

Clinical Experience

  - Clinical Internship
  - Inpatient rehab physical therapy
- St. Rose Dominican Hospital - Siena Campus : Las Vegas, Nevada: July-October 2016.
  - Clinical Internship
  - Acute rehab physical therapy
- Select Physical Therapy: Henderson, Nevada: July-August 2015.
  - Clinical Internship
  - Outpatient orthopedic physical therapy

Work Experience

  - Physical Therapy Technician.

Continuing/Supplemental Education

• Combined Sections Meeting (CSM) 2016: Anaheim, California.
• UNLV Distinguished Lecture Series: Dr. Shaw Bronner. November 2015.
• Pain Neuroscience Seminar: Dr. Adriaan Louw. April 2015, 2016.
• Trunk Neuromechanics During Turning: a Window Into Recurrent Lower back Pain: Dr. Jo Armour Smith. April 2015.
• UNLV Distinguished Lecture Series: Dr. Timothy Flynn. November 2014.

Professional Association Membership

• American Physical Therapy Association (APTA) member: 2014-present.
  o Orthopedic Section member: 2015-present.
• Nevada Physical Therapy Association (NPTA) member: 2014-present.
• American Heart Association Healthcare Provider CPR and AED Certification since 2014.
  o Expires in April 2017.

Scholarships and Awards

• UNLV Physical Therapy Student Opportunity Research Grant. Summer 2015
Rebeka Hicks

Education

- University of Nevada Las Vegas: Las Vegas, Nevada
  - Doctor of Physical Therapy, Expected degree: May 2017
- Auburn University: Auburn, Alabama
  - Bachelor of Arts

Clinical Experience

- Boulder City Hospital: Boulder City, Nevada. October-December 2016
  - Clinical Internship
  - Outpatient orthopedic physical therapy
- Sunrise Hospital: Las Vegas, Nevada. July-October 2016
  - Clinical Internship
  - Acute Rehab physical therapy
- Tim Soder Physical Therapy: Las Vegas, NV. July-August 2015
  - Clinical Internship
  - Outpatient orthopedic physical therapy

Work Experience

  - Physical Therapy Technician
  - Outpatient orthopedic physical therapy

Continuing/Supplemental Education

• UNLV Distinguished Lecture Series: Dr. Shaw Bronner. November 2015.

• Trunk Neuromechanics During Turning: A Window Into Recurrent Lower back Pain: Dr. Jo Armour Smith. April 2015.

• UNLV Distinguished Lecture Series: Dr. Timothy Flynn. November 2014.

Professional Association Membership

• American Physical Therapy Association (APTA) member since 2014.

• Nevada Physical Therapy Association (NPTA) member since 2014.

• American Heart Association Healthcare Provider CPR and AED Certification since 2014.

Scholarships and Awards

• UNLV Physical Therapy Student Scholarship Award. Spring 2016

• UNLV Physical Therapy Student Opportunity Research Grant. Summer 2015.
Matthew Kimber

Education

- University of Nevada, Las Vegas: Las Vegas, Nevada.
- University of Nevada, Reno: Reno, Nevada
  - Bachelor of Science in Community Health Sciences. May 2013.

Clinical Experience

- Saint Mary’s Regional Medical Center: Reno, Nevada. October-December 2016.
  - Clinical internship
  - Acute Rehab physical therapy
  - Clinical Internship
  - Inpatient Rehab physical therapy
- Registered Physical Therapy: Elko, Nevada July-August 2015.
  - Clinical Internship
  - Outpatient orthopedic physical therapy

Work Experience

  - Physical therapy aide.
  - Office of two neurosurgeons with in-house physical therapy.

Continuing/Supplemental Education

• UNLV Interprofessional Education Seminar. March 2016.
• What to Ask When Job Hunting, and Other Related Topics: Dr. Beren Shaw. February 2016.
• American Physical Therapy Association Combined Sections meeting 2016: Anaheim, California
• UNLV Distinguished Lecture Series: Dr. Shaw Bronner. November 2015.
• American Physical Therapy Association National Student Conclave 2015: Omaha, Nebraska
• Trunk Neuromechanics During Turning: A Window Into Recurrent Lower back Pain: Dr. Jo Armour Smith. April 2015.
• UNLV Distinguished Lecture Series: Dr. Timothy Flynn. November 2014.

Professional Association Membership
• American Physical Therapy Association (APTA) member 2014-present.
• Nevada Physical Therapy Association (NPTA) member 2014-present.
• American Heart Association Healthcare Provider CPR and AED Certification 2014-present.
  • Expires in April 2017.

Scholarships and Awards
• UNLV Physical Therapy Student Opportunity Research Grant. Summer 2015
• UNLVPT Student Scholarship Summer 2016