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The Influence of Strength and Mobility on Lumbar Biomechanics During Lifting

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LOMA LINDA UNIVERSITY
School of Allied Health Professions
In conjunction with the
Faculty of Graduate Studies

The Influence of Strength and Mobility on Lumbar Biomechanics During Lifting

by

Christopher S. Patterson PT, DPT, PhD, OCS

A Dissertation submitted in partial satisfaction of
the requirements for the degree
Doctor of Philosophy in Physical Therapy

January 2021

Each person whose signature appears below certifies that this dissertation, in his/her opinion is adequate, in scope and quality, as a dissertation for the degree Doctor of Philosophy.

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ABSTRACT

The Influence of Strength and Mobility on Lumbar Biomechanics During Lifting

by

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Doctor of Philosophy, Graduate Program in Physical Therapy
Loma Linda University, January 2021
Dr. Everett B. Lohman III, Chairperson

Weakness of the lumbar and hip extensors muscles as well as limited hip flexion mobility have been proposed to contribute to greater lumbar spine loading and greater lumbar flexion during functional tasks. The purpose of the current study was to examine the associations among hip and lumbar spine extension strength, hip flexion mobility and lumbar spine biomechanics during a squat lifting task. Fifty healthy adults participated in the study. Strength of the lumbar extensors and hip extensors was measured using a motor driven dynamometer. Hip range of motion was assessed using a 3D motion capture system. Participants lifted boxes of various weights utilizing a squat lifting technique. Peak lumbar spine and hip flexion were quantified during the final 10% of the descent phase of the squat lifting task. Lumbar spine moments and lumbar paraspinal muscle activity (as measured by electromyography) were quantified during the concentric phase of the squat lifting task. There was a significant positive association between lumbar extensor strength and average lumbar extensor moment during lifting ($r=0.50$, $p<0.01$). Similarly, hip extensor strength was positively associated with the average lumbar extension moment ($r=0.38$, $p<0.05$). Hip extensor strength was negatively associated with activation of the lumbar paraspinal muscles during lifting ($r=-0.38$, $p<0.05$). There was a significant negative association between hip flexion capacity and peak lumbar spine flexion during squat lifting (r=-0.48, p<.001). Similarly, peak lumbar spine flexion was negatively associated with lumbar paraspinal strength (r=-0.38, p<.01). During the squat lift task, peak hip motion was positively associated with hip flexion capacity (r=0.79, p<.001). Stronger individuals are more likely to use their hip extensors and lumbar spine extensors to lift. In contrast, those with lower strength employ subtle biomechanical changes to reduce lumbar spine loading. Diminished hip flexion capacity and lumbar extension strength resulted in greater amounts of lumbar flexion during a squat lifting task. Individuals with greater hip flexion capability utilize less lumbar flexion and greater hip flexion to complete the task. In contrast, those with diminished hip flexion capability and lower lumbar extension strength utilize greater amounts of lumbar flexion.

CHAPTER ONE

INTRODUCTION

Low back pain is a common health problem in both the United States and worldwide. Eighty-percent of adults will experience low back pain in their life time. [1] The symptoms and limitations of low back pain related disorders are the number one cause of disability in the world and one of the top three reasons patients seek medical attention from a physician. [2, 3] Consistent with a 54% increase in disability from 1990 – 2015, low back pain related disability is projected to increase over the next 20 years. [2, 4] The incidence rate for low back pain is 7% in the United States which is the highest rate worldwide. [1] Individuals of working age are thought to be most at risk for injury which is proposed to contribute to the growing economic burden associated with low back pain related disability. [4]

The continued growth of low back pain related disability cases can be attributed, in part, to the difficulty of diagnosing and treating low back disorders. It is estimated that 80% of low back pain cases are identified as “non-specific”. [5] A diagnosis of “non-specific” low back pain denotes pain localized to the low back without a known cause or tissue source of pain. [5] Without a known tissue source attributed to the cause of pain and symptoms, providing diagnosis and treatment remain difficult. This has led to a shift in the treatment paradigm away from tissue source classification toward a movement-based classification system that focuses on identifying maladaptive movement patterns that are associated with excessive loading of the lumbar spine and low back pain. [6, 7]

There is strong evidence that aberrant functional movement patterns are associated with both loading of the tissues of the lumbar spine and lumbar spine pain. [8-

10] Lifting, bending, twisting and loading of the lumbar spine are proposed to increase the risk of low back injury and are considered modifiable risk factors. [11] A report examining the mechanism of injury in patients presenting in the emergency room with acute low back pain indicated that the primary mechanism of injury was bending and lifting. [12] There is further evidence that individuals with a history of low back pain, current low back pain, or who later develop low back pain demonstrate distinctive movement strategies during forward flexion, bending, and lifting when equated to healthy individuals. [8, 9, 13-15] Although the observed differences in movement strategies are associated with low back pain, the contributions to the altered movement patterns are unclear.

As lifting is a common cause of low back injury, much of the previous research has been aimed at determining a safe lifting strategy. [16] There are two distinct styles of lifting that have been considered in the literature: the stoop lift, defined by limited knee flexion and greater degrees of lumbar flexion, and the squat lift, which requires knee and hip flexion and theoretically less lumbar and trunk flexion. [10, 17] There is disagreement as to which lifting style results in reduced loading of the lumbar spine. [10, 16, 18] Stoop lifting results in increased loading of the passive structures of the spine as greater lumbar spine flexion and bending are required to reach the object on the floor. [10] In contrast, squat lifting is proposed to increase the load on the active structures of the spine (i.e., lumbar paraspinal muscles) in order to maintain the spine in a more neutral position. [19] A crucial biomechanical concern for lumbar spine injury during lifting, regardless of the style of lift, is greater lumbar loading and flexion stress. [18, 20] Movement strategies that result in reduced loading and flexion stress to the lumbar spine are suggested as appropriate interventions to reduce injury and low back pain. [7]

In a biomechanically based movement classification treatment paradigm, intervention is aimed at addressing the related impairments that contribute to alteration in movement strategies that are associated with injury. Three common impairments associated with both low back pain and lifting are hip extensor weakness, lumbar extensor weakness, and limited hip flexion mobility. [21-24]

Hip Extension Strength & Lumbar Loading

From a muscular standpoint, the hip extensors (i.e., gluteus maximus and hamstrings) and the lumbar extensors (i.e., erector spinae muscles) work together to extend the hip and trunk during the concentric phase of squat lifting. [10, 25] Given the synergistic demands on the hip extensors and lumbar spine extensors during squat lifting, it has been proposed that hip extensor weakness may result in a compensatory lifting strategy that places greater demands on the lumbar spine. [21] This premise is supported by the work of Puniello et al. who reported that individuals with deficits in hip extensor strength exhibited greater lumbar spine moments. [21] Although the findings of Puniello et al. [21] suggest that hip extensor strength influences an individual's selected lifting strategy, the direct association between hip extensor strength and the demand on the back extensors has not been quantified.

Lumbar Extensor Strength & Lumbar Loading

Apart from the influence of hip extensor strength on lifting mechanics, weakness of the paraspinal muscles has also been proposed to contribute to lumbar spine loading during lifting. [22, 26] Using a computational model to load the lumbar spine through the trunk, Zhu et al. observed an increase in anterior shearing load on the lumbar spine with a 25% reduction in erector spinae force production. [26] Lumbar shearing was significantly greater as force production of the lumbar erector spinae muscles was further reduced to 50% and 75% of normal. [26] Given that the erector spinae muscles stabilize the spine during lifting, it is possible that individuals with erector spinae weakness may be exposed to greater lumbar spine moments during lifting. This assumption is consistent with the work of Hu and Ning who reported a significant increase in lumbar spine moments during a lifting task following an erector spinae muscle fatigue protocol. [22]

Hip Flexion Mobility & Lumbar Flexion

Lifting an object from the ground is a multi-joint functional task requiring lumbopelvic coordination of hip and lumbar flexion. [16, 27] Greater degrees of lumbar spine flexion are associated with increased bending stress, increased shear stress, higher compression stress of the lumbar discs, and greater tensile stress of the passive structures of the spine. [10, 19, 28-30] The flexion stress experienced by the lumbar spine during lifting is proposed to contribute to lumbar spine injury and subsequent low back pain. [10]

During tasks requiring both hip and lumbar flexion, a movement strategy that utilizes proportionally less hip flexion motion is proposed to increase the required lumbar spine flexion motion. [31-34] Kim et al. examined the influence of hip flexion range of motion capacity on lumbar spine flexion during the seated hip flexion test in subjects with and without low back pain. [33] Subjects with a limitation in passive hip flexion range of motion demonstrated significantly less hip flexion and greater lumbar flexion during the task. [33] The study incorporated subjects with limited hip mobility and low back pain making it difficult to separate the influences of hip mobility and lumbar pain on movement strategy. [33] A similar pattern between hip and lumbar spine coordination was observed during standing hip flexion in healthy adults suggesting that as the contribution from hip flexion decreased lumbar spine flexion increased. [34] Although seated and standing hip flexion are used as screening tools to clinically assess movement coordination strategy between the hip, pelvis and lumbar spine, it is unclear if the observed movement patterns are transferrable to standing functional tasks such as lifting.

Lumbar Extensor Strength & Lumbar Flexion

Apart from the influence of hip flexion range of motion capacity on lifting mechanics, weakness of the paraspinal muscles has also been proposed to contribute to greater lumbar spine flexion during lifting. [22, 26] Using a 3D finite element model to provide a flexion torque to the lumbar spine, Zhu et al. observed an increase in anterior shearing load on the lumbar spine with a 25% reduction in erector spinae muscle strength. [26] Lumbar shearing was further increased as the strength of the lumbar erector spinae muscles was reduced to 50% and 75% of normal. [26] Given the lumbar erector spinae muscles stabilize the spine during lifting, it is possible individuals with paraspinal weakness may expose the spine to greater amounts of flexion. This assumption is consistent with the work of Hu and Ning who reported a significant increase in lumbar spine flexion during a lifting task following a lumbar paraspinal muscle fatigue protocol. [22]

Previous studies evaluating the relationship between hip and lumbar spine flexion have primarily focused on individuals with low back pain resulting in mixed findings.

Esola et al. and Porter and Wilkinson concluded that subjects with a history of low back pain utilized greater amounts of lumbar flexion and reduced hip flexion during a forward bending task. [35, 36] Whereas Wong et al. indicated that both lumbar spine and hip flexion were reduced in subjects with low back pain. [37] The literature on the relationship of the hip and lumbar spine during forward flexion tasks is inconclusive. Interpretation of the observed variability in hip and lumbar spine coordination during functional tasks in subjects with low back pain is problematic without a better understanding of movement strategy variability in the pain free population.

Identifying the potential relationship between hip extensor strength, lumbar extensor strength, and hip flexion range of motion to strategies utilized to complete a squat lift, will provide a better understanding of the contributing impairments to movement strategies that result in increased lumbar spine loading and flexion stress. Squat lifting is an ideal movement task for observation of this relationship in that it requires significant utilization of hip and lumbar motion and strength, is associated with low back injury, and has yet to be considered in the previous literature. [16] The influences on movement strategy variability across the healthy population is essential to interpreting the observed difference between healthy subjects and those with low back pain. A better understanding of these influences will direct future interventions aimed at reducing low back pain through addressing impairments that constrain optimal movement.

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CHAPTER TWO

THE INFLUENCE OF HIP EXTENSOR AND LUMBAR SPINE EXTENSOR STRENGTH ON LUMBAR SPINE LOADING DURING A SQUAT LIFT

Abstract

Background

Weakness of the hip extensors and lumbar spine extensors has been proposed to contribute to greater loading of the lumbar spine during lifting. The purpose of the current study was to examine the associations among strength of the hip and lumbar spine extensors and lumbar spine extensor moments and lumbar paraspinal muscle activation during a squat lift task.

Methods

Twenty-seven healthy females participated. Strength of the hip and lumbar spine extensors was measured using a dynamometer. Participants lifted a box equal to forty percent of body weight using a squat lifting strategy. Lumbar spine moments and lumbar paraspinal muscle activity (as measured by electromyography) were quantified during the concentric phase of the squat lifting task.

Findings

There was a significant positive association between lumbar extensor strength and average lumbar extensor moment during lifting ($r=0.50$, $p<0.01$). Similarly, hip extensor strength was positively associated with the average lumbar extension moment ($r=0.38$, $p<0.05$). Hip extensor strength was negatively associated with activation of the lumbar paraspinal muscles during lifting ($r=-0.38$, $p<0.05$).

Interpretation

The results of this paper do not support the premise that reduced strength of the hip extensors or lumbar spine extensors results in greater lumbar spine loading during a squat lift. Stronger individuals are more likely to use their hip extensors and lumbar spine extensors to lift. In contrast, those with reduced strength employ subtle biomechanical changes to reduce lumbar spine loading.

Introduction

Lifting an object from the ground is a common functional task. A lifting strategy frequently utilized to move an object from the floor to waist height is the squat lift. [1, 2] The eccentric or descending phase of the squat lift requires ankle dorsiflexion and knee, hip and trunk flexion to lower the body center of mass to allow the hands to reach forward to contact the object. [3] The concentric phase of the squat lift requires the generation of extensor moments from the ankle, knee, hip and lumbar spine to bring the object to waist height. [3] Compared to the moments at the ankle and knee, the moments at the hip and lumbar spine during the ascending phase of the squat lift are considerably higher. [1, 3]

From a muscular standpoint, the hip extensors (i.e., gluteus maximus and hamstrings) and the lumbar extensors (i.e., lumbar paraspinals) work together to extend the hip and trunk during the concentric phase of lifting. [4, 5] Given the synergistic demands on the hip extensors and lumbar spine extensors during squat lifting, it is conceivable that hip extensor weakness may result in a compensatory lifting strategy that places greater demands on the lumbar spine (i.e., greater lumbar spine moments and paraspinal muscle activation). This premise is supported by the work of Puniello et al. who reported that individuals with deficits in hip extensor strength exhibited greater lumbar spine moments. [2] Although the findings of Puniello et al. [2] suggest that hip extensor strength influences an individual's selected lifting strategy, the direct association between hip extensor strength and the demand on the lumbar spine extensors was not quantified.

Apart from the influence of hip extensor strength on lifting mechanics, weakness of the lumbar extensor muscles has also been proposed to contribute to lumbar spine loading during lifting. [6, 7] Using a computational model to load the lumbar spine through the trunk, Zhu et al. observed an increase in anterior shearing load on the lumbar spine with a 25% reduction in paraspinal force production. [6] Lumbar shearing was significantly greater as force production of the lumbar paraspinal muscles was further reduced to 50% and 75% of normal. [6] Given that the lumbar paraspinal muscles stabilize the spine, it is possible that individuals with paraspinal weakness may be exposed to greater lumbar spine moments during lifting. This assumption is consistent with the work of Hu and Ning who reported a significant increase in lumbar spine moments during a lifting task following a lumbar paraspinal muscle fatigue protocol. [7]

Given that the increased load on the lumbar spine during lifting has been postulated to contribute to low back injury during lifting, [1, 8] the purpose of the current study was to examine the associations among strength of the hip and lumbar spine extensors, lumbar spine extensor moments, and lumbar paraspinal muscle activation during a squat lift task. We hypothesized that reduced hip extensor strength and lumbar spine extensor strength would be associated with greater lumbar extensor moments during the concentric phase of the squat lift. We also hypothesized that those with reduced hip extensor strength would exhibit greater compensatory lumbar paraspinal muscle activity as measured by electromyography (EMG). A better understanding of the relationship between muscular strength and muscular demands during squat lifting may provide insight into compensatory strategies employed during lifting thereby exposing the spine to greater demands.

Methods

Participants

Twenty-seven healthy females between 18-40 years of age participated in this study. Only females were studied owing to the findings that women exhibit differences in lower extremity power, force, lumbar loading and coordination during lifting when compared to men. [9-11] The average age, height and mass of the study participants was 24.5 ± 2.6 years, 163.5 ± 6.7 cm and 62.9 ± 12.2 kg, respectively.

Prospective participants were included if they were in good general health and did not report a history of low back or lower extremity pain in the previous 12 months. Additionally, individuals were excluded if they were non-English speaking, currently pregnant or reported a previous history of low back or lower extremity surgery. All participants provided written consent as approved by the Loma Linda University Institutional Review Board (Loma Linda University, USA).

Instrumentation

Hip and lumbar spine extensor strength were assessed using a motor-driven dynamometer (PrimusRS, BTE Hanover, MD). Three-dimensional trunk and lower-extremity kinematic data were obtained using a 16-camera motion-capture system (Miqus, Qualisys, Gotenburg, Sweden) at a sampling rate of 100 HZ. Ground reaction force data was obtained using 2 force plates (AMTI, Newton, MA) sampling at 2000 Hz.

Surface EMG signals of the bilateral lumbar paraspinal muscles were collected at a sampling rate of 2000 Hz using a wireless EMG system (Trigno, Delsys, Natick, MA). The EMG system had a differential input impedance of greater than 10 GΩ, a common-mode rejection ratio greater than 80 dB, and baseline noise of < .5 mV. The electrodes consisted of rectangular bars with an inter-electrode distance of 10 mm.

Procedures

Prior to placement of the surface electrodes, the skin was cleaned with alcohol, shaved and abraded to reduce electrical impedance. Electrodes were placed bilaterally on the lumbar paraspinal muscles, parallel to the muscle fiber orientation, 4 cm lateral to the spinous process of the 3rd lumbar vertebrae (L3). [12]

Isometric hip extensor torque was assessed bilaterally in the prone position with the hip and knee flexed to 45 and 90 degrees, respectively. [13, 14] The axis of rotation of the dynamometer was aligned with the greater trochanter of the hip being tested. The resistance pad was positioned at the distal end of the femur, proximal to the popliteal fossa and secured with Velcro straps (Fig. 1). Participants were instructed to extend the hip by pushing the heel upward with maximum effort. The non-tested limb was stabilized by the tester to eliminate possible assistance from foot contact with the ground. Verbal encouragement was provided throughout all trials. Three trials consisting of 5-second maximal contractions were performed with a 1-minute rest period between each trial.

Figure 1. Participant positioning for the measurement of peak hip extensor torque production.

Isometric torque production of the lumbar extensors was measured with the participant prone with the trunk flexed 20 degrees off the end of the dynamometer testing table. The resistance bar for the dynamometer was placed across the thoracic spine at the level of the 7th thoracic vertebrae (T7) and the pelvis was secured to the table with a Velcro strap (Fig. 2). The axis of rotation of the dynamometer was aligned with the spinous process of the 5th lumbar vertebrae (L5). Participants were instructed to extend the trunk against the resistance bar with maximum effort for 5 seconds. Verbal encouragement was provided. Three trials were performed with a 1-minute rest period between each trial. Lumbar paraspinal muscle EMG data were collected during the lumbar extensor strength test for normalization purposes.


[redacted]

Figure 2. Participant positioning for the measurement of peak lumbar extensor torque production.

Following strength testing, reflective markers (12-mm spheres) were placed on the following anatomical landmarks bilaterally: the first and fifth metatarsals, medial and lateral malleoli, calcanei, medial and lateral femoral epicondyles, anterior superior iliac spines, iliac crests, and the posterior superior iliac spines. The trunk was defined by markers placed on the following landmarks: the spinous process of L5, one marker 4 cm lateral to each side to the spinous process of L4, the spinous process of L3, one marker 4 cm lateral to each side of the spinous process of the 1st lumbar vertebrae (L1), the spinous process of the 12th thoracic vertebrae (T12), one marker 4 cm lateral to each side of the spinous process of the 7th thoracic vertebrae (T7), the spinous process of the 3rd thoracic vertebrae (T3), acromioclavicular joint, sternal notch and xiphoid process. A rigid plate with 4 reflective markers was placed over the lateral aspect of the bilateral shanks and thighs.

Once the markers were secured, a static calibration trial was obtained. Participants were then instructed to stand with each foot on one of the force plates. Stance width was normalized so the distance between the midline of left and right calcanei was equal to the distance between the left and right acromioclavicular joints. A plywood box with a weight equal to 40% of the participant's body weight was placed at midline, anterior to the feet at a normalized distance equal to one-half the length of the participant's foot (Fig. 3). The height of the box handles used for lifting was normalized to one-half the distance from the floor to the tibial plateau. [15]

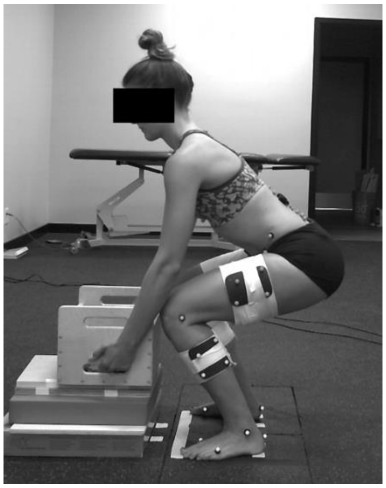

Figure 3. Participant positioning for the squat lift task.

Participants were instructed to lift the box from the floor by gripping the box at the handles, using a squat lift strategy while maintaining elbows in extension. Lifting trials were performed at a self-selected speed. Each trial consisted of lifting the box and extending to a fully upright position. A total of 3 trials were performed with a 2-minute rest in between each trial. EMG, kinematic and ground reaction force data were collected simultaneously.

Data processing

All data were exported to Visual 3D software for processing (v.6.01.26; C-Motion; Germantown, MD). EMG signals were band-pass filtered at 30-500 Hz, full wave rectified, and a low pass 4th-order Butterworth filter of 2.5 Hz was applied to create a linear envelope. EMG data were normalized and reported as a percentage of the highest one second average of the EMG signal during the lumbar extensor strength testing trials. Kinematic data were filtered using a 4th order Butterworth filter with a cut-off frequency of 2 Hz. The lumbar extensor moments were calculated about the L5-S1 junction using inverse dynamics equations as previously described by de Looze et al. [16] Moment data were normalized to body mass.

The concentric phase of the squat lift was time normalized to 101 data points. The start of the lift was defined as the point at which vertical trunk segment vertical velocity was greater than zero, and the end of the movement was at the point when trunk segment vertical velocity was zero. The kinetic variable of interest was the average lumbar extensor moment during the first 50% of the concentric lifting phase. Similarly, the EMG variable of interest was the average, normalized EMG activity of the lumbar paraspinal muscles during the first 50% of the concentric lifting phase. EMG data from both sides were averaged for statistical analysis.

Additional variables of interest included peak hip extensor and lumbar extensor torque production as obtained from the dynamometer. The highest hip extensor torque obtained from the 3 trials for the right and left sides were averaged and used for data analysis. The highest value obtained from the 3 trials of lumbar extensor torque production testing was used for data analysis. Hip and lumbar extension torque values were normalized to body mass.

Data Analysis

Normality of the variables of interest was assessed using the Shapiro-Wilk test and box plots. Pearson correlation coefficients were used to assess the association among variables that were found to be normally distributed. Spearman correlation coefficients were used to evaluate the association among variables in which the assumption of normality was not satisfied. Data was analyzed using SPSS Statistics Software version 27.0 (SPSS Inc, Chicago, IL, USA). All analyses were performed at an alpha level of 0.05.

Results

Descriptive statistics for the variables of interest for all participants are presented in Table 1. The normality assumption for the lumbar paraspinal EMG data was not satisfied. Thus, Spearman correlation coefficients were used to evaluate the association between hip extensor strength and lumbar paraspinal EMG.

There was a significant positive association between lumbar extensor strength and the average lumbar extensor moment (r=0.50, p<0.01; Fig. 4). Similarly, hip extensor strength was positively associated with the average lumbar extension moment (r=0.38, p<0.05; Fig. 5). Hip extensor strength was negatively associated with activation of the lumbar paraspinal muscles during lifting (r=-0.38, p<0.05; Fig. 6).

Table 1. Descriptive Statistics for the Variables of Interest (n=27)

Variables	Mean±SD (Min, Max)
Hip extensor strength (Nm/Kg)	2.2 ± 0.7 (1.0,4.0)
Lumbar extensor strength (Nm/Kg)	1.6± 0.4 (0.9,2.2)
Lumbar spine moment (Nm/Kg)	1.9 ± 0.3 (1.3,2.6)
Lumbar paraspinal EMG (% MVIC)	58.8 ± 18.8 (41.4,103.0)

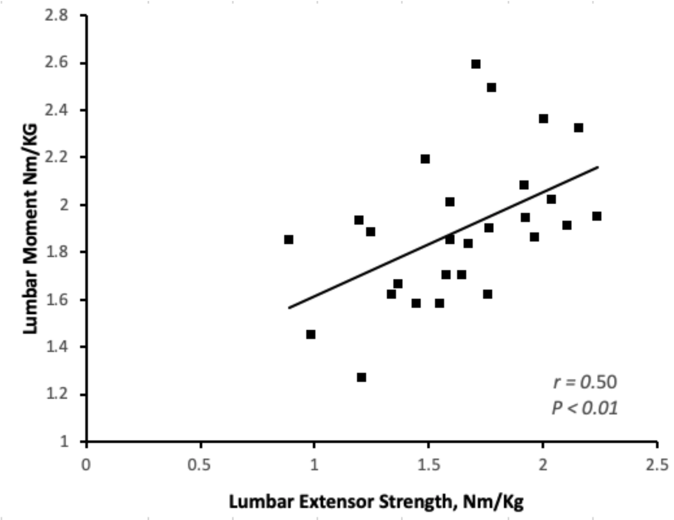

Figure 4. Relationship between the normalized lumbar-extensor strength and average lumbar extensor moment during the first 50% of the squat lift.

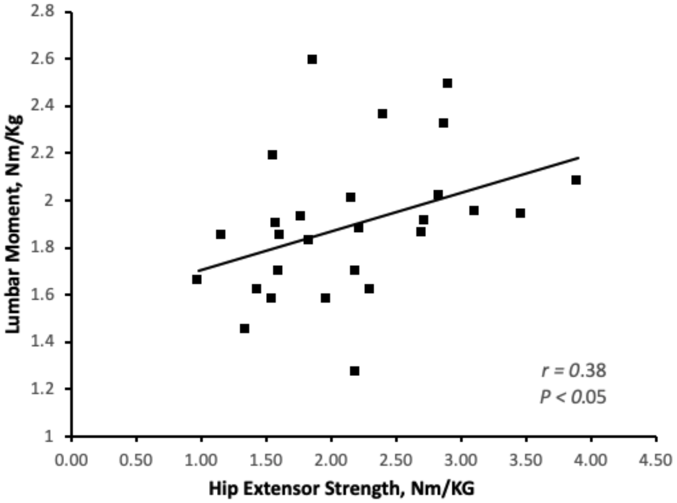

Figure 5. Relationship between the normalized hip-extensor strength and average lumbar extensor moment during the first 50% of the squat lift.

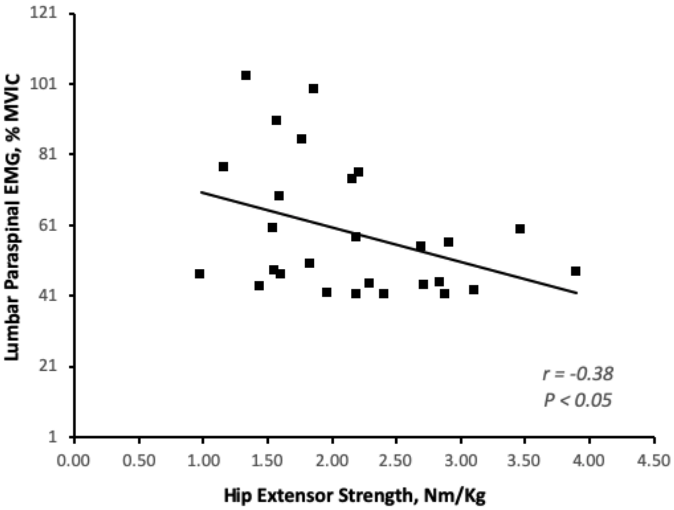

Figure 6. Relationship between the normalized hip-extensor strength and average lumbar paraspinal EMG activity during the first 50% of the squat lift.

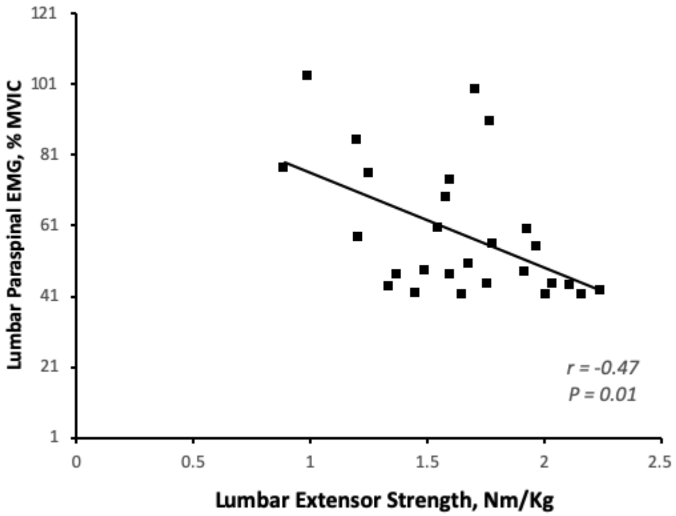

Figure 7. Relationship between the normalized lumbar-extensor strength and average lumbar paraspinal EMG activity during the first 50% of the squat lift.

Discussion

The current study examined the relationships among hip extensor and lumbar spine extensor strength, moments at the lumbar spine, and muscle activity of the lumbar paraspinal muscles during a squat lifting task in females. Contrary to our hypothesis, hip extensor strength and lumbar spine extensor strength were found to be positively associated with the average lumbar spine extensor moments. Specifically, participants with greater isometric torque production capacity of the hip and lumbar spine extensors demonstrated higher moments at the lumbar spine during the first 50% of the concentric ascending phase of squat lifting. In addition, hip extensor strength was found to be negatively associated with average EMG activity of the lumbar paraspinal muscles. Taken together, our results suggest that females with greater hip extensor and back extensor strength make use of this capacity during a lifting task. Conversely, females with lower hip and back extensor strength appear to avoid loading the lumbar spine.

The finding of a positive association between hip extensor strength and lumbar spine moments are in contrast to the observations of Puniello et al. who reported that individuals with hip extensor weakness exhibited greater lumbar spine extensor moments during a lifting task. [2] Our contradictory findings may be due to differences in study design. Puniello et al. [2] allowed participants to self-select a lifting strategy, while the current study required participants to use a squat-lift approach. Although the current study limited the style of lifting employed, participants were still able to modulate the demands on the hip and lumbar extensors within the constraints of the task. The modulation of lumbar spine loading was most likely accomplished through subtle kinematic adjustments within the confines of the squat lift requirements and/or changes in the center of pressure.

Similar to the results related to hip extensor strength, individuals with lower lumbar spine extensor strength performed the squat lift task with lower average lumbar spine extensor moments. This finding is in contrast to what was hypothesized based on the computational work of Zhu et al. [6] Given that weakness of the lumbar spine extensor muscles has been shown to increase lumbar spine anterior shearing and lumbar flexion moments [6, 7], it was our expectation that a negative relationship would have been observed. Taken together our results suggest that individuals with reduced strength of the hip and lumbar spine extensor muscles avoid loading the lumbar spine, similar to what has been reported in persons with chronic low back pain (e.g. avoidance behavior). [17]

In regard to the EMG findings, we hypothesized that females with reduced hip extensor strength would exhibit greater lumbar paraspinal muscle activity. This hypothesis was confirmed, however not necessarily for the reasons originally suggested. As noted above, females with reduced hip extensor strength also exhibited lower lumbar spine extensor moments. Given this finding, it would be intuitive to assume that reduced hip extensor strength would be associated with lower paraspinal muscle EMG, however this was not the case.

To better understand the relationship between hip extensor strength and lumbar paraspinal EMG, a post-hoc analysis was performed to evaluate the relationship between lumbar spine extensor strength and lumbar paraspinal muscle activity. This analysis revealed that lumbar spine extensor strength was negatively associated with average lumbar erector spinae muscle activity (r=-0.47, p= 0.01; Fig. 7).   As such, it could be argued that reduced strength of the lumbar extensor muscles accounted for higher erector spinae activity during the lifting task. The inverse relationship between muscle activity of the lumbar paraspinals and lumbar extension torque production is similar to other studies that have previously investigated relationships among measures of muscle strength and EMG during functional tasks. [13,18] Our findings are consistent with the premise that individuals with reduced muscle torque production capacity may require relatively greater muscle activation to generate sufficient muscle force to complete a given task.

Greater activity of the lumbar paraspinal muscles during functional tasks has been observed in persons with low back pain. [18-20] Although the exact cause of elevated muscle activity in persons with low back pain is not clearly understood, previous studies have proposed that elevated muscle activity may be a neuromuscular strategy to reduce the load placed on the spine during functional movement. [18-22] While the current study only evaluated healthy females, our finding of higher EMG values associated with lower strength values may explain the increased activity of the erector spinae seen in the low back pain population. This premise is supported by studies that have shown that persons with low back pain exhibit reduced muscle performance of the lumbar paraspinal muscles (i.e., strength and endurance). [23, 24]

The results of the current study should be interpreted in light of several limitations. First, we only evaluated a small sample of young, healthy females without a recent history of low back pain. As such, our results cannot be generalized to males, older individuals, or those with low back pain. Second, our requirement to perform a squat lift may have limited the ability of participants to fully compensate for hip extensor and lumbar extensor deficits. It is possible that allowing for a self-selected lifting strategy (i.e, any variation of a stoop or squat lift) may have resulted in a different outcome. Third, although an association between hip and lumbar extensor strength and hip and lumbar moments was observed, cause and effect relationships cannot be inferred based on the study design.

Conclusion

Our findings do not support the premise that reduced strength of the hip extensors or lumbar spine extensors results in greater lumbar spine loading during a squat lift. Instead, it appears that stronger individuals are more likely to use their hip extensor and lumbar spine extensors to perform a squat lift, while those with lower strength employ subtle biomechanical changes to reduced lumbar spine loading. Further studies are needed to investigate the contribution of hip and lumbar extensor strength to lifting strategy in individuals with low back pain.

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CHAPTER 3

THE INFLUENCE OF HIP MOBILITY AND LUMBAR EXTENSOR STRENGTH ON LUMBAR FLEXION DURING A SQUAT LIFT

Abstract

Background

Hip flexion mobility and lumbar paraspinal strength have been proposed to contribute to greater lumbar flexion during stoop lifting and seated hip flexion testing. The purpose of the current study was to examine the associations among hip flexion capacity, lumbar paraspinal strength and peak lumbar flexion during a squat lifting task.

Methods

Fifty healthy adults participated in the study. Strength of the lumbar paraspinals was measured using a motor-driven dynamometer. Hip range of motion capacity was assessed using a 3D motion capture system. Peak lumbar spine and hip flexion were quantified during the final 10% of the descent phase of the squat lifting task.

Findings

There was a significant negative association between hip flexion capacity and peak lumbar spine flexion during squat lifting (r=-0.48, p<.001). Similarly, peak lumbar spine flexion was negatively associated with lumbar paraspinal strength (r=-0.38, p<.01). During the squat lift task, peak hip motion was positively associated with hip flexion capacity (r=0.79, p<.001).

Interpretation

The findings of this study support the premise that diminished hip flexion capacity and lumbar extension strength result in greater amounts of lumbar flexion during a squat lifting task. Individuals with greater hip flexion capability utilize less lumbar flexion and greater hip flexion to complete a squat lifting task. In contrast, those with less hip flexion capability and lower lumbar extension strength utilize greater amounts of lumbar flexion.

Introduction

Lifting an object from the ground is a multi-joint functional task requiring lumbopelvic coordination of hip and lumbar flexion. [1, 2] Greater degrees of lumbar spine flexion are associated with increased bending stress, increased shear stress, higher compression stress of the lumbar discs, and greater tensile stress of the passive structures of the spine. [3-7] The flexion stress experienced by the lumbar spine during lifting is proposed to contribute to lumbar spine injury and subsequent low back pain. [6]

During tasks that require both hip and lumbar flexion, a movement strategy that utilizes proportionally less hip flexion motion is proposed to increase lumbar spine flexion requirements. [8-11] Kim et al. examined the influence of hip flexion range of motion capacity on lumbar spine flexion during a seated hip flexion test in subjects with and without low back pain. [10] Participants with less passive hip flexion range of motion demonstrated significantly less hip flexion and greater lumbar flexion during the task. [10] A similar pattern between hip and lumbar spine flexion coordination was observed during standing hip flexion in healthy adults suggesting that as the contribution from hip flexion decreased lumbar spine flexion increased. [11] Although seated and standing hip flexion are used as screening tools to clinically assess movement coordination strategy between the hip, pelvis and lumbar spine, it is unclear if the observed movement patterns are applicable to standing functional tasks such as lifting.

Apart from the influence of hip flexion range of motion capacity on lifting mechanics, weakness of the lumbar paraspinal muscles has also been proposed to contribute to greater lumbar spine flexion during lifting. [12] This is consistent with the work of Hu and Ning who reported a significant increase in lumbar spine flexion during a lifting task following a lumbar paraspinal muscle fatigue protocol. [12] The participants in the study implemented a stoop lifting task, a strategy that utilizes minimal knee flexion and greater lumbar flexion in comparison to a squat lift. [13] A squat lifting task by comparison, requires greater knee flexion motion and varying degrees of lumbar flexion to lower the upper extremities to the ground. [1, 13] Given that the lumbar paraspinal muscles help stabilize the spine during lifting, it is plausible that individuals with lumbar paraspinal deficiencies may also demonstrate greater lumbar spine flexion during a squat lift task.

Previous studies evaluating the relationship between hip and lumbar spine flexion have focused on individuals with low back pain and have resulted in mixed findings. Esola et al. and Porter and Wilkinson concluded that subjects with a history of low back pain utilized greater amounts of lumbar flexion and reduced hip flexion during a forward bending task. [14, 15] Whereas Wong et al. indicated that both lumbar spine and hip flexion were reduced in subjects with low back pain. [16] The literature on the relationship of the hip and lumbar spine during forward flexion tasks is inconclusive and requires further inquiry.

Identifying the potential relationship between hip flexion range of motion capacity and lumbar flexion during a squat lift in healthy individuals will provide a better understanding of the contributing impairments to movement strategies that result in greater lumbar flexion and resultant low back pain. Squat lifting is an ideal and important movement task to explore this potential relationship because it requires significant utilization of both hip and lumbar spine flexion, and is a task associated with low back injury. [1] Identifying the influences of impairments on movement strategy variability across the healthy population is essential to interpreting the observed difference between healthy subjects and those with low back pain.

Given that increased lumbar flexion has been associated with low back injury during lifting, the purpose of this study was to investigate the associations of hip joint flexion capacity and lumbar extensor strength on hip and lumbar spine flexion during a squat lifting task in healthy individuals. Previous studies have focused on the contributions of the hip to stoop lifting but not squat lifting. We hypothesized that reduced hip joint flexion range of motion capacity and reduced lumbar extensor muscle strength would be associated with greater lumbar flexion motion and less hip joint flexion utilization during the squat lifting task.

Methods

Participants

Fifty subjects (N=50), 27 females and 23 males, between 18-40 years of age participated in the study. The average and standard deviation of age, height and weight of the participants was 25.3 ± 2.6 years, 169.07± 10.6 cm, and 70.1 ± 13.3 kg, respectively.

Prospective participants were included if they were in good general health and did not report a history of low back or lower extremity pain in the previous 12 months. Additionally, individuals were excluded if they were non-English speaking, currently pregnant, or reported a previous history of low back or lower extremity surgery. All participants provided written consent as approved by the Loma Linda University Institutional Review Board (Loma Linda University, CA).

Instrumentation

Lumbar extensor muscle torque production was assessed using a motor-driven dynamometer (PrimusRS, BTE, Hanover, MD). Three-dimensional trunk and lower-extremity kinematic data were obtained using a 16-camera motion-capture system (Qualisys, Gotenburg, Sweden) at a sampling rate of 100 HZ.

Procedures

Isometric torque production of the bilateral lumbar extensor muscles was assessed in the prone position with the trunk flexed to 20 degrees on the dynamometer testing table (Fig. 1). The resistance bar for the dynamometer was placed across the thoracic spine at the level of the 7th thoracic vertebrae (T7), the pelvis was secured to the table with a Velcro strap and visual assessment was utilized during the extension test to confirm that the pelvis was secure. The rotational axis of the dynamometer was aligned with the spinous process of the 5th lumbar vertebrae (L5). Participants were instructed to extend the trunk into the resistance bar with maximal effort for 5 seconds. Three trials were performed while verbal encouragement was provided. There was a 1-minute rest period between each trial.

Figure 1. Participant positioning for the measurement of peak lumbar extension torque production

Following strength testing, reflective markers (12 mm spheres) were placed on the following anatomical landmarks bilaterally: first and fifth metatarsals, medial and lateral malleoli, calcanei, medial and lateral femoral epicondyles, posterior superior iliac spines (PSIS), iliac crests, and the anterior superior iliac spines (ASIS). The trunk was defined by 13 markers placed on the following landmarks: the spinous process of L5, one marker 4 cm lateral to each side of the spinous process of the 4th lumbar vertebrae (L4), the spinous process of the 3rd lumbar vertebrae (L3), one marker 4 cm lateral to each side of the spinous process of the 1st lumbar vertebrae (L1), the spinous process of the 12th thoracic vertebrae (T12), one marker 4 cm lateral to each side of the spinous process of the 7th thoracic vertebrae (T7), the spinous process of the 3rd thoracic vertebrae (T3), acromioclavicular joint, sternal notch and xiphoid process. A rigid plate with 4 reflective markers was placed over the lateral aspect of the bilateral shanks and thighs.

A static calibration trial was performed once the reflective markers were secured. For the squat lift, the participant's stance width was normalized so that the distance between the midline of left and right calcanei was equal to the distance between the left and right acromioclavicular joints. A plywood box with a weight equal to 10% of the participant's body weight was placed at midline and anterior to the feet at a normalized distance equal to one-half the length of the participant's foot. The height of the box handles used for lifting was normalized to one-half the distance from the floor to the tibial plateau. [17] Participants were instructed to lift the box from the floor by gripping the box at the handles, and maintaining the elbows in extension while utilizing a squat lifting strategy at a self-selected speed (Fig. 2). The participant performed one lift prior to starting the recorded trials to confirm understanding of the movement task. Each trial consisted of: 1) squatting to grasp the box, 2) lifting the box, and 3) extending to a fully upright position. A total of three trials were performed with a two-minute rest between each trial. Kinematic data was collected throughout each movement trial.

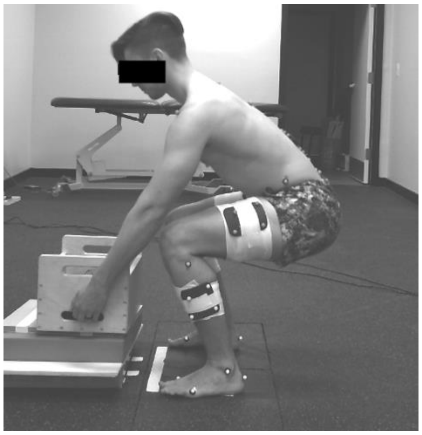
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Figure 2. Participant positioning for the squat lift task.

Following completion of the squat lifting task, hip range of motion capacity was measured using the 3D motion capture system. Participants were seated on an adjustable bench at a height normalized to the level of the popliteal fossa. In the seated position, the hips and knees were flexed to 90 degrees with the feet flat on the floor. Femur position was normalized in the frontal plane through alignment with the anterior superior iliac spine. The participant was instructed to perform a maximal anterior tilt followed by maximal forward and downward trunk flexion to achieve full hip flexion motion (Fig. 3). The participant's femurs were secured by the investigator to maintain alignment with the ASIS in the frontal plane. Three trials were performed with a one-minute rest between trials.


[redacted]

Figure 3. Participant positioning for measurement of hip flexion range of motion capacity

Data Processing

All data was exported from Qualisys to Visual 3D for processing (v.6.01.26) (Germantown, MD). Kinematic data were filtered using a 4th order Butterworth filter with a cut-off frequency of 2 Hz. Lumbar spine motion was calculated as the peak angular measurement between the segments of the lumbar spine and the pelvis. Markers on the L3 spinous process and the markers 4 cm bilateral to the spinous process of L1 defined the rigid segment of the lumbar spine. [18] A negative lumbar flexion value indicated that the lumbar spine remained in an extended position and a positive value denoted lumbar motion into flexion. The pelvis was defined by the markers on the iliac crest, ASIS and PSIS bilaterally. Hip motion was calculated as the peak angular measurement between the segment of the pelvis and thigh. The hip joint center, defined as the proximal end of the segment, was calculated as 50% of the distance between the markers on the bilateral ASIS. The distal end of the segment was defined using markers on the medial and lateral epicondyles.

The descending phase of the squat lift was time normalized to 101 data points. The start of the descent (0%) was defined as the point at which vertical trunk segment velocity was greater than zero, and the end of the movement (100%) was the point at which trunk segment vertical velocity returned to zero. The kinematic variables of interest were peak lumbar flexion and peak hip flexion during the final 10% of the descending phase of the squat. Peak lumbar flexion was calculated as the average peak lumbar flexion over three trials. Peak hip flexion of the right and left hip was averaged together for three trials and used for data analysis.

Additional variables of interest included peak hip flexion range of motion capacity and lumbar extensor muscle strength. The highest value of peak lumbar extensor torque production during testing, normalized to body weight, represented lumbar extensor strength. The average of the left and right peak hip flexion motion during three trials of seated hip flexion testing represented hip flexion motion capacity.

Data analysis

Normality assumption of variables was assessed using the Shapiro-Wilk test and box plots. Pearson correlation coefficients were used to evaluate the association between hip range of motion capacity, lumbar extensor strength and peak hip and lumbar flexion. Data was analyzed using SPSS Statistics Software version 27.0 (SPSS Inc, Chicago, IL, USA). All analyses were performed at an alpha level of .05.

Results

Descriptive statistics for the variables of interest for all subjects are presented in Table 1. There was a significant negative correlation between hip flexion range of motion capacity and peak lumbar spine flexion motion (r=-0.48, p<.001) (Fig. 4). Hip flexion range of motion capacity was positively correlated with peak hip flexion during the squat lift task (r=0.79, p<.001) (Fig. 5). Additionally, lumbar extensor strength was negatively correlated (r=-0.38, p<.01) with peak lumbar spine flexion during the last 10% of the descending portion of the squat lift (Fig. 6).

Table 1. Descriptive Statistics for the Variables of Interest

	Mean±SD Total (n=50)	Mean±SD Female (n=27)	Mean±SD Male (n=23)	*P*
Peak Hip Flexion (deg.)	104.6 ± 8.4	102.8 ± 8.9	106.6 ± 7.5	0.106
Peak Lumbar Flexion (deg.)	9.2 ± 8.0	11.3 ± 7.7	6.8 ± 7.8	0.48
Lumbar Extensor Strength (Nm/Kg)	1.8 ± 0.4	1.6 ± 0.35	1.9 ± 0.3	0.03
Hip Flexion ROM (deg.)	110.6 ± 7.9	109.4 ± 8.9	111.98 ± 6.5	0.248

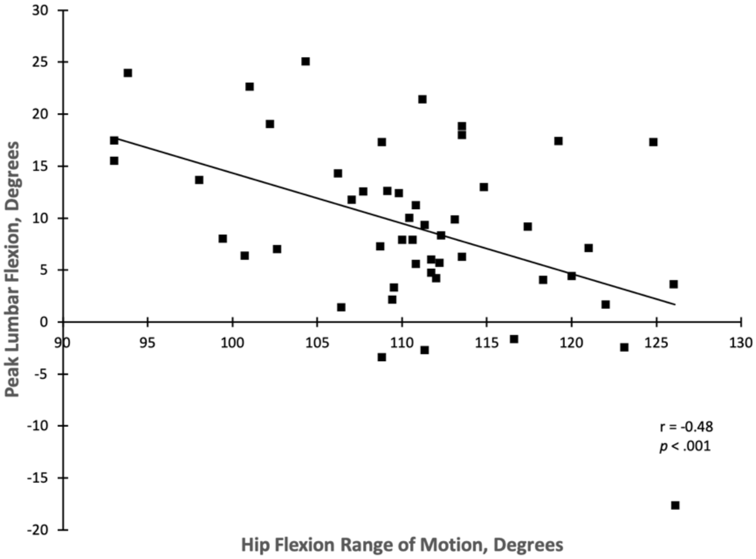

Figure 4. Relationship between hip flexion range of motion and peak lumbar spine flexion during the last 10% of the descent phase of the squat lift. Negative lumbar flexion represents lumbar extension.

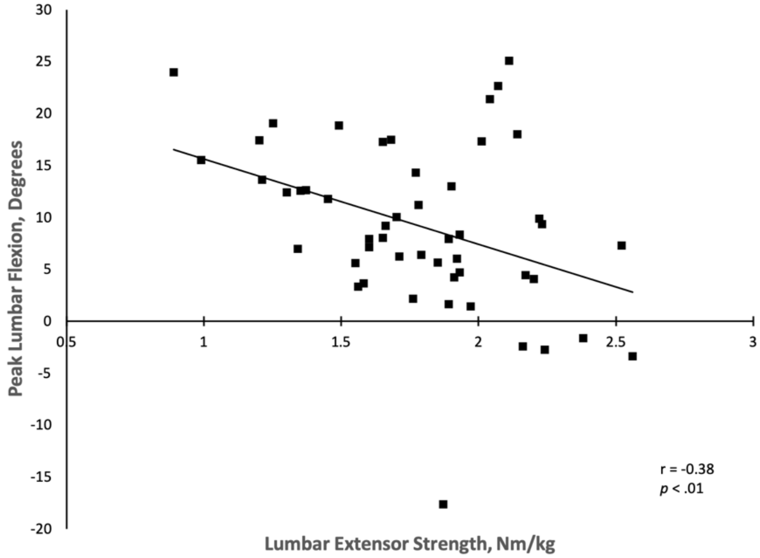

Figure 5. Relationship between lumbar extensor strength and peak lumbar spine flexion during the last 10% of the descent phase of the squat lift. Negative lumbar flexion represents lumbar extension.

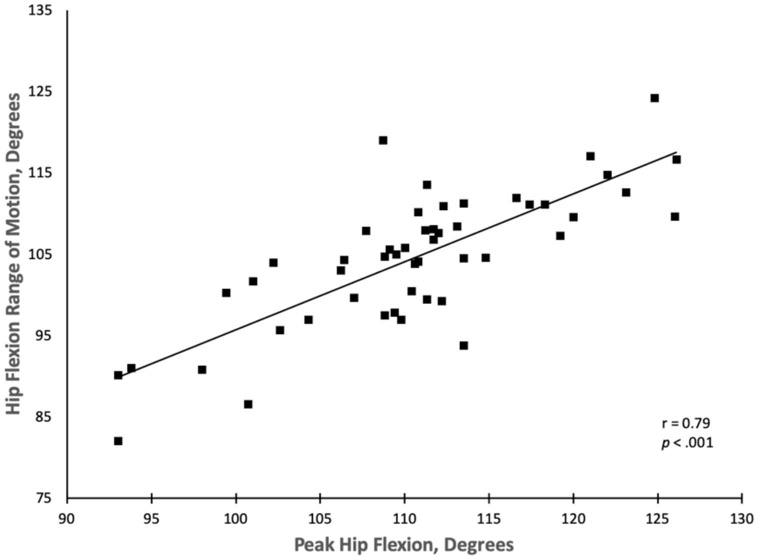

Figure 6. Relationship between hip flexion range of motion and peak hip flexion during the last 10% of the descent phase of the squat lift.

Discussion

The purpose of the current study was to assess the relationship of hip flexion range of motion capacity and lumbar spine extensor strength as it relates to peak lumbar flexion during the final 10% of the descent phase of a squat lift. Consistent with our hypothesis, hip flexion range of motion capacity and lumbar extensor strength were found to be negatively associated with peak lumbar spine flexion during the squat lift task. Specifically, participants with less hip flexion range of motion capacity demonstrated greater peak lumbar flexion and less peak hip flexion during the final 10% of the descent phase of the squat lift. Additionally, individuals with decreased lumbar extension torque production capability also demonstrated higher peak lumbar flexion. Taken together, these results suggest that individuals with less available hip flexion range of motion capacity and lower lumbar extension torque production capability utilize greater amounts of lumbar flexion during a squat lifting task.

Our findings of a negative association between hip flexion range of motion capacity and peak lumbar flexion are consistent with previous studies that examined the influence of hip range of motion on lumbar spine kinematics. [10, 11] Kim et al. reported that subjects with limitations in hip flexion range of motion and a history of low back pain demonstrated greater lumbar flexion during a seated hip flexion task. [10] The group with limited hip flexion range of motion capacity included individuals with low back pain making it difficult to determine if greater lumbar flexion was associated with limited hip flexion capacity or with low back pain. Kuo et al. examined standing hip flexion in healthy older adults and reported that the amount of lumbar flexion contribution to end range motion increased as hip motion reached full flexion capacity. [11] Other research has focused on subjects with low back pain and utilization of a stoop lifting task to investigate the relationship between the hip and lumbar spine kinematics. Indirectly, limited hip mobility by way of hamstring tightness was proposed to contribute to greater amounts of lumbar flexion during this style of lift. [14] The current study indicates that hip mobility may similarly contribute to lumbar flexion motion during a squat lifting task, further supporting the relationship between the hip and lumbar spine during functional tasks which are associated with low back pain.

Peak hip flexion motion capacity acquired during the seated flexion measurement and the peak hip and lumbar flexion ranges observed during the squat lifting task were consistent with previous studies. [13, 19] Although participants with greater hip flexion motion capacity demonstrated higher peak hip flexion during the squat lift, it appears that they did not fully utilize their available hip flexion motion to complete the task. Limited hip flexion motion capacity may be the result of pelvic and femur bony structural changes or progressively increasing tension of the posterior capsule and hip extensor musculature as the hip approaches end range flexion. The height of the box, placed at a distance equal to one-half the height of the tibia, may also have limited the depth of squat required of the participants making it more likely that hip motion was limited by posterior capsule or hip extensor muscle tension and not morphological factors. It is also possible that observed differences in lumbar and hip contributions to squat lifting may be due to learned motor control strategies to maintain the center of mass within the base of support. [20] Regardless of the exact cause of the hip motion limitation, participants with less available hip flexion motion preferred a movement strategy that utilized greater lumbar flexion.

The finding that lumbar extensor strength is negatively associated with peak lumbar flexion suggests that decreased lumbar extensor torque production may also contribute to greater lumbar flexion during squat lifting. This is consistent with a previous study that investigated sagittal plane lumbar kinematics in the presence of fatigue induced paraspinal weakness. [12] Hu et al. reported that individuals with decreased muscle tension generation capabilities demonstrated greater lumbar flexion during the descent phase of a stoop lifting task. [12] Although stoop and squat lifting are inherently different movement tasks, both motions require coordination between the lumbopelvic complex and similar eccentric and concentric control of the lumbar spine. [13] Taken together with the current study, it could be argued that a decreased ability to produce tension in the lumbar extensor muscles may result in greater lumbar flexion regardless of the lifting style chosen.

The lumbar spine extensors are responsible for the eccentric control of lumbar flexion during the descending phase of squat lifting. [21] In order to control the amount of lumbar flexion during lifting, the lumbar extensor muscles resist the external load of the flexing trunk. [7] A decrease in muscle tension production capability may result in greater amounts of lumbar flexion as the load exceeds the capability of the contracting muscles. It has been suggested that greater amounts of lumbar flexion during lifting decreases the torque production capabilities of the muscle resulting in greater reliance on the passive tissues of the spine. [7] Therefore, reduced strength of the lumbar extensor muscles may contribute to greater tensile stress of the passive structures of the lumbar spine.

Greater amounts of lumbar flexion during repetitive lifting tasks is associated with increased compressive stress and shearing loads on the intervertebral discs. [4, 6] Lumbar flexion during daily tasks is thought to contribute to, and has been demonstrated in, individuals with low back pain. [14, 22] A squat lifting strategy that increases flexion of the lumbar spine may therefore increase the bending stress experienced by the lumbar structures. A limitation in hip flexion range of motion capacity and lumbar extension strength may be contributing factors to squat lifting movement strategies that result in greater lumbar flexion.

There are several limitations that should be considered when interpreting the results found in this study. First, the study involved young and healthy adults without a recent history of low back pain. Therefore, the results cannot be generalized to other groups including older individuals or those with a history of, or currently experiencing, low back pain. The current findings are applicable within the context of a specific style of lifting that was controlled through the placement of the lifted object and normalized to the individual’s anthropometrics. Our data indicate an association between hip range of motion capacity and lumbar erector spinae strength and peak lumbar and hip flexion during squat lifting but does not establish a causative relationship.

Summary

Our findings indicate that both hip flexion range of motion capacity and lumbar erector spinae weakness may contribute to movement strategies that result in greater lumbar spine flexion stress during squat lifting. When assessing movement strategies that are associated with lumbar flexion, hip mobility and lumbar strength impairments warrant consideration as possible contributors to altered movement strategies. Strength of the lumbar erector spinae, although previously linked to low back pain, have not been linked to squat movement lifting strategies. Whether or not these relationships increase the likelihood of an individual developing low back pain requires further investigation.

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CHAPTER 4

DISCUSSION

Understanding the contributions to movement strategies that result in increased stress to the tissues of the lumbar spine is crucial to developing interventions aimed at restoring ideal movement patterns. Prior to investigating the effects of contributing impairments to stressful movement patterns in individuals with low back pain, it is valuable to observe these relationships without the influence of pain. Healthy individuals, without a history of low back pain, allow for such observations. The majority of studies in the current literature reflect changes in movement strategies that are associated with both low back pain and a related impairment. These studies make it difficult to distinguish mechanical contributions from those related to pain. The current study focused on movement patterns of healthy individuals as a precursor to understanding the impairments that are seen in individuals with low back pain.

Regional interdependence is a concept that suggests that contributions of impairments from a more remote region of the body may contribute to localized dysfunction and tissue stress. [1] For example, a significant amount of research has attempted to explain the association between hip strength, trunk posture and the resulting lower extremity movement patterns that place higher loads on the quadriceps muscle and the structure of the knee joint. [2, 3] There is a paucity of research that has examined the associations between hip weakness, trunk position and the resulting loads on the lumbar spine. With respect to the influence of the trunk and hip on lower extremity loading, trunk flexion is positively associated with muscle activity of the gluteus maximus. [3] For example, greater amounts of trunk flexion during running results in increased hip extension moments and decreased knee extension moments. [2] When examining the variations in load at the hip and knee during running and squatting, hip extension load is increased when knee extension is decreased based on the position of the trunk and the adjustment of the center of mass. Thus, hip weakness may result in a more upright trunk as a strategy to decrease hip extension load, contributing to greater knee extensor loads.

The relationship of the hip extensors and lumbar extensors during squatting and lifting may be inconsistent with the previous example. The findings of our first paper support the premise that individuals with lower hip extension torque production capabilities preferred a lifting strategy that reduced the load at the lumbar spine and the hip. This is in contrast to our expectation that diminished hip extension strength would result in greater lumbar loading, as seen in the knee. A more forward trunk position may increase extension moment at the hip but also increase the extension moment at the lumbar spine. Through this mechanism it could be argued that an individual with reduced hip extension torque production capacity cannot adjust the trunk position to shift the loads from the hip to the lumbar spine, as a shift in trunk position to move the center of mass will result in a decrease or increase of both hip and lumbar moments. It is possible that the requirements of the participants, to complete a squat lift, may have influenced our results. It is also plausible that individuals with diminished hip extensor strength avoid positions that increase both hip extension moments and lumbar extension moments. As hip and lumbar spine strength were found to be correlated, it is difficult to determine if strength of the lumbar extensors or strength of the hip extensors influenced the squat lift strategy. Dissimilar to what has been observed in the knee, weakness of the hip extensor muscles does not appear to result in overuse of the lumbar spine extensor muscles during a squat lift.

Based on incidental findings of our research, diminished strength of the hip extensors is associated with diminished strength of the lumbar extensors. As these muscles work together to produce lumbar and hip extension when lifting, decreased torque production of these muscles as a group may result in altered movement patterns. Clinically, this may be problematic for individuals who are instructed to utilize a movement strategy that requires greater hip and lumbar extensor force production (i.e., a hip dominant strategy). Anecdotally, this has been observed in individuals who are instructed to demonstrate a more forward trunk as a way to increase the contribution of the hip extensors. Although this type of movement strategy can reduce the loading of the knee joint, it may inadvertently increase the muscle force requirements of the lumbar extensor muscles resulting in low back pain. It may be of significant benefit to address the strength deficits of both the hip extensors and lumbar extensors prior to instituting a change in movement pattern that would require greater force production from these muscles.

Hip flexion mobility has been previously shown to contribute to greater lumbar flexion during stoop lifting, standing hip flexion, and seated hip flexion. [4, 5] A limitation in hip mobility is proposed to contribute to lumbar spine flexion through posterior tilting of the pelvis as the hip approaches maximal flexion capacity. [6] For example, during lifting the pelvis anteriorly tilts on the femur causing hip flexion. As the pelvis reaches maximal anterior tilting capacity (i.e., maximal hip flexion), further motion into relative hip flexion may be obtained through posterior pelvic tilt. [6]

Posterior tilting of the pelvis in this position may contribute to greater lumbar flexion. The exact contribution to end range hip flexion during this scenario is unclear. A morphologic or bony barrier of the coxofemoral joint is a likely cause but not the only possibility. Joint capsule tightness, hip extensor muscle tension, or neuromuscular coordination may also limit hip flexion mobility.

The results of our second study support the premise that limited hip motion capacity is associated with greater amounts of lumbar flexion. Although the exact cause of the limitation of hip motion is not known, our data did not indicate that end range hip flexion resulted in posterior pelvic tilt and resulting lumbar flexion. The participants in the study may not have been required to squat low enough to pick up the box thus reducing the requirements for maximal end range hip flexion. It is more likely that those participants with limited hip flexion capacity preferred to flex the lumbar spine to approach the box as hip flexion became more restricted. Again, it is unclear what caused the limitation in hip motion or the chosen movement strategy but neuromuscular coordination to maintain the center of mass within the base of support should be considered a contributor.

From a clinical application standpoint, hip flexion mobility should be considered a possible contributor to greater lumbar flexion observed during squatting. Providing patients adequate hip flexion mobility may be the first step to addressing aberrant movement patterns that utilize greater amount of lumbar flexion. The combination of both limited hip flexion mobility and a lumbar extensor strength deficit may be problematic as both variables were associated with increased lumbar spine flexion during the squat lift.

Study Limitations and Future Recommendations

The current study included healthy male and female subjects without a history of low back pain. Previous studies report significant biomechanical differences between genders when performing squat lifting movements. [7-9] Data from the first study indicated that male individuals demonstrated significantly greater lumbar extensor strength compared to females and experienced greater lumbar loading during the concentric phase of the squat lift, Table 1. The differences in lumbar extensor strength may have contributed to the lack of correlation between lumbar moments and lumbar extensor strength in the male group. The correlations may have also been influenced by a lack of true muscle weakness. It is possible that the healthy individuals tested were above the threshold of muscle weakness which would result in significant changes in movement patterns. Differences in movement patterns between males and females could also explain the lack of correlation in the male group and movement patterns between males and females may best be examined separately.

Table 1. Male Vs. Female Comparison

	Total (n=50)	Female(n=27)	Male (n=23)	P-Value
	Mean±SD (Min, Max)	Mean±SD (Min, Max)	Mean±SD (Min, Max)	
Hip Strength (Nm/Kg)	2.12 ± .57 (.94,3.65)	2.02 ± .68 (.94,3.65)	2.25 ± .39 (1.7,3.08)	.153
Lumbar ES Strength (Nm/Kg)	1.69±.35(.82,2.36)	1.57±.35(.82,2.11)	1.83±.30(1.22,2.36)	.007
Lumbar Moment (Nm/Kg)	2.06 ± .34 (1.27,2.59)	1.89 ± .31 (1.27,2.59)	2.25 ± .25 (1.59,2.56)	.000
Paraspinal EMG (% MVIC)	56.01 ± 15.33 (35.21,102.96)	58.75 ± 18.78 (41.42,102.96)	52.80 ±9.30 (35.21,69.46)	.676

Further studies are needed to examine the relationship of hip range of motion availability, hip and lumbar extensor strength and resulting lumbar flexion and loading of the lumbar spine in individuals with low back pain. We have established a relationship between these variables in healthy individuals, but it is not clear if individuals with low back pain and with similar impairments will demonstrate similar patterns.

To more clearly reveal the differences in movement patterns secondary to muscle strength, it would be advantageous to recruit individuals who are on both ends of the strength spectrum. This would allow for a more accurate comparison of individuals with significant muscle strength deficits compared to a group with higher muscle torque production capabilities. Likewise, inclusion of a group with significantly lower muscle strength and low back pain would further clarify the contributions to aberrant movement patterns in the low back pain population.

The requirements of a squat lifting strategy may have biased the participants of the current study to utilize a hip strategy. It may be more appropriate for future studies to allow for a self-selected lifting strategy using heavier weights, to more appropriately capture the participants natural movement patterns when the load exceeds the capabilities of the involved muscles. To this same end, lifting may also provide more variation in movement patterns as greater hip range of motion is required to complete this task.

During the design of the current study, a pain protocol was developed in order to address the contributions of cognitive variables to movement. In particular, we were interested in the influence of fear on movement strategy. To select for the fear of pain, but not the experience of pain itself, the study was designed to be completed on healthy individuals. Participants would be asked to complete the lifting tasks as seen in this study while expecting a painful shock. The level of pain for the electrically induced pain would be established at 8/10 prior to beginning the movement trials. The participant would be told that they would be shocked during the movement trial. Three trials of lifting would be performed however, the shock would not occur. The investigator would continue with each trial, explaining an error occurred for that trial but the participant could expect a shock on the subsequent trial. Through this mechanism, a tool was developed for future studies to examine the effects of fear of pain on movement without inducing pain.

The collected data for this study included forward flexion and return from forward flexion, stoop lifting various weights, self-selected squat lifting and squat lifting while maintaining a neutral spine. Future studies may include comparison of stoop lifting and squat lifting strategies, the effects of maintaining a neutral spine during a squat lift as compared to a self-selected strategy, and lumbo-pelvic coordination during stoop and squat lifting in healthy individuals.

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CHAPTER 5

APPENDIX

Informed Consent Form

LOMA LINDA UNIVERSITY

Physical Therapy

Loma Linda University
Nichol Hall 1810
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Phone: 909.558.4632
Fax: 909.558.1000

INFORMED CONSENT

TITLE: THE INFLUENCE OF MOBILITY AND STRENGTH ON LUMBAR BIOMECHANICS DURING FUNCTIONAL ACTIVITY

INVESTIGATOR: Everett Lohman III MPT, D.Sc., P.T., OCS

KEY INFORATION

Voluntary Consent - You are being asked to volunteer for a research study. It is up to you whether you choose to participate or not. There will be no penalty or loss of benefits to which you are otherwise entitled if you choose not to participate or discontinue participation.

Purpose - The purpose of the study is to evaluate the different factors that cause back pain with bending, lifting, and squatting. This study seeks to determine the motions that lead to low back pain.

Duration – It is expected your participation in this study will last 2 hours on one day.

Procedures and Activities – You will be asked to bend and lift a box with weights up to 40% of your body weight while being filmed with 3D cameras. You will be asked to lift using a squat lift and a stoop lift.

Risks - Some of the foreseeable risks or discomforts for your participation may be muscle soreness following lifting and or strain when lifting the different weights. There is also the possibility that the personal information you have provided could be viewed by individuals not associated with the study.

Benefits – There are no direct benefits to you for your participation in this study. We hope to better understand why people who have low back pain move differently so that we can better help those who suffer from low back pain.

Alternatives – Participation is voluntary and the only alternative is not to participate.

WHY IS THIS STUDY BEING DONE?

This study is a graduate student research project aimed at evaluating the different factors that cause back pain with bending, lifting, and squatting. This study seeks to determine the motions that lead to low back pain. You are invited to be in this study because you are a healthy individual. You will be excluded if you have a history of LBP for past 12 months that has restricted functional activity, pain greater than 0 on 0-10 scale, currently pregnant or pregnant in the past 12 months, previous hip, spine or lower extremity surgery in the last year, or lower extremity injury within the past 6 months. Approximately 50 participants will participate in this study at Loma Linda University. Your participation in this study may last up to 2 hours on one day.

HOW WILL I BE INVOLVED?

Participation in this study involves the following:
If you agree to participate in this you will be asked to schedule a time to come to the movement laboratory so that we can record the way you move. You will then change into shorts without a shirt, or a sports bra and shorts for women, in order to expose the skin. We will measure the following while in the movement lab.

- Height
- Weight
- Hip motion
- Hip strength
- Back strength
- Knee strength
- Abdominal strength

We will then apply small markers, with two-sided tape, to your skin at points on your feet & ankles, knees, hips, back, shoulders and chest. We will also apply muscle sensors to the skin, using two-sided tape, over your back muscles, buttock muscles, thigh muscles and stomach muscles. You will be instructed to perform the following movements.

- Bend forward to touch your toes
- Lift a box, weighing 10%, and up to 30% of your body weight, from the ground with your knees straight
- Lift a box, weighing 10%, and up to 40% of your body weight, from the ground while bending your knees and hips

During the movements, you will be recorded on 3D cameras as well as digital video recordings.

WHAT ARE THE REASONABLY FORESEEABLE RISKS OR DISCOMFORTS I MIGHT HAVE?

This study poses no greater risk to you than what you routinely encounter in day-to-day life. Participating in this study will involve the following risks:

You may note discomfort or muscle soreness following the bending and lifting activities. It is possible that you could become injured while lifting the heavier weights during bending and lifting. You should not have pain or discomfort while performing the movements. If you do have pain, please notify the investigator as soon as possible. Finally, there is the possibility that your personal information could be seen by others who are not part of this project. This information is limited to that which you are asked on the personal informational sheet of the study.

All records and research materials that identify you will be held confidential. Any published document resulting from this study will not disclose your identity without your permission. Information identifying you will only be available to the study personnel. The personal information sheet that you complete at the start of the study will be kept separate from all of the information and data gathered during the study. You will be given a random identification code that will be used to identify your specific data throughout the study. Any questionnaires or survey answers will not be identified with your personal information.

The use of your Protected Health Information is explained in the separate authorization form.

WILL THERE BE ANY BENEFIT TO ME OR OTHERS?

Although you may not personally benefit from this study, your participation may help practitioners better provide treatment to future patients who are suffering from low back pain.

WHAT ARE MY RIGHTS AS A SUBJECT?

Your participation in this study is entirely voluntary. You may refuse to participate or withdraw once the study has started. Your decision whether or not to participate or terminate at any time will not affect your future standing with the researchers. You do not give up any legal rights by participating in this study.

If you feel uncomfortable answering any of the questions on the survey you may refuse to answer questions.

WHAT COSTS ARE INVOLVED?

There is no cost to you for participating in this study.

WILL I BE PAID TO PARTICIPATE IN THIS STUDY?

You will not be paid to participate in this research study.

WHO DO I CALL IF I AM INJURED AS A RESULT OF BEING IN THIS STUDY?

If you feel you have been injured by taking part in this study, consult with a physician or call 911 if the situation is a medical emergency. No funds have been set aside nor any plans made to compensate you for time lost for work, disability, pain or other discomforts resulting from your participation in this research.

WHO DO I CALL IF I HAVE QUESTIONS?

Call 909-558-4647 or e-mail patientrelations@llu.edu for information and assistance with complaints or concerns about your rights in this study.

SUBJECT'S STATEMENT OF CONSENT

- I have read the contents of the consent form and have listened to the verbal explanation given by the investigator.
- My questions concerning this study have been answered to my satisfaction
- Signing this consent document does not waive my rights nor does it release the investigators, institution or sponsors from their responsibilities.
- I hereby give voluntary consent to participate in this study.

I understand I will be given a copy of this consent form after signing it.

______________________________	______________________________
Signature of Subject	Printed Name of Subject

____

Date

INVESTIGATOR'S STATEMENT

I have reviewed the contents of this consent form with the person signing above. I have explained potential risks and benefits of the study.

______________________________	______________________________
Signature of Investigator	Printed Name of Investigator

____

Date

Recruitment Flyer

A Research Opportunity

"The Influence of Mobility and Strength on Lumbar Biomechanics During Functional Activity"

A Graduate Student Research Study

Who Can Participate?

Healthy Males and Females
Adults 18-40 years of age

You May Be Excluded If You…

Have a history of low back pain in the past 12 months that limits functional activity
Pain greater than zero on a 0-10 scale
Had previous hip, spine or lower extremity surgery in the last year
Are currently pregnant or pregnant in the last 12 months
Lower Extremity Injury within the past 6 months

What is Involved?

Bending and lifting tasks, strength testing of the hips, back and abdominal muscles

How Long Does it Take?

Up to 2 hours on one day including movement testing and muscle testing

Where?

Loma Linda University, School of Allied Health Professions, Department of Physical Therapy, Movement Lab located in Nichol Hall, Room A640

Principal Investigator

Everett Lohman, III MPT, D.Sc., P.T., OCS

Contact Information

Graduate Student Investigator: Chris Patterson PT, DPT, OCS
Email: cpatterson@apu.edu

Phone 714-273-4444

LOMA LINDA UNIVERSITY
School of Allied Health Professions