THE EFFECTS OF SPINAL MOBILIZATION ON HAMSTRING STRENGTH AND ENDURANCE

AMY M KALA JAINEN
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Reviewed and approved* by the following:

Sayers John Miller III
Assistant Professor of Kinesiology
Thesis Supervisor

Giampietro “John” Vairo
Instructor of Kinesiology
Coordinator, Athletic Training Research Laboratory
Co-Thesis Supervisor

Steriani Elavsky
Assistant Professor of Kinesiology
Honors Adviser

* Signatures are on file in the Schreyer Honors College.
ABSTRACT

THE EFFECTS OF SPINAL MOBILIZATION ON HAMSTRING STRENGTH AND ENDURANCE

Kalajainen AK*, Miller SJ*, Sebastianelli WJ†, Vairo GL*†: Athletic Training and Sports Medicine Research Laboratory, *Department of Kinesiology, The Pennsylvania State University, University Park, PA; †Penn State Hershey Bone and Joint Institute – State College, PA

Objective: To primarily investigate the immediate and one-week delayed effects of spinal Grade V mobilization on knee flexor strength and endurance in individuals with limited hamstring extensibility. We hypothesized that spinal mobilization would increase strength and endurance immediately following and one-week post-mobilization. Design and Settings: A pre-test, post-test study was conducted in a controlled laboratory. The independent variable was spinal mobilization. Dependent variables included concentric isokinetic knee flexor strength and endurance. Participants underwent three separate testing sessions. The first session included baseline testing. The second session was separated by 48-72 hours and included spinal mobilization and knee flexor testing. The third session was separated by seven days and included only knee flexors testing. The order of testing the dominant and non-dominant leg was randomized to prevent order effects. Subjects: Twenty-one (14 male, 7 female) healthy, physically active participants (20.0 ± 1.2 years, 1.7 ± 0.1 m, 69.9 ± 12.4 kg) with a straight leg raise of less than 70° (61.1 ± 5.3°) were enrolled. Measurements: Peak moment normalized to body mass, time to peak moment, peak moment angle, average power and total work to body mass were collected using valid and reliable isokinetic testing protocols. Group means and standard deviations were calculated by testing session. One-way analyses of variance with Tukey’s post hoc test calculated differences among testing sessions. P ≤ 0.05 denoted statistical significance. Results: No statistically significant differences existed for all the strength and endurance measures among testing sessions for the dominant and non-dominant legs; [dominant flexion: peak moment (baseline = 1.036 ± 0.402, immediately post = 1.046 ± 0.435, week-post = 1.046 ± 0.435; P = 0.993); total work (baseline = 14.676 ± 8.883, immediately post =14.455 ± 8.454, week-post = 15.791 ± 11.211; P=0.890)]; [non-dominant flexion: peak moment (baseline = 0.920 ± 0.390, immediately post = 0.973 ± 0.462, week-post = 0.982 ± 0.475; P=0.885); total work (baseline = 13.525 ± 8.739, immediately post = 15.004 ± 9.186, week-post = 13.931 ± 8.377, P=0.853)]. Conclusions: Our findings suggest that one bout of spinal mobilization elicits no significant immediate or delayed effect on knee flexor strength or endurance measures in a healthy, physically active population with limited hamstring extensibility. Additional investigation is warranted to determine the effects of spinal mobilization on knee flexor performance. Word Count: 379

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I would like to thank my family and friends for their support throughout this process. I am blessed to be surrounded by people who I can depend on for support, encouragement and advice. This network has been uplifting and motivating as I have journeyed through this process. I am forever grateful for their unconditional love.

I would lastly like to thank the Department of Kinesiology for their funding for this research project through the “Marie Underhill Noll Endowment for Undergraduate Research”.
Chapter 1

Introduction

An association between spinal manipulation and improved muscle function has been established in the quadriceps,\(^1\) erector spinae\(^2\) and deep neck flexors.\(^3\) The biological mechanism by which this occurs is not fully understood, but there is a proposed mechanism by which manipulation increases muscle function and activation via a neurophysiologic effect.\(^4\) This effect may be related to an alteration of motorneuron excitability.\(^4\)\(^-\)\(^6\) It is proposed that manipulation activates mechanoreceptors and proprioceptors surrounding the associated joint, which alters afferent input.\(^7,\)\(^8\) This results in the changes in motorneuron excitability, causing regional or local muscular inhibition or activation surrounding the associated joint.\(^4\) Another proposed mechanism is a reflexogenic effect, which involves evoking muscle reflexes, which alter central or peripheral neural pathways.\(^4\) Dunning et al,\(^9\) for example, demonstrated an increase in excitation of the biceps brachii following manipulation of the right C5/6 joint.

Abnormal neuromuscular and biomechanical factors, particularly associated with the vastus medialis\(^10\), have been proposed as factors leading to altered patellar tracking which contributes to increased patellofemoral joint contact, and ultimately, pain and discomfort.\(^11\) The results of various studies\(^10\)\(^12,\)\(^13\) have described a significant decrease of quadriceps inhibition and related increased strength following manipulation of the sacroiliac (SI) joint. This led to the hypothesis that SI joint manipulation could therefore decrease patellofemoral joint discomfort.\(^11\) Iverson et al\(^11\) found that for 45% of their subjects, SI joint manipulation was a successful treatment to decrease pain associated with patellofemoral dysfunction. From that finding, a clinical prediction rule was created, indicating SI joint manipulation as an effective treatment of patellofemoral joint pain in a subset of patients.\(^11\)
Marshall et al\textsuperscript{14} studied the effect of SI joint manipulation on feed-forward activation times of the transverse abdominis. It was found that there was a significant difference between the onset-time of the transverse abdominis during a shoulder flexion task after manipulation of the SI joint in patients who presented with a delayed response for 6 months prior to manipulations.\textsuperscript{14} This study demonstrated a link between stability of a specific joint and central nervous system coordination of muscles associated with that specific joint.\textsuperscript{14} Spinal manipulation has been shown to affect muscle activation and function and this alteration has been shown to improve conditions such as core stability and patellofemoral joint tracking.\textsuperscript{4, 10, 11}

While research has been done investigating the effect of spinal mobilization on various other muscle groups, there is a lack of research investigating the effect that mobilization can have on the knee flexors. The purpose of this study is to determine the effect of spinal mobilization on the strength and endurance of the knee flexor muscles, both immediately following spinal mobilization as well as one week post-mobilization. The hypothesis for this study is that Grade V spinal mobilization will increase the strength and endurance of the knee flexor muscles immediately post-mobilization, but the effects will diminish one week post-mobilization. This hypothesis is based on previous findings that spinal mobilization has an effect on the strength of related musculature such as the quadriceps, and multifidi.\textsuperscript{11 4}. Additionally, Brenner et al\textsuperscript{4} determined that the increased thickness of the multifidi remained present 24 hours following mobilization but little to no evidence exists to support the presence of long-term changes.
Chapter 2

Methods and Materials

Experimental Design

This study employed a pre-test, posttest prospective cohort design with level 2b\textsuperscript{15} evidence. The independent variable was the Grade V spinal mobilization. The dependent variables were the concentric isokinetic strength and endurance of the knee flexors. The specific measures of strength and endurance recorded included average power (W/kg), total work to body mass ratio at 240º/s (J/kg), peak moment angle (°), time to peak moment (s), and peak moment to body mass (Nm/kg). Measures were recorded at baseline, immediately following spinal mobilization and one-week following spinal mobilization. Dependent variable measurements for dominant and non-dominant leg knee flexion and extension were compared as repeated measures over the one-week time period.

Participants were recruited using University Institutional Review Board (IRB) approved recruitment materials (Appendix A). Materials directed potential participants to the principal investigator (GLV). Interested participants were assessed for eligibility through the use of a screening questionnaire and self-selected Tegner activity level (Appendix A) to determine their eligibility for enrollment. A straight leg raise test was performed to ensure that the participant had limited hamstring extensibility, defined as SLR < 70°. Prior to official enrollment, all qualifying participants were asked to complete an IRB approved written informed consent form (Appendix B) in accordance with standards set forth by the Penn State Office for Research Protections. Participants completed three sessions, each lasting approximately one hour. The first session tested baseline measures for knee flexor strength and endurance. Due to the nature of
isokinetic testing, knee flexor and extensor measures were recorded, but the focus of this study was the effect of spinal mobilization on the knee flexors; therefore, the focus of the analysis remained on the knee flexors. The second session, approximately 48-72 hours later, involved the intervention of the spinal mobilization followed by testing of immediate change in knee flexor strength and endurance. The final session, seven days after mobilization, tested knee flexor strength and endurance to determine lasting changes.

During the first session, all participants reported their dominant leg, followed by anthropometric measures of height and weight (Appendix A). Prior to every testing session, participants then walked for five minutes on a flat treadmill (Woodway USA, Waukesha, WI) at a common speed of 1.2 m/s as a warm up (Figure 2.1). Randomization for the sequence of testing a patient's dominant and non-dominant leg was completed by way of a coin toss, which was repeated for each testing session.

Strength and endurance measures were then performed on the opposite leg. This comprised the entirety of session one. Session two began with thoracic and lumbopelvic mobilization performed by a practicing licensed physical therapist with extensive manual therapy experience. The strength and endurance measures were then collected in the same manor. The third session was identical to the first session.

Thoracic spine mobilization was performed in accordance with previously used methods (Figure 2.2). The participant was positioned supine and was instructed to link their hands behind the neck by clasping the hands. The shoulders were passively horizontally adducted until the elbows touched one another. The practitioner then rolled the participant forward and placed a “pistol grip” on the participant’s back before rolling the participant back onto the table. The practitioner pulled the participant’s arm down to induce spinal flexion. The participant was
instructed to take a deep breath and a Grade V mobilization was performed as the participant breathed out, through the participant’s arms.

Grade V lumbopelvic mobilization was performed bilaterally. The term lumbopelvic is used to describe this technique because it targets a large region and is not specific to the lumbar, sacral or pelvic regions. The mobilization technique performed was consistent with previously used methods. The participant was passively side-bent toward and rotated away from the selected side, followed by a posterior/inferior force through the opposite anterior superior iliac spine (Figure 2.3).

Finally, lumbar spine mobilization was performed in accordance with previously utilized techniques (Figure 2.4). The participant was positioned supine in a neutral/extended posture. Trunk rotation was created by pushing the upper shoulder of the participant away from the practitioner. Rotation and side bending were introduced in the same direction until segment movement was detected. A high velocity, low amplitude thrust was then applied rotationally through the hips. If a cavitation was not heard or perceived, the mobilization was attempted a second time. If a cavitation was not heard to perceived in the second attempt, the practitioner continued to the opposite side.
Figure 2.1 Electric Treadmill
Figure 2.2 Thoracic Mobilization Technique
Figure 2.3 Lumbopelvic Mobilization Technique
Participants

Twenty-one individuals participated in this study. In order to be considered a qualified participant, individuals must have met the following inclusion criteria: physically active men and women 18-35 years of age, of good health, nonsmoker, and limited hamstring flexibility. No exclusion criteria were based upon sex, race or ethnicity. Physically active was defined as a score of 5 or higher on the self-reported Tegner Scale (Appendix A). Limited hamstring flexibility was defined as a straight leg raise of less than 70 degrees with the ankle in 0 degrees of dorsiflexion and the knee controlled in 180 degrees of extension.25
Demographic and anthropometric measures comprised height, mass, activity level, age, sex and leg dominance. Height was measured using a wall mounted analogue stadiometer (Cardinal/Detecto Scale Mfg. Co., Webb City, MO) and mass was measured using a calibrated eye-level analog scale (Cardinal/Detecto Scale Mfg. Co., Webb City, MO). Leg dominance was defined as the leg with which the patient would prefer to kick a soccer ball for distance and accuracy, which complements previous research studies.\textsuperscript{16, 17}

**Straight Leg Raise**

The first experimental measure taken was a straight leg raise (Figure 2.5, Figure 2.6, Figure 2.7). Participants presenting with a straight leg raise of less than 70 degrees were determined to have limited hamstring flexibility, and therefore were eligible to continue the study.\textsuperscript{25} Participants who presented as eligible were recorded and their individual straight leg raise measurement was documented. To perform the straight leg raise test, a hard ankle splint was applied to the ankle in 0º of dorsiflexion. This splint controlled the effect of the gastrocnemius in the exam and created a consistent measure between participants. The knee joint excursion was controlled using a metal knee brace locked at 180º. The pelvis was secured to the table using a belt across the pelvis and around the table. Another belt was secured around the nondominant leg, across the mid-thigh. Lifting of the leg stopped when pelvis rotation was observed or based on subjective evaluation of the participant, indicating that end range had been met. One examiner held the leg in position, while the other examiner used the goniometer. The fulcrum of the goniometer was placed over the lateral aspect of the hip joint at the greater trochanter. The proximal arm was in line with the lateral midline of the pelvis, and the distal arm
was aligned with the lateral midline of the femur, using the lateral epicondyle as a reference point.\textsuperscript{18}

Figure 2.5 Straight Leg Raise Set Up
Figure 2.6 Straight Leg Raise Technique
Strength and endurance were measured using an isokinetic dynamometer (Biodex Medical Inc., Shirley, NY, USA) (Figure 2.8, Figure 2.9, Figure 2.10). Biodex isokinetic concentric testing has been found to have high test-retest reliability in seven day intervals.\textsuperscript{21} Due to the nature of isokinetic testing, knee flexor and extensor data was collected. Each set of data was statistically analyzed, but the focus of this study remained on the knee flexors. The participant completed a coin toss to determine the first leg tested. The participant was then asked
to lay in a prone position on the Biodex table with the base of the patella approximately one inch off the end of the table. This position placed the hip in approximately 0° of flexion. The hips and mid-thigh were strapped snug to limit accessory motion. The fulcrum of the lever arm was positioned in line with the lateral joint line of the knee, using the lateral epicondyle of the femur as a reference point. The strap of the lever arm was attached around the distal shank of the tested leg. Once the set up was complete, the participant was instructed to keep their hands at their side, not grasping the side of the table. The participant was also instucted to keep the back relaxed and head in the neutral position, without arching throughout testing (Figure 2.4).

Figure 2.8 Electronic exercise machine (Biodex Medical Inc., Shirley, NY, USA)
Figure 2.9 Isokinetic Strength and Endurance Measures Set Up
Figure 2.10 Isokinetic Strength and Endurance Measures Technique

Strength was measured first at a rate of 60 degrees per second. For the warm up, the participant was instructed to perform three full range knee flexion and extension repetitions at 50% of their perceived maximum strength potential, followed by a one-minute rest interval. The warm up continue with one set of three repetitions at 75% maximum perceived effort followed by a one-minute rest interval. The test was then performed, and the participant was instructed to perform three knee flexion and extension repetitions at maximum effort. These values were recorded and the participant had a two-minute rest interval prior to endurance testing. Peak moment was defined as the peak torque in joules per kilogram of body mass. Time to peak moment was defined in seconds. Angle of peak moment was defined as the angle of peak torque
relative to full knee extension in degrees. Average power was defined as the average power in watts during the three repetitions per kilogram of body mass.

The endurance measures were taken at 240 degrees per second. The warm up consisted of one set of five repetitions. The first four repetitions were instructed to be at a self-selected effort, followed by the final repetition at maximum effort. The participant was then instructed to perform as many knee flexion and extension repetitions as quickly as possible in a 45-second time interval. Total work was defined as joules per kilogram of body mass during the 45 second interval.

**Statistical Analyses**

Descriptive statistics, such as group means and standard deviations were calculated for the dependent variables. Separate one-way analysis of variance (ANOVA) tests were calculated to determine statistically significant differences among the testing sessions (baseline, immediately following, one week after) for each dependent variable for the dominant and non-dominant leg. An *a priori* alpha level of *P* < 0.05 indicated statistical significance. Tukey’s Honestly Significant Difference post hoc test assessed pairwise comparisons with respective statistical significance determined by way of a 95% simultaneous confidence interval. Concurrent inspection of the standardized residuals was conducted to verify the data meet the necessary assumptions for ANOVA.

To calculate magnitude of difference for the dependent variable measures between each testing session, effect sizes were calculated accordingly for the dominant and non-dominant legs. Effect size was calculated using the guidelines described by Cohen\textsuperscript{20}, and interpreted in a manner
such that values ≤ 0.40 signified weak, values ranging from 0.41 to 0.70 signified moderate and values ≥ 0.71 signified strong effects.
Chapter 3

Results

The results indicate that there is no significant effect of spinal mobilization on dominant (Table 3.1) or non-dominant (Table 3.2) knee flexor strength or knee flexor endurance. Additionally, associated assessments demonstrated no statistically significant effect of spinal mobilization on dominant (Table 3.3) or non-dominant (Table 3.4) knee extensor strength or endurance. Of the measures collected, no measurements demonstrated a statistically significant increase or decrease immediately post-mobilization or one week post-mobilization. For most measures, effect size was small for baseline to immediately post as well as baseline to one-week post, but select time to peak moment and angle of peak moment measures demonstrated a moderate effect size.

Time to peak torque comparisons demonstrated a moderate effect size from baseline to one-week post for dominant knee extension and non-dominant knee flexion. Additionally, peak moment angle comparisons demonstrated a similar effect. Baseline to one-week post in dominant knee extension and non-dominant knee flexion revealed a moderate effect size.
### Table 3.1 Dominant Knee Flexor Strength and Endurance Measures

#### STRENGTH

<table>
<thead>
<tr>
<th>Trial</th>
<th>Peak Moment (Nm/kg)</th>
<th>% difr</th>
<th>95 % SCI (Upper, Lower)</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>1.031 ± 0.433</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>v Immediately-post</td>
<td>1.036 ± 0.402</td>
<td>0.49</td>
<td>(0.319, -0.309)</td>
<td>0.011</td>
</tr>
<tr>
<td>v One Week-post</td>
<td>1.046 ± 0.435</td>
<td>1.46</td>
<td>(0.330, -0.299)</td>
<td>0.035</td>
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<table>
<thead>
<tr>
<th>Trial</th>
<th>% difr</th>
<th>95 % SCI (Upper, Lower)</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>v Immediately-post</td>
<td></td>
<td>(0.319, -0.309)</td>
<td>0.011</td>
</tr>
<tr>
<td>v One Week-post</td>
<td></td>
<td>(0.330, -0.299)</td>
<td>0.035</td>
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</table>

<table>
<thead>
<tr>
<th>Trial</th>
<th>Time to Peak Moment (s)</th>
<th>% difr</th>
<th>95 % SCI (Upper, Lower)</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>0.708 ± 0.261</td>
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<tr>
<td>v Immediately-post</td>
<td>0.748 ± 0.291</td>
<td>5.593</td>
<td>(0.242, -0.160)</td>
<td>0.156</td>
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<tr>
<td>v One Week-post</td>
<td>0.688 ± 0.258</td>
<td>2.867</td>
<td>(0.181, -0.221)</td>
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<table>
<thead>
<tr>
<th>Trial</th>
<th>Peak Moment Angle (degree)</th>
<th>% difr</th>
<th>95 % SCI (Upper, Lower)</th>
<th>d</th>
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<tbody>
<tr>
<td>Baseline</td>
<td>78.524 ± 15.407</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>v Immediately-post</td>
<td>76.758 ± 17.309</td>
<td>2.274</td>
<td>(9.98, -13.52)</td>
<td>0.115</td>
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<tr>
<td>v One Week-post</td>
<td>79.810 ± 14.675</td>
<td>1.624</td>
<td>(13.03, -10.46)</td>
<td>0.083</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial</th>
<th>Average Power (W/kg)</th>
<th>% difr</th>
<th>95 % SCI (Upper, Lower)</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>0.477 ± 0.246</td>
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<tr>
<td>v Immediately-post</td>
<td>0.459 ± 0.152</td>
<td>3.861</td>
<td>(1.913, -1.949)</td>
<td>0.073</td>
</tr>
<tr>
<td>v One Week-post</td>
<td>0.455 ± 0.224</td>
<td>4.684</td>
<td>(2.892, -0.970)</td>
<td>0.089</td>
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#### ENDURANCE

<table>
<thead>
<tr>
<th>Trial</th>
<th>Total Work (J/kg)</th>
<th>% difr</th>
<th>95 % SCI (Upper, Lower)</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>14.676 ± 8.883</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>v Immediately-post</td>
<td>14.455 ± 8.454</td>
<td>1.517</td>
<td>(6.896, -7.338)</td>
<td>0.025</td>
</tr>
<tr>
<td>v One Week-post</td>
<td>15.791 ± 11.211</td>
<td>7.326</td>
<td>(8.233, -6.001)</td>
<td>0.126</td>
</tr>
</tbody>
</table>

Values are mean ± standard deviation; SCI = simultaneous confidence interval; v = versus; % difr = percent difference; d = Cohen’s effect size; (P < 0.05) denotes statistical significance
Table 3.2 Non-dominant Knee Flexor Strength and Endurance Measures

<table>
<thead>
<tr>
<th>Trial</th>
<th>Peak Moment (Nm/kg)</th>
<th>% difr</th>
<th>95 % SCI (Upper, Lower)</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>0.920 ± 0.390</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>v Immediately-post</td>
<td>0.973 ± 0.462</td>
<td>5.624</td>
<td>(0.383, -0.276)</td>
<td>0.136</td>
</tr>
<tr>
<td>v One Week-post</td>
<td>0.982 ± 0.475</td>
<td>6.603</td>
<td>(0.392, -0.267)</td>
<td>0.161</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Trial</th>
<th>Time to Peak Moment (s)</th>
<th>% difr</th>
<th>95 % SCI (Upper, Lower)</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>0.884 ± 0.358</td>
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</tr>
<tr>
<td>v Immediately-post</td>
<td>0.818 ± 0.406</td>
<td>7.737</td>
<td>(0.203, -0.334)</td>
<td>0.184</td>
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<tr>
<td>v One Week-post</td>
<td>0.691 ± 0.315</td>
<td>24.494</td>
<td>(0.076, -0.461)</td>
<td>0.539</td>
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</table>

<table>
<thead>
<tr>
<th>Trial</th>
<th>Peak Moment Angle (°)</th>
<th>% difr</th>
<th>95 % SCI (Upper, Lower)</th>
<th>d</th>
</tr>
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<tbody>
<tr>
<td>Baseline</td>
<td>67.762 ± 21.764</td>
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<tr>
<td>v Immediately-post</td>
<td>73.079 ± 22.961</td>
<td>7.551</td>
<td>(21.01, -10.38)</td>
<td>0.244</td>
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<tr>
<td>v One Week-post</td>
<td>79.667 ± 18.489</td>
<td>16.150</td>
<td>(27.60, -3.79)</td>
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<table>
<thead>
<tr>
<th>Trial</th>
<th>Average Power (W/kg)</th>
<th>% difr</th>
<th>95 % SCI (Upper, Lower)</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>0.589 ± 0.516</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>v Immediately-post</td>
<td>0.452 ± 0.238</td>
<td>26.350</td>
<td>(0.126, -0.400)</td>
<td>0.266</td>
</tr>
<tr>
<td>v One Week-post</td>
<td>0.425 ± 0.231</td>
<td>32.383</td>
<td>(0.099, -0.427)</td>
<td>0.318</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial</th>
<th>Total Work (J/kg)</th>
<th>% difr</th>
<th>95 % SCI (Upper, Lower)</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>13.525 ± 8.739</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>v Immediately-post</td>
<td>15.004 ± 9.186</td>
<td>10.366</td>
<td>(7.988, -5.031)</td>
<td>0.169</td>
</tr>
<tr>
<td>v One Week-post</td>
<td>13.931 ± 8.377</td>
<td>2.954</td>
<td>(6.915, -6104)</td>
<td>0.046</td>
</tr>
</tbody>
</table>

Values are mean ± standard deviation; 
SCl = simultaneous confidence interval; v = versus; % difr = percent difference; 
$\text{d} = \text{Cohen’s effect size;}$

$(P < 0.05)$ denotes statistical significance
Table 3.3 Dominant Knee Extensor Strength and Endurance Measures

<table>
<thead>
<tr>
<th>Trial</th>
<th>Peak Moment (Nm/kg)</th>
<th>% difr</th>
<th>95 % SCI (Upper, Lower)</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>1.079 ± 0.239</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>v Immediately-post</td>
<td>1.029 ± 0.187</td>
<td>4.758</td>
<td>(0.107, -0.207)</td>
<td>0.210</td>
</tr>
<tr>
<td>v One Week-post</td>
<td>1.007 ± 0.204</td>
<td>6.827</td>
<td>(0.085, -0.228)</td>
<td>0.299</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial</th>
<th>Time to Peak Moment (s)</th>
<th>% difr</th>
<th>95 % SCI (Upper, Lower)</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>0.482 ± 0.207</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>v Immediately-post</td>
<td>0.481 ± 0.307</td>
<td>0.325</td>
<td>(0.172, -0.175)</td>
<td>0.008</td>
</tr>
<tr>
<td>v One Week-post</td>
<td>0.363 ± 0.165</td>
<td>28.15</td>
<td>(0.055, -0.293)</td>
<td>0.575</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial</th>
<th>Peak Moment Angle (°)</th>
<th>% difr</th>
<th>95 % SCI (Upper, Lower)</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>29.381 ± 11.111</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>v Immediately-post</td>
<td>30.052 ± 16.158</td>
<td>2.257</td>
<td>(4.397, -4.597)</td>
<td>0.060</td>
</tr>
<tr>
<td>v One Week-post</td>
<td>22.952 ± 8.200</td>
<td>24.568</td>
<td>(4.806, -4.188)</td>
<td>0.579</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial</th>
<th>Average Power (W/kg)</th>
<th>% difr</th>
<th>95 % SCI (Upper, Lower)</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>0.686 ± 0.159</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>v Immediately-post</td>
<td>0.685 ± 0.144</td>
<td>0.391</td>
<td>(0.108, -0.114)</td>
<td>0.017</td>
</tr>
<tr>
<td>v One Week-post</td>
<td>0.642 ± 0.145</td>
<td>6.479</td>
<td>(0.068, -0.154)</td>
<td>0.271</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial</th>
<th>Total Work (J/kg)</th>
<th>% difr</th>
<th>95 % SCI (Upper, Lower)</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>24.295 ± 6.132</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>v Immediately-post</td>
<td>24.195 ± 5.548</td>
<td>0.412</td>
<td>(4.397, -4.597)</td>
<td>0.016</td>
</tr>
<tr>
<td>v One Week-post</td>
<td>24.604 ± 6.467</td>
<td>1.264</td>
<td>(4.806, -4.188)</td>
<td>0.050</td>
</tr>
</tbody>
</table>

Values are mean ± standard deviation;
SCI = simultaneous confidence interval; v = versus; % difr = percent difference;
d = Cohen’s effect size;
(P < 0.05) denotes statistical significance
Table 3.4 Non-dominant Knee Extensor Strength and Endurance Measures

**STRENGTH**

<table>
<thead>
<tr>
<th>Trial</th>
<th>Peak Moment (Nm/kg)</th>
<th>% difr</th>
<th>95 % SCI (Upper, Lower)</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>1.026 ± 0.204</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>v Immediately-post</td>
<td>0.998 ± 0.196</td>
<td>2.78</td>
<td>(0.125, -0.181)</td>
<td>0.138</td>
</tr>
<tr>
<td>v One Week-post</td>
<td>1.000 ± 0.218</td>
<td>2.49</td>
<td>(0.128, -0.178)</td>
<td>0.124</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial</th>
<th>Time to Peak Moment (s)</th>
<th>% difr</th>
<th>95 % SCI (Upper, Lower)</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>0.543 ± 0.278</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>v Immediately-post</td>
<td>0.464 ± 0.230</td>
<td>15.628</td>
<td>(0.121, -0.279)</td>
<td>0.284</td>
</tr>
<tr>
<td>v One Week-post</td>
<td>0.453 ± 0.297</td>
<td>17.973</td>
<td>(0.111, -0.290)</td>
<td>0.323</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial</th>
<th>Peak Moment Angle (°)</th>
<th>% difr</th>
<th>95 % SCI (Upper, Lower)</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>32.667 ± 15.752</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>v Immediately-post</td>
<td>29.361 ± 14.386</td>
<td>10.658</td>
<td>(8.95, -15.56)</td>
<td>0.210</td>
</tr>
<tr>
<td>v One Week-post</td>
<td>28.381 ± 19.075</td>
<td>14.041</td>
<td>(7.97, -16.54)</td>
<td>0.272</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial</th>
<th>Average Power (W/kg)</th>
<th>% difr</th>
<th>95 % SCI (Upper, Lower)</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>0.676 ± 0.128</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>v Immediately-post</td>
<td>0.660 ± 0.115</td>
<td>2.494</td>
<td>(0.076, -0.109)</td>
<td>0.130</td>
</tr>
<tr>
<td>v One Week-post</td>
<td>0.665 ± 0.130</td>
<td>1.635</td>
<td>(0.082, -0.103)</td>
<td>0.086</td>
</tr>
</tbody>
</table>

**ENDURANCE**

<table>
<thead>
<tr>
<th>Trial</th>
<th>Total Work (J/kg)</th>
<th>% difr</th>
<th>95 % SCI (Upper, Lower)</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>23.872 ± 4.913</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>v Immediately-post</td>
<td>25.219 ± 5.096</td>
<td>5.490</td>
<td>(5.071, -2.376)</td>
<td>0.274</td>
</tr>
<tr>
<td>v One Week-post</td>
<td>24.050 ± 5.043</td>
<td>0.742</td>
<td>(3.901, -3.545)</td>
<td>0.036</td>
</tr>
</tbody>
</table>

Values are mean ± standard deviation; SCI = simultaneous confidence interval; v = versus; % difr = percent difference; d = Cohen’s effect size; (P < 0.05) denotes statistical significance
Chapter 4
Discussion

Contrary to the stated hypothesis of this study, no statistically significant differences in strength or endurance were found among the baseline, immediately post or one-week post-mobilization conditions for both legs. Thus, the results of this study compliment those of de Almeida et al\textsuperscript{24} that demonstrated Grade V spinal mobilization had no effect on strength or endurance of the related perineal musculature. This experiment represents one of the first to examine the effects of spinal mobilization on clinical indices of strength and endurance, whereas the majority of investigations centered on this theme have explored EMG responses.\textsuperscript{2, 22, 23} While this limits comparisons to other related studies, its direct applicability in the clinical setting makes it a worthwhile contribution to the literature. The outcomes of this study contrast the EMG findings of Dunning et al\textsuperscript{9}, Marshall et al\textsuperscript{14} and Suter & McMorland\textsuperscript{10}. Thus, our results to an extent supplement the conflicting EMG studies specific to this body of work and reinforce the theme that, spinal mobilization does not appear to change knee flexor strength or endurance.

The inclusion criteria of a SLR $<70^\circ$ was used as a proxy for potential neuromuscular or contractile sources of range of motion limitation. This source of limitation could lead to potential susceptibility to change by mobilization, which could affect neuromuscular components. Due to previous studies showing improved muscle activation after manipulation\textsuperscript{9,10,24}, we hypothesized that strength may change accordingly. A SLR of $<70^\circ$ may not have been a large enough limitation to detect neurally limited causes.

While no statistically significant differences between measures were found, non-dominant knee flexion time to peak torque demonstrated a moderate effect size, indicating a
decrease in time to peak torque one-week post-mobilization compared to baseline measures. This trend complements the findings of de Almeida et al\textsuperscript{24}, which noted a decreased time to peak moment for musculature following spinal mobilization. This study concluded that the manipulation performed on the sacrum only affected the related timing and strength of contraction, not the pelvic floor muscle endurance or synergistic muscle contraction. Additionally, non-dominant knee flexion angle of peak torque increased one-week post-mobilization compared to baseline measures with a moderate effect size. Concurrently, dominant knee extension time to peak torque decreased and dominant knee extension angle of peak torque increased from baseline to one-week post-mobilization, both with a moderate effect size. It is possible that participants were more comfortable with the isokinetic testing by the third session, therefore affecting performance. Additionally, due to the lack of statistical significance, it is possible that this moderate effect size was due to chance rather than the spinal mobilization.

The study indicates that spinal mobilization potentially has no direct effect on the strength or endurance of the knee flexors. Limited studies have investigated the effect of mobilization on muscle group action; therefore, there is limited evidence to support or refute our findings. This study does implicate that despite possible EMG changes following spinal mobilization, that activity does not necessarily increase the total force created by the muscle or the endurance capabilities of the muscle. Our findings do not support the use of one session of spinal mobilization to improve knee flexor strength in healthy individuals with limited hamstring range of motion.
Limitations

This study was conducted on a relatively young population, consisting primarily of college-age participants who presented with no low back pain or relevant injury. All participants presented with limited hamstring extensibility as demonstrated by a SLR of less than 70° prior to participation. These conditions limit the generalizability of this study to young and healthy individuals with limited hamstring extensibility as measured in this experiment. Thus, we cannot extrapolate these outcomes to different populations, such as those presenting with spinal dysfunction, asymmetrical differences in SLR, pathological neural sciatic nerve irritation or the elderly. Although this constrains the external validity of this investigation, it does considerably boost the internal validity.

The small sample size may underpin the lack of statistical significance. Thus, further research should be performed to determine if the results of this experiment are comparable or differ from similar investigations. Additionally, we did not control for activities of the participants outside of the lab. Therefore, performance on the associated tests could have been affected by a number of confounding variables such as exhaustion, muscle soreness, lack of motivation, or anxiety. Such factors may have varied between the three sessions, therefore, impacting the results. Additionally, some patients did not mobilize well. Although an audible “pop” was achieved with the majority of mobilization attempts, it was not achieved with all. This may indicate a lack of success of the mobilization procedure and therefore a limitation of effect on strength and endurance measures. Finally, the required SLR criterion for inclusion was less than 70° of hip flexion. It has been noted that a population with greater limited hamstring extensibility may lead to different results. Further research should investigate the effects of spinal mobilization on a population with less hamstring extensibility to determine if the effect
would be present in a more limited population. Additionally, participants completed measures for another variable between mobilization and isokinetic testing. According to Grindstaff et al\textsuperscript{1}, the effects of spinal mobilization are extremely transient, lasting less than one hour. Further research should move directly from mobilization to isokinetic testing, as efficiently as possible.

Continued research in the field of neuromuscular adaptations to spinal mobilization is needed to clarify the potential indications and contraindications for spinal mobilization in a clinical setting. Research should investigate whether a more limited SLR range of motion would lead to more significant results. Research should also investigate the effects of spinal mobilization on knee flexor strength and endurance in a population with limited strength rather than limited extensibility. Additional study is necessary to determine in what situations spinal mobilization causes an inhibitory effect as opposed to an activating effect. Research can investigate if the clinical practitioner can control the effects or if patient demographics or pre-existing conditions affect the results. Further research should also investigate if spinal mobilization affects performance on purely functional tasks via a physiological effect or via a placebo effect.

**Conclusions**

In conclusion, our research study demonstrated that spinal mobilization had no effect on concentric isokinetic knee flexor strength or endurance in individuals with limited hamstring extensibility. We attribute our lack of significance to the lack of change in neural activation of the related musculature following mobilization. Based on our results, a single trial of spinal mobilization did not change strength or endurance of knee flexors in healthy individuals with mild limitations in SLR range of motion. Further research is warranted to
clarify the current research regarding the effect of spinal mobilization on muscle activation and inhibition.
REFERENCES


Appendix A

IRB Approval

Date: July 30, 2012
From: Philip C. Frum, Compliance Coordinator
To: Giampietro L. Vairo
Subject: Research Proposal - Modification (IRB #38956)
Approval Expiration Date: June 26, 2013
(Note: This date reflects the anniversary date of the actual submission approval date.)

“Neuromuscular Adaptations to Spinal Mobilizations in a Young, Healthy and Physically Active Cohort.”

The revision(s) to the above-referenced study has been reviewed and approved by the Institutional Review Board (IRB). You may proceed with your study. Please continue to notify the IRB of any further changes to your study.

COMMENT: Modifications approved on 7/30/12 Include: 1) Addition of Funding Source, 2) Changes in Compensation

ICF has also been updated and approved to reflect changes in compensation.

On behalf of the IRB and the University, thank you for your efforts to conduct research in compliance with the federal regulations that have been established for the protection of human participants.

Please Note: The ORP encourages you to subscribe to the ORP listserv for protocol and research-related information. Send a blank email to: L-ORP-Research-L-subscribe-request@lists.psu.edu

PCF/pcf
Appendix B

Recruitment Flyer

Athletic Training Research Laboratory

Research Volunteers Needed

Are you interested in learning more about the potential causes of hamstring stiffness?

If so, you may be interested in participating in our research study at Penn State.

**Measurements:** hamstrings strength, endurance and stiffness

**Purpose:** Study the effects of spinal mobilization on the strength, endurance and stiffness of the hamstrings

Three 1-hour sessions at the Athletic Training Research Laboratory in 21D Recreation Building

**Requirements:**
- Men and women ages 18 – 35 years old
- Good general health and recreationally active
- Limited hamstring flexibility
- Non-smoker or consumer of nicotine products

Dr S. John Miller, John Vairo, and Dr Wayne Sebastianelli

Departments of Kinesiology, Orthopaedics and Rehabilitation

For more information, contact John Vairo at glv103@psu.edu or 814-865-2725
Appendix C

Screening Questionnaire

Title of Project: The Effects of Video Game-Based Balance Training on Postural Control in Healthy Young Adults

Principal Investigator: Giampietro L Vairo, MS, ATC

Other Investigator(s): Sayers J Miller III, PhD, PT, ATC and Wayne J Sebastianelli, MD

Research Assistant(s): Amy M Kalajainen and Carina G Osborn

Screening Checklist: Healthy Young Adults (18-35 years old)

Participant Identification Number: ________________________________

As a general health screen, you must be able to answer 'YES' to the following questions.

1. Are you between 18 to 35 years old?  Yes  No

2. Do you speak English?  Yes  No

3. Are you generally healthy (not overweight and a non-smoker or non-consumer of nicotine products)?
   Yes  No

As a general health screen, you must be able to answer 'NO' to the following questions.

1. Do you have a history of musculoskeletal or neurological injury to the low-back or lower body within the last six months?  Yes  No

2. Do you have a history of low-back or lower body surgery?  Yes  No

3. Have you sustained a concussion within the past six months?  Yes  No

4. Have you followed a formal physical rehabilitation program in the last six months?  Yes  No
5. Do you have any low-back or lower body pain described as above ‘1’ on a 10-point pain scale?  Yes  No

6. Are you diabetic or suffer from peripheral neuropathy?  Yes  No

7. Have you ever been diagnosed with epilepsy?  Yes  No

8. Are you pregnant?  Yes  No
Appendix D

Demographic Data Template

Title of Project: The Effects of Video Game-Based Balance Training on Postural Control in Healthy Young Adults

Principal Investigator: Giampietro L Vairo, MS, ATC

Other Investigator(s): Sayers J Miller III, PhD, PT, ATC and Wayne J Sebastianelli, MD

Research Assistant(s): Amy M Kalajainen and Carina G Osborn

Screening Checklist: Healthy Young Adults (18-35 years old)

Participant Identification Number: ________________________________

Participant Information:

Height: _________

Weight: _________

Dominant Leg: _________
**Appendix E**  

**Tegner Activity Level Scale**

<table>
<thead>
<tr>
<th>Level</th>
<th>Activity Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 10</td>
<td>Competitive sports- soccer, football, rugby (national elite)</td>
</tr>
<tr>
<td>Level 9</td>
<td>Competitive sports- soccer, football, rugby (lower divisions), ice hockey, wrestling, gymnastics, basketball</td>
</tr>
<tr>
<td>Level 8</td>
<td>Competitive sports- racquetball or bandy, squash or badminton, track and field athletics (jumping, etc.), down-hill skiing</td>
</tr>
<tr>
<td>Level 7</td>
<td>Competitive sports- tennis, running, motorcars speedway, handball</td>
</tr>
<tr>
<td></td>
<td>Recreational sports- soccer, football, rugby, bandy, ice hockey, basketball, squash, racquetball, running</td>
</tr>
<tr>
<td>Level 6</td>
<td>Recreational sports- tennis and badminton, handball, racquetball, down-hill skiing, jogging at least 5 times per week</td>
</tr>
<tr>
<td>Level 5</td>
<td>Work- heavy labor (construction, etc.)</td>
</tr>
<tr>
<td></td>
<td>Competitive sports- cycling, cross-country skiing, Recreational sports- jogging on uneven ground at least twice weekly</td>
</tr>
<tr>
<td>Level 4</td>
<td>Work- moderately heavy labor (e.g. truck driving, etc.)</td>
</tr>
<tr>
<td>Level 3</td>
<td>Work- light labor (nursing, etc.)</td>
</tr>
<tr>
<td>Level 2</td>
<td>Work- light labor</td>
</tr>
<tr>
<td></td>
<td>Walking on uneven ground possible, but impossible to back pack or hike</td>
</tr>
<tr>
<td>Level 1</td>
<td>Work- sedentary (secretarial, etc.)</td>
</tr>
<tr>
<td>Level 0</td>
<td>Sick leave or disability pension because of knee problems</td>
</tr>
</tbody>
</table>

Appendix F

Informed Consent

Informed Consent Form for Biomedical Research
The Pennsylvania State University
HEALTHY PARTICIPANTS (18 – 35 years old)

Title of Project: Neuromuscular Adaptations to Spinal Mobilizations in a Young, Healthy and Physically Active Cohort

Principal Investigator: Giampietro L Vairo, MS, ATC, Instructor of Kinesiology PhD Candidate (ABD), Department of Kinesiology 146 Recreation Building, University Park PA 16802 glv103@psu.edu; 814-865-2725

Other Investigator(s): Sayers J Miller, PhD, PT, ATC, Assistant Professor of Kinesiology
Department of Kinesiology 146 Recreation Building, University Park PA 16802 sjm221@psu.edu; 814-865-6782

Wayne J Sebastianelli, MD, Staff Physician and Surgeon Penn State | Hershey Orthopaedics – State College 1850 East Park Ave, Suite 112, State College PA 16803 wqs1@psu.edu; 814-865-3566

Carina Osborn, Athletic Training Student Schreyer Honors College Scholar 21D and 21E Recreation Building, University Park, PA 16802 cwo5038@psu.edu; 240-731-5325

Amy Kalajainen, Athletic Training Student Schreyer Honors College Scholar 21D and 21E Recreation Building, University Park, PA 16802 amk5595@psu.edu; 703-517-8869

1. Purpose of the study: The purpose of this research is to study the effects of spinal mobilizations on hamstring stiffness, strength and endurance. Thirty people between the ages of 18-35 years old will be taking part in this study.

2. Criteria for inclusion of participants: You are being invited to participate in this research study because you are healthy, physically active and between the ages of 18-35 years old.
3. **Procedures to be followed:** If you choose to participate in this research study, you will be asked to perform the following procedures:

**Procedures**

**First Session**

A. We will begin the study by measuring your height and weight. We will also ask you what leg you like to kick a ball with. We will ask you to rate your physical activity level with a short survey. We will then ask you to lie on your back on an exam table so we can measure your right and left leg lengths. To calculate the length of your legs we will measure the distance between your hip and ankle bones.

B. After we complete the leg measurements you’ll be asked to warm-up by walking at a common walking speed for five minutes on a flat electronic treadmill.

C. We will then measure the strength and endurance of your leg muscles (hamstrings, quadriceps and calves) with an electronic exercise machine. You will be secured in the machine while asked to bend and straighten your knee against two different resistances. You will also be asked to flex and extend your knee against two different resistances. We will ask you to perform three maximum effort repetitions against a high resistance to measure strength. We will ask you to perform as many repetitions as you can in 45 seconds against a low resistance to measure endurance. You will be given practice trials and rest between strength and endurance tests. You will be asked to perform strength and endurance tests for both legs separately. You will be asked to flip a coin to decide which leg is tested first.

D. After strength and endurance testing we will ask to place 10 sticky surface electrodes on both of your legs. We will put the surface electrodes over the skin covering your hamstrings, quadriceps and calves muscles. Surface electrodes look and feel like small stickers. Surface electrodes are small sticky discs that are connected to a computer system and measure muscle activity. For surface electrodes to stick well on your skin a one-inch square area will have to be shaved, lightly rubbed with an emery board and cleaned with rubbing alcohol. The muscle activity of your legs will be recorded when we measure the stiffness of your hamstrings muscles. Measuring muscle activity this way is not dangerous or painful.

E. After applying the surface electrodes we will perform hamstrings muscles stiffness testing. First, you will be asked to sit on an electronic exercise machine. While you quietly sit and relax your leg the machine will straighten and bend your knee three times at a slow comfortable speed. Secondly, we will ask you to lie on your stomach on a table with your hip and knee slightly bent. In this position a boot will be put on your foot. The boot has a small electronic tool attached to it that is connected to a computer system and measures the movement of your leg. The boot can also have weights placed on it. Once the boot is on your foot we will put a weight on it that is equal to 45% of your maximal knee bending strength. We will then ask you to keep your knee slightly bent with the weight on the boot. At times we will lightly tap your ankle to slightly straighten your knee. We will tap your ankle five times. When your ankle is tapped you should try to keep the slight bend in your knee. You will be given practice trials and rest
between these hamstrings muscles stiffness tests. You will be asked to perform hamstrings muscles stiffness tests for both legs separately. You will be asked to flip a coin to decide which leg is tested first. This will conclude the first session.

Second Session
F. At your second session a licensed and practicing physical therapist will ask permission to perform spinal mobilization techniques on you for approximately 15 minutes. You will lie down on a training table while the mobilizations are performed. These mobilizations are not dangerous or painful; however you may feel some popping or cracking which is normal for these techniques.

G. After the spinal mobilization techniques have been performed we will ask to take your measurements again, repeating procedures C through E. This is will conclude session two.

Third Session
H. At your third session we will ask to take the same measurements as the first session, procedures C through E.

4. **Discomforts and risks:** The discomforts and risks with participation in this type of research study are minimal. The tests used are within expected ranges for physically active people. Possible discomforts may be mild skin irritation from applying surface electrodes to your legs or bruising from the electronic exercise machine straps. Additional discomforts may be muscle soreness for two to three days after testing. It is possible that unknown harmful effects may happen. However, the chance for injury in this type of research study is minimal and happens in less than 1% of people. Examples of injuries that may happen are muscle strains, ligament sprains or bone breaks. We will make every possible effort to watch for and help prevent against any discomforts and risks.

5. **Benefits:** There is no direct benefit to you from participating in this research study. The benefits to society include possibly finding advantages and disadvantages for using spinal mobilizations for individuals with decreased hamstring stiffness.

6. **Duration/time of the procedures and study:** Two 60 minute testing sessions and one 60-minute treatment and testing session. All testing takes place in the Athletic Training Research Laboratory in 21E Recreation Building on Penn State’s University Park Campus.

7. **Statement of confidentiality:** Your participation in this research study is strictly confidential. All research records from your participation in this study will be kept confidential similar to medical records at your doctor’s office or hospital. All records will be secured in locked file cabinets at the Athletic Training Research Laboratory. A unique case number will indicate your identity on research records. In the event of any publication resulting from this research study, no personally identifiable information will be disclosed. Penn State’s Office for Research Protections, the Institutional Review Board and the Office for Human Research Protections in the Department of Health and Human Services may review records related to this research study. Three years following the end of this research study all records will be appropriately destroyed.
8. **Right to ask questions:** Please contact Giampietro “John” L Vairo at 814-865-2725 or 412-225-5276 with questions, complaints or concerns about this research. You can also call this number if you feel this study has harmed you. If you have any questions, concerns, problems about your rights as a research participant or would like to offer input, please contact Penn State University’s Office for Research Protections at 814-865-1775. The Office for Research Protections cannot answer questions about research procedures. Questions about research procedures can be answered by the research team.

9. **Voluntary participation:** Your decision to be in this research study is voluntary. You can stop at any time. You do not have to answer any questions you do not want to answer. Refusal to take part in or withdrawing from this research study will not involve penalty or loss of benefits you would receive otherwise. You may be removed from this research study by investigators in the event you cannot complete the testing procedures.

10. **Injury clause:** In the unlikely event you become injured as a result of your participation in this research study, medical care is available. It is the policy of this institution to provide neither financial compensation nor free medical treatment for research-related injury. By signing this document, you are not waiving any rights that you have against The Pennsylvania State University for injury resulting from negligence of the University or its investigators.

    If you become injured during testing procedures the investigators listed on this informed consent form will provide you with appropriate first aid care and instruct you on proper steps for follow-up care. If you were to experience any unexpected pain or discomfort from participating in this research study after leaving the Athletic Training Research Laboratory please contact Giampietro “John” L Vairo immediately at 814-865-2725 or 412-225-5276. If you cannot reach John please leave him a voicemail and contact your doctor (Wayne J Sebastianelli) at 814-865-3566.

    If you are a Penn State student and cannot reach John or your doctor (Wayne J Sebastianelli) please leave them voicemails and contact Penn State University Health Services at:
    - Student Health Center
    - University Park PA 16802
    - 814-863-0774

    If you are not a Penn State student and cannot reach John or your doctor (Wayne J Sebastianelli) please leave them voicemails and contact your private medical provider.

11. **Abnormal test results:** In the event abnormal test results are obtained, you will be informed of the results in three days and recommended to contact your private medical provider for follow-up consultation.

12. **Payment for participation:** You will receive $10.00 for participation in this study.

    You must be 18 years of age or older to sign consent for participating in this research study. If you agree to participate in this research study as described in this informed consent form, please sign your name and indicate the date below.
You will be given a copy of this signed and dated consent form for your records.

______________________________________________  ________________________
Participant Signature                        Date

______________________________________________  ________________________
Investigator Signature                      Date
Review of Literature

Spinal manipulation can be performed in multiple ways, one of which being through articulation mobilization with high-velocity and low amplitude stimulus on the vertebral segment that presents with mobility restriction.\textsuperscript{20} Spinal mobilization has been hypothesized to free entrapped synovial tissue within a joint, decrease muscular hypertonus, rupture adhesions and correct the movement of articular segments.\textsuperscript{20} These biomechanical effects seem to be independent of the neurophysiologic effects that can be created using spinal manipulation.\textsuperscript{20} Spinal manipulation has also been shown to stimulate the peripheral sympathetic nervous system in participants with and without low back pain, resulting in decreased blood flow, decreased skin temperature and increased skin conductance in the upper extremities.\textsuperscript{9} High velocity, low amplitude thrust (HVLAT)\textsuperscript{9} to zygoapophyseal joints has been shown to result in transient reflexive contractions of the local paraspinal muscles. In addition, low back pain patients have demonstrated immediate increases in muscle strength of the erector spinae following lumbar HVLAT.\textsuperscript{9} On the contrary, low back pain patients have also demonstrated an immediate reduction in paraspinal electromyographic (EMG) activity following HVLAT in a similar study (CITE). Therefore, controversy remains as to whether HVLAT has an excitatory or inhibitory effect on the paraspinal musculature.\textsuperscript{9} Similarly, there is a void in the literature in regards to the effects of HVLAT on the musculature of the extremities.

Spinal Mobilization and Muscular Activation

In certain instances, it has been demonstrated that spinal manipulation affects muscle activation and function, and these alterations have been shown to improve conditions such as core stability and patellofemoral joint tracking.\textsuperscript{4} An association between spinal manipulation and
improved muscle function has been established in the quadriceps, erector spinae and deep neck flexors. Grindstaff et al found this effect to be transient in nature and therefore not clinically relevant. The results of Dunning et al provided support for studies demonstrating an excitatory effect of HVLAT on motor activity, specifically of the biceps brachii. The findings of the related study displayed an increase in resting EMG activity of the right and left biceps brachii following HVLAT of the right C5/6 facet joint. Although this study looked at the effect of spinal HVLAT on extremity musculature, there remains a lack of literature regarding the long-term effects of manipulation on the musculature.

Marshall et al studied the effect of sacroiliac (SI) joint manipulation on feed-forward activation of the deep abdominal musculature. The transverse abdominus activates as a stabilizer muscle prior to movement of the upper and lower extremity. Spinal stability can be defined as the interaction of the skeleton, the muscle and the nervous system. When this early activation, known as feed forward activation, does not function properly, there is a lack of core stability when performing tasks with the extremities. An associated lack of transverse abdominus activity has been identified in patients complaining of nonspecific low back pain. Evidence has also been discovered demonstrating that laxity of the SI joint in patients not presenting with low back pain is associated with the ability to consciously contract the transverse abdominus. Marshall et al examined the onset time for the transverse abdominus during multiple upper extremity activities pre- and post-manipulation of the SI joint. This study showed a significant difference in the onset time of the transverse abdominus during the shoulder flexion task, decreasing/improving by 34.8%. Each shoulder task presented with significant differences in onset time. Nineteen percent of asymptomatic patients presented with a lack of the feed forward activation of the transverse abdominus, which was significantly changed following SI
joint manipulation. The presence of delayed feed forward activation in asymptomatic patients indicated that the delay was not due to transient pain causing inhibition, but a motor control alteration that existed without the presence of pain. This study demonstrated a link between stability of a specific joint and central nervous system coordination of muscles associated with that specific joint.

Suter & McMorland researched chronic neck pain patients. The study utilized the interpolated twitch technique and electromyography of the biceps brachii, which is a muscle that has demonstrated inhibition in chronic neck pain patients. Cervical ranges of motion and pain thresholds were assessed. Measures were assessed pre- and post-manipulation. In pre-manipulation measures, patients presented with significant inhibition of the biceps as well as restricted lateral cervical range of motion with associated pain. Following manipulation, force produced by the biceps increased, indicated a decrease in inhibition. In addition, range of motion and pain thresholds increased significantly.

Abnormal neuromuscular and biomechanical factors, particularly related to the vastus medialis, have been proposed as factors leading to altered patellar tracking which contributes to increased patellofemoral joint contact, and ultimately, pain and discomfort. Constant knee pain or an impairment of sensory feedback can lead to weakness and inhibition of the knee extensor muscles, particularly the vastus medialis. Several authors have shown a significant decrease of quadriceps inhibition and increased quadriceps strength following manipulation of the SI joint. These findings led to the hypothesis that SI joint manipulation could therefore decrease patellofemoral joint discomfort. Iverson et al found that for 45% of their subjects, patellofemoral pain patients, SI joint manipulation was a successful treatment to decrease pain associated with patellofemoral dysfunction. From the results of this study, a clinical prediction
rule was created, that identifies a subset of patients in which SI joint manipulation will be effective treatment for patellofemoral joint pain.¹¹

Suter et al¹⁰ propose that the lack of success in rehabilitation of injury can be attributed to muscle inhibition, specifically in anterior knee pain patients. This pathology is often linked to SI joint pathology. This connection led to the Suter et al¹⁰ study concerning whether SI joint manipulation would alter the inhibition present in the knee extensors, therefore increasing strength, in anterior knee pain patients. Prior to manipulation, it was determined that patients presented with significant muscle inhibition, 10% to 15% higher than normal subjects, in the ipsilateral and contralateral knee extensors as determined by the interpolated twitch technique. Post-manipulation, patients presented with a decrease in inhibition and an increase in torque of the ipsilateral extensors.¹⁰ Suter et al¹⁰ attribute the findings to a relief of referred pain or dysfunctional afferent feedback from the SI joint, which were leading to inhibition of the knee extensors.

Grindstaff et al¹ studied quadriceps force output and activation in healthy participants following lumbopelvic joint manipulation as compared to passive range of motion. Participants in the lumbopelvic manipulation group presented with a significant increase in quadriceps force and activation following manipulation, but the effects were not present after a 20-minute interval. It was proposed that this effect could be a result of motorneuron facilitation at the spinal or cortical level.¹

Keller & Colloca² performed a study of low back pain patients in which they created lumbar manipulation group, a sham treatment group and a control group to determine the effects of spinal manipulation on paraspinal strength. The study found 19 of 20 patients in the treatment group presented a positive increase in isometric paraspinal sEMG output following manipulation.
No changes were found in the sham treatment or control groups. It is controversial whether low back pain patients present with decreased paraspinal strength, but this study found an increase in paraspinal sEMG activity following spinal manipulation of low back pain patients.

Jesus-Moraleida et al\textsuperscript{23} researched the effect of cervical spine mobilization on neck flexor musculature in chronic neck patients. The study specifically assessed the recruitment of the longus colli musculature and the sternocleidomastoid using ultrasonography. It was concluded that mobilization of the cervical spine could act as a modulator of the neck musculature, as the deep musculature presented an increase in recruitment and the superficial musculature presented a decrease in recruitment.

The biological mechanism by which this occurs is not fully understood, but there is a proposed mechanism by which manipulation increases muscle function and activation via a neurophysiologic effect.\textsuperscript{4} This may be related to an alteration of motoneuron excitability. It is proposed that manipulation activates mechanoreceptors and proprioceptors surrounding the associated joint, which alters afferent input. This results in the changes in motoneuron excitability, causing regional or local muscular changes surrounding the associated joint.\textsuperscript{4}

Another proposed mechanism is a reflexogenic effect, which involves evoking muscle reflexes, which alter central or peripheral neural pathways.\textsuperscript{4} Dunning et al\textsuperscript{9} provided support for previous studies that suggested motoneuron excitability changes after HVLAT by demonstrating an increase in excitation of the biceps brachii following manipulation of the right C5/6 joint.\textsuperscript{9}

**Spinal Mobilization and Muscular Inhibition**

Research - Herzog et al\textsuperscript{8} researched asymptomatic participants and the reflex response to spinal manipulative treatment. They performed a set of 11 cervical, thoracic, lumbar and SI joint
mobilizations in a set order. Bipolar surface electrodes were placed on the back and proximal limb musculature. Electromyographic response was defined as an increase to at least three times of baseline electromyographic values within 500 msec of the onset of treatment thrust. Mobilization resulted in a reflexive response within 50-200 msec after the mobilization and lasted approximately 100-400 msec. Manipulation of the cervical spine caused a reflexogenic response in the musculature of the neck and back, but produced no systematic response in the deltoid or gluteus maximus. Manipulation of the upper and mid thoracic region resulted in a strong electromyographic response in all back musculature tested, and a positive electromyographic response in 50% of the deltoids. No response was observed in the gluteus maximus. Lower thoracic and lumbar manipulation resulted in an electromyographic response in the neck, back and gluteal musculature. No response was found in the deltoids during this condition. Manipulation of the SI joint resulted in a reflexogenic response in the back musculature close to the treatment area as well as in 50% of the deltoids. Herzog et al\textsuperscript{8} concluded that the findings demonstrated no active recruitment of muscle fibers after manipulation because the time to response was too short for an active contraction. Herzog et al\textsuperscript{8} argue that this reflexogenic response could cause some of the beneficial clinical effects that have been observed in patients with low back pain, such as reduced pain and decreased muscle hypertonicity.

Dishman et al\textsuperscript{24} sought to determine if the inhibitory effects of spinal mobilization on the alpha-motorneuron are limited to the local region of the mobilization or if effects are global. The study utilized asymptomatic participants who report no low back pain. The protocol measured the effect of cervical and lumbar manipulation on the amplitude of the tibial nerve Hoffmann reflex as recorded via the gastrocnemius. Dishman et al\textsuperscript{24} found that cervical manipulation had no effect on lumbar motorneuron activity. In contrast, lumbar manipulation resulted in
transiently suppressed motorneuron excitability. Excitability returned to baseline within 60 seconds of manipulation. These findings led to the conclusion that inhibitory effects of spinal manipulation on excitability of the motorneuron are transient and regional, as opposed to global.

It is proposed that spinal manipulation may cause mechanoreceptors and free nerve endings in the annulus fibrosus, ligaments of the spine and zygoapophyseal capsule to discharge afferent signals. These signals synapse on the inhibitory interneuron’s, which results in inhibition of motorneurons. Dishman et al\textsuperscript{24} also propose that an alleviation of the “pain-spasm-pain” cycle may be involved in the inhibition of motorneurons.

In a study by Bicalho et al\textsuperscript{25}, chronic low back pain patients were divided into manipulation and control groups to compare the effect of lumbar manipulation on EMG signals of the paraspinals, perceived pain and finger to floor distance. The manipulation group demonstrated a significant decrease in paraspinal EMG activity during the static flexion and active extension phases. No change was present in the active flexion phase. This finding is significant because chronic low back pain patients often fail to reach muscular relaxation during trunk flexion due to muscle spasm, limited range of motion or protection of affected structures. Additionally, the manipulation group presented a significant decrease in pain intensity as opposed to the control group.

Lehman & McGill\textsuperscript{26} had overall inconclusive results when they examined the effect of spinal manipulation on spine kinematics and trunk EMG activity. Trunk kinematics were measured in low back pain patients in 3 planes pre- and post-manipulation. Additionally, bilateral paraspinal and abdominal EMG signals were recorded pre- and post-manipulation. This study found no consistent changes within the cohort of participants. Of the participants that presented with change in muscle activity, 16 of 17 of these changes were decreases in muscle
amplitude. Additionally, the largest individual differences in muscle activity and range of motion occurred in the participants presenting with the greatest perceived pain. Overall, Lehman & McGill\textsuperscript{26} concluded that kinematic and muscle activation changes were dependent on the individual, with no systematic increase or decrease.

Spinal manipulative therapy is proposed to cause reflexogenic pain relief and loss of hypertonicity in proximal musculature.\textsuperscript{8} It is proposed that spinal manipulation may cause mechanoreceptors and free nerve endings in the annulus fibrosus, ligaments of the spine and zygoapophyseal capsule to discharge afferent signals. These signals synapse on the inhibitory interneurons, which results in inhibition of motorneurons. Dishman et al\textsuperscript{24} also propose that an alleviation of the “pain-spasm-pain” cycle may be involved in the inhibition of motorneurons.

**No Effect of Spinal Mobilization**

De Almeida et al\textsuperscript{20} studied the effects of high velocity, low-amplitude spinal manipulation on strength and the basal tonus of female pelvic floor muscles. They reported that chronic lumbar and pelvic pain are leading causes of medical visits within the female population. The pelvic floor musculature in the female population significantly contributes to stability of the pelvis, continence, sexual performance and the passage of the fetus during childbirth.\textsuperscript{20} De Almeida et al\textsuperscript{20} measured the intravaginal pressure using a perineometer before and after spinal manipulation in healthy participants. The only statistically significant increase in pressure was found in the fast contraction of the anus elevating muscles, whereas the prolonged contraction of anus elevating muscles and the combined contraction of the anus elevating muscles, transverse abdominis, gluteus and adductor muscles showed no statistically significant change.\textsuperscript{20} They concluded that
the spinal manipulation performed on the sacrum only affects the related timing and strength of contraction, not the pelvic floor muscle endurance or synergistic muscle contraction.

**Effect of Spinal Mobilization on Pain**

Muscle performance can suffer from neurophysiologic degradation that is most likely a result of pain-mediated inhibition and/or reflexogenic inhibition. Research has found that patients present with higher pain tolerance and/or pain thresholds following spinal manipulation. It is theorized that as a result of spinal manipulation, receptive nerve endings have a reduction of input signals to the central nervous system from the paraspinal tissues such as skin, muscle, tendons, facet joints, ligaments and innervated disc tissue. This input reduction influences systems controlled by the nervous system, such as pain producing systems. Change in afferent discharge rates delivered from these receptors is suggested to change alpha motoneuron excitability following HVLAT, leading to a change in muscle activity.

As previously described, Suter & McMorland studied chronic neck pain patients. Cervical ranges of motion and pain thresholds were assessed. Measures were assessed pre- and post-mobilization. In pre-mobilization measures, patients presented with significant inhibition of the biceps as well as restricted lateral cervical range of motion with associated pain. Following mobilization, range of motion and pain thresholds increased significantly. Additionally, in the study by Bicalho et al, chronic low back pain patients were divided into manipulation and control groups to compare the effect of lumbar mobilization on EMG signals of the paraspinals, perceived pain and finger to floor distance. The manipulation group presented a significant decrease in pain intensity as opposed to the control group.
Shum et al\textsuperscript{27} studied low back pain patients and healthy participants and compared the changes in pain, range of motion, stiffness, and spine curvature following grade III posteroanterior mobilization at the L4 level. Following mobilization, low back pain patients presented with a significant decrease in pain magnitude. Additionally, a significant decrease in bending stiffness of the lumbar spine and normalized spine curvature were found, restoring the stiffness to that of asymptomatic patients.

It is proposed that spinal manipulation may cause mechanoreceptors and free nerve endings in the annulus fibrosus, ligaments of the spine and zygoapophyseal capsule to discharge afferent signals. These signals synapse on the inhibitory interneurons, which results in inhibition of motorneurons. Dishman et al\textsuperscript{24} also propose that an alleviation of the “pain-spasm-pain” cycle may be involved in the inhibition of motorneurons.
REFERENCES


ACADEMIC VITA

Amy M. Kalajainen
329 Toftrees Avenue Apt 226
State College, PA 16803
amk5595@psu.edu

Education

B.S., Athletic Training, 2013, The Pennsylvania State University, University Park, PA

Awards/Honors

- Dean’s List, The Pennsylvania State University  
  Fall ’09, Spring ’10, Fall ’10, Spring ’11,  
  Fall ’11, Spring ’12, Fall ’12
- Thomas J. Watson Scholarship, IBM  
  2009-2010, 2010-2011, 2011-2012,  
  2012-2013
- President’s Freshman Award,  
  The Pennsylvania State University  
  2009
- The Marie Underhill Noll Endowment for Undergraduate Research  
  2011
- Sayers J. “Bud” Miller, Jr. Memorial Award  
  2011

Association Memberships/Activities

- National Athletic Trainers’ Association
- Eastern Athletic Trainers’ Association
- Pennsylvania Athletic Trainers’ Association
- Penn State University Athletic Training Club
- Pennsylvania Special Olympics Medical Staff
- College of Health and Human Development Women’s Leadership Initiative, 2010-2011
- Penn State Dance MaraTHON
- Alliance Christian Fellowship
- Penn State University Blue and White Society