The Influence Over Time of Abdominal Strength Changes on Gluteus Maximus Strength

Taylor M. Opperhauser

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The Influence Over Time of Abdominal Strength Changes on Gluteus Maximus Strength

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Thesis submitted to the
College of Physical Activity and Sports Sciences
At West Virginia University
In partial fulfillment-of the requirements
For the degree of

Masters of Science
In
Athletic Training

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Morgantown, West Virginia
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Keywords: Core strength, Double-leg lowering test, Gluteus maximus, Hand-held dynamometer
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Context: Core stability is vital for appropriate functional activity and performance. The core is the primary link to the kinetic chain that allows for optimal performance. When one component of the core is either inhibited or overactive, an imbalance occurs. Antagonist and agonist muscles must function together to maintain appropriate muscle balance. Both the lower abdominal muscles and gluteus maximus muscle work together to create appropriate kinetic chain functioning. However, it is unknown whether a change in lower abdominal strength influences a change in gluteus maximus strength over time. Objective: The purpose was to determine if a change in lower abdominal strength influenced a change in gluteus maximus strength over time. Design: The study was conducted as a prospective longitudinal repeated measures design. Setting: The testing took place at a sports medicine research lab at a DI University. Only one clinician administered the testing. Patients and Other Participants: A total of 47 participants (13 males, 21.54±1.45 years, 177.21±6.74 cm, 80.77±12.80 kg; 34 females, 20.06±1.51 years, 166.14±6.73 cm, 72.16±14.08 kg), from a pre-athletic training and athletic training program were used in the study. All participants volunteered for the study, were current students in the pre-athletic training or athletic training programs, and had no history of injury within six months of testing. Interventions: The participants were asked to complete the double leg lowering test (DLL) and gluteus maximus manual muscle test (GM MMT) to the best of their ability. There was no warm up prior to testing, but the testing protocol was demonstrated. The data was collected over a ten week period, in increments of five weeks. Participants completed a baseline test. Two post-testing measurements were taken and occurred every 5 weeks. The post testing measurements were completed to the exact specifications as the first testing period. Main Outcome Measures: The dependent variables were both lower abdominal strength as assessed by the DLL (in degrees), and gluteus maximus strength as tested by the GM MMT (%MAXEXT). Results: Positive, medium relationships were found from DLL posttest two to right GM MMT baseline (r=.306, p=.036), to right GM MMT posttest one (r=.319, p=.029) and to right GM MMT posttest two (r=.316, p=.030). The correlations between the DLL and left GM MMT were all found to be small relationships (r=.177-.190). A positive, medium relationship was found between DLL baseline and DLL posttest two (r=.414, p=.004), as well as DLL posttest one and DLL posttest two (r=.365, p=.012). Further analysis of the left and right GMax, yielded significance between baseline and posttest two for DLL (P=.004) and left GM MMT (P<.001). There was also significance between baseline and posttest one for right GM MMT (P=.046), as well as posttest one and posttest two for right GM MMT (P=.033). There was no significance between gender and activity, and the muscle strength tests. Conclusions: Gluteus maximus strength changes and lower abdominal strength changes were shown to correlate over time. Both gluteus maximus strength and abdominal strength were shown to decrease overtime without intervention. However, gender and activity did not play a significant role in muscle strength over time.
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INTRODUCTION

The core is a complex anatomical space that incorporates more than just the abdominal muscles. The shape of the core has been described as a box, as well as a cylinder, that attaches the rib cage to the pelvis. However, the exact components that comprise the core are fairly inconsistent throughout the literature. The components are said to change based on postural adjustments or the load placed on the body. Nonetheless, a consistent factor is the concept of local, global and transfer muscles. These muscles function to control intersegmental position, increase intraabdominal pressure, provide a stable base for the extremities, and transfer force between the thoracic cage and pelvis to the distal extremities. The core has been defined as an integrated spinal stabilizing system (ISSS), which includes the deep cervical flexors, deep spinal extensors, diaphragm, pelvic floor, all sections of abdominals and spinal extensors of the lower thoracic and lumbar regions. Due to this all-encompassing facet, the core is also called the lumbo-pelvic-hip complex.

The local, global and transfer muscles that comprise and act on the lumbo-pelvic-hip complex are the lumbar muscles, abdominals, and hip muscles. The lumbar muscles specifically include the transversospinal group, erector spinae, quadratus lumborum and latissimus dorsi. These structures act as postural stabilizers as well as intra- and intersegmental stabilizers of the spine during motion. Incorporated in the transversospinal group is the multifidus muscle. This muscle is the most important in this group because of the ability to stabilize the lumbar spine in all lumbar positions. Also incorporated in the lumbar muscle group is the latissimus dorsi (LD), which is connected to the thoracolumbar fascia. The LD is a bridge between the upper extremity and the lumbo-pelvic-hip complex.
The abdominal muscle group contributes to efficient function of the lumbo-pelvic-hip complex and includes the transverse abdominis (TA), rectus abdominis (RA), internal oblique (IO) and external oblique (EO) muscles. These muscles maintain optimal spinal kinematics during movement. The TA is considered the most important abdominal muscle based on function during motion. When a load is placed on the body the transverse abdominis is the first muscle to contract. Specifically in hip extension, the TA, RA, and IO activate before the gluteus maximus muscle. Further, when the TA contracts, the multifidi activates as well. This co-activation creates the cylindrical girdle in the midsection to allow for stabilization. The oblique muscles and rectus abdominis muscle are recruited equally as well during trunk stabilization exercises, but after the TA and multifidus contract. The attachment of the obliques and RA to the thoracolumbar fascia lends to the ability to stabilize the trunk by preventing mediolateral rotation. While the RA assists during mediolateral rotation, the primary action is stabilization of the pelvis during anteroposterior tilting. Souza found that there is no significant difference between right and left muscle activation during pelvic stabilization, and noted that the muscles are symmetrically stabilizing the pelvis, regardless of the extremity that is moving.

The final component of the lumbo-pelvic-hip complex is the hip muscles. The gluteus maximus (GM), gluteus medius (Gmed) and psoas muscles are prime movers of the hip. The gluteus maximus, works concentrically to accelerate hip extension, externally rotate the femur, and generate a large amount of force and power to be disseminated throughout the kinetic chain. The gluteus maximus attaches to the thoracolumbar fascia to create a functional relationship between the lumbo-pelvic-hip complex and the lower extremity. The gluteus medius is divided into anterior, middle and posterior sections. The posterior portion of the muscle acts as a
hip stabilizer, while the anterior and middle sections perform hip abduction.\textsuperscript{30} A strong Gmed minimizes the likelihood of developing a Trendelenburg gait, which is a biomechanical abnormality due to Gmed weakness. As the psoas works to dynamically decelerate the hip extension generated by the GM, an anterior shearing force is created at the lumbar spine. The psoas becomes overactive and tight to counteract the GM’s motion. The aforementioned abdominal muscles counteract the shearing force generated by the psoas. A tight psoas coupled with an increase in anterior shearing motion causes reciprocal inhibition of the GM, multifidus, deep erector spinae, internal oblique, and transverse abdominis.\textsuperscript{17} An overall dysfunction and instability occurs at the hip, which causes the hamstrings and erector spinae group to become the primary movers during hip extension.

While it is known that the hip, abdominal and lumbar muscles work together to create a stable base in the lumbo-pelvic-hip complex, it is unknown whether a change in abdominal strength influences a change in gluteus maximus strength over time. When functioning at an optimal level, the abdominal muscles stabilize the pelvis and counteract the shearing force generated by the psoas. When the shearing force is activated by the psoas muscle, the abdominals generate a force couple to maintain an appropriate length-tension relationship.\textsuperscript{31} Furthermore, when the lumbopelvic stabilizers and abdominals, are not contracting in the appropriate order, are fatigued or weak, optimal trunk stabilization does not occur during static and dynamic activities. This weakness causes an over activation of the gluteals, which does not allow the gluteus maximus to create the self-bracing mechanism at the sacroiliac joint to stabilize the spine and pelvis.\textsuperscript{32-38} When a weak core is present with strong extremities, there is not enough stabilization to generate efficient movement.\textsuperscript{17} Thus, it is understood how the abdominals
impact the GM by way of the psoas. However, it is unknown whether the abdominals directly influence the GM.

Muscle strength can be effected by many internal and external factors. Activity level, gender and sitting time are simply a few of the possible influences on the strength of muscles. The literature is inconsistent as to whether gender and activity level play a role in muscle strength. When evaluating males and females’ abdominal and gluteus maximus muscle strength, studies\textsuperscript{44,45} have found there to be no difference between gender. In contrast, studies\textsuperscript{8,43,46,47} have found males to have slightly greater muscle strength of both the gluteus maximus and abdominals. The core and gluteus maximus musculature is activated during menial activities of daily living. Tasks such as laughing are even found to generate the similar muscle activation than that of conventional training exercises (crunch and back lifting).\textsuperscript{44} While walking on level surfaces, up and down stairs, and even running are shown to activate the gluteus maximus.\textsuperscript{48} Since these menial tasks have an effect on muscle activation, it is vital to understand if greater levels of activity have an impact on subsequent muscle strength. When not engaging in activity, the average adult spends eight hours sitting each day.\textsuperscript{48} The literature explores the effect of prolonged sitting on structures of the lumbar spine, stating that greater amounts of sitting increase shearing forces on the vertebrae\textsuperscript{49}, increase the stiffness of passive spine structures\textsuperscript{50}, and place an individual at an increased risk for low back musculoskeletal injury.\textsuperscript{49} While the literature shows a correlation between prolonged sitting and the hamstrings\textsuperscript{51} and hip flexors,\textsuperscript{17} its effect on the gluteus maximus is yet to be determined. Thus, the purpose of this study was to determine if a change in abdominal strength influences a change in gluteus maximus strength over time. A secondary purpose of this study was evaluate gender, activity level and sitting time on the changes in the DLL and GM MMT strength tests.
METHODS

The design of the study was a repeated measures and correlation design with a convenience sample of pre-major and major athletic training students. Subjects were tested every 5 weeks, over a 10-week period. The dependent variables were the double-leg lowering test (DLLT) to measure lower abdominal strength and the gluteus maximus manual muscle test (GM MMT) to measure gluteus maximus strength. The independent variable was gender (male and female), activity level (none, low, moderate, intense), sitting time, and time over all (baseline, posttest one, posttest two) which was obtained from the questionnaire.

Subjects

Forty-seven college-age male and female subjects were recruited (13 males, 21.54±1.45 yrs, 177.21± 6.74 cm, 80.77±12.80 kg; 34 females, 20.06±1.51 yrs, 166.14±6.73 cm, 72.16±14.08 kg). The main researcher approached each prospective and curriculum athletic training class at a Mid-Atlantic University to present the research idea and to ask for volunteers. A questionnaire was given to each subject to determine demographic information, activity level, and injury history to determine eligibility for the study. Each subject was a non-injured, non-athletic individual, with no history of lower extremity injury or surgery within six months leading up to the study. Inclusion criteria included status in either the pre-athletic training or athletic training program. Exclusion criteria included subjects currently engaged in a core stability training program, and surgery involving the knee, hip or ankle within six months of the study. Results were only included in this study for those subjects who completed all three testing periods (1 baseline, 2 follow-up). The approval of the study was obtained from the Office of Research Compliance at the Institution.
Instrumentation

The strength of the lower abdominals was tested using the Double Leg Lowering Test (DLLT). The leg lowering test using the sphygmomanometer was considered reliable and valid for adults. The Hudl app (Agile Sports Technologies, Inc., Lincoln, Nebraska) on an iPad, was used during the DLLT to determine the change in subjects’ angle of hip flexion from the table. Validity and reliability of this app is unknown.

Due to the feasibility, manual muscle tests (MMT) have been used in the clinical setting as a way to gauge muscle strength. MMT performed with a handheld dynamometer can be used to determine a more definitive measurement than ordinary MMT simply determined by the clinician. A digital scale (XPress XBL Bench Scale, Model XBL150L-XID, Mettler-Toledo, Inc, Columbus, OH) was used to weigh the subjects to normalize weight with the gluteus maximus strength scores. The scale accurately weighed to the closest 0.1 lb. A Lafayette manual muscle test system (MMTS; Model 01163, Lafayette Instruments, Lafayette, IN) handheld dynamometer was used to test the subjects’ hip-extension strength. The MMTS measures the static force produced by a muscle against the force pad. This handheld dynamometer can effectively measure static force ranging from 0 to 300 lb with an accuracy of 0.5 lb. It is important that the subject performed 3 practice trials, and an average of the 3 testing trials used for data collection. A related study, using a similar handheld dynamometer, found a high reliability for measuring hip-extension strength with an ICC1,1 of 0.93.

Procedures

Those subjects who met all inclusion criteria and completed the informed consent form (Table CI) and demographic questionnaire (Table C2), were invited to volunteer to participate in the study. Prior to the testing period, times were established for subjects to meet with the
researcher once a week, every 5 weeks, for approximately 15 min/sessions. During the first testing session, subjects chose a subject number in which they would be referred to for the duration of the study. The researcher was blinded to the allocation of subject numbers. During each testing session, the subject completed the demographic questionnaire and performed the gluteus maximus strength and lower abdominal strength tests. Both the dominant and non-dominant leg were used for testing of the gluteus maximus. One reading was taken for the lower abdominals from the double leg lowering test. The order of testing for the dominant/non-dominant leg GM MMT and DLLT was randomized during each session. All exercises were performed in the research laboratory in the College of Physical Activity and Sports Science building at West Virginia University to serve as an environmental control. Administration and supervision of all testing was done by one researcher.

Testing Protocol

First, subjects completed the demographic questionnaire. This sheet was coded using the subject number chosen by the participant. The subject answered questions regarding activity level, male or female, if female, the first day of the last menstrual cycle, approximately how many hours spent seated each day, injury history in the past six months, medications that may affect balance, and involvement in a core stability program.

At the beginning of each session, the subjects were oriented to the DLLT and GM MMT. The subjects first completed either the dominant/non-dominant GM MMT or DLLT, as the testing order was randomized. Before testing the gluteus maximus, each subject was weighed using a digital scale to normalize the strength values to the subject’s body weight. A Lafayette MMTS handheld dynamometer was used to test the subjects’ gluteus maximus strength. The subject was prone with the knee flexed to 90 degrees or more (Table C3). The force pad of the
handheld dynamometer was placed just against the lower part of the posterior thigh, in the direction of hip flexion. The primary researcher stabilized the pelvis at the level of the posterior superior iliac spine. The subject took 3 practice trials. The dynamometer was zeroed, and the subject was instructed to extend the hip with the knee flexed by building up force for 2 seconds and then a maximal effort for 4 seconds. The value on the dynamometer was recorded and the dynamometer was zeroed out again before the next trial. The subject had 15 seconds of rest between trials. The 3 trials were averaged and normalized to the individual’s body weight.

During the same testing session, the subject was given a two minute rest before completing the other test, as the order was randomized. The subject completed the DLLT for lower abdominal strength (Table C4). Each subject was asked to wear a sleeveless shirt and shorts, in order to have a visual of the lateral femoral condyle of the knee and greater tubercle of the humerus. Reflective markers were placed on the lateral femoral condyle, greater tubercle of the humerus and greater trochanter of the femur, which were used to determine angle of hip flexion. The subject was placed on a treatment table, supine, with arms folded across the chest. The sphygmomanometer was placed under the subjects’ low back at the level of the posterior superior iliac spine. Minimal air was pumped into the sphygmomanometer prior to the placement. Video recording commenced using an iPad. The subject was instructed to raise both legs to a vertical position with both knees in full extension. At this time, the initial mmHg on the sphygmomanometer was noted. The test began when the subject posteriorly rotated the pelvis to flatten the back to the table, while contracting the abdominal muscles. The subject then slowly lowered both legs to the table. The test concluded when the mmHg strayed ±10mm from the initial reading. At this point, the video was stopped and the angle of the subjects’ hip flexion was determined using the Hudl app (Table C5). The final degrees of hip flexion was subtracted from
the initial degrees to determine the overall change. Markers for the location of the treatment table, ten feet from the tripod holding the iPad, were placed on the floor of the testing room to ensure consistency in angle measurements.

Data Analysis

A coded sheet (Table C5) containing the subject number, was used to record the strength measurement for the lower abdominals. To determine the initial and final degrees of hip flexion, reflective points were placed on the subject’s greater tubercle of the humerus, greater trochanter of the hip and lateral femoral condyle at the knee. A line was drawn from the greater tubercle to the greater trochanter, and a subsequent line from the greater trochanter to the lateral condyle. An angle was given. The process was repeated to determine the subjects’ angle at the start of the test. The final degrees were subtracted from the initial degrees to determine the difference.

On a separate coded sheet containing the subject number, the gluteus maximus strength values were recorded. To determine the normalization to body weight for gluteus maximus strength, the primary investigator divided the average gluteus maximus strength by the subject’s body weight and then multiplied by 100. Upon test completion by all subjects, values were entered into a spreadsheet on SPSS Version 21.0 for Windows (SPSS Inc, Chicago, IL)

Statistical Analysis

Descriptive analysis consisted of means and standard deviations of all subjects for the DLLT and GM MMT. To determine the strength of the relationship between DLL and GM MMT, Pearson’s Correlation Coefficient was used. Relationship strengths are defined as small (.1-.29), medium (.3-.49), and large (.5-1.0). For the double leg lowering test and left gluteus maximus strength test, two separate multivariate ANCOVAs were used with baseline values as the covariate. Gender and activity level were used as the fixed factors (independent
variables). Tukey post hoc tests were calculated as needed. A repeated measures ANOVA was used in place of a multivariate ANCOVA as there was a violation of the assumption of homogeneity for the right GL MMT with activity level and sitting time, and for left GM MMT and DLL with sitting time. The level of significance used for all analyses was \( P = 0.05 \).

RESULTS

Overall means and standard deviations for all subjects can be found in Table D1. A Pearson Product Moment Correlation was run for DLL baseline, posttest one and posttest two, with GM MMT baseline, posttest one and posttest two. Positive, medium relationships were found from DLL posttest two to right GM MMT baseline \( (r = 0.306, P = 0.036) \), to right GM MMT posttest one \( (r = 0.319, p = 0.029) \) and to right GM MMT posttest two \( (r = 0.316, P = 0.030) \). All other relationships between DLL and right GM MMT were considered small \( (r = 0.157 \text{ to } 0.252) \). (Refer to Table D2) The correlations between the DLL and left GM MMT were all found to be small relationships \( (r = 0.177 \text{ to } 0.190) \). (Refer to Table D2) A positive, medium relationship was found between DLL baseline and DLL posttest two \( (r = 0.414, P = 0.004) \), as well as DLL posttest one and DLL posttest two \( (r = 0.365, P = 0.012) \).

Strength Tests, Gender, Activity Level and Sitting Time

A Multivariate Analysis of Covariance was run for gender, and activity level, with a covariate being baseline for both the DLL and left and right GM MMT. A custom model test was run to determine whether the interaction between the covariate (baseline measurement) and fixed factors (gender and activity level) was significant. The significance determined if the assumption of homogeneity was violated. All interaction analyses were not significant, except for the right GM MMT with activity level, gender and sitting time; left GM MMT with sitting time, and DLL with sitting time, which violated the assumption of homogeneity. Therefore, a
2x3 Repeated Measures Analysis of Variance was run for gender, a 3x4 Repeated Measures ANOVA for activity level and a 3 x 3 Repeated Measures ANOVA for sitting time.

DLL and Gender

A significant difference was found for DLL baseline. (F=4.822, P=.013). Significance was found between DLL baseline to DLL posttest two (P=.004). No significant differences were found between gender and DLL posttest one (F=.400, P=.531), and gender and DLL posttest two (F=1.618, P=.210). Means and standard deviations can be found in Table D2.

DLL and Activity Level

A significant difference was found for DLL baseline (F=6.050, P=.005). Significance was found between DLL baseline to DLL posttest two (F=12.166, P=.001). No significant differences were found between activity level and DLL posttest one (F=1.952, P=.136), and activity level and DLL posttest two (F=1.378, P=.263). Means and standard deviations can be found in Table D3.

DLL and Sitting Time

A significant main effect for time (F=9.333, P<.001) was found. The significance was found specifically between baseline and posttest two (P<.001). A significance was also found between posttest one and posttest two (P<.001). No significant main effect was found for sitting time. There was also no time by sitting time interaction (F=1.221, P=.299). Means and standard deviations can be found in Table D1.

Left GM MMT and Gender

A significant difference was found for left GM MMT baseline (F=245.775, P<.001). Significance was found between left GM MMT baseline to left GM MMT for posttest one (P<.001) and posttest two (P<.001). A significant difference was also found between gender and left GM MMT posttest two (F=4.268, P=.045). No significant differences were found between gender and
left GM MMT posttest one (F=1.070, P=.307). Means and standard deviations can be found in Table D4.

Left GM MMT and Activity Level

A significant difference was found for left GM MMT baseline (F=212.197, P<.001). Significance was found between left GM MMT baseline to left GM MMT for posttest one (P<.001) and posttest two (P<.001). No significant differences were found between activity level and left GM MMT posttest one (F=.491, P=.691), and activity level and left GM MMT posttest two (F=.851, P=.474). Means and standard deviations can be found in Table D4.

Left GM MMT and Sitting Time

A significant main effect for time (F=15.714, P<.001) was found. The significance was found specifically between baseline and posttest one (P<.001). A significance was also found between baseline and posttest two (P=.002). No significant main effect was found for sitting time. There was also no time by sitting time interaction (F=1.176, P=.318). Means and standard deviations can be found in Table D1.

Right GM MMT and Gender

A significant main effect for time (F=.570, P=.030) was found. The significance was found specifically between time point one/baseline, and time point two/posttest one, (P=.046). A significance was also found between time point two/posttest one and time point three/posttest two (P=.033). No significant main effect was found for gender. There was also no time by gender interaction (F=.570, P=.532). Means and standard deviations can be found in Table D4.
Right GM MMT and Activity Level

No significant main effects were found for activity level (F= 2.009, P=.127), time (F=1.021, P=.348), nor for the interaction between activity level and time (F=.601, P=.686). Means and standard deviations can be found in Table D4.

Right GM MMT and Sitting Time

A significant interaction was found for sitting and right GM MMT (F=4.433, P<.001). The interaction occurred between GM MMT baseline and sitting posttest one (P<.001) and GM MMT baseline and sitting posttest two (P=.002). A significant main effect for time (F=15.714, P<.001) was also found. The significance occurred between baseline and posttest one (P=<.001). There was also a significance between baseline and posttest two (P=.002). Means and standard deviations can be found in Table D1.

DISCUSSION

The main purpose of this study was to determine if lower abdominal strength had an influence on gluteus maximus strength over time. The secondary purpose was to determine if over time, activity level and gender influenced a change in both abdominal and gluteus maximus strength. The results of this analysis showed that there was a significant correlation between lower abdominal muscle strength and gluteus maximus muscle strength over time for the DLL posttest two with the right GM MMT. The angle measurements for DLL and the strength measurements for GM MMT continually decreased over time from baseline through posttest two. No difference was found between gender, activity level and sitting time on muscle strength measurements, although there was a difference for time between the three time points. For the nine experimental hypothesis, six were accepted in relation to a decrease in muscle strength over time, as well as a decrease in muscle strength for both males and females. As this is the first study to evaluate the
influence of lower abdominal strength on gluteus maximus strength, the ability to compare significant findings is limited.

Correlation of Lower Abdominal Strength to GM Strength

The core is described as both a box \(^1,18\) and a cylinder\(^2\) that creates a stable spine or base for activities involving extremities required for daily life and sport.\(^7,14\) The primary function of the core is stability, however there is not a widespread, accepted definition for core stability nor are there consistent components or elements associated with it. The core can be defined by endurance, stability or strength. The components are said to change based on postural adjustments or the load placed on the body.\(^4\) Though the research on core stability is minimal, the importance remains apparent. While it is known that the hip, abdominal and lumbar muscles work together to create a stable base in the lumbo-pelvic-hip complex, it is unknown whether a change in abdominal strength influences a change in gluteus maximus strength over time.

The anatomy and biomechanics of the trunk and lower extremities can be used to understand the correlation between lower abdominal strength and gluteus maximus strength. The thoracolumbar fascia (TLF) located on the posterior torso, acts as an attachment point for numerous muscles, including the lower abdominals and gluteus maximus. The TLF anatomically bridges the gap between the upper extremity and lower extremity musculature, termed the “serape effect.” The TLF, latissimus dorsi and contralateral gluteus maximus create a functional relationship between the core and the lower extremity.\(^1,18,19\)

One factor that may influence core strength or stability, is the strength of the gluteus maximus muscle. The gluteus maximus is a transfer muscle and a prime hip extensor. The GM is linked to the local muscles of the core through the thoracolumbar fascia. Within the kinetic chain, the GM generates force and power, yet within the core it acts as a dynamic stabilizer. The local
abdominal muscles stabilize the spine and pelvis, similar to the gluteus maximus. During hip extension, the abdominals activate before the gluteus maximus muscle. However, when the GM is inhibited due to over activity and weak abdominal muscles are present, optimal pelvic and spinal stabilization does not occur, i.e. the self-bracing mechanism at the SI joint. Without stabilization, the generation of efficient movement cannot occur. Overall muscle weakness and inefficient movement can lead to joint instability, and eventually injury. The gluteus maximus specifically, has been correlated with incidence of knee injury.

Lower Abdominal Strength

From this study, a significance was found in relation to the DLL test and time. The greatest difference in muscle strength occurred between baseline measurement and posttest two, a period of 10 weeks. While strength changes were found to decrease over time, no significant differences were found between abdominal strength and gender. Both males and females were found to have extremely weak abdominals that steadily decreased with each measurement. In contrast, Brophy et al concluded that males had slightly greater lower abdominal strength compared to females, as measured by a Pressure Biofeedback Stabilizer and graded using the Sahrmann system. Other studies have found females to have weaker abdominal musculature when compared to males. One variable that could influence female abdominal strength could be the menstrual cycle. Although not evaluated in this study, menstrual cycle was incorporated in the demographic questionnaire at each time point. Based on this questionnaire, majority of subjects were found to not be currently on their menstrual cycle (Baseline: 24%, n=8; Posttest One: 24%, n=8; Posttest Two: 15%, n=5). Statistics were run on this data and no significance was found. Menstrual cycle however, was noted as a possible variable for ACL injury and should be further explored in relation to lower abdominal strength and the correlation with gluteus maximus strength.
Activity level was indicated at each measurement session as none, low, moderate or intense by all subjects. A majority of the subjects self-reported low (n=23) to moderate (n=19) levels of activity. Although not evaluated further, most subjects reported engaging in cardiovascular and weightlifting activity, consisting mostly of sit-ups for abdominal strength. It was assumed that lower abdominal strength would increase over time with activity. However, no significant relationships occurred between DLL strength measurements and activity level. As all subjects were excluded if currently involved in a core strengthening program, it was doubtful whether the subjects were participating in a core stabilization program, as activity level was included in the questionnaire completed at the three testing times. However, it is not known if subjects were not consciously activating the targeted lower abdominal musculature. Despite not being involved in specific abdominal muscle training exercises, the core musculature of each subject is activated during menial activities of daily living. Tasks such as laughing are even found to generate the similar muscle activation than that of conventional training exercises (crunch and back lifting). Thus, the overall steady decrease in muscle strength may be explained by other factors, including prolonged period of sitting. Subjects reported in the questionnaire that they were in a seated position an average of 6.62±2.08 hours per day. This average slightly increased from baseline to each posttest (Table D1). While a significance was found for time overall, no significance was found between lower abdominal strength and time seated. With the information that is available in regards to hip flexor tightness due to prolonged shortening in the seated position, and the effect of hip flexor tightness on lower abdominal strength, this factor should be further studied.

Gluteus Maximus Strength

A significant relationship was found between gluteus maximus strength and time. A significant interaction was also found between gluteus maximus strength and sitting time. While
strength differences were found to be different between right and left legs, both progressively decreased over time. GM MMT strength measurements did not vary between genders. Both males and females were found to be weak. Findings are supported by Zeller et al,\textsuperscript{45} who examined gender differences and hip EMG activity during a single-leg squat. In contrast to this study and the current study, a study conducted by Zazulak et al\textsuperscript{46} on the comparison of hip muscle activity of males and females during single landing standing. Zazulak\textsuperscript{46} found that female athletes had less gluteus maximus activity compared to males following contact with the floor. This notion can be further supported by observations made by Decker et al\textsuperscript{47} that males displayed greater muscle activity in the gluteus maximus. Without using EMG, and only relying on strength measurements repeated in this study, both males and females should consider gluteus maximus strength training.

Gluteus maximus strength was not shown to have been influenced by activity level throughout this study. While each subject was not placed specifically into a strengthening intervention program for the hip extensors, it is not known if the subjects were using these muscles. Even if the subjects were not engaged in gluteus maximus strengthening exercises specifically, activities of daily living substantially engage the gluteals. Walking on level surfaces, up and down stairs, and even running are shown to activate the gluteus maximus.\textsuperscript{52} In theory then, gluteus maximus strength should increase over time because as humans, we are constantly walking or moving. Effective strength of the gluteus maximus during daily activity will allow for proper stabilization, motion, and force production at the trunk and hips. However, it can be questioned whether activity is enhancing gluteus maximus strength, as there was a steady decline in strength over time. This steady decrease in strength could be explained by the amount of time the subjects spent seated each day. As sitting time increased, muscle strength of the right gluteus maximus decreased. A sufficient explanation for unilateral weakness can simply be speculated, as that
information is beyond the scope of this study. Leg dominance, muscle imbalance, postural deformity, and biomechanical dysfunction are all potential explanations. An explanation for general gluteus maximus weakness due to prolonged sitting can be postulated using the anatomical positioning of the gluteals in the seated position. Significant hip flexion is present, shortening the hip flexors and elongating the hip extensors. Proper posture in the seated position consists of 90 degrees of hip flexion, a neutral pelvis, lordotic curvature at the lumbar spine, upright torso and neutral head placement. Improper posture however, can increase the amount of rotation of the pelvis and the lordotic curvature of the lumbar spine, thus increasing gluteal length even further. Al Dirini et al\textsuperscript{53} found the gluteals to significantly deform while subjects were in the seated position. This deformation increased the surface area of gluteals that came in contact with the seat, further elongating their structure and putting them at risk for inhibition. This inhibition was only further impaired as sitting time increased and sitting posture progressively deteriorated.

Clinical Importance

Although this study found statistical significance in a variety of variables, the benefits lie in the clinical relevance. In this study, a relationship is present between gluteus maximus strength and lower abdominal strength. As one muscle decreases in strength, so does the other. This is vital to the athletic population where stabilization, strength and associated power and force are vital to optimal performance. The demonstrated weakness of the gluteus maximus does not allow for proper mechanics at the trunk and extremities, thus predisposing athletes to injury.\textsuperscript{32-38} Many studies have suggested that knee\textsuperscript{49} and low back pain have been apparent in those with weak hip musculature, specifically the gluteus maximus. Despite the use of relatively active, healthy, college-aged subjects, the decrease in muscle strength still occurred. Hence, the clinical application
of gluteus maximus and core should be further evaluated focusing on the injured. This may provide guidelines for advocating core and GM strengthening programs.

The usefulness of the double-leg lowering test to measure lower abdominal strength has been reported in literature and has been used clinically. However, the validity and reliability of the double-leg lowering test has been questioned. The test was considered moderately reliable by one study (CC=0.55)\textsuperscript{55}, and highly reliable by another (r=0.932).\textsuperscript{55} Unlike Ladeira\textsuperscript{55} et al, Zannotti\textsuperscript{54} et al. failed to use cues to coach the subject in maintaining abdominal contraction throughout the testing period. The degree of difficulty of this test also lends to its questionable usefulness for measuring abdominal strength. Zannotti et al.\textsuperscript{54}, studied the kinematics of the DLL and used a muscle grading scheme (Poor=2, 0°; Fair=3, 15°; Fair plus=3+, 30°; Good minus=4-, 45°; Good=4, 60°; Good plus= 4+, 75°; Normal=5, 90°) based on the angle in which the pelvis initially rotated anteriorly. He found that all subjects were unable to prevent anterior tilting of the pelvis from about the beginning of the test until completion, thus receiving a poor score of 2.\textsuperscript{54} These results are similar to the results obtained in this study, with an average of 14.70° at baseline, 10.06° at posttest one, and 6.85° at posttest two. If using the grading system previously explained, a majority of subjects would have scored poorly at all three testing points. These consistent findings of low scores throughout various studies lead to the questioning of the test. All subjects in the mentioned studies were healthy individuals without injury. It is not known whether these same results would be evident in an athletic or injured population.

While the DLL was found to sufficiently activate the abdominal muscles,\textsuperscript{56,57} the use of the test for strength versus motor control\textsuperscript{55} is indefinite. Although the difficulty of the test may be extreme, the lower abdominal musculature is activated for strength testing purposes. Therefore, the reasoning behind the low, inadequate scores by all healthy subjects is unexplainable. Based on
these findings and the findings within this study for the DLL test, a suggestion would be to discontinue the use of the DLL test as a means for measuring lower abdominal strength in the clinical setting.

However, use of other tests may be questionable as not one single test is considered a “gold standard.” The Straight-leg-lowering test, trunk curl, active straight-leg-raise test, Biering Sorensen test, McGill extensor endurance test, Kendall’s trunk curl, timed-prone bridge test and the side-bridge test. A far more advanced machine for testing abdominal muscle strength is the cybex machine. The cybex machine can be used to depict a muscle fatigue curve, but was also found to be useful in clinical medicine for measuring abdominal muscle strength. What to consider for which test to use within the clinical setting or for research should be explored further, as this was not the intent of this study.

Manual muscle test (MMT) were once considered the gold standard for muscle strength testing. Reliability and validity was highly dependent on clinician experience, knowledge and skill. However, with recent technological advancements, the MMT has come to develop low test-retest coefficients (.63). While the handheld dynamometer (HDD) has yielded better results, a dynamometer anchoring station has showed to be more reliable. However, van der Linden reported exceptional test-retest repeatability (.85 at p<.001, .80 at p<.005). The HDD for GM MMT was also found reliable by Crompton. While there are numerous tools and tests published for assessment of muscle strength, a gold standard measurement does not exist. The accessibility and feasibility of the MMT using the handheld dynamometer makes it a useful tool for the clinical setting.
Limitations of the Study

Several limitations to this study have been identified. The first being the number of female subjects (n=34) to male subjects (n=13). A limitation of this study may also be the use of non-injured, college-aged subjects. The subjects were also non-athletic population, with majority of the population having an activity level of moderate to low. To determine the significance to the athletic population, that study population should be used, potentially the injured athletic population. The size of the sample was also a limitation, as the sample was of convenience and limited to pre-athletic training and curriculum athletic training major students at one university. The number of data collection time points was also a limitation, due to the university break schedule. Further research should incorporate the use of a more time points to further determine the significance of time on muscle strength. The use of the Hudl app may also be a limitation, as the validity and reliability of the Hudl app for measuring DLL has not been determined.

CONCLUSION

The results from the study indicate a relationship between lower abdominal strength and gluteus maximus strength, as well as a change in strength over time. Over a ten week period, muscle strength for the lower abdominals and gluteus maximus decreased, leading to a moderate correlation. Further, there was a decrease in strength from baseline through posttest two. While gender, activity level and sitting time influenced the results, other factors should be considered, which were beyond the scope of this study. Thus, additional research should be conducted to verify if what was noted in this study would be evident in a larger population of healthy subjects, before moving to an athletic or injured population.
REFERENCES


51. McCaffrey S. Effects of prolonged sitting on a lifting task. Thesis. California State University, Fullerton. 2015


APPENDIX A

THE PROBLEM

Research Question

There is not one single, widespread definition for core stability.\textsuperscript{3} The terms stability and strength are often used interchangeably, thus creating inconsistencies and confusion. While terminology is inconsistent, the components incorporated in the terms are inconsistent as well.\textsuperscript{3} The components of core stability are said to change based on the postural adjustments or load placed on the body.\textsuperscript{4} In some cases, core stability encompasses pelvic positioning, rib cage positioning, and neuromuscular recruitment of both anterior and posterior trunk musculature.\textsuperscript{2} With the addition of muscular capacity, motor control, coordination and stiffness incorporated,\textsuperscript{49,50} In this instance, core stability can be described as “the ability to achieve and sustain control of the trunk region at rest and during precise movement.”\textsuperscript{3}

The specific structures considered a part of the core vary across the literature, as did the definition for core stability. However, the incorporation of both local and global muscles is consistent.\textsuperscript{3,4,12,52} Global muscles are defined as the primary movers that have no direct attachment to the spine.\textsuperscript{10} The rectus abdominis and erector spinae are considered the large global muscles. The smaller, local muscles act to maintain posture and are considered stabilizing muscles due to the proximity to the axis with direct attachments.\textsuperscript{10} The local muscles are the transverse abdominus, multifidus, rotators, and internal and external obliques. The transverse abdominus specifically, attaches to the thoracolumbar fascia and is critical in anticipating movement or perturbation with balance. These factors are key in decreasing injury rates.\textsuperscript{53} Together, the local and global muscles create the core, which functions as a stable foundation for movement, which ultimately provides proximal and distal balance and strength.\textsuperscript{3,12} Although it is
not directly incorporated in the core musculature, the gluteus maximus (GM) plays a vital role in activity and proper function of the core. Like the transverse abdominis, the gluteus maximus attaches to the thoracolumbar fascia. The primary function is hip extension and femoral external rotation, with assistance in deceleration of hip flexion and femoral internal rotation.

The gluteus maximus and the core, along with the hip flexors, work as a force couple to stabilize the trunk and lower extremity during activity. When the hip flexors are dynamically decelerating hip extension generated by the GM, an anterior shearing force is created at the lumbar spine. This shearing force is generated specifically by the psoas muscle, which becomes overactive and tight. In order to counteract the shearing force, the abdominal muscles, specifically the TA are activated. Thus, reciprocal inhibition of the GM and TA occurs. The reciprocal inhibition over time, causes muscle weakness, decreased stability and decreased force generation.

It is important to understand the human body as a kinetic chain. The kinetic chain is described as the sequenced physiologic muscle activations in the upper and lower extremity that result in an integrated biomechanical task. Ultimately, all muscles in the body are linked in order to properly function. The lumbopelvic-hip complex is the link between the upper and lower extremities. By way of the thoracolumbar fascia (TLF), the stabilizing muscles of the pelvis and spine connect to the prime movers of the back and hips. The prime movers are then linked to the global muscles of the upper and lower extremity. When a link is inhibited or over-activated, the entire kinetic chain becomes dysfunctional. This dysfunction generally originates at the lumbopelvic-hip complex, or core, where all movement begins and energy is transferred.

The anatomy and function of the core, gluteals, and abdominals is thoroughly understood. However, there is limited research on the direct influence of a change in abdominal strength on
gluteus maximus strength over time. Efficient abdominal and GM strength are vital to core stability, as core stability is critical for efficient and accurate movement. Thus, the following research questions are asked:

**Research Questions**

1. Does a change in abdominal strength lead to a change in gluteus maximus strength over time?

2. Does activity level influence a change in gluteus maximus and lower abdominal strength over time?

3. Does gender influence a change in gluteus maximus and lower abdominal strength over time?

**Experimental Hypothesis**

1. There will be a large correlation between DLL and gluteus maximus strength measurements.

2. The GM strength will decrease over time.

3. The change in DLL angle will decrease over time when compared to baseline.

4. Both male and female subjects’ GM strength will decrease when compared to baseline.

5. Both male and female subjects’ change in DLL angle will decrease when compared to baseline.

6. The GM strength will increase for subjects at all activity levels.

7. The change in DLL angle will increase for subjects at all activity levels.

8. As sitting time increases, gluteus maximus muscle strength will decrease.

9. As sitting time increases, lower abdominal muscle strength will decrease.

**Assumptions**

1. All subjects will meet the inclusion criteria for the research study.

2. The instruments being used are valid and reliable.

3. The evaluation tests being used are valid and reliable.

4. The documentation of each subjects’ testing scores will be accurate.
5. Every five weeks, the test will be administered following identical procedures.

6. The same tests will be used every five weeks.

7. All subjects will listen, understand directions and perform the tests to the best of their ability.

Delimitations

1. Subject population is not generalizable to the athletic population. Subject population is specific to athletic training students.

2. The participants’ are college-aged students at one institution. The subject population is specific only to one institution.

Operational Definitions

1. CATS- The curriculum athletic training students that are currently enrolled in the CAATE accredited athletic training program at West Virginia University.  

2. Core stability- “The ability of passive and active stabilizers in the lumbo-pelvic region to maintain appropriate trunk and hip posture, balance and control during both static and dynamic movements.”

3. Core strength- The ability of the core to generate and maintain force.

4. DLL- The double leg lowering test is an active functional test used to assess lower abdominal strength.

5. Global muscles- Primary movers that have no direct attachment to the spine.

6. HHD- A handheld dynamometer is a device used during manual muscle testing to measure the amount of force exerted manually by the examiner.

7. Kinetic chain- The sequenced physiologic muscle activations in the upper and lower extremity that result in an integrated biomechanical task.

8. Local muscles- Maintain posture and are considered stabilizing muscles due to the proximity to the axis with direct attachments.

9. Lumbopelvic-hip complex- the core; where a person’s center of gravity is located and all movement begins

10. MMT- A manual muscle test is a strength test used to determine the capability of muscles or muscle groups to function in movement and their ability to provide stability and support.
11. PATS- The prospective athletic training students currently enrolled in the pre-athletic training program at West Virginia University. 

Limitations

1. Participant can drop out of the study at any time.

2. External validity will exist due to the study not being generalizable to the athletic population.

3. An external validity will exist from the subject population and the choice of participants.

4. Participants may not perform 100% effort for each test.

5. The internal factors of each subject cannot be controlled: health, nutrition, weight training, etc.

Significance of Study

Core stability and strength has been incorporated into rehabilitation programs for a variety of injuries. A thorough and accurate knowledge as to the individual benefits of a core strengthening program is unknown, due to its incorporation with other programs. While little is known about the direct effects of increased core strength and stability on athletic performance, the research is evolving on the effects of decreased core strength on the kinetic chain.

The core is the main link in the kinetic chain that allows for generation and power of force. The abdominals and gluteus maximus in particular play key roles in stabilizing the pelvis and generating adequate force for efficient movement. These muscles that link to the core to allow for the transfer of these forces can be directly affected by dysfunction. While dysfunction has been expressed in terms of ankle injuries, low back pain and patellofemoral pathologies, the direct cause has yet to be determined. When the abdominals and gluteus maximus are inhibited, weak or firing in the inappropriate pattern, stability is compromised. The direct influence of abdominal strength on gluteus maximus strength over time has yet to be determined. This could however, lead to an explanation for dysfunction in the athletic population.
At the completion of this study, dissemination of information will occur. This information is vital to ensure proper function and health of athletes. Due to the limited amount of research on this topic, an enhanced knowledge of the influence of the abdominals on the GM could potentially shift the focus of rehabilitation programs. To go a step further, prevention programs could focus on specific muscle groups that may be directly linked to injury likelihood. The research will be presented at workshops and seminars at local universities.
APPENDIX B
LITERATURE REVIEW

Introduction

The term “core” has come to have a plethora of meanings and definitions. Core stability, core strength, core endurance, trunk, and lumbopelvic-hip complex are several of the terms used interchangeably throughout the literature in reference to the core. Despite the varying terminology, the importance of the core in activity and injury prevention is parallel. According to Kibler et al, the core is simply proximal stability for distal mobility. Specifically, the core has been compared to the motion of cracking a whip. The active and passive structures provide static and dynamic stability, allowing the generation and transfer of forces from smaller to larger body parts throughout the entire kinetic chain. These forces must be generated or activated in a specific pattern in order to create the appropriate motion at the distal extremity. Any small change that occurs at the core is likely to result in a larger change in the distal segments. Therefore, all roads lead back to the core. The core is comprised of local, global and transfer muscles. (Refer to Table B1 for extensive lists of each) The local muscles are said to be deep, small and short, while the global muscles are superficial, prime movers and producers of trunk motion that may span several joints. The transfer muscles act to allocate forces through the kinetic chain. The hip flexors, extensors, abductors and adductors are the primary transfer muscles in the lower extremity. Together, the local, global and transfer muscles aid in proper function and motion.

The primary function of the core is stability, however there is not a widespread, accepted definition for core stability nor are there consistent components or elements associated with it. The core can be defined by endurance, stability or strength. The components are said to change
based on postural adjustments or the load placed on the body. Though the research on core stability is minimal, the importance remains apparent. One factor that may influence core strength or stability, is the strength of the gluteus maximus muscle. The gluteus maximus is a transfer muscle and a prime hip extensor. The GM is linked to the local muscles of the core through the thoracolumbar fascia. The local abdominal muscles stabilize the spine and pelvis, similar to the gluteus maximus. However, when the GM is inhibited due to over activity and a weak abdominal muscles are present, optimal pelvic and spinal stabilization does not occur. Without stabilization, efficient movement cannot occur. During this literature review core is defined; the anatomy and biomechanics of the core, the gluteus maximus muscle, abdominal muscles, and strength measurements of both are included.

Definition of Core Stability

The core is describe as both a box\textsuperscript{1,18} and a cylinder\textsuperscript{2} that creates a stable spine or base for activities involving extremities required for daily life and sport.\textsuperscript{7,14,65,67} The box-shape of the core is bordered by the diaphragm at the ceiling, the pelvic floor muscles and hip and thigh muscles at the base, abdominal muscles anteriorly and laterally, and the paraspinal muscles posteriorly.\textsuperscript{18} The cylinder associated with the core is comprised of all structures from the rib cage to the pelvis.\textsuperscript{2} Also referred to as the lumbopelvic-hip complex,\textsuperscript{7,18} the core is responsible for posture maintenance, bending, and twisting at the lumbar and pelvic regions. Improper or impaired postural stability has been shown to be a risk factor for lower extremity injury regardless of a person’s injury history.\textsuperscript{69,70}

According to Wilson,\textsuperscript{72} core stability can be defined as the muscle strength and endurance level necessary to control movement of the lumbopelvic-hip complex. Core stability can be divided into three subsystems, passive, active and neural control, that work together to ensure
proper core functioning. The passive structures include vertebrae, intervertebral discs, ligaments, joint capsules and the passive properties of muscles. These structures stabilize end-range motion and transmit position and loading information to the neural subsystem. The active subsystem also sends information to the neural subsystem, but movement is of greater focus in the active subsystem. The core muscles are the primary structure that create dynamic stabilization for the spine and proximal appendicular skeleton. Core stability is maintained by the third subsystem, neural control. All incoming and outgoing signals are filtered through this system, which is a complex web of muscle innervations. Each muscle is innervated by nerves which allow for communication between systems, to create stability during movement, loading and position change. Core stability is a complex phenomenon that uses the lumbar complex, pelvis, and hips to prevent the spinal column from buckling while maintaining and regaining balance during swaying. A thorough understanding of the anatomy of the core is vital to understanding the biomechanics and how injury can occur due to inappropriate biomechanics or dysfunction.

The Anatomy and Physiology of the Core

The core is comprised of local, global and transfer muscles (Table B1). The local muscles tend to span single joints which leads to small lever arms. These muscles are activated in “length dependent” muscle activation patterns, specifically for precision and control of performance. Providing segmental stability is also a function of the local muscles. The more dominant local muscles, include the multifidus, quadratus lumborum(QL) and transverse abdominus(TA), due to the direct attachment to the spine and pelvis. However, the rotatores, interspinalis and intertransversalis play important roles in stability. The primary stabilizers (i.e. QL, TA, Multifidus), are responsible for the most central portion of core stability.
The TA specifically, has an attachment point on the thoracolumbar fascia (TLF). The TA contracts to increase intra-abdominal pressure and tension on the TLF to stabilize the lumbar spine, similar to the function of a corset. This fascia located on the posterior torso, acts as an attachment point for numerous muscles. The TLF anatomically bridges the gap between the upper extremity and lower extremity musculature, termed the “serape effect.” The TLF, latissimus dorsi and contralateral gluteus maximus create a functional relationship between the core and the lower extremity. The force generated by the global muscles is able to be transferred to the transfer muscles because of their attachment to the TLF. The fascia also blends with the sacroiliac joint ligaments to stabilize the pelvis.

Table B1. Local, Global and Transfer Muscles

<table>
<thead>
<tr>
<th>Local Muscles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multifidus</td>
</tr>
<tr>
<td>Quadratus Lumborum</td>
</tr>
<tr>
<td>Interspinalis</td>
</tr>
<tr>
<td>Intertransversarii</td>
</tr>
<tr>
<td>Longissimus lumborum</td>
</tr>
<tr>
<td>Iliocostalis lumborum</td>
</tr>
<tr>
<td>Transversus abdominus</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Global Muscles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longissimus thoracis</td>
</tr>
<tr>
<td>Iliocostalis thoracis</td>
</tr>
<tr>
<td>Quadratus lumborum</td>
</tr>
<tr>
<td>Rectus abdominis</td>
</tr>
<tr>
<td>External oblique</td>
</tr>
<tr>
<td>Internal oblique</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transfer Muscles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip flexors</td>
</tr>
<tr>
<td>Hip extensors</td>
</tr>
<tr>
<td>Hip abductors</td>
</tr>
<tr>
<td>Hip adductors</td>
</tr>
<tr>
<td>Scapular stabilizers</td>
</tr>
<tr>
<td>Muscles that act on GHJ</td>
</tr>
</tbody>
</table>
The aforementioned global muscles integrate several joints to produce force, and are activated strictly in “force dependent” activation patterns. Included as global muscles are the rectus abdominis, external and internal obliques, erector spinae and latissimus dorsi. Also considered prime movers, but have distal attachments to the pelvis and spine, is the pectoralis major, hamstrings, quadriceps and iliopsoas muscles. The prime movers work in conjunction with the transfer muscles, also referred to as axial-appendicular transfer muscles. By way of the TLF, these muscles connect the upper extremity to the pectoral girdle, and the lower extremity to the pelvic girdle. According to Bergmark, the transfer muscles include the hip extensors, flexors, abductors, adductors, scapular stabilizers and muscles acting on the glenohumeral joint. The force dependent and length dependent activation patterns of the local, global and transfer muscles must coordinate and function together to generate core stability. The length-tension relationship is critical to functional muscle recruitment and activation. Global muscles of the core are prone to shortness and tightness. Local muscles on the other hand, are prone to lengthening and weakness. When overactive global muscles and underactive local muscles occur, the shortening and lengthening is exaggerated.

Table B2. Muscles of the Core

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Origin</th>
<th>Insertion</th>
<th>Action</th>
<th>Innervation</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multifidus</td>
<td>Sacral region: Posterior sacrum, medial posterior iliac spine, postero-SI ligaments Transverse process of C4-L5</td>
<td>Spinous process</td>
<td>Extension of vertebral column and rotation to opposite side</td>
<td>Posterior primary divisions of the spinal nerves</td>
<td>Local</td>
</tr>
<tr>
<td>Quadratus Lumborum</td>
<td>Iliolumbar ligament, iliac crest</td>
<td>Inferior border of last rib and transverse processes of upper four lumbar vertebrae</td>
<td>Extension, lateral flexes lumbar vertebral column, depresses last rib, fixes last</td>
<td>Lumbar plexus</td>
<td>Local and global</td>
</tr>
<tr>
<td>Muscle</td>
<td>Surface and Key Structures</td>
<td>Function</td>
<td>Motor Nerves</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------</td>
<td>---------------------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longissimus</td>
<td>Posterior surfaces of transverse process</td>
<td>2 ribs during respiration</td>
<td>Posterior primary divisions of spinal nerves, Local and Global</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iliocostalis</td>
<td>Spinous process of L spine, 11 &amp; 12 T, posterior medial lip of iliac crest, supraspinous ligament, lateral crests of sacrum</td>
<td>Inferior borders of angles of lower six or seven ribs</td>
<td>Posterior primary divisions of spinal nerves, Local and Global</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transverse abdominus</td>
<td>Lower 6 ribs, lateral 1/3 inguinal ligament, lip of iliac crest</td>
<td>Extension of vertebral column</td>
<td>Thoracoabdominal nerves, 1st lumbar nerve, Posterior primary divisions of spinal nerves, Local</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rectus abdominus</td>
<td>Pubic crest and symphysis</td>
<td>Stabilization, holds internal organs in</td>
<td>Ventral rami, Global</td>
<td></td>
<td></td>
</tr>
<tr>
<td>External oblique</td>
<td>Ribs 5-8</td>
<td>Flexion of vertebral column</td>
<td>Iliohipoasstric, Ilioinguinal, Ventral rami, Global</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal oblique</td>
<td>Lateral 2/3 of inguinal ligament</td>
<td>Rotation, trunk flexion</td>
<td>Iliohipoasstric, Ilioinguinal, Ventral rami, Global</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iliacus</td>
<td>Superior 2/3 of iliac fossa, internal lip of iliac crest, iliolumbar and ventral SI ligaments, ala of sacrum</td>
<td>Trunk flexion, lateral flexion</td>
<td>Femoral, Transfer</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ASIS = anterior superior iliac spine

Notes:
- Thoracoabdominal nerves refer to the posterior primary divisions of spinal nerves involved in the thoracoabdominal region.
- Posterior primary divisions of spinal nerves are those that innervate the posterior aspects of the body, including the muscles and tissues associated with the thoracic and abdominal regions.
<table>
<thead>
<tr>
<th>Muscle</th>
<th>Origin</th>
<th>Insertion</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Psoas Major</td>
<td>Ventral surface of transverse process of all L vertebrae, sides of bodies and corresponding intervertebral disks of last thoracic and all lumbar vertebrae, membranous arches that extend over sides of bodies of lumbar vertebrae</td>
<td>Lesser trochanter of femur</td>
<td>Hip flexion</td>
</tr>
<tr>
<td>Gluteus maximus</td>
<td>Posterior surface of lower part of sacrum, posterior gluteal line, side of coccyx, aponeurosis of erector spinae, sacrotuberous ligament and gluteal aponeurosis</td>
<td>ITB, gluteal tuberosity of femur</td>
<td>Extension and lateral rotation of hip; adduction of hip; stabilize knee in extension through ITB</td>
</tr>
<tr>
<td>Gluteus minimus</td>
<td>External surface of ilium, between anterior and inferior gluteal lines and margin of greater sciatic notch</td>
<td>Anterior border of greater trochanter of femur and hip joint capsule</td>
<td>Abducts, medially rotates and flexes hip</td>
</tr>
<tr>
<td>Gluteus medius</td>
<td>External surface of ilium, between iliac crest and posterior gluteal line dorsally and anterior gluteal line ventrally, gluteal aponeurosis</td>
<td>Oblique ridge on the lateral surface of the greater trochanter</td>
<td>Abducts hip, medially rotate and flex hip, laterally rotate and extend hip</td>
</tr>
</tbody>
</table>

The Gluteus Maximus

According to Kendall et al.\textsuperscript{61} the gluteus maximus(GM) originates at the posterior gluteal line of the ilium, the posterior surface of the lower part of the sacrum, side of the coccyx, aponeurosis of the erector spinae, sacrotuberous ligament and gluteal aponeurosis. The insertion
points include the larger proximal portion and superficial fibers of the distal portion of the muscle into the iliotibial tract of the fascia lata, and deep fibers of the distal portion into the gluteal tuberosity of the femur. The gluteus maximus is properly named for the rather large surface area on the posterior body. While the main function is hip extension, the GM also functions to laterally/externally rotate the hip. The lower fibers also assist in adduction, while the upper fibers assist in abduction. Due to the insertion point into the iliotibial tract, the GM also helps to stabilize the knee in extension. The gluteus maximus is classified as a transfer muscle. It has also been referenced as a local muscle, which is prone to lengthening and weakness. Overall muscle weakness can lead to joint instability, and eventually injury. Beckman et al, reported that patients with seriously sprain ankles showed delayed periods of gluteal muscle contraction on the injured and non-injured sides. A weakness of the gluteus maximus, a hip external/lateral rotator also correlated with an incidence of knee injury.

Within the kinetic chain, the GM generates force and power, yet within the core it acts as a dynamic stabilizer. Throughout the structure of the core, the GM becomes a base of support. The gluteus maximus is eccentrically working against the psoas to generate hip extension. While the psoas is working to decelerate hip extension, an anterior force is created at the lumbar spine. The abdominal muscles work to minimize the shear force generated by the tight psoas muscle. The overactive and tight psoas coupled with the shearing force causes reciprocal inhibition of the gluteus maximus and transverse abdominis, among other muscles. The inhibition of these muscles causes incorrect firing patterns and weakness.

Abdominal Muscles

While the core incorporates muscles from the hip, pelvis and lumbar regions, the focus lies primarily on the abdominal muscles. The abdominal muscles contributing to proper function
of the lumbo-pelvic hip complex are the transverse abdominis (TA), rectus abdominis (RA), internal oblique (IO) and external oblique (EO). These muscles are the primary pelvis and spine stabilizers, however they may also be responsible for trunk motion. When load is placed on the body, the TA contracts to maintain spinal kinematics. Following TA contraction, is activation of the EO, IO and RA. The attachment of the obliques and the RA to the thoracolumbar fascia allows for increased stabilization from the transfer muscles (i.e. gluteus maximus). When the abdominal stabilizers are not contracting in the appropriate order, are weak, or fatigued, spinal stabilization is not at its prime, causing instability of the entire trunk. Without a stable trunk, efficient movement and force cannot be generated through the kinetic chain.

Measurements of Abdominal Strength

While abdominal strength is vital to proper functioning, accurate and reliable quantitative measurement of abdominal strength is imperative to the evaluation and rehabilitation processes. Abdominal strength has been measured using the Double Leg Lowering test (DLLT), Straight-leg-lowering test, trunk curl, active straight-leg-raise test, Biering Sorensen test, McGill extensor endurance test, Kendall’s trunk curl, timed-prone bridge test and the side-bridge test. Although many tests are used for assessment, not one single test is considered a gold standard. Tan et al. used the side bridge with a single-leg raise to measure core strength with electromyography. A far more advanced machine for testing abdominal muscle strength is the cybex machine. The cybex machine can be used to depict a muscle fatigue curve, but was also found to be useful in clinical medicine for measuring abdominal muscle strength. Patient positioning for testing of the abdominals using the cybex varies. While Hasue found the supine position reliable, Smidt found the seated position more accurate.
For this purpose, the focus was placed on the DLLT. The DLLT differs from other abdominal strength tests because it assesses the ability of the abdominal muscles to stabilize the pelvis versus flex the trunk. A study used 28 subjects to access core strength using the DLLT and a handheld dynamometer. The DLLT was found to be significantly reliable (.932), yet extremely invalid (-.338 to -.446). This study argued that the DLLT was reliable in the athletic training setting, but was found inconsistent in other clinical settings. Another study using 100 healthy volunteers found the DLLT to have an excellent intratester reliability (.98). This same study found a sex difference in the performance of the DLLT. While there are several tests to measure core strength, several more have been used to develop core stability change throughout rehabilitation programs. Much research conducted on core strength is completed using a lay population, not involving athletes, so validity and reliability to the athletic population is unknown.

Measurements of Gluteus Maximus Strength

Manual muscle test (MMT) were once considered the gold standard for muscle strength testing. Reliability and validity was highly dependent on clinician experience, knowledge and skill. However, with recent technological advancements, the MMT has come to develop low test-retest coefficients (.63). While the handheld dynamometer (HDD) has yielded better results, a dynamometer anchoring station has showed to be more reliable. With this instrument, the subject pushes up against a stabilized force plate, which removes the clinician strength bias associated with the traditional MMT and HHD. Gluteus maximus muscle strength testing has been assessed in two different ways. Kendall describes the first with the patient prone, the knee flexed to 90 degrees or more, the clinician stabilizing the low back and pressure being applied to the lower part of the posterior thigh in the direction of hip flexion. The modified version involves
the athlete’s trunk prone on the table with the legs hanging off. The clinician passively flexes the involved knee and applies the same pressure as previously mentioned. The modified test is used when the back extensor muscles are weak or the hip flexor muscles are tight.\textsuperscript{60} This MMT was used by van der Linden et al.,\textsuperscript{82} to determine the test-retest repeatability of using a handheld dynamometer to test GM strength. Using eleven children with cerebral palsy and 11 matched children, van der Linden reported exceptional test-retest repeatability (.85 at p<.001, .80 at p<.005).\textsuperscript{82} The HHD for GM MMT was found reliable by Crompton.\textsuperscript{83} Twenty-three cerebral palsy patients were assessed during two sessions. Within session reliability was reported as >.79 and between-session reliability with ICC of >.70.\textsuperscript{83} While there are numerous tools and tests published for assessment of muscle strength, there is no gold standard measurement. For the purposes of this thesis, the focus will be on the gluteus maximus and abdominal muscle testing, using the DLLT and MMT with a HHD.

Effect of Sitting Time, Gender and Activity on Muscle Strength

A decrease in muscle strength due to prolonged sitting is an unexplored area of interest. The population spends an extensive amount of time, roughly eight hours per day,\textsuperscript{48} in the seated position. In this position, it is believed that the muscles significantly active in core stability that are greatly affected by prolonged sitting are the gluteus maximus and iliopsoas. The concept that local core muscles like the gluteus maximus are prone to lengthening and weakness, and global core muscles like the iliopsoas are prone to shortening and tightening can be supported; yet, their inherent impact due the periods of prolonged sitting are vague. In a sitting posture, the gluteus maximus is lengthened, causing weakness and inhibition. In this same position, the iliopsoas is shortened, constantly contracting, causing overall tightness. Sitting can significantly alter lumbar, sacrum and pelvis posture.\textsuperscript{90} This places the individual in a lumbar flexed position,
which can place stress on the passive tissues, especially the thoracolumbar fascia\textsuperscript{90}. A further concern is whether the individual is in a slumped sitting position at the end of the chair or with the spine upright against the back of the chair could potentially place stress on the muscle tissues. Following a prolonged two hour sitting study that involved a lifting protocol, McCaffrey\textsuperscript{51} noted that there was not a decrease in EMG activity of the gluteus maximus muscle, but rather a decrease in the biceps femoris muscle during the eccentric phase of lifting. He surmised that this may be related to the sitting position in which the chair puts direct pressure on the ischial tuberosity. Since the biceps femoris and other hamstring muscles do originate from that structure and that the gluteus maximus is above, this may be why there was no effect on the gluteus maximus muscle. The vague information associated specifically with the impact of sitting on the gluteus maximus and lower abdominals, ultimately lends to an ignorance as to prolonged sitting on core stability and its entirety.

Although it is not directly incorporated in the core musculature, the gluteus maximus (GM) plays a vital role in activity and proper function of the core. Like the transverse abdominis, the gluteus maximus attaches to the thoracolumbar fascia. Its primary function is hip extension and femoral external rotation, but it also aids in deceleration of hip flexion and femoral internal rotation. The gluteus maximus and the core, along with the hip flexors, work as a force couple to stabilize the trunk and lower extremity during activity.

The aforementioned force couple may become dysfunctional due to prolonged sitting. In a seated position, the GM is continually put on a stretch, which over time, is thought to inhibit its function. While the GM is being stretched, the hip flexors are being incessantly shortened. The hip flexors are responsible for hip flexion, while the lower abdominals or core muscles are responsible for trunk flexion. These groups of muscles work together to shorten the lumbopelvic-
hip complex. Overtime, the length-tension relationship needed for the aforementioned force couple to work properly, fails. This can inherently be caused by the continuous lengthening as well as shortening of the muscles. Without the proper force couples, the lumbopelvic-hip complex cannot function appropriately, which may cause instability. Instability of the core may eventually lead to injury down the kinetic chain.

Gender, male and female, is hypothesized to have an impact on muscle strength. The literature however, is contradictory to this notion. Brophy et al\textsuperscript{43} concluded that males had slightly greater lower abdominal strength compared to females, as measured by a Pressure Biofeedback Stabilizer and graded using the Sahrmann system. Other studies have found females to have weaker abdominal musculature when compared to males.\textsuperscript{8} Zeller et al,\textsuperscript{45} who examined gender differences and hip EMG activity during a single-leg squat. In contrast to this study, a study was conducted by Zazulak et al\textsuperscript{46} on the comparison of hip muscle activity of males and females during single landing standing. Zazulak\textsuperscript{46} found that female athletes had less gluteus maximus activity compared to males following contact with the floor. This notion can be further supported by observations made by Decker et al\textsuperscript{47} that males displayed greater muscle activity in the gluteus maximus. For the purpose of this thesis, a secondary focus was placed on gender and muscle strength.

Additional influence on muscle strength may come in the form of inactivity or activity level. Regardless of activity level, the core musculature is activated to an extent during menial activities of daily living. Tasks such as laughing are even found to generate the similar muscle activation than that of conventional training exercises (crunch and back lifting).\textsuperscript{44} As well, activities of daily living substantially engage the gluteals. Walking on level surfaces, up and down stairs, and even running are shown to activate the gluteus maximus.\textsuperscript{48} While the literature
has found muscles to activate during these daily tasks, the literature is limited as to the effect of activity level on a change in muscle strength over time.

Summary

Core has been defined, the anatomy, physiology and biomechanics of the core, the function of the gluteus maximus and abdominal muscles, and the strength measurements used for each was focused on during this literature review. The core has several definitions and interchangeable terminology. Components vary throughout the literature, causing a thorough understand of its impact on functional and dysfunctional activity to be inconsistent. While the gluteus maximus and abdominal muscles function together by way of the TLF to allow for stability and force generation, the effects of the strength of the abdominals on the strengths of the gluteus maximus is vague.
APPENDIX C

ADDITIONAL METHODS

Table C1. Consent Information and HIPAA Form

CONSENT INFORMATION AND HIPAA FORM

**Principal Investigator**  
Michelle A. Sandrey, PhD, ATC

**Department**  
College of Physical Activity and Sport Sciences

**Protocol Number**  
1510880241

**Study Title**  
The Influence Over Time of Abdominal Strength Changes on Gluteus

**Maximus Strength**  
Taylor Opperhauser, ATC

**Contact Persons**

In the event you experience any side effects or injury related to this research, you should contact PI Dr. Michelle A. Sandrey, PhD, ATC at (304)293-0870 or at msandrey@mail.wvu.edu or Co Taylor Opperhauser, ATC at 304-293-0866 or at taopperhauser@mix.wvu.edu.

For information regarding your rights as a research subject, to discuss problems, concerns, or suggestions related to the research, to obtain information or offer input about the research, contact the Office of Research Compliance at (304) 293-7073.

**Introduction**

You have been asked to participate in this research study, which has been explained to you by Taylor Opperhauser, ATC. This study is being conducted by the principal investigator, Michelle A. Sandrey, PhD, ATC and Co-investigator, Taylor Opperhauser, ATC, in the College of Physical Activity and Sport Sciences at West Virginia University. This research is being conducted to fulfill the requirements for a Thesis in Athletic Training in the College of Physical Activity and Sport Sciences at West Virginia University under the supervision of Michelle A. Sandrey, PhD, ATC.

**Purpose(s) of the Study**

The purpose of this study is to determine if a change in abdominal strength has an influence on gluteus maximus strength over a period of time.

**Description of Procedures**

You will be asked to fill out a questionnaire to gather demographic information (age, gender, past medical history, last menstrual cycle, current activity level) as well as to determine eligibility to participate in this study. This will take approximately five to ten minutes to complete. You do not have to answer all of the questions. You will have the opportunity to see the questionnaire before signing this consent form. All completed forms will be kept confidential. If you are an eligible subject, you will be asked to participate in three sessions of measurement. The first will be a baseline session to allow you to become familiar with the testing measure and determine a starting measurement. Each of the remaining two sessions will be strictly testing sessions without
prior familiarity to the measures. During each testing session, the subject will complete the questionnaire to gather demographic information. Each testing session will take approximately 10 to 15 minutes to complete. During each session, the subject will be videotaped on an iPad. The videotaped information will be used to analyze angle measurements using the Hudl app. The information recorded on the iPad will be deleted at the conclusion of the study. Testing will occur on the date and time given to you by the principle instructor. The testing dates will be every 5 weeks, for a total of 15 weeks.

Double Leg Lowering Test

The DLL is used to assess lower abdominal muscle strength or stability in your core. A sphygmomanometer will be used to determine the angle of hip flexion in which your core fails to properly activate. The lower the degrees of hip flexion, the stronger the lower abdominal muscles. For this test, you will have a brief demonstration period prior to official testing. You will be asked to lie supine with arms across your chest. You will then raise your legs with knees fully extended. You will then be asked to lower your legs while actively watching the sphygmomanometer. When the sphygmomanometer strays 10 mmHg, you will be asked to stop.

Gluteus Maximus Manual Muscle Test

The GM MMT is performed using a handheld dynamometer to measure the strength of the gluteus maximus muscle. You will first be weighed to normalize your strength values to your body weight. You will have a brief demonstration of the GM MMT prior to official testing. You will be asked to lie prone with one knee bent. You will then be asked to raise that bent leg against a force. You will have two seconds to build up force and four seconds to hold your maximal force. The average of three trials will be taken.

Discomforts

There are no known risks involved in participation in this research study. If at any point during the testing procedures you begin to feel any pain or discomfort, please indicate this to the present investigator. If this occurs, the measurements will be suspended immediately and may be rescheduled to a later date once the pain has resolved.

Alternatives

You do not have to participate in this study. You may withdraw at any time with no penalty.

Benefits

You may not receive any direct benefit from this study. However, this study procedures and results may help aid in other research. It could help determine if prolonged sitting has an effect on core or gluteus maximus strength. The information gained through this study may eventually help others.

Financial Considerations

There will be no payments made for participation in this study. There is no cost to participants in this study. You will not earn extra credit for participating in this study, nor will you be penalized academically for not participating.
Confidentiality

Any information about you that is obtained as a result of your participation in this research will be kept as confidential as legally possible. Your research records and test results, just like hospital records, may be subpoenaed by court order or may be inspected by the study sponsor or federal regulatory authorities without your additional consent. Audiotapes or videotapes will be kept locked up and will be destroyed as soon as possible after the research is finished. In any publications that result from this research, neither your name nor any information from which you might be identified will be published without your consent.

HIPAA

We know that information about you and your health is private. We are dedicated to protecting the privacy of that information. Because of this promise, we must get your written authorization (permission) before we may use or disclose your protected health information or share it with others for research purposes. This form gives that permission. It also helps us make sure that you are correctly told how this information will be used or disclosed. Please read the information below carefully before signing this form. Please ask any questions you may have about this form or its uses. You can decide to sign or not to sign this authorization form. However, if you choose not to sign this authorization form, you will not be able to take part in the research study.

USE AND DISCLOSURE COVERED BY THIS AUTHORIZATION. DO NOT SIGN A BLANK FORM. You or your authorized representative should thoroughly read the information below before signing this form. This form will authorize the following person(s), class(es) of persons, and/or organization(s) to disclose, use, and receive the information: WVU, Michelle A. Sandrey, PhD, ATC, Taylor Oppenhauser, ATC. The research site(s) carrying out this study includes WVU. If, during the course of the research, the institution listed above merges with, or is purchased by, another company or institution, this authorization to use or disclose protected health information in the research will extend to the successor, company, or institution. A self-reported demographic history that includes information on height, weight, past dance history, past medical history of any upper extremity, lower extremity, or spine injury is included in this study.

SPECIFIC UNDERSTANDINGS. By signing this research authorization form, you give permission for the use and/or disclosure of your protected health information described above. The purpose for the uses and disclosures you are authorizing us to carry out the research study explained to you during the informed consent process. It is also to ensure that the information relating to the research is available to all parties who may need it for research purposes. Your protected health information may be used as necessary for you research related treatment. This information may be redisclosed or used for other purposes if a recipient described in this form is not required by law to protect the privacy of the information. You have a right to refuse to sign this authorization if you do not sign this form. If you sign this authorization, you will have the right to cancel at any time, except to the extent that WVU has already taken action based upon your authorization or needs information to complete analysis and reports of data for this research study. This authorization will expire six months from today unless you cancel this sooner. To cancel this authorization, please write to the Principal Investigator, Michelle A. Sandrey, PhD, ATC at: West Virginia University, PO Box 6116, Morgantown, WV 26506. If you cancel this authorization, any information that was collected already for this study cannot be withdrawn. You will NOT be allowed to see or copy the information described on this form as long as the research is in progress, but you have a right to see and copy the information upon completion of the research in accordance with hospital policies. You have a right to receive a copy of this form after you have signed it. In any
publications that result from this research, neither your name nor any information from which you might be identified will be published without your consent.

**Voluntary Participation**
Participation in this study is voluntary. You are free to withdraw your consent to participate in this study at any time. Refusal to participate or withdrawal will not affect your class standing or grades and will involve no penalty to you. Refusal to participate or withdrawal will not affect your future care, or your employee status at West Virginia University. In the event new information becomes available that may affect your willingness to participate in this study, this information will be given to you so that you can make an informed decision about whether or not to continue your participation. You have been given the opportunity to ask questions about the research, and you have received answers concerning areas you did not understand. Upon signing this form, you will receive a copy.
I willingly consent to participate in this research.

**Signatures**
Signature of Subject

______________________________________________________________________________

Printed Name                                                                 Date          Time

______________________________________________________________________________

The participant has had the opportunity to have questions addressed. The participant willingly agrees to be in the study.

Signature of Investigator or Co-Investigator

______________________________________________________________________________

Printed Name                                                                 Date          Time

______________________________________________________________________________
Table C2: Subject Questionnaire

Subject number: ________________

Age: _______

Gender: (Circle one) Male / Female

If female, when was the first day of your last menstrual cycle? _______________________

On average, how many hours per day do you spend seated? _______________________

Year in School: (Circle one) Freshman / Sophomore / Junior / Senior

Are you currently a Prospective Athletic Training Student (PATS) or Curriculum Athletic Training Student (CATS)? (Circle one) Yes / No

Height: __________

Weight: __________

Current level of activity: (Circle one) None / Low / Moderate / Intense

| Low: Cardiovascular activity, weightlifting, or other physical activity ~1-2 days per week. |
| Moderate: Cardiovascular activity, weightlifting, or other physical activity ~3-4 days per week. |
| Intense: Cardiovascular activity, weightlifting, or other physical activity ~5-7 days per week. |

1. Have you had a history of lower body injury in the past six months that has required medical intervention? If so, what was the diagnosis?
   a. Ankle? ________________________________
   b. Knee? ________________________________
   c. Hip? ________________________________
   d. Low back? ____________________________

2. Are you currently taking any medications that may affect your balance or coordination?

3. Are you currently doing any core stability training? If yes, please explain what core stability training you are currently involved in.
Table C3. Gluteus Maximus Manual Muscle Test

Step 1. Each subject will be weighed using a digital scale to normalize the strength values to the subject’s body weight.

Step 2. The subject will be placed prone on a treatment table with the knee flexed to 90 degrees or more. The Co-PI will stand on the involved leg side.

Step 3. The force pad of the handheld dynamometer will be placed just against the lower part of the posterior thigh, in the direction of hip flexion. The Co-PI will stabilize the pelvis at the level of the PSIS.
Step 4. The subject will take 3 submaximal practical trials. The dynamometer will be zeroed. The subject will be instructed to extend the hip with the knee flexed by building up force for 2 seconds, then a maximal contraction effort for 4 seconds. The value of the dynamometer will be recorded and zeroed out before the next trial. The subject will have 15 seconds of rest between trials. A total of three trials will be completed.

Step 5. The three trials will be averaged and normalized to the subject’s body weight. This information will be recorded on the data collection sheet.
Table C4. Double Leg Lowering Test

Step 1. The subject will lie supine on a treatment table with arms folded over the chest. A reflective dot will be placed on the lateral epidcondyle, greater trochanter and greater tubercle of the humerus.

Step 2: A sphygmomanometer will be placed under the subject’s low back at the level of the PSIS. Minimal air will be pumped into the sphygmomanometer prior to placement. The subject will then be instructed to raise both legs to a vertical position with both knees in full extension.
Step 3: The initial mmHg on the sphygmomanometer will be noted. At this point until the conclusion of the test, an ipad will be used to video record the test.

Step 4: The test will begin when the subject posteriorly rotates the pelvis to flatten the back, and the Co-PI raises her hand. The subject will slowly begin to lower both legs to the table.
Step 5: The test will conclude when the mmHg noted by the sphygmomanometer strays 10 mm from the initial reading. The Co-PI will raise her hand.

Step 6: The Hudl app will be used to determine the subject’s angle of hip flexion from the iPad video. The reflective points on the lateral epicondyle, greater trochanter and greater tubercle of the humerus will be connected and an angle measurement will be recorded on the data collection sheet.
Table C5: Data Collection Sheet

Subjects Number: _________

Weight: _________

Height: _________

Data collection Sheet for DLL test and GM MMT

Trial: Baseline / One / Two

Gluteus maximus MMT:

<table>
<thead>
<tr>
<th></th>
<th>Left Leg</th>
<th>Right Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>_________</td>
<td>_________</td>
</tr>
<tr>
<td>#2</td>
<td>_________</td>
<td>_________</td>
</tr>
<tr>
<td>#3</td>
<td>_________</td>
<td>_________</td>
</tr>
</tbody>
</table>

Average: _________ Average: _________
Double-Leg Lowering Test:

Start Degrees: ________________

End Degrees: ________________

Change in Degrees: ________________
### APPENDIX D

### ADDITIONAL RESULTS

Table D1. DLL, GM MMT, Sitting Time Means and Standard Deviations for Subjects (n=47)

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Baseline Measurement</th>
<th>Post-test One (5 weeks)</th>
<th>Post-test Two (10 weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double-Leg Lowering Test</td>
<td>14.70±8.29</td>
<td>10.06±5.92</td>
<td>6.85±4.79</td>
</tr>
<tr>
<td>R Gluteus Maximus MMT</td>
<td>35.63±7.04</td>
<td>36.48±6.91</td>
<td>36.00±6.66</td>
</tr>
<tr>
<td>L Gluteus Maximus MMT</td>
<td>34.80±7.70</td>
<td>36.29±7.28</td>
<td>35.62±6.66</td>
</tr>
<tr>
<td>Sitting Time</td>
<td>6.57±2.08</td>
<td>7.08±2.52</td>
<td>7.61±2.80</td>
</tr>
</tbody>
</table>

Table D2. DLL and GM MMT Correlations

<table>
<thead>
<tr>
<th></th>
<th>DLL</th>
<th>DLL1</th>
<th>DELL</th>
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<th>GMN</th>
<th>GMNL</th>
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</thead>
<tbody>
<tr>
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<td></td>
<td>Baseline</td>
<td>mBaseline</td>
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<td>Norm1</td>
<td>Norm1</td>
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<td>Norm1</td>
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<tr>
<td>DLLBaseline</td>
<td>1.000</td>
<td>.058</td>
<td>.414</td>
<td>.157</td>
<td>.177</td>
<td>.214</td>
<td>.190</td>
<td>.195</td>
<td>.155</td>
</tr>
<tr>
<td>DLL1</td>
<td>.058</td>
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<td>.252</td>
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<td>.221</td>
</tr>
<tr>
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Table D3. DLL for Gender and Activity Level Means and Standard Deviations

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<tr>
<th>Fixed Variable</th>
<th>Baseline Measurement</th>
<th>Post-test One (5 weeks)</th>
<th>Post-test Two (10 weeks)</th>
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</thead>
<tbody>
<tr>
<td>Male (n=13)</td>
<td>14.38±9.68</td>
<td>9.15±5.24</td>
<td>5.46±4.09</td>
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<tr>
<td>Female (n=34)</td>
<td>14.82±7.86</td>
<td>10.41±6.19</td>
<td>7.38±4.98</td>
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<tr>
<td>No Activity (n=2)</td>
<td>21.00±4.24</td>
<td>12.00±1.41</td>
<td>6.00±2.82</td>
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<tr>
<td>Low Activity (n=23)</td>
<td>14.70±9.40</td>
<td>8.78±4.74</td>
<td>7.04±4.85</td>
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<tr>
<td>Moderate Activity (n=19)</td>
<td>13.16±6.55</td>
<td>12.11±7.16</td>
<td>7.16±5.26</td>
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<tr>
<td>Intense Activity (n=3)</td>
<td>20.33±10.26</td>
<td>5.67±2.08</td>
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Table D4. GM MMT for Gender and Activity Level Means and Standard Deviations

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<th>Fixed Variable</th>
<th>L Baseline Measurement</th>
<th>L Post-test One (5 weeks)</th>
<th>L Post-test Two (10 weeks)</th>
<th>R Baseline Measurement</th>
<th>R Post-test One (5 weeks)</th>
<th>R Post-test Two (10 weeks)</th>
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<td>Male (n=13)</td>
<td>32.48±5.21</td>
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<td>32.68±5.52</td>
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<td>34.80±8.36</td>
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<td>43.54±5.01</td>
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<td>44.13±5.40</td>
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<tr>
<td>Low Activity (n=23)</td>
<td>36.11±8.18</td>
<td>37.50±7.86</td>
<td>36.29±6.43</td>
<td>36.72±7.19</td>
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<tr>
<td>Intense Activity (n=3)</td>
<td>36.58±9.18</td>
<td>37.10±9.05</td>
<td>36.70±8.92</td>
<td>36.61±9.12</td>
<td>37.09±9.54</td>
<td>37.04±9.08</td>
</tr>
</tbody>
</table>
APPENDIX E

RECOMMENDATIONS FOR FUTURE RESEARCH

1. Use an athletic population.

2. Complete at least four data points to account for the menstrual cycle and to increase to duration of the study, so that more significant differences may be found.

3. Incorporate an intervention for lower abdominal and gluteus maximus strength using varying time points to evaluate.


5. Find a relationship between gender, gluteus maximus strength and lower abdominal strength.

6. Find a relationship between activity level, gluteus maximus strength and lower abdominal strength.

7. Focus on activity level, activity rating, and self-reporting measures.

8. Measure whether hip flexor tightness is present or absent, then compare lower abdominal and gluteus maximus strength.
ADDITIONAL REFERENCES


