THE PENNSYLVANIA STATE UNIVERSITY
SCHREYER HONORS COLLEGE

DEPARTMENT OF KINESIOLOGY

THE RELATIONSHIP OF CORE ENDURANCE TO DYNAMIC BALANCE AND FUNCTIONAL HOP TASK PERFORMANCE UNDER LOADED AND UNLOADED CONDITIONS

SARAH LOPEZ
Spring 2012

A thesis
submitted in partial fulfillment
of the requirements
for a baccalaureate degree
in Kinesiology
with honors in Kinesiology

Reviewed and approved* by the following:

S. John Miller
Assistant Professor of Kinesiology
Thesis Supervisor

Jinger S. Gottschall
Assistant Professor Kinesiology
Honors Adviser

Giampietro "John" L. Vairo
Instructor of Kinesiology
Coordinator, Athletic Training Research Laboratory
Thesis Reader

Stephen Piazza
Associate Professor of Kinesiology
Honors Adviser

* Signatures are on file in the Schreyer Honors College.

ABSTRACT

THE RELATIONSHIP OF CORE ENDURANCE TO DYNAMIC BALANCE AND FUNCTIONAL HOP TASK PERFORMANCE UNDER LOADED AND UNLOADED CONDITIONS

Lopez SM, Miller SJ, Vairo GL: Athletic Training and Sports Medicine Research Laboratory, Department of Kinesiology, The Pennsylvania State University, University Park, PA

Objective: To describe core endurance profiles under unloaded and loaded conditions, and associations to functional performance in a physically active population. **Design and Settings:** This descriptive study was conducted in a controlled laboratory. The order of testing sessions and performance measures were randomized to prevent order effects. **Subjects:** Fifty (17 women, 33 men) young, healthy and physically active participants (20.8 ±1.5 years,175.6 ± 8.1 cm, 71.9 ± 10.6 kg) were enrolled. **Measurements:** Core endurance isometric tests, as described by McGill, (Biering-Sorensen back extension, trunk flexion, right and [RLP] left lateral planks [LLP]) were assessed under unloaded and loaded conditions. The loaded condition involved the addition of an arbitrary external load equal to 10% of body mass. The amount of time (s) to fatigue for each test was measured. Crossover hop distance, normalized to leg length, was recorded as a measure of functional performance. Paired t-tests analyzed differences between unloaded and loaded core endurance conditions. Pearson product moment correlation coefficients identified associations among core endurance and functional performance measures. $P < 0.05$ denoted statistical significance. **Results:** Statistically significant differences existed between all unloaded and loaded core endurance isometric tests (extension: unloaded = 127.2 ± 56.9 s, loaded = 78.9 ± 20.7 s, P = < 0.001; flexion: unloaded = 224.1 s ± 142.4 s, loaded = 194.3 ± 117.4 s, P = 0.048; right lateral plank: unloaded = 98.0 s ± 39.5 s, loaded = 73.5 ± 32.4 s, P = < 0.001; left lateral plank: unloaded = 104.2 ± 38.1 s, loaded = 73.3 ± 27.2 s, P = < 0.001). Statistically significant positive correlations existed between unloaded and loaded RLP and LLP to crossover hop distances for dominant and non-dominant legs (RLP-unloaded dominant: r = 0.584, P = < 0.001; LLP-unloaded dominant: r = 0.610, P = < 0.001; RLP-unloaded non-dominant: r = 0.612, P = < 0.001; LLP-unloaded non-dominant: r = 0.596, P = < 0.001; RLP-loaded dominant: r = 0.668, P = < 0.001; LLP-loaded dominant: r = 0.653, P = <0.001, RLP-loaded non-dominant: r = 0.735, P = < 0.001; LLP-loaded non-dominant: r = 0.664, P = < 0.001). All other analyses were statistically insignificant. **Conclusions:** Loaded core endurance tests appear to enhance associations to functional performance compared to unloaded, when using an absolute measure of time. Further investigation is required to identify the association of relative core endurance measures to functional performance. **Word Count:** 398

ACKNOWLEDGEMENTS

I want to thank everyone who made this research experience possible. First, I would like to express my gratitude to the participants that volunteered their time to participate in this study. Next, I would like to thank my thesis supervisor, Dr. Miller, and my thesis co-supervisor, John Vairo, whose encouragement, guidance, time and full dedication to this project made this experience possible. Your patience and support were more than I could have ever hoped for and your dedication and professionalism were truly inspiring. I would also like to thank my Honors Advisor, Jinger Gottschall, for her time, support and feedback throughout the completion of this project. Also, I would like to thank Stephen Piazza, for his guidance and support during the initial stages of this process. Lastly, I would like to thank DJ, Marissa, Ryan, and Matt for their help as laboratory assistants.

Finally, I would like to thank my parents for their full support in everything that I do. Thank you for the sacrifices you have made, the countless lessons you have taught, and your unconditional love.

TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION

Core strength and endurance provide stability and control during functional body movements by controlling the position and motion of the trunk over the pelvis in response to internal and external perturbations.[1-3] The stabilizing effect is accomplished through the coordinated interaction between passive structures of the thoracolumbar spine and pelvis, and contractile musculotendinous structures controlled by the nervous system.[1,2] The specific anatomical components contributing to core stability include musculoskeletal tissues of the spine, hips, pelvis, proximal lower limbs and abdominal structures.[3] The central location of these muscles and joints facilitate most of the stabilizing processes required for distal segments to perform their specific functions[3]. For example, multi-body segment functional activities, such as running, kicking and throwing involve core activation. [3] Therefore, core stability is noted as a focal component in the production, transfer, and control of forces and motions to the distal segments of the kinetic chain.[3-4]

The action of balance involves the interaction of several physiological mechanisms including our visual, vestibular, somatosensory, musculoskeletal and cognitive systems and can be characterized as either static or dynamic [5-6]. Static postural control is classified as one's ability to maintain a position while standing in a unilateral or bilateral stance. [5, 7] Dynamic postural control involves maintaining a stable base of support through the completion of purposeful movements of a prescribed task [7]. These tasks usually involve displacing one's center of mass toward the limits of stability outside the base of support.[5-7] The activation of muscles to regain equilibrium of the center of mass is classified as automatic or pre-programmed reactions. These reactions involve the coordinated activation of the leg and trunk muscles which establish postural control through generating movements around the ankle and hip. Biomechanically, when body weight is shifted toward a limit of stability, the synergistically groups muscles contract to counteract the movement in order to restore the center of mass over the base of support. Hence, the core also serves as a key component for balance, transfer of weight, and gait.

Most functional activities require coordinated movement through the kinetic chain and many athletic activities activate the core musculature to produce trunk stability preceding extremity movements. Due to the activation of core musculature preceding the activation of lower extremity function, programs focusing on improving dysfunctions of the core and trunk have been documented as preventative measures for other injuries.[2,4,9,10] Oliver et al[9] concluded that improved core stability could enhance the functions of the kinetic chain, therefore reducing deficits that result in injuries and dysfunctions. Thus, weakness or delayed activation of core muscles may lead to an unstable core platform, resulting in trunk or extremity injury. Research conducted by Cholewicki et al[10] demonstrated that delayed trunk muscle reflexes predicted low-back injuries in college athletes. In addition, Zazulak et al[2], concluded that error in core proprioception was associated with a risk of knee injury due to the altered valgus positioning, ligament strain and increased knee abduction and torque produced. Therefore, improved core stability through strengthening of the core muscles could lead to more efficient movement and ultimately decrease the kinetic chain deficits that result in injury or dysfunction, as supported by Oliver et al[9].

Function of the trunk musculature has been measured via isokinetic, isotonic and isometric testing methods. McGill et al[12] identified endurance-based exercises as the safest testing approach and the most mechanically justifiable for core stability enhancement when combined with neutral spine posture during exercises (which avoid end-range positions) and when abdominal contraction and bracing are performed in a functional mode. Additionally, isometric endurance testing recruits trunk muscles commonly associated with injuries, therefore acting as a preeminent method in measuring core strength and endurance [11-15.]

The concept of body loading in testing surrounds the understanding of muscle activation in regards to forces acting on or within the body. When additional weight is added during an isometric exercise, increased muscle force production will be required to maintain body position and compensate for the increases in force being applied. This increase in muscle force production requirement may expose muscle strength and endurance deficits. Therefore, performing an exercise with external loads will increase the requirement in force production, allowing for a greater delineation in performance test results.[76,77] External loading of isometric core endurance tests may enhance the information obtained and expose relationships between core endurance and functional task performance that were previously unknown.

Measurements of dynamic balance can be conducted through the usage of functional performance testing (FPT). The importance of FPT, in relation to clinical settings, surrounds the dynamic assessment completed through the FPT measures. Although functional tests are unable to identify specific abnormalities, they allow for a general measure of lower extremity function to be calculated in relation to joint stability, pain, muscle strength and power[72]. Elements of neuromuscular coordination and coactivation, proprioception and agility are also measured [72]. These combined measures comprise the essentialities for performance of dynamic movement. Two specific tests yielding valid and reproducible results are the Star Excursion Balance Test and the Cross-Over Hop test[22,72].

Although evidence exists supporting the relationship between core endurance and lower-extremity function and injuries, minimal research has been conducted examining the relationship between core endurance and the performance of specific functional tasks. Furthermore, limited current research exists exploring the evaluation of core endurance under loaded conditions. Therefore, the purpose of this research study was to examine the relationship between loaded and unloaded core endurance measures to dynamic balance and functional hop task performance. It was hypothesized that a relationship would exist between core endurance and performance in the dynamic balance and hopping tasks[7,36,88] and that the loaded core testing would provide a more accurate analysis of core endurance .

CHAPTER 2: MATERIALS AND METHODS

Experimental Design and Procedures

This investigation represents a descriptive study conducted in the controlled setting of the Penn State Athletic Training and Sports Medicine Research Laboratory and took place over an 8-week period. The participants completed three testing sessions over the course of six days. These sessions included an unloaded core endurance testing session, a loaded core endurance testing session, and a dynamic balance and functional performance testing session. The independent variable was the core endurance measures. The dependent variables were the dynamic balance assessment of the Star Excursion Balance Test (SEBT) and the functional testing measure of the cross-over hop test. Statistical software (Minitab 16, Minitab, Inc., State College, PA) was used to generate arbitrary permutations to randomize the order of the testing sessions, the sequence of reach directions for the SEBT, the core endurance tests for the unloaded and loaded condition, and dominant and non-dominant legs for the participants, to prevent order effects.

The core endurance testing involved the completion of the Biering-Soresen back extension test, the endurance flexion test, and the right and left lateral plank endurance tests. Each of the isometric tests required the participants to maintain the proper form of each isometric position for as long as possible and was completed on a cushioned table placed against a wall.[11, 14 -15, 18, 33] Each test was evaluated by the same examiner and only one trial of each test was performed, with a five-minute break between tests, to prevent fatigue.[14] One verbal warning was given to adjust posture during the back extension and lateral plank tests if needed. Tse et al[87] indicated that lumbar kyphosis deviation away from the correct abdominal flexor test posture could significantly skew test reliability. Therefore, consistent posture corrections were given during the flexion test to ensure the 60 degree angle was maintained and the back remained straight.

During the loaded core endurance testing, an additional 10% body weight load was included in each assessment. The load was determined based off an estimated 10% body weight calculation of each participants measured body weight (APPENDIX E). Ankle weight straps and individual 1-lb weight inserts were used to create the loaded apparatus.

During the dynamic balance and functional performance testing session the SEBT was always completed first, followed by the cross-over hop test. Before the SEBT testing began, four warm up trials were completed. Three trials were then performed in each designated direction. A 30 second break was given between each reach and a 2 minute break was given between each directional change.[22] The tape was marked for each trial with a colored pen and the trials were measured to the nearest millimeter using a standard tape measure. The same examiner administered this test to each participant to avoid variability.

For the cross-over hop test each participant was given one practice trial for each limb, followed by three measured and recorded trials.[73] No restrictions were placed on arm movement during testing and no instructions were provided regarding where to look.[73] The total hop distance, after the third cross-over hop, was measured to the nearest millimeter and marked with a colored pen. Participants were given 30 second breaks between each hop [30, 32,73] and each trial was evaluated by the same examiner for all participants..

Participants

Fifty (33 men, 17 women) healthy, recreationally active participants, ranging in age from 18 to 35 years of age, were enrolled in this study. Participants were recruited from The Pennsylvania State University (University Park Campus) student population. All participants were of normal weight (BMI >30), were non-smokers and non-consumers of nicotine products. None of the participants had a history of injury to the low-back or lower body or occurrence of a cerebral concussion, six months prior to the study. None of the participants had received physical rehabilitation within the last six months and also had no history of low-back or lower body surgery. They reported having minimal to no significant low-back or lower body pain, had no history of diabetes or peripheral neuropathy, and currently, had no lower body joint swelling.

Each participant completed an Institutional Review Board approved written informed consent form, and a general health screen (Appendix A & C) prior to data collection. Anthropometric measures were also taken, which included: height, weight, Body Mass Index (BMI), Reciprocal Ponderal Index (RPI), and bilateral leg length measures of both legs. Leg length was measured with the participant lying in a supine position, to allow for clearing of the hips. Measurements were taken from the inferior ridge of the anterior superior iliac spine to the apex of the medial malleolus. These leg length measures were used to normalize reach distances for the SEBT and jump distances in the cross-over hop test, to allow for comparisons to be made amongst participants. Leg dominance was also verified for each applicant by having the participant identify which leg they would use to kick a soccer ball. All participant demographics are displayed in Table 1.

Table 1. Participant Demographics Mean ± SD

	Men	**Women**
Sex (Men/Women)	33	17
Age (years)	20.7 ±1.6	20.9 ± 1.4
Height (cm)	178.5 ± 7.5	66.7 ± 2.3
Mass (kg)	76.1 ± 9.6	63.9 ± 7.4
BMI (kg/m^2)	23.6 ± 2.6	22.2 ± 1.9
RPI ($s/cm/kg^{1/3}$)	42.6 ± 1.5	42.3 ± 2.0
Right Leg Length (cm)	92.9 ± 4.1	88.6 ± 4.4
Left Leg Length(cm)	92.9 ± 4.0	88.1 ± 4.4
Dominant Leg (Right/Left)	32/1	15/2

Performance Measures

Core Endurance

Isometric endurance tests of trunk muscles are viewed as a functional measure of core strength and have been proven to be a reliable and valid method to assess the endurance of the core musculature.[11-18] Furthermore, isometric endurance testing recruits trunk muscles commonly associated with injuries, therefore are the preeminent method for measuring core endurance.[11-15]

Biering-Sorensen Back Extension Test

For the Biering-Sorensen Back Extension the participants were placed in a prone position on a treatment table, parallel to the floor. The lower body was fixed to the table by two straps around the knees and the ankles and their upper body was extended beyond the support of the table (from the anterior superior iliac spine) as seen in Figure 1. Before the beginning of the test, the participants were allowed to rest the upper body on a chair in front of the examination table. They were then asked to lift the upper trunk from the chair, place their arms folded across their chest, with their hands on opposite shoulders, and to maintain the trunk in neutral alignment for as long as possible. Neutral alignment was monitored by means of an inclinometer, which was secured to their upper arm with a Velcro strap. When the participant's body alignment began to deviate from the neutral position, the participant was given one warning to regain neutral alignment. Time to fatigue was measured in seconds and if the participant could no longer maintain the position or dropped below 10 degrees from the horizontal line, the test was terminated. Reliability studies conducted by Paalanne et al[15] and Latimer et al[20] demonstrated Correlation Coefficient (ICC) values of 0.93 and 0.83 respectively for this test.

During the loaded version of the back extension test the loaded apparatus was placed on the chair in front of the participants. The participants were instructed to assume the neutral alignment and support the weight in the antecubital fossa region of their arm with the weights flat against their chest. Their forearms were crossed over the weights and their hands on opposite shoulders (Figure 2). The amount of time taken to fatigue was measured in seconds and if the participant could no longer maintain the position, dropped below 10 degrees from the horizontal line, or dropped the weights the test was terminated.

Figure 1. Biering-Sorensen Back Extension Test – Unloaded

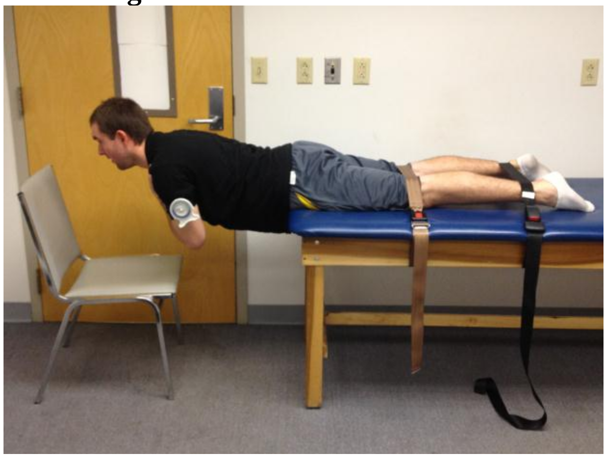


Figure 2. Biering-Sorensen Back Extension Test – Loaded

Endurance Flexion Test

The endurance flexion test initially placed participants in a sit-up position on a treatment table, with their back resting against a wedge angled at 60^{o} from the horizontal[21] (Figure 3).

Both the knees and hips were flexed to approximately 90^o. Their arms were crossed against their chest, with hands on opposite shoulders and their toes were placed under toe straps. Their head and neck were aligned with their trunk for the duration of the test. The participants were instructed to maintain the body position while the supporting wedge was pulled back 10 cm (Figure 4). The amount of time taken to fatigue was measured in seconds and when the participants back touched the wedge the test was terminated. Reliability tests [14,15] demonstrated ICC values of 0.87 and 0.92, concluding the test as a reliable measure.

During the loaded version of the flexion test the loaded apparatus was handed to the participants before they assumed the positioning stance. The participants were instructed to support the weight in the antecubital fossa region of their arm with the weights flat against their chest. Their forearms were crossed over the weights and their hands on opposite shoulders. The participants were instructed to maintain the body position while the supporting wedge was pulled back 10 cm (Figure 5). The amount of time taken to fatigue was measured in seconds and when the participants back touched the wedge the test was terminated.

Figure 3. Endurance Flexion Positioning Stance - Unloaded

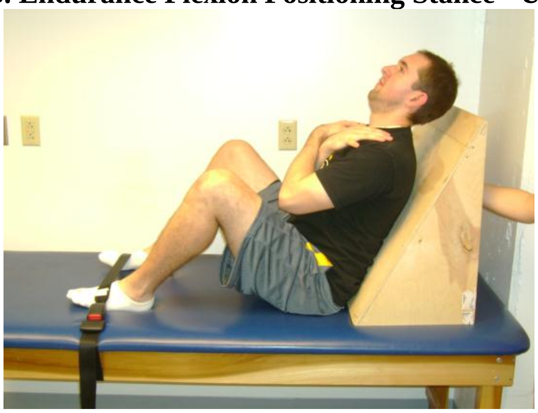


Figure 4. Endurance Flexion Test – Unloaded

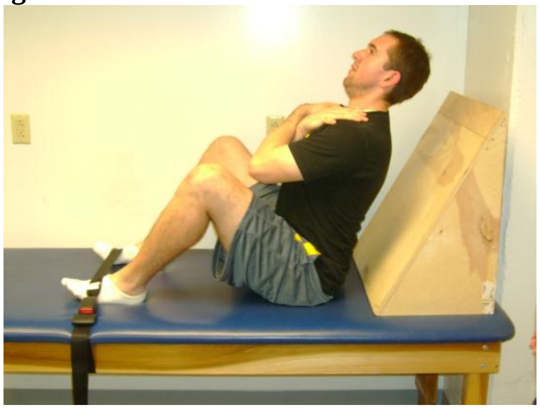
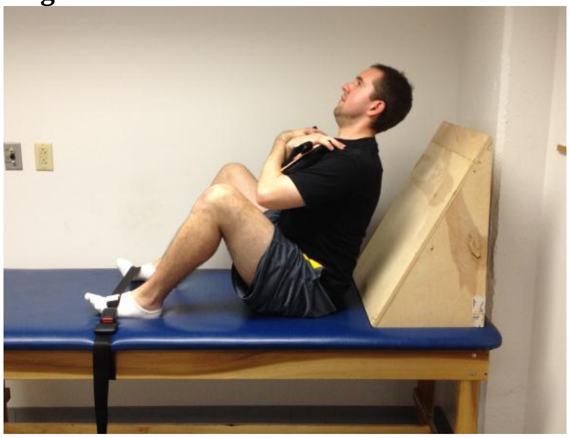


Figure 5. Endurance Flexion Test – Loaded



Lateral Plank Endurance Tests

Right and left lateral plank tests placed participants on their respective sides. Their supporting forearm was on the table and their legs were fully extended, with their top foot placed in front of the lower foot for support. Hips were then lifted upward, off the mat, establishing a straight line over their full body length and their forearm and both feet supported their body weight on a treatment table [14] (Figures 6 &7). The support arm forearm was on the table with the elbow bent 90 degrees and the shoulder abducted 90 degrees. The un-supporting arm was held across the chest and the hand was placed on the opposite shoulder. The amount of time the participant could maintain the straight line position was measured in seconds. The test concluded when the hips returned to the exercise mat. This test has been demonstrated as a reliable measure of lateral trunk strength with an ICC value of 0.84 for the right side plank and an ICC value of 0.99 for the left side plank.[14-15]

During the loaded versions of the right and left lateral plank tests the participants were instructed to lie on their side and the weights were placed across the upward facing hip region (Figure 8 & 9). The weights were then secured to the hip using two ace bandage wraps. The amount of time the participant could maintain the straight line position was measured in seconds. The test concluded when the hips returned to the exercise mat.

Figure 6. Right Lateral Plank – Unloaded

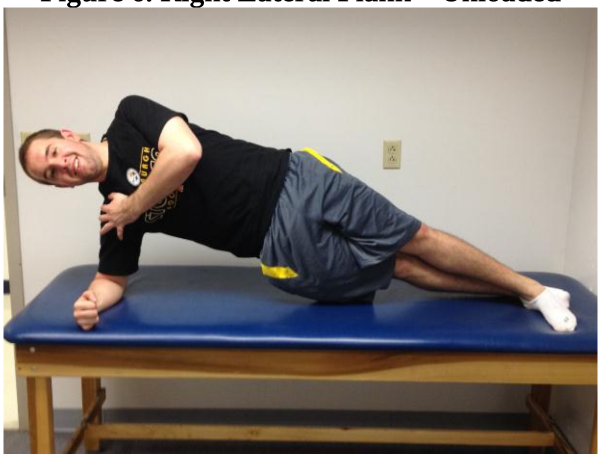


Figure 7. Left Lateral Plank – Unloaded

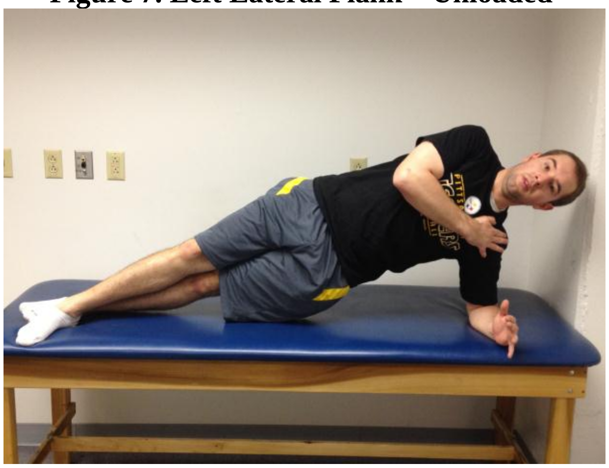


Figure 8. Right Lateral Plank Loaded

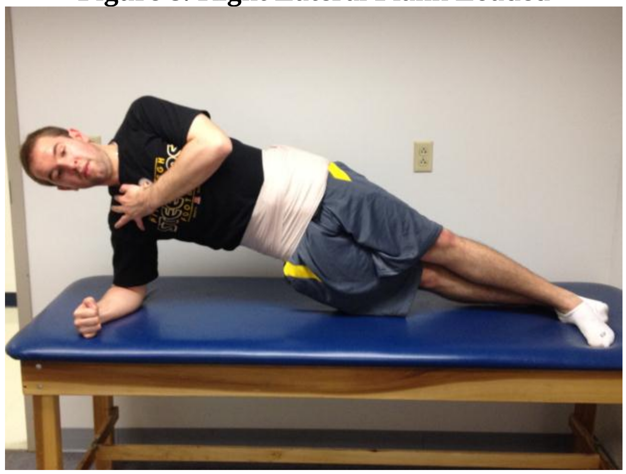


Figure 9. Left Lateral Plank Loaded

Dynamic Balance

Modified Star Excursion Balance Test

The SEBT required participants to stand barefoot, on one leg, at the center of an 8-spoke grid taped on the floor. Each line was spaced 45^{o} apart, as illustrated in Figure 10. The participants were then instructed to reach, with their non-stance leg, as far as possible in one of three directions (anterior, posteromedial and posterolateral) while keeping their hands on their hips (Figure 11-13). Significant correlations were found by Hertel et al[22], between the three reach directions tested and the remaining five directions of the grid. Therefore, due to functional redundancy across directions, the validity of the test was not compromised when reducing the number of directions administered from eight to three.

The participants' toes were aligned with the horizontal line of the grid for the anterior reach and their heel was aligned with the horizontal line of the gird for the posteriorly directed reaches. Once the subject attained their maximal reach point, they lightly touched the floor, producing minimal transfers of body weight to the reach foot, and then returned to the starting position.[5, 7, 23-24] Before the testing began, four warm up trials were completed and a verbal and visual demonstration was administered by the same examiner for all the participants.[5, 7] Three trials were then performed in each designated direction. A 30-second break was given between each reach and a 2-minute break was given between each directional change.[22]

Trials were discarded if excessive transfers in weight occurred with the reaching leg when touching the tape, if the participants removed their hands from their hips, if a loss of balance occurred, or if the supportive, stance leg moved from its original mark.[5, 24] The reach distance was marked on the tape with a colored pen for each trial and the trials were measured to the nearest millimeter, using a standard tape measure. Reliability studies of the SEBT determined ICC values of 0.81 – 0.86, indicating that this test proves to be a reliable measure to asses reach deficits in participants.[2]

Figure 10. SEBT Directions

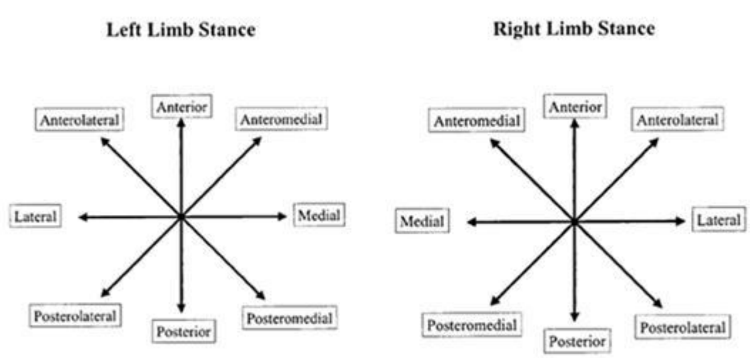


Figure 11. Anterior Reach Stance

Figure 12. Posteromedial Reach Stance

Figure 13. Posterolateral Reach Stance

Functional Capacity

Cross-Over Hop Test

For the cross-over hop test, strips of tape were placed along the floor in front of the participant that outlined a thick line, 15 cm wide and 6 m long.[71-73] The subject was instructed to perform three consecutive single leg hops, aiming for maximum distance, while crossing over the line in between each hop[71-73] (Figures 14-18). Each participant was given one practice trial for each limb, followed by two measured and recorded trials.[73] No restrictions were placed on arm movement during testing, and no instructions were provided regarding where to look.[73] The hops were deemed successful only if the participant maintained a stable posture for 2 seconds upon landing and participants were given 30-second breaks between each hop.[30, 32,73] The total hop distance, after the third cross-over hop, was measured to the nearest millimeter and marked with a colored pen and each trial was evaluated by the same examiner for all participants.[71] Trials were deemed unsuccessful if during the hop the subject touched down with either upper extremity or the contralateral lower extremity, if there was a loss of balance, or if the participant performed an additional hop upon landing.[71] The cross-over hop test has been found as a reliable testing measure with an ICC of 0.94–0.98.[73]

Figure 14. Cross-Over Hop Test

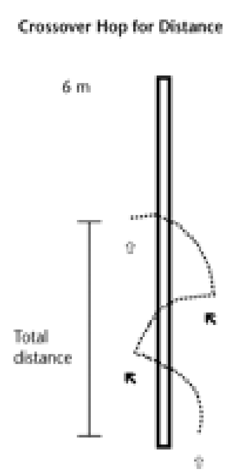


Figure 15. Cross-Over Hop Start Stance

Figure 16. Cross-Over Hop First Landing

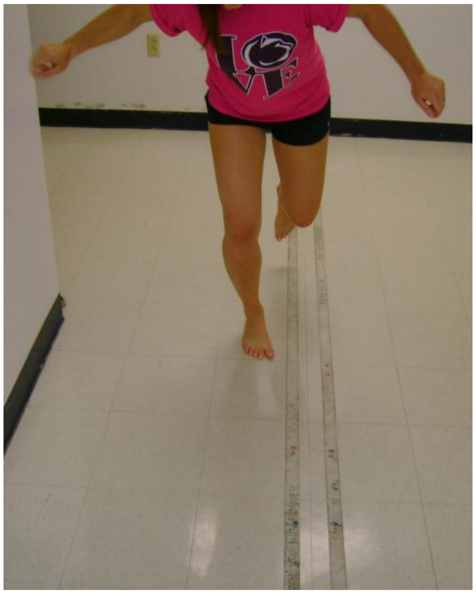
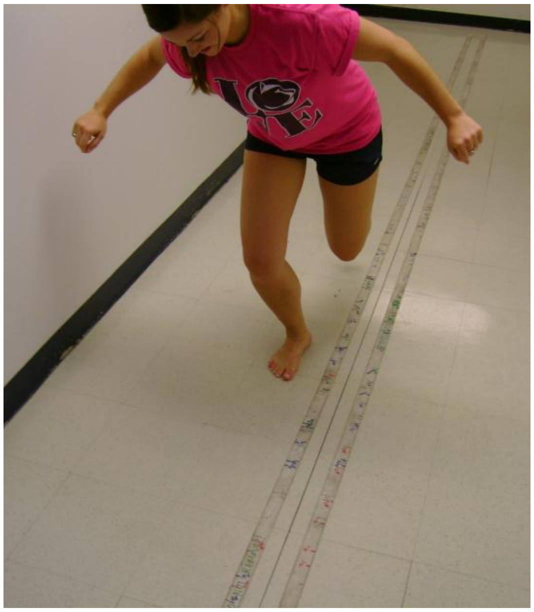


Figure 17. Cross-Over Hop Second Landing

Figure 18. Cros- Over Hop Third Landing



Statistical Analyses

The core measures were analyzed as absolute and relative normalized measures by body mass, RPI and BMI. To interpret the relationship between the three muscle groups (flexors, extensors, obliques) ratios between the core endurance measures were calculated.[62] An average distance was calculated for each reach distance in the SEBT and for the hop distance in the cross-over hop test. Reach distances for the SEBT were expressed as a percentage of leg length (%LL) and were calculated by dividing the average reach distance (cm) by leg length (cm) multiplied by 100.[5] Hop distances were expressed as a percent of leg length (%LL) calculated by dividing the average hop distance (cm) by leg length (cm) then multiplying by 100.[5] Furthermore, the hop distances were normalized to the participants body weight (cm/kg) calculated by dividing the average hop distance (cm) by body mass (kg) then multiplying by 100. Paired t-tests were conducted to assess differences between the unloaded and loaded conditions in the core endurance measures and in the core endurance ratios. Relationships between core endurance measures and core endurance ratios to dynamic balance and functional performance were determined using the Pearson Correlation Coefficient. Statistical significance was set at $p < 0.05$. Minitab statistical software (Minitab 16, Minitab, Inc., State College, PA) was used for all data analyses.

CHAPTER 3: RESULTS

Comparative Core Endurance Measures Between Conditions

Statistically significant differences existed between the unloaded and loaded conditions for all the core endurance tests (Table 1).

Table 1. Non-Normalized Core Endurance Measures (s)

	Unloaded Condition		Loaded Condition		p-value
	M	SD	M	SD	
EXT	127.18	56.88	78.85	20.67	< 0.001*
FLEX	224.1	142.4	194.3	117.4	0.048*
RLP	98.02	39.47	73.50	32.36	< 0.001*
LLP	104.19	38.11	73.26	27.20	< 0.001*

Note: EXT – back extension; FLEX –flexion; RLP – right lateral plank; LLP – left lateral plank; Values are Mean (M) and Standard Deviation (SD); * Denotes statistical significance

Statistically significant differences were present between unloaded and loaded conditions, when normalized to body mass (s/kg), for the back extension, right lateral plank and left lateral plank tests, but not for the flexion test (Table 2).

Table 2. Normalized Core Endurance Measures to Body Mass (s/kg)

	Unloaded Condition		Loaded Condition		p-value
	M	SD	M	SD	
EXT	1.844	1.109	1.123	0.357	< 0.001*
FLEX	3.243	2.449	2.827	1.994	0.092
RLP	1.3696	0.5362	1.0248	0.4388	< 0.001*
LLP	1.4577	0.5109	1.0261	0.3846	< 0.001*

Note: EXT – back extension; FLEX –flexion; RLP – right lateral plank; LLP – left lateral plank; Values are Mean (M) and Standard Deviation (SD); * Denotes statistical significance

Statistically significant differences were present between the unloaded and loaded conditions, when normalized to RPI (s/cm/kg$^{1/3}$), for all the core endurance measures (Table 3).

Table 3. Normalized Core Endurance Measures to RPI (s/cm/kg$^{1/3}$)

	Unloaded Condition		Loaded Condition		p-value
	M	SD	M	SD	
EXT	153.92	58.86	96.52	27.39	< 0.001*
FLEX	272.0	163.6	234.3	130.3	0.025*
RLP	121.56	53.09	91.20	43.07	< 0.001*
LLP	129.06	52.56	90.73	36.59	< 0.001*

Note: EXT – back extension; FLEX –flexion; RLP – right lateral plank; LLP – left lateral plank; Values are Mean (M) and Standard Deviation (SD); * Denotes statistical significance

Statistically significant differences existed between the unloaded and loaded conditions, when normalized to BMI (s/kg/m^2), for the back extension, right lateral plank and left lateral plank tests but not for the flexion test (Table 4).

Table 4. Normalized Core Endurance Measures to BMI (s/kg/m^2)

	Unloaded Condition		Loaded Condition		p-value
	M	SD	M	SD	
EXT	5.596	2.950	3.450	0.997	< 0.001*
FLEX	9.843	6.761	8.547	5.516	0.067
RLP	4.250	1.683	3.192	1.390	< 0.001*
LLP	4.518	1.604	3.184	1.192	< 0.001*

Note: EXT – back extension; FLEX – flexion; RLP – right lateral plank; LLP – left lateral plank; Values are Mean (M) and Standard Deviation (SD); * Denotes statistical significance

Functional Task Performance Measures

Table 5 displays means and standard deviations for the cross-over hop normalized by leg length and body mass and for the anterior, posteromedial and posterolateral reach directions of the SEBT normalized to leg length.

Table 5. Dominant Leg Functional Task Performance

	Dominant Leg		Non-Dominant Leg	
	M	**SD**	**M**	**SD**
COH (%LL)	428.4	105.8	417.4	117.3
COH (cm/kg)	549.7	137.2	538.7	151.9
SEBT				
ANT (%LL)	74.8	6.6	75.1	6.2
PM (%LL)	78.2	11.7	77.4	10.5
PL (%LL)	84.2	8.9	84.2	9.7

Correlation Analyses of Unloaded Core Endurance Measures to Functional Tasks

Dominant Leg

Statistically significant positive correlations were found between non-normalized right lateral plank and left lateral plank times to cross-over hop distances as well as between the non-normalized right lateral plank and left lateral plank times to the posteromedial and the posterolateral reach distances (Table 6, Figures 1-4). No other statistically significant correlations existed for these specific comparisons.

Table 6. Unloaded Non-Normalized Core Endurance Measures (s) to Dominant Leg Functional Task Performance

	EXT	r value	p value	FLEX	r value	p value	RLP	r value	p value	LLP	r value	p value
COH (%LL)		-0.021	0.886		0.023	0.873		0.584	< 0.001*		0.610	< 0.001*
COH (cm/kg)		0.053	0.715		0.057	0.695		0.451	0.001*		0.481	< 0.001*
SEBT												
ANT (%LL)		0.149	0.302		0.215	0.135		0.217	0.131		0.146	0.310
PM (%LL)		0.062	0.669		0.107	0.458		0.656	< 0.001*		0.662	< 0.001*
PL (%LL)		-0.005	0.975		-0.035	0.810		0.583	< 0.001*		0.581	< 0.001*

Note: EXT – back extension; FLEX – flexion; RLP – right lateral plank; LLP – left lateral plank; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

Statistically significant positive correlations existed between the right lateral plank and left lateral plank times, normalized to body mass (s/kg), to cross-over hop distances as well as between the right lateral plank and left lateral plank times, normalized to body mass (s/kg), to the posteromedial and posterolateral reach distances (Table 7, Figures 1-4). No other statistically significant correlations existed for these specific comparisons.

Table 7. Unloaded Normalized Core Endurance Measures to Body Mass (s/kg) to Dominant Leg Functional Task Performance

	EXT	r value	p value	FLEX	r value	p value	RLP	r value	p value	LLP	r value	p value
COH (%LL)		-0.120	0.405		-0.076	0.598		0.501	< 0.001*		0.526	< 0.001*
COH (cm/kg)		0.064	0.657		0.055	0.707		0.541	< 0.001*		0.589	< 0.001*
SEBT												
ANT (%LL)		0.137	0.343		0.220	0.125		0.232	0.105		0.176	0.222
PM (%LL)		-0.008	0.955		0.040	0.782		0.586	< 0.001*		0.597	< 0.001*
PL (%LL)		-0.062	0.668		-0.081	0.575		0.517	< 0.001*		0.513	< 0.001*

Note: EXT – back extension; FLEX –flexion; RLP – right lateral plank; LLP – left lateral plank; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

Statistically significant positive correlations were present between the right lateral plank and left lateral plank times, normalized to RPI (s/cm/kg$^{1/3}$), to cross-over hop distances as well as between the right lateral plank and left lateral plank times, normalized to RPI (s/cm/kg$^{1/3}$), to the posteromedial and posterolateral reach distances (Table 8, Figures 1-4). No other statistically significant correlations existed for these specific comparisons.

Table 8. Unloaded Normalized Core Endurance Measures to RPI (s/cm/kg$^{1/3}$) to Dominant Leg Functional Task Performance

	EXT	r value	p value	FLEX	r value	p value	RLP	r value	p value	LLP	r value	p value
COH (%LL)		0.090	0.535		0.112	0.440		0.593	< 0.001*		0.609	< 0.001*
COH (cm/kg)		0.018	0.901		0.048	0.740		0.394	0.013*		0.361	0.010*
SEBT												
ANT (%LL)		0.139	0.336		0.185	0.198		0.192	0.181		0.117	0.416
PM (%LL)		0.133	0.356		0.169	0.242		0.657	< 0.001*		0.650	< 0.001*
PL (%LL)		0.056	0.701		0.013	0.929		0.584	< 0.001*		0.574	< 0.001*

Note: EXT – back extension; FLEX –flexion; RLP – right lateral plank; LLP – left lateral plank; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach;* Denotes statistical significance

Statistically significant positive correlations existed between the right lateral plank and left lateral plank times, normalized to BMI (s/kg/m^2), to cross-over hop distances as well as between the right lateral plank and left lateral plank times to the posteromedial and posterolateral reach distances (Table 9, Figures 1-4). No other statistically significant correlations existed for these specific comparisons (Table 9).

Table 9. Unloaded Normalized Core Endurance Measures to BMI (s/kg/m^2) to Dominant Leg Functional Task Performance

	EXT	r value	p value	FLEX	r value	p value	RLP	r value	p value	LLP	r value	p value
COH (%LL)		-0.076	0.600		-0.036	0.804		0.549	< 0.001*		0.575	< 0.001*
COH (cm/kg)		0.084	0.561		0.070	0.629		0.538	< 0.001*		0.581	< 0.001*
SEBT												
ANT (%LL)		0.145	0.316		0.221	0.123		0.223	0.120		0.156	0.280
PM (%LL)		0.022	0.879		0.056	0.697		0.617	< 0.001*		0.627	< 0.001*
PL (%LL)		-0.044	0.764		-0.076	0.598		0.535	< 0.001*		0.533	< 0.001*

Note: EXT – back extension; FLEX –flexion; RLP – right lateral plank; LLP – left lateral plank; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

Figure 1. Correlation of Unloaded Core Endurance Measures to Posteromedial Reach Distances (Dominant Leg)

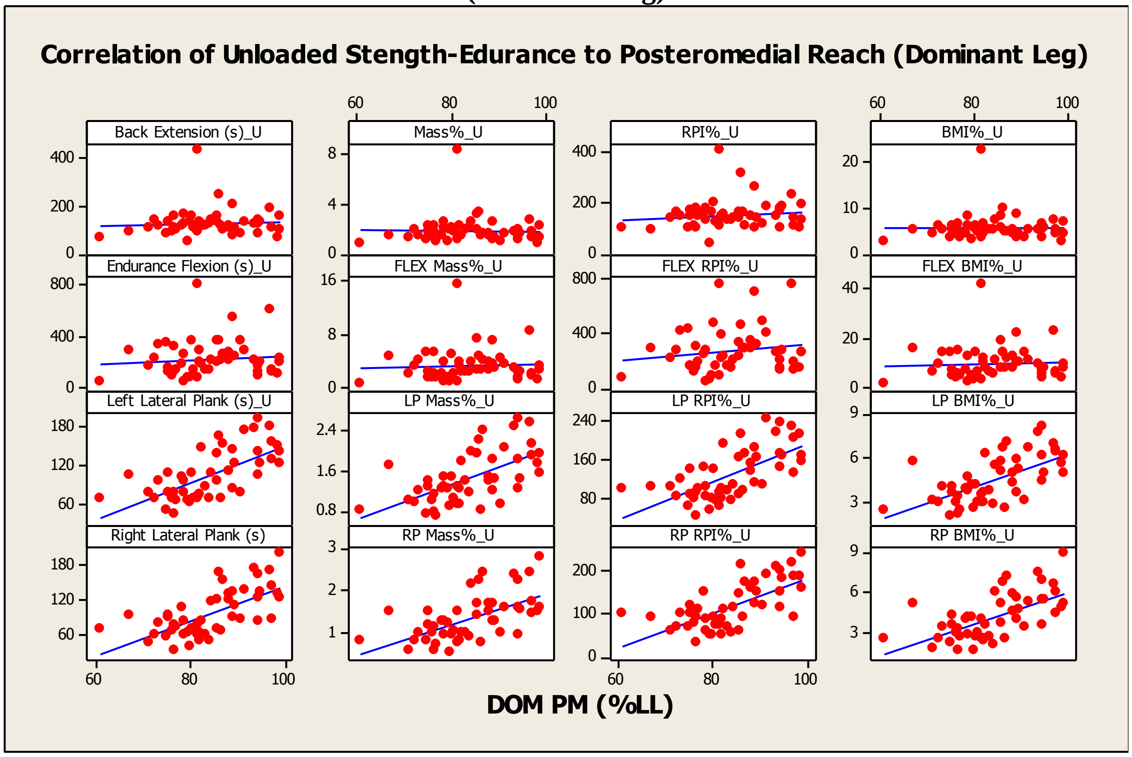


Figure 2. Correlation of Unloaded Core Endurance Measures to Posterolateral Reach Distances (Dominant Leg)

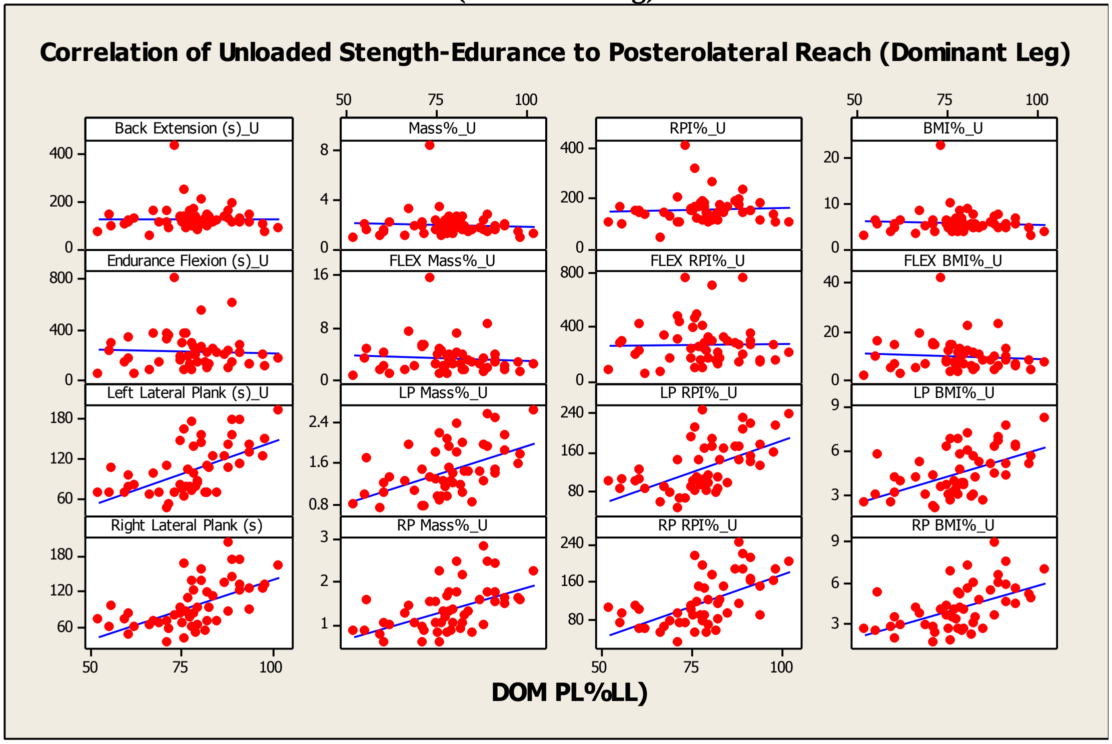


Figure 3. Correlation of Unloaded Core Endurance Measures to Normalized Cross-Over Hop Distances to Leg Length (%LL) (Dominant Leg)

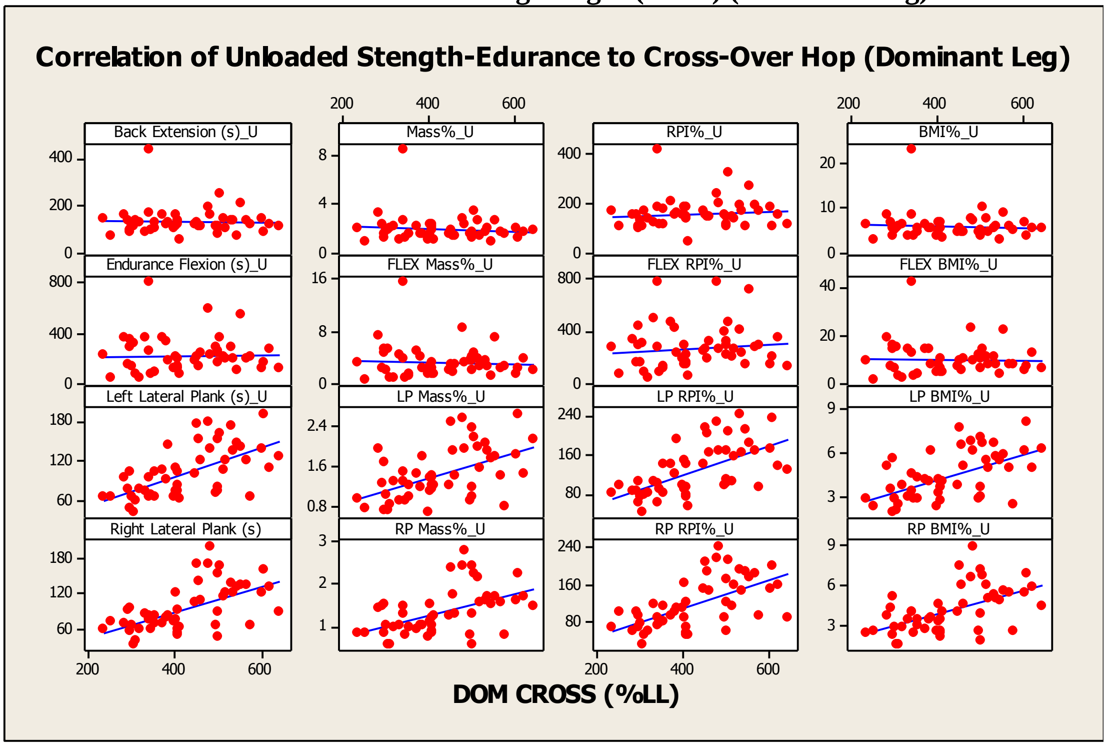
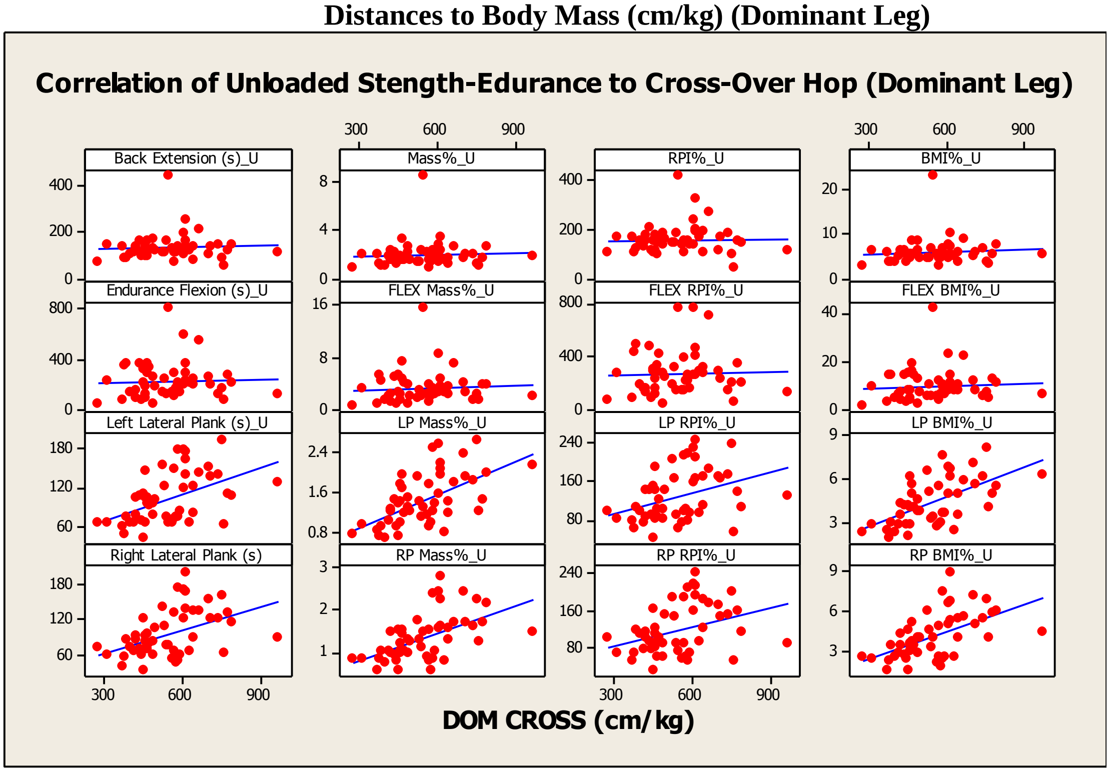


Figure 4. Correlation of Unloaded Core Endurance Measures to Normalized Cross-Over Hop Distances to Body Mass (cm/kg) (Dominant Leg)



Correlation Analyses of Loaded Core Endurance Measures to Functional Tasks

Dominant Leg

Statistically significant positive correlations were present between the non-normalized right lateral plank and left lateral plank times to cross-over hop distances as well as between the non-normalized right lateral plank and left lateral plank times to the posteromedial reach and posterolateral reach distances(Table 10, Figures 5-9). Furthermore, positive correlations existed between non-normalized back extension, flexion, and right lateral plank times to the anterior reach distance (Table 10, Figures 5-9). No other statistically significant correlations existed for these specific comparisons.

Table 10. Loaded Non-Normalized Core Endurance Measures (s) to Dominant Leg Functional Task Performance

	EXT	r value	p value	FLEX	r value	p value	RLP	r value	p value	LLP	r value	p value
COH (%LL)		0.204	0.156		-0.096	0.506		0.668	< 0.001*		0.653	< 0.001*
COH (cm/kg)		0.180	0.211		-0.031	0.830		0.543	< 0.001*		0.530	< 0.001*
SEBT												
ANT (%LL)		0.325	0.021*		0.438	0.001*		0.285	0.045*		0.122	0.400
PM (%LL)		0.226	0.115		0.046	0.752		0.615	< 0.001*		0.546	< 0.001*
PL (%LL)		0.164	0.255		-0.051	0.727		0.548	< 0.001*		0.490	< 0.001*

Note: EXT – back extension; FLEX –flexion; RLP – right lateral plank; LLP – left lateral plank; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

Statistically significant positive correlations existed between right lateral plank and left lateral plank times, normalized to body mass (s/kg), to cross-over hop distances as well as between the right lateral plank and left lateral plank times, normalized to body mass (s/kg), to the posteromedial and posterolateral reach distances (Table 11, Figures 5-9). Furthermore, positive correlations were present between back extension, flexion, and right lateral plank times, normalized to body mass (s/kg), to the anterior reach distance (Table 11, Figures 5-9). No other statistically significant correlations existed for these specific comparisons.

Table 11. Loaded Normalized Core Endurance Measures to Body Mass (s/kg) to Dominant Leg Functional Task Performance

	EXT	r value	p value	FLEX	r value	p value	RLP	r value	p value	LLP	r value	p value
COH (%LL)		-0.000	0.999		-0.178	0.215		0.592	< 0.001*		0.533	< 0.001*
COH (cm/kg)		0.218	0.129		-0.021	0.883		0.628	< 0.001*		0.609	< 0.001*
SEBT												
ANT (%LL)		0.315	0.026*		0.462	0.001*		0.299	0.035*		0.128	0.375
PM (%LL)		0.081	0.576		-0.009	0.948		0.559	< 0.001*		0.458	0.001*
PL (%LL)		0.024	0.869		-0.099	0.493		0.487	< 0.001*		0.396	0.004*

Note: EXT – back extension; FLEX –flexion; RLP – right lateral plank; LLP – left lateral plank; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

Statistically significant positive correlations were found between right lateral plank and left lateral plank times, normalized to RPI (s/cm/kg$^{1/3}$), to cross-over hop distances as well as between the right lateral plank and left lateral plank times, normalized to RPI (s/cm/kg$^{1/3}$), to the posteromedial and posterolateral reach distances (Table 12, Figures 5-9). Positive correlations existed between back extension time, normalized to RPI (s/cm/kg$^{1/3}$), and the cross-over hop distance, normalized to leg length (%LL), as well as between the back extension time, normalized to RPI (s/cm/kg$^{1/3}$), to the posteromedial reach distance (Table 12, Figures 5-9). Lastly, positive correlations existed between the flexion time, normalized to RPI (s/cm/kg$^{1/3}$), to the anterior reach distance (Table 12, Figures 5-9). No other statistically significant correlations existed for these specific comparisons.

Table 12. Loaded Normalized Core Endurance Measures to RPI (s/cm/kg$^{1/3}$) to Dominant Leg Functional Task Performance

	EXT	r value	p value	FLEX	r value	p value	RLP	r value	p value	LLP	r value	p value
COH (%LL)		0.316	0.025*		-0.012	0.935		0.675	< 0.001*		0.667	< 0.001*
COH (cm/kg)		0.088	0.545		-0.045	0.758		0.444	0.001*		0.413	0.003*
SEBT												
ANT (%LL)		0.257	0.071		0.370	0.008*		0.263	0.065		0.110	0.445
PM (%LL)		0.292	0.040*		0.105	0.468		0.617	< 0.001*		0.556	< 0.001*
PL (%LL)		0.234	0.102		0.000	0.999		0.554	< 0.001*		0.504	< 0.001*

Note: EXT – back extension; FLEX –flexion; RLP – right lateral plank; LLP – left lateral plank; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

Statistically significant positive correlations were found between the right lateral plank and left lateral plank times, normalized to BMI (s/kg/m^2), to cross-over hop distances as well as between the right lateral plank and left lateral plank times, normalized to BMI (s/kg/m^2), to the posteromedial reach and the posterolateral reach distances (Table 13, Figures 5-9). Furthermore, positive correlations existed between the back extension, flexion, and right lateral plank times, normalized to BMI (s/kg/m^2), to the anterior reach distance (Table 13, Figures 5-9). No other statistically significant correlations existed for these specific comparisons.

Table 13. Loaded Normalized Core Endurance Measures to BMI (s/kg/m^2) to Dominant Leg Functional Task Performance

	EXT	r value	p value	FLEX	r value	p value	RLP	r value	p value	LLP	r value	p value
COH (%LL)		0.098	0.499		-0.145	0.313		0.631	< 0.001*		0.590	< 0.001*
COH (cm/kg)		0.257	0.071		-0.009	0.953		0.623	< 0.001*		0.613	< 0.001*
SEBT												
ANT (%LL)		0.317	0.025*		0.463	0.001*		0.285	0.045*		0.117	0.419
PM (%LL)		0.146	0.313		0.005	0.970		0.575	< 0.001*		0.489	< 0.001*
PL (%LL)		0.069	0.633		-0.093	0.522		0.498	< 0.001*		0.418	0.003*

Note: EXT – back extension; FLEX –flexion; RLP – right lateral plank; LLP – left lateral plank; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach* Denotes statistical significance

Figure 5. Correlation of Loaded Core Endurance Measures to Anterior Reach Distances (Dominant Leg)

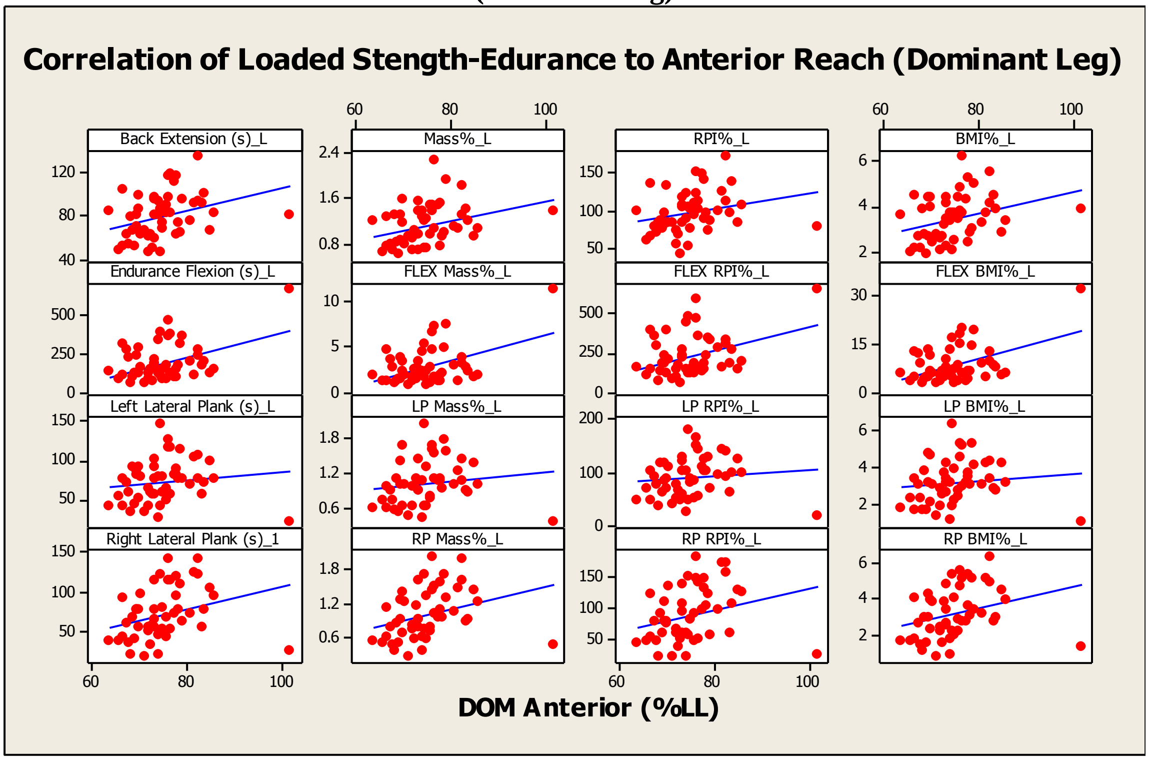


Figure 6. Correlation of Loaded Core Endurance Measures to Posteromedial Reach Distances (Dominant Leg)

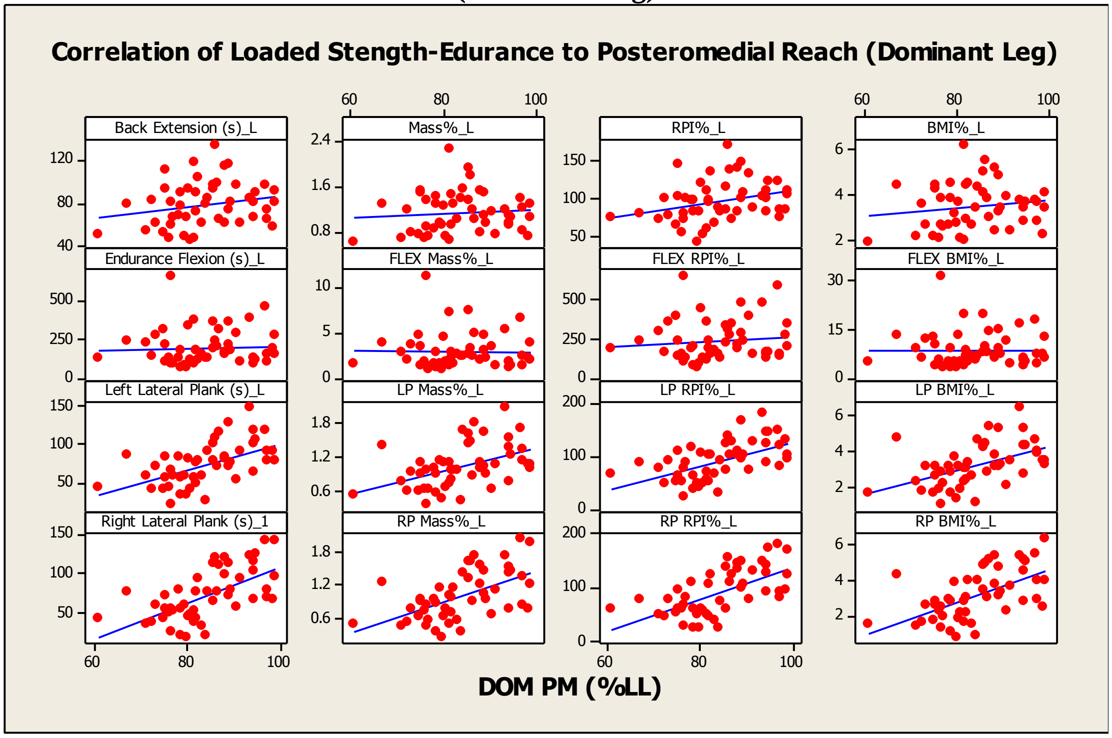


Figure 7. Correlation of Loaded Core Endurance Measures to Posterolateral Reach Distances (Dominant Leg)

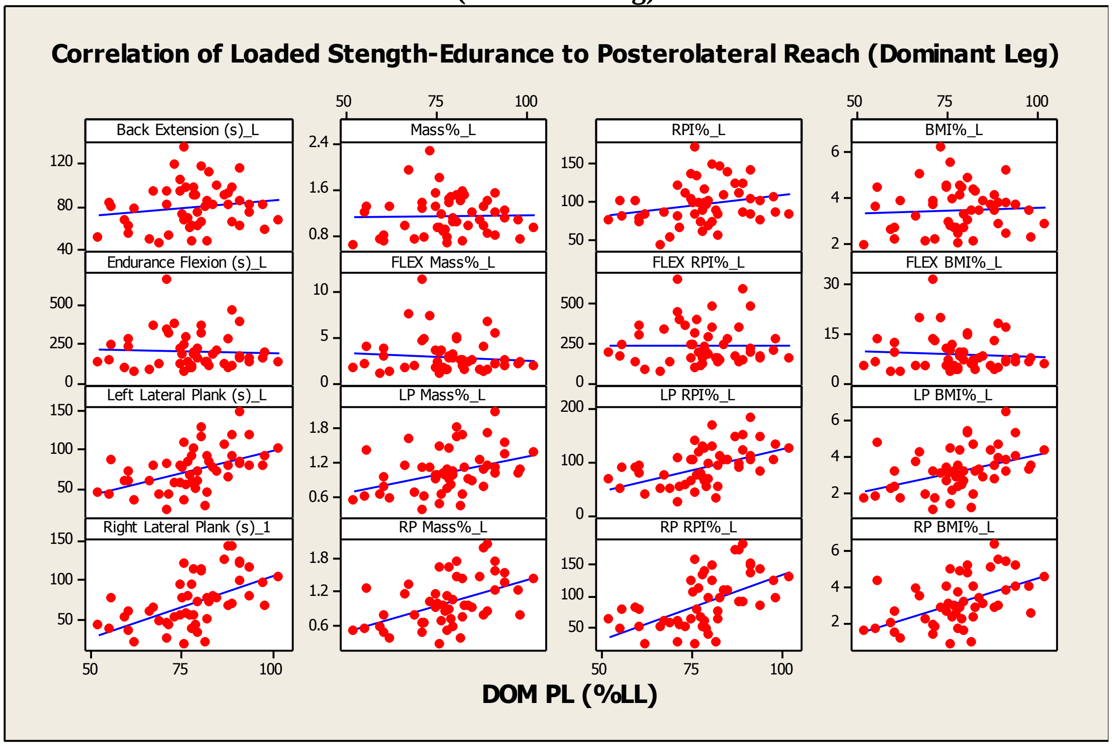


Figure 8. Correlation of Loaded Core Endurance Measures to Normalized Cross-Over Hop Distance to Leg Length (%LL) (Dominant Leg)

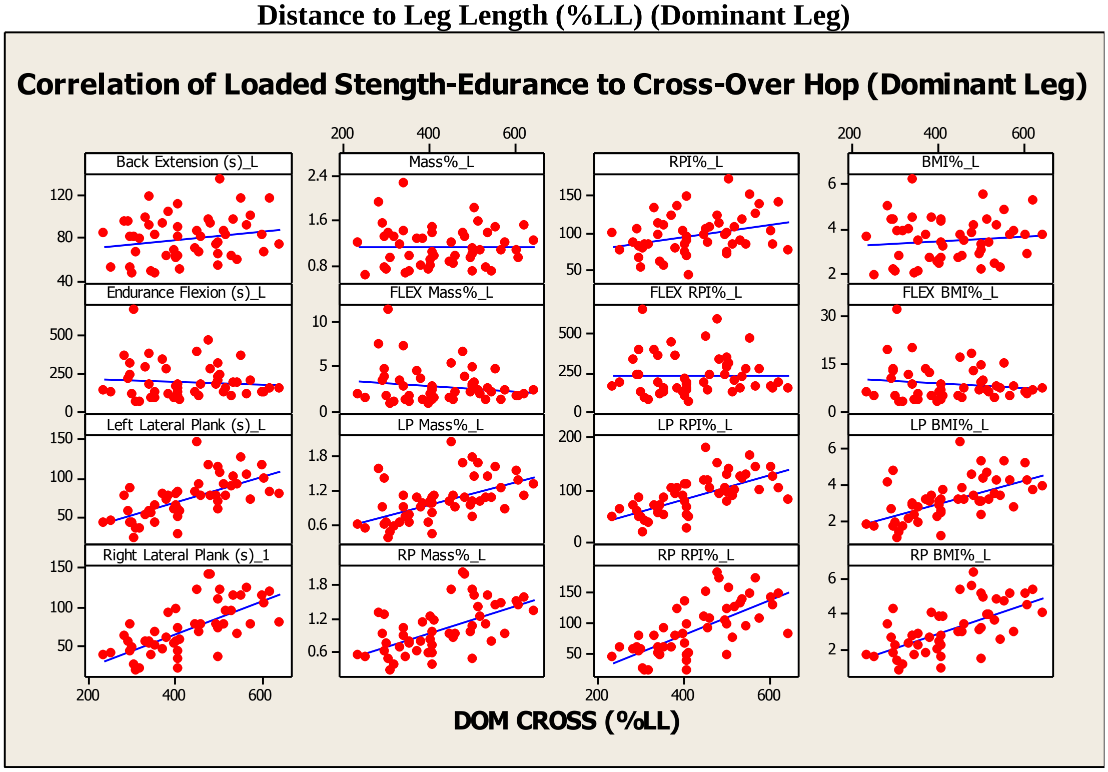
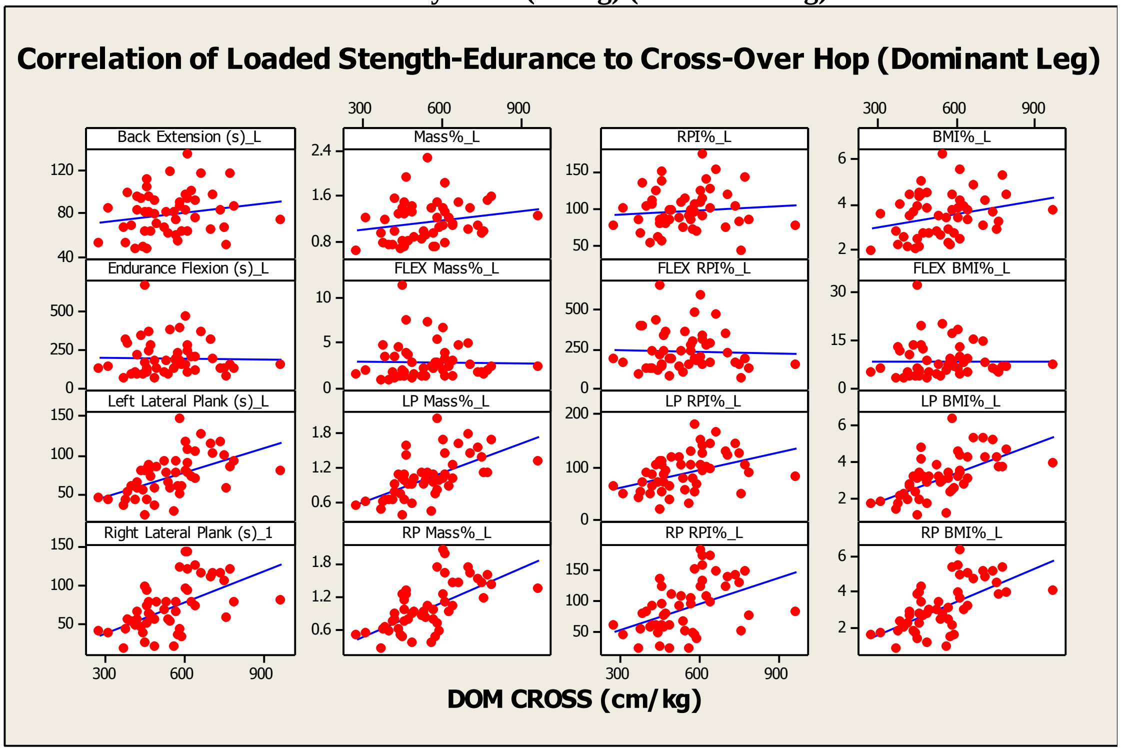


Figure 9. Correlation of Loaded Core Endurance Measures to Normalized Cross-Over Hop Distance to Body Mass (cm/kg) (Dominant Leg)



Correlation Analyses of Unloaded Core Endurance Measures to Functional Tasks

Non-Dominant Leg

Statistically significant positive correlations were present between non normalized right lateral plank and left lateral plank times to cross-over hop distances as well as between non-normalized right lateral plank and left lateral plank times to the anterior reach, posteromedial reach, and posterolateral reach distances (Table 14, Figures 10-14). No other statistically significant correlations existed for these specific comparisons.

Table 14. Unloaded Non-Normalized Core Endurance Measures (s) to Non-Dominant Leg Functional Task Performance

	EXT	r value	p value	FLEX	r value	p value	RLP	r value	p value	LLP	r value	p value
COH (%LL)		0.057	0.695		0.032	0.824		0.612	< 0.001*		0.596	< 0.001*
COH (cm/kg)		0.095	0.510		0.035	0.810		0.503	< 0.001*		0.497	< 0.001*
SEBT												
ANT (%LL)		0.157	0.276		0.160	0.266		0.433	0.002*		0.447	0.001*
PM (%LL)		0.156	0.279		0.090	0.535		0.561	< 0.001*		0.610	< 0.001*
PL (%LL)		0.127	0.379		0.096	0.505		0.485	< 0.001*		0.500	< 0.001*

Note: EXT – back extension; FLEX –flexion; RLP – right lateral plank; LLP – left lateral plank; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

Statistically significant positive correlations existed between right lateral plank and left lateral plank times, normalized to body mass (s/kg), to cross-over hop distances as well as between right lateral plank and left lateral plank times, normalized to body mass (s/kg), to the anterior reach, posteromedial reach, and posterolateral reach distances (Table 15, Figures 10-14). No other statistically significant correlations existed for these specific comparisons.

Table 15. Unloaded Normalized Core Endurance Measures to Body Mass (s/kg) to Non-Dominant Leg Functional Task Performance

	EXT	r value	p value	FLEX	r value	p value	RLP	r value	p value	LLP	r value	p value
COH (%LL)		-0.051	0.724		-0.057	0.695		0.546	< 0.001*		0.526	< 0.001*
COH (cm/kg)		0.089	0.539		0.034	0.817		0.576	< 0.001*		0.581	< 0.001*
SEBT												
ANT (%LL)		0.119	0.411		0.142	0.326		0.434	0.002*		0.467	0.001*
PM (%LL)		0.081	0.577		0.046	0.751		0.496	< 0.001*		0.554	< 0.001*
PL (%LL)		0.066	0.648		0.054	0.711		0.435	0.002*		0.440	0.001*

Note: EXT – back extension; FLEX –flexion; RLP – right lateral plank; LLP – left lateral plank; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

Statistically significant positive correlations were found between right lateral plank and left lateral plank times, normalized to RPI (s/cm/kg$^{1/3}$), to cross-over hop distances as well as between right lateral plank and left lateral plank times, normalized to RPI (s/cm/kg$^{1/3}$), to anterior reach, posteromedial reach, and posterolateral reach distances (Table 16, Figures 10-14). No other statistically significant correlations existed for these specific comparisons.

Table 16. Unloaded Normalized Core Endurance Measures to RPI (s/cm/kg$^{1/3}$) to Non-Doming Leg Functional Task Performance

	EXT	r value	p value	FLEX	r value	p value	RLP	r value	p value	LLP	r value	p value
COH (%LL)		0.169	0.240		0.113	0.436		0.611	< 0.001*		0.587	< 0.001*
COH (cm/kg)		0.080	0.582		0.031	0.832		0.415	0.003*		0.395	0.005*
SEBT												
ANT (%LL)		0.174	0.226		0.161	0.265		0.397	0.004*		0.395	0.004*
PM (%LL)		0.213	0.138		0.120	0.407		0.555	< 0.001*		0.586	< 0.001*
PL (%LL)		0.185	0.199		0.137	0.343		0.491	< 0.001*		0.503	< 0.001*

Note: EXT – back extension; FLEX –flexion; RLP – right lateral plank; LLP – left lateral plank; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

Statistically significant positive correlations were present between right lateral plank and left lateral plank times, normalized to BMI (s/kg/m^2), to cross-over hop distances as well as between right lateral plank and left lateral plank times, normalized to BMI (s/kg/m^2), to anterior reach, posteromedial reach, and posterolateral reach distances (Table 17, Figures 10-14). No other statistically significant correlations existed for these specific comparisons.

Table 17. Unloaded Normalized Core Endurance Measures to BMI (s/kg/m^2) to Non-Dominant Leg Functional Task Performance

	EXT	r value	p value	FLEX	r value	p value	RLP	r value	p value	LLP	r value	p value
COH (%LL)		-0.004	0.978		-0.023	0.876		0.582	< 0.001*		0.567	< 0.001*
COH (cm/kg)		0.112	0.438		0.044	0.760		0.571	< 0.001*		0.575	< 0.001*
SEBT												
ANT (%LL)		0.153	0.289		0.164	0.256		0.453	0.001*		0.497	0.001*
PM (%LL)		0.124	0.391		0.068	0.637		0.540	< 0.001*		0.596	< 0.001*
PL (%LL)		0.088	0.543		0.063	0.666		0.449	0.001*		0.457	0.001*

Note: EXT – back extension; FLEX –flexion; RLP – right lateral plank; LLP – left lateral plank; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

Figure 10. Correlation of Unloaded Core Endurance Measures to Anterior Reach (Non-Dominant Leg)

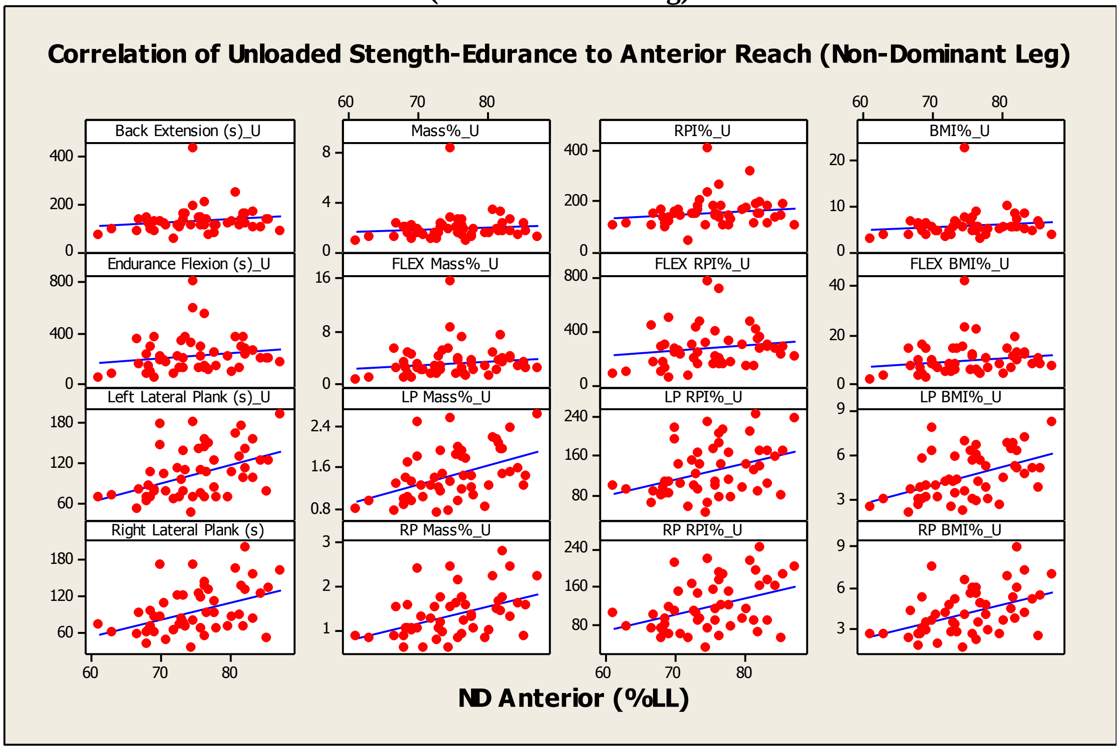


Figure 11. Correlation of Unloaded Core Endurance Measures to Posteromedial Reach (Non-Dominant Leg)

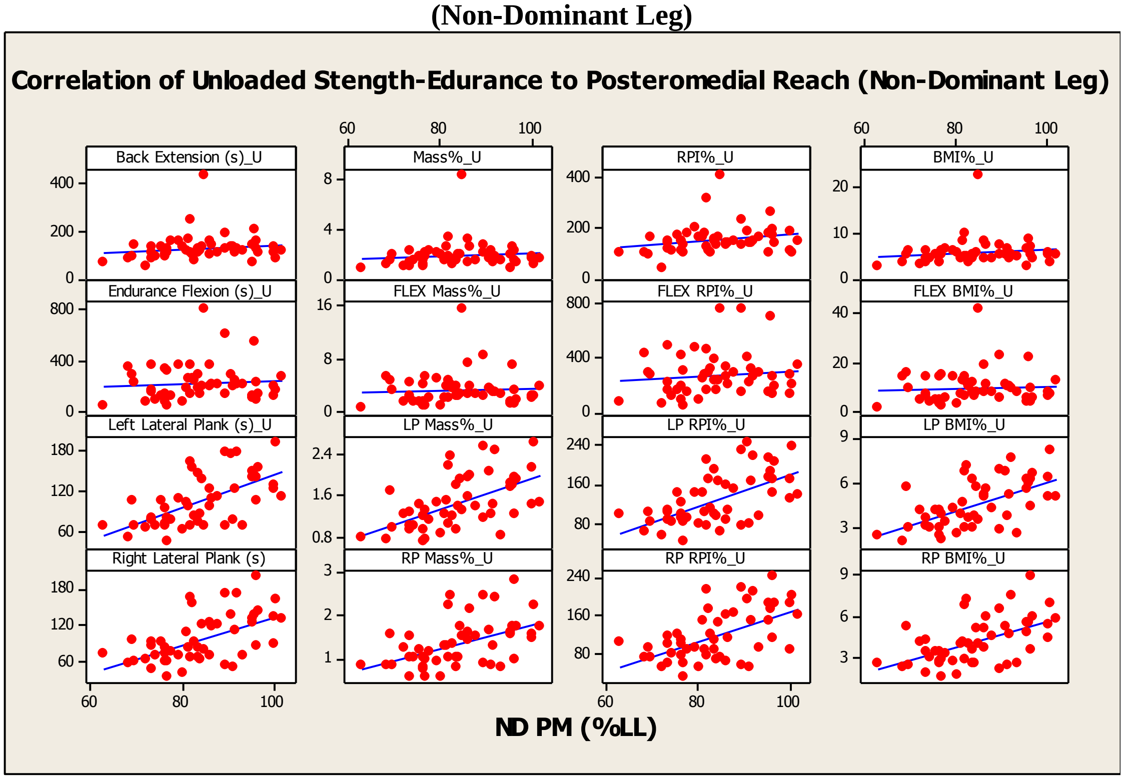


Figure 12. Correlation of Unloaded Core Endurance Measures to Posterolateral Reach (Non-Dominant Leg)

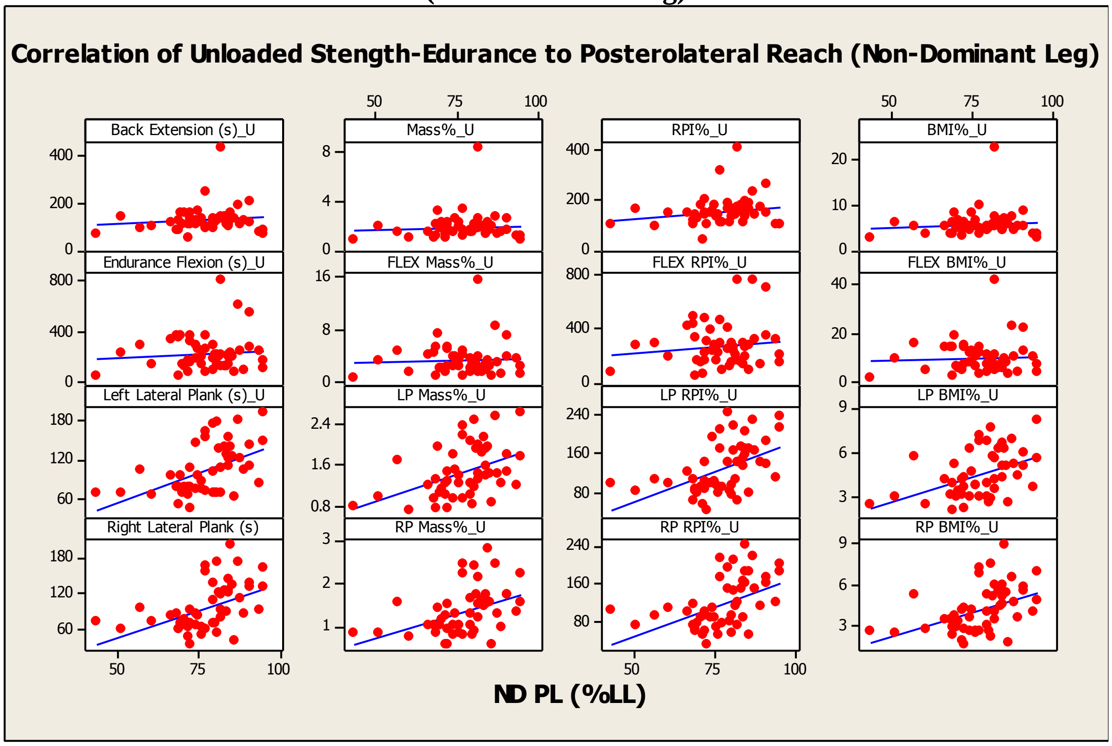


Figure 13. Correlation of Unloaded Core Endurance Measures to Normalized Cross-Over Hop Distance to Leg Length (%LL) (Non-Dominant Leg)

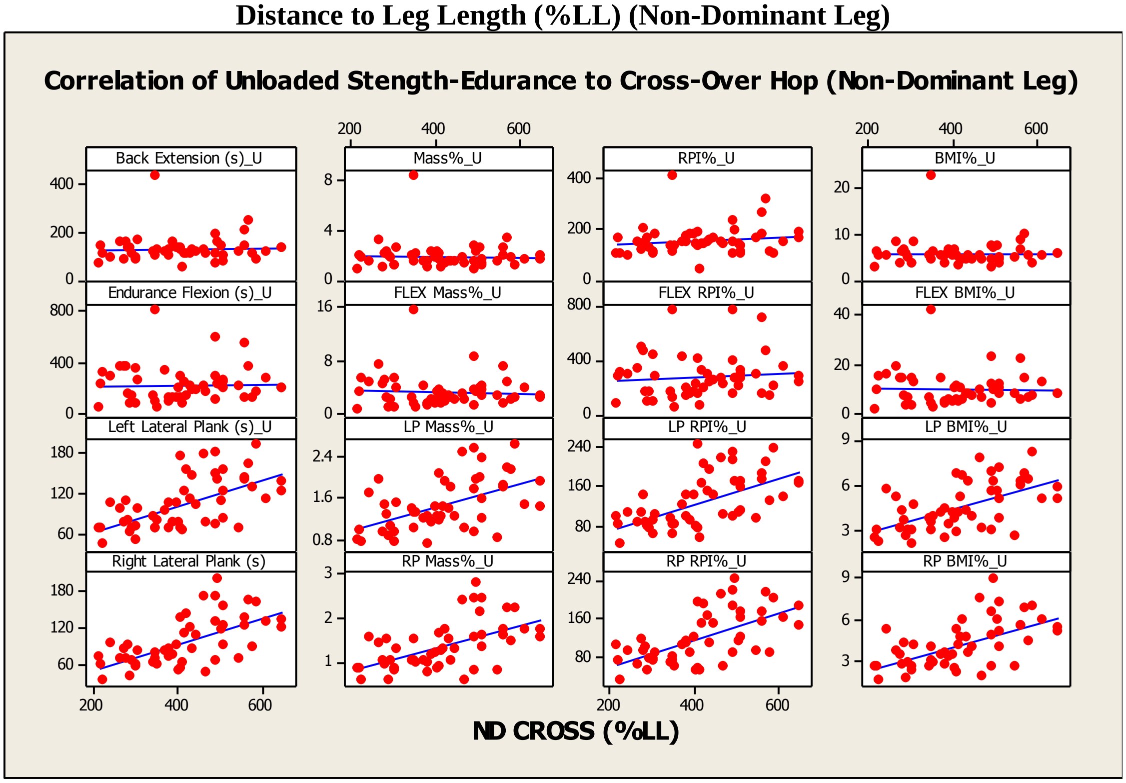
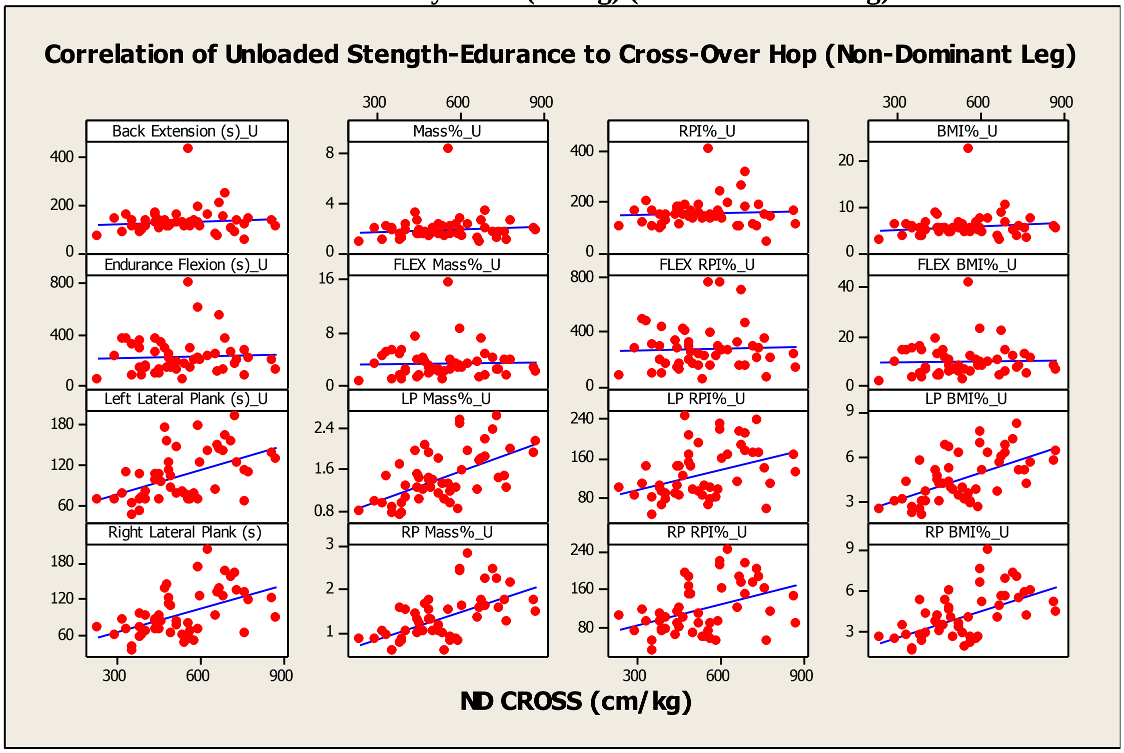


Figure 14. Correlation of Unloaded Core Endurance Measures to Normalized Cross-Over Hop Distance to Body Mass (cm/kg) (Non-Dominant Leg)



Correlation Analyses of Loaded Core Endurance Measures to Functional Tasks

Non-Dominant Leg

Statistically significant positive correlations existed between non-normalized right lateral plank and left lateral plank times to cross-over hop distances as well as between non-normalized right lateral plank and left lateral plank times to anterior reach, posteromedial reach, and posterolateral reach distances (Table 18, Figures 15-19). Positive correlation were present between non-normalized back extension time to cross-over hop distance, normalized to leg length (%LL), as well as between non-normalized back extension time to anterior reach and posteromedial reach distances (Table 18, Figures 15-19). No other statistically significant correlations existed for these specific comparisons.

Table 18. Loaded Non-Normalized Core Endurance Measures (s) to Non-Dominant Leg Functional Task Performance

	EXT	r value	p value	FLEX	r value	p value	RLP	r value	p value	LLP	r value	p value
COH (%LL)		0.291	0.040*		-0.126	0.383		0.735	< 0.001*		0.664	< 0.001*
COH (cm/kg)		0.240	0.094		-0.075	0.603		0.603	< 0.001*		0.557	0.000*
SEBT												
ANT (%LL)		0.326	0.021*		0.028	0.846		0.475	< 0.001*		0.355	0.011*
PM (%LL)		0.299	0.035*		-0.031	0.831		0.581	< 0.001*		0.531	< 0.001*
PL (%LL)		0.226	0.114		-0.002	0.988		0.467	0.002*		0.435	0.002*

Note: EXT – back extension; FLEX – flexion; RLP – right lateral plank; LLP – left lateral plank; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

Statistically significant positive correlations were found between right lateral plank and left lateral plank times, normalized to body mass (s/kg), to cross-over hop distances as well as between non-normalized right lateral plank and left lateral plank times to the anterior reach, posteromedial reach, and posterolateral reach distances (Table 19, Figures 15-19). No other statistically significant correlations existed for these specific comparisons.

Table 19. Loaded Normalized Core Endurance Measures to Body Mass (s/kg) to Non-Doming Leg Functional Task Performance

	EXT	r value	p value	FLEX	r value	p value	RLP	r value	p value	LLP	r value	p value
COH (%LL)		0.084	0.562		-0.200	0.163		0.667	< 0.001*		0.556	< 0.001*
COH (cm/kg)		0.242	0.090		-0.073	0.613		0.668	< 0.001*		0.661	< 0.001*
SEBT												
ANT (%LL)		0.276	0.053		0.047	0.745		0.481	< 0.001*		0.352	0.012*
PM (%LL)		0.168	0.243		-0.057	0.693		0.520	< 0.001*		0.443	0.001*
PL (%LL)		0.113	0.434		-0.039	0.787		0.419	0.002*		0.356	0.011*

Note: EXT – back extension; FLEX –flexion; RLP – right lateral plank; LLP – left lateral plank; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

Statistically significant positive correlations existed between right lateral plank and left lateral plank times, normalized to RPI (s/cm/kg$^{1/3}$), to cross-over hop distances as well as between non-normalized right lateral plank and left lateral plank times to the anterior reach, posteromedial reach, and posterolateral reach distances (Table 20, Figures 15-19). Positive correlation were present between back extension time, normalized to RPI (s/cm/kg$^{1/3}$), to cross-over hop distance, normalized to leg length (%LL), as well as between back extension time, normalized to RPI (s/cm/kg$^{1/3}$), to anterior reach and posteromedial reach distances (Table 20, Figures 15-19). No other statistically significant correlations existed for these specific comparisons.

Table 20. Loaded Normalized Core Endurance Measures to RPI (s/cm/kg$^{1/3}$) to Non-Doming Leg Functional Task Performance

	EXT	r value	p value	FLEX	r value	p value	RLP	r value	p value	LLP	r value	p value
COH (%LL)		0.390	0.005*		-0.043	0.764		0.735	< 0.001*		0.671	< 0.001*
COH (cm/kg)		0.170	0.238		-0.073	0.614		0.518	< 0.001*		0.460	0.001*
SEBT												
ANT (%LL)		0.228	0.042*		0.007	0.963		0.441	0.001*		0.322	0.023*
PM (%LL)		0.323	0.022*		-0.005	0.971		0.577	< 0.001*		0.530	< 0.001*
PL (%LL)		0.276	0.052		0.043	0.768		0.478	< 0.001*		0.456	0.001*

Note: EXT – back extension; FLEX –flexion; RLP – right lateral plank; LLP – left lateral plank; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

Statistically significant positive correlations were found between right lateral plank and left lateral plank times, normalized to BMI (s/kg/m^2) , to cross-over hop distances as well as between right lateral plank and left lateral plank times, normalized to BMI (s/kg/m^2) , to the anterior reach, posteromedial reach, and posterolateral reach distances (Table 21, Figures 15-19). Positive correlations existed between back extension time, normalized to BMI (s/kg/m^2), to cross-over hop distance, normalized to body mass (cm/kg), as well as between back extension time, normalized to BMI (s/kg/m^2) , to anterior reach distance (Table 21, Figures 15-19). No other statistically significant correlations existed for these specific comparisons.

Table 21. Loaded Normalized Core Endurance Measures to BMI (s/kg/m^2) to Non-Dominant Leg Functional Task Performance

	EXT	r value	p value	FLEX	r value	p value	RLP	r value	p value	LLP	r value	p value
COH (%LL)		0.181	0.207		-0.173	0.229		0.697	< 0.001*		0.605	< 0.001*
COH (cm/kg)		0.286	0.044*		-0.063	0.664		0.662	< 0.001*		0.616	< 0.001*
SEBT												
ANT (%LL)		0.327	0.021*		0.053	0.714		0.490	< 0.001*		0.366	0.009*
PM (%LL)		0.245	0.086		-0.044	0.764		0.555	< 0.001*		0.489	< 0.001*
PL (%LL)		0.151	0.294		-0.034	0.814		0.427	0.002*		0.374	0.008*

Note: EXT – back extension; FLEX –flexion; RLP – right lateral plank; LLP – left lateral plank; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

Figure 15. Correlation of Loaded Core Endurance Measures to Anterior Reach (Non-Dominant Leg)

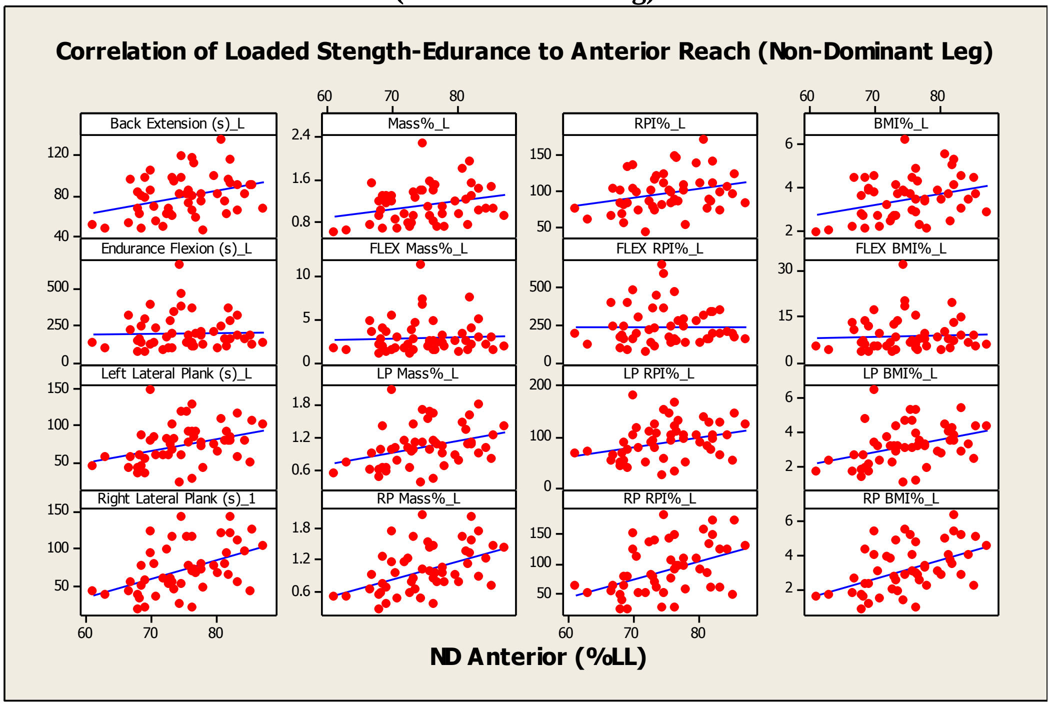


Figure 16. Correlation of Loaded Core Endurance Measures to Posteromedial Reach (Non-Dominant Leg)

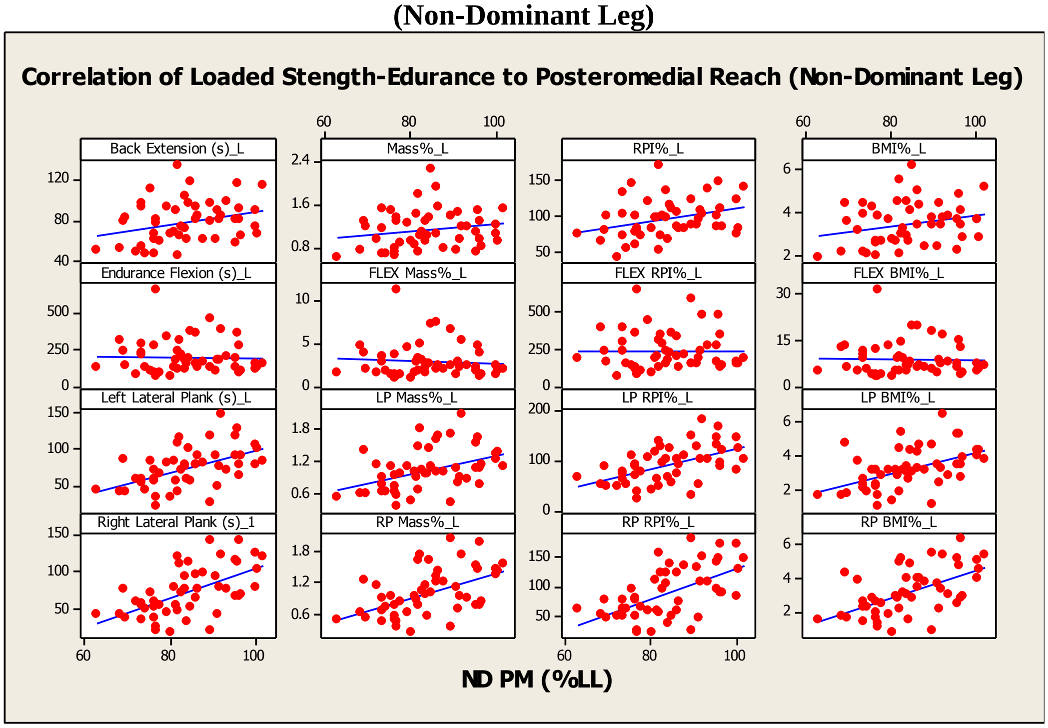


Figure 17. Correlation of Loaded Core Endurance Measures to Posterolateral Reach (Non-Dominant Leg)

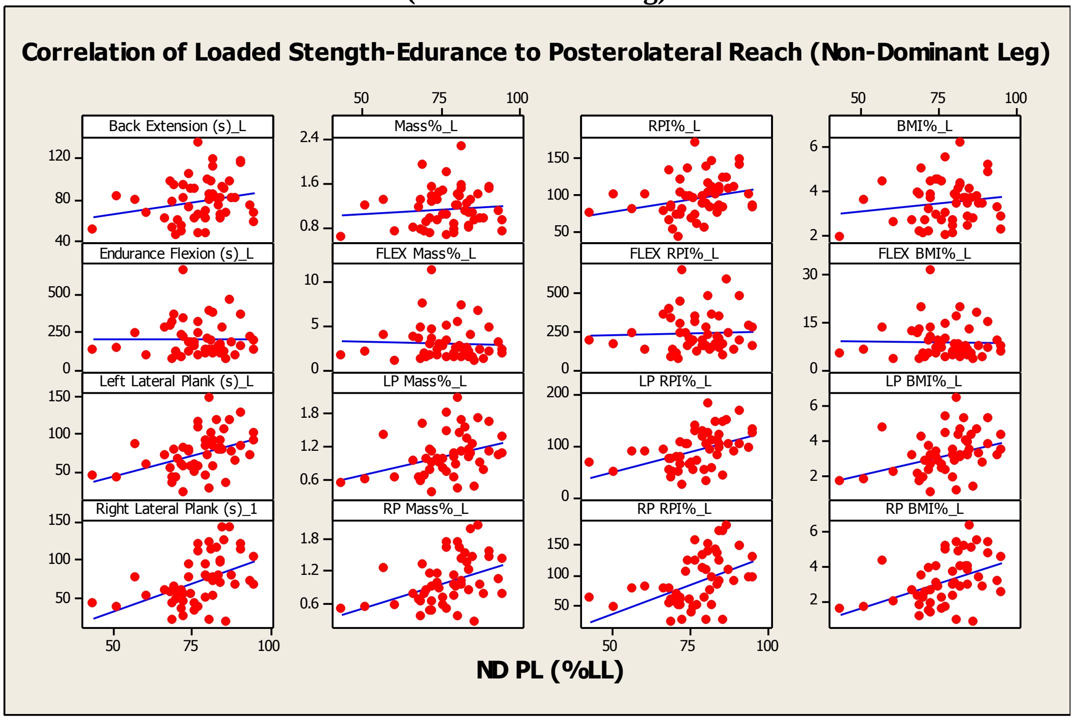


Figure 18. Correlation of Loaded Core Endurance Measures to Normalized Cross-Over Hop Distance to Leg Length (%LL) (Non-Dominant Leg)

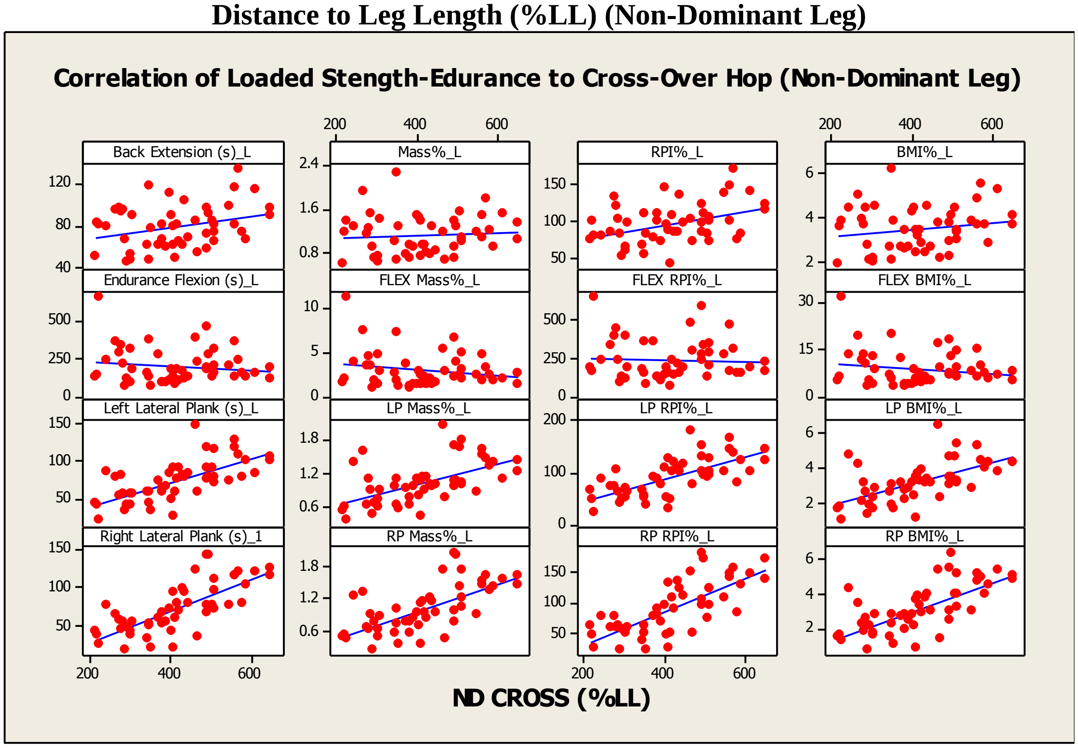
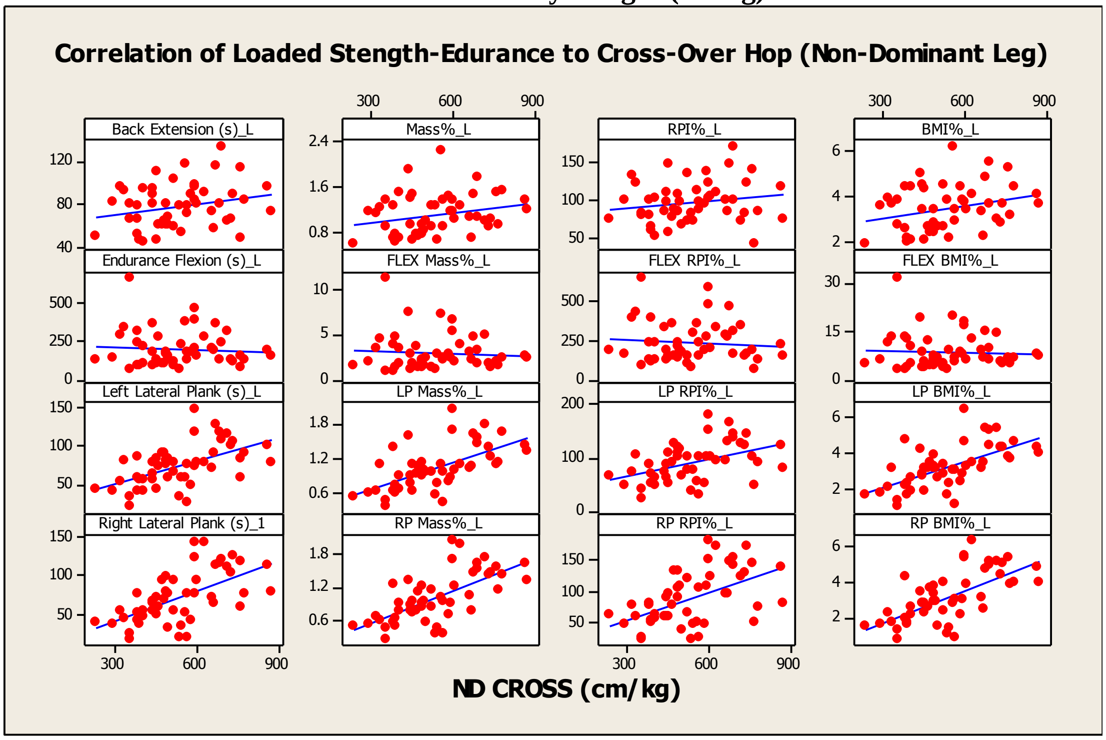


Figure 19. Correlation of Loaded Core Endurance Measures to Normalized Cross-Over Hop Distances to Body Weight (cm/kg)



Comparative Core Endurance Ratios Between Conditions

Statistically significant positive correlations existed between the unloaded and loaded flexion/extension ratios, right plank/extension ratios, right plank/flexion ratios, left plank/flexion ratios, and flexion/extension/BMI ratios (Table 22). No other statistically significant correlations existed for these specific comparisons.

Table 22. T-Test of Non-Normalized (s) Core Endurance Times

	Unloaded Condition		**Loaded Condition**		**p-value**
	M	SD	M	SD	
FLEX/EXT	1.785	0.887	2.503	1.427	< 0.001*
RP/LP	0.9441	0.1743	0.9974	0.2277	0.055
LP/RP	1.0969	0.2153	1.0546	0.2483	0191
RP/EXT	0.8468	0.3950	0.9503	0.3754	0.011*
LP/EXT	0.9007	0.4113	0.9603	0.3491	0.149
RP/FLEX	0.5710	0.3233	0.4654	0.2467	0.018*
LP/FLEX	0.6186	0.3620	0.4690	0.2278	0.001*
FLEXEXT/BMI	0.08045	0.04020	0.10963	0.06558	< 0.001*

Note: EXT – back extension; FLEX – endurance flexion; RLP – right lateral plank; LLP – left lateral plank; Values are Mean (M) and Standard Deviation (SD); * Denotes statistical significance

Correlation Analyses of Core Endurance Ratios to Functional Tasks

Dominant Leg

Statistically significant positive correlations were present between the loaded flexion/extension ratio and the anterior reach distance (Table 23, Figures 20-28). No other statistically significant correlations existed for these specific comparisons.

Table 23. Flexion/Extension Ratios to Dominant Leg Functional Task Performance

	FLEX/EXT _U	r value	p value	FLEX/EXT_L	r value	p value
COH (%LL)		0.023	0.874		-0.179	0.213
COH (cm/kg)		-0.003	0.985		-0.122	0.398
SEBT						
ANT (%LL)		0.158	0.272		0.285	0.045*
PM (%LL)		0.069	0.634		-0.203	0.158
PL (%LL)		-0.048	0.743		-0.137	0.341

Note. FLEX/EXT_U– flexion/extension unloaded; FLEX/EXT_L – flexion/extension loaded; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

Statistically significant positive correlations were found between the loaded right plank/left plank ratio to the anterior reach distance as well as between the loaded right plank/left plank ratio to the posterolateral reach distance (Table 24, Figures 20-28). No other statistically significant correlations existed for these specific comparisons.

Table 24. Right Plank/Left Plank Ratios to Dominant Leg Functional Task Performance

	RP/LP _U	r value	p value	RP/LP_L	r value	p value
COH (%LL)		0.049	0.736		0.210	0.142
COH (cm/kg)		0.007	0.963		0.174	0.228
SEBT						
ANT (%LL)		0.104	0.473		0.443	0.001*
PM (%LL)		0.088	0.542		0.251	0.079
PL (%LL)		0.105	0.466		0.284	0.046*

Note. RP/LP_U– right plank/left plank unloaded; RP/LP_L – right plank/left plank loaded; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

Statistically significant negative correlations existed between the loaded left plank/right plank ratio and the anterior reach distance (Table 25, Figures 20-28). No other statistically significant correlations existed for these specific comparisons.

Table 25. Left Plank/Right Plank Ratios to Dominant Leg Functional Task Performance

	LP/RP _U	r value	p value	LP/RP_L	r value	p value
COH (%LL)		-0.058	0.687		-0.204	0.156
COH (cm/kg)		-0.016	0.911		-0.181	0.209
SEBT						
ANT (%LL)		-0.126	0.385		-0.416	0.003*
PM (%LL)		-0.089	0.541		-0.210	0.143
PL (%LL)		-0.122	0.399		-0.256	0.073

Note. LP/RP_U–left plank/right plank unloaded; LP/RP_L – left plank/right plank loaded; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

Statistically significant positive correlations were present between the unloaded and loaded right plank/extension ratios to the cross-over hop distances the unloaded and loaded right plank/extension ratios to the posteromedial reach distance, and the unloaded and loaded right plank/extension ratios and the posterolateral reach distance (Table 26, Figures 20-28). No other statistically significant correlations existed for these specific comparisons.

Table 26. Right Plank/Extension Ratios to Dominant Leg Functional Task Performance

	RP/EXT_U	r value	p value	RP/EXT_L	r value	p value
COH (%LL)		0.473	0.001*		0.575	<0.001*
COH (cm/kg)		0.363	0.009*		0.471	0.001*
SEBT						
ANT (%LL)		0.078	0.589		0.114	0.430
PM (%LL)		0.493	<0.001*		0.424	0.002*
PL (%LL)		0.497	<0.001*		0.494	<0.001*

Note. RP/EXT_U–right plank/extension unloaded; RP/EXT_L –right plank/extension loaded; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

Statistically significant positive correlations existed between unloaded and loaded left plank/extension ratios to the cross-over hop distances, as well as the unloaded and loaded left plank/extension ratios to the posteromedial reach distance and posterolateral reach distance (Table 27, Figures 20-28). No other statistically significant correlations existed for these specific comparisons.

Table 27. Left Plank/Extension Ratios to Dominant Leg Functional Task Performance

	LP/EXT_U	r value	p value	LP/EXT_L	r value	p value
COH (%LL)		0.489	<0.001*		0.518	<0.001*
COH (cm/kg)		0.389	0.005*		0.416	0.003*
SEBT						
ANT (%LL)		0.030	0.837		-0.101	0.486
PM (%LL)		0.488	<0.001*		0.323	0.022*
PL (%LL)		0.492	<0.001*		0.386	0.006*

Note. LP/EXT_U–left plank/extension unloaded; LP/EXT_L –left plank/extension loaded; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach;
* Denotes statistical significance

Statistically significant positive correlations were found between the loaded right plank/flexion ratio to the cross-over hop distances, as well as between the loaded right plank/flexion ratio to the posteromedial reach distance and posterolateral reach distance (Table 28, Figures 20-28). No other statistically significant correlations existed for these specific comparisons.

Table 28. Right Plank/Flexion Ratios to Dominant Leg Functional Tasks Performance

	RP/FLEX_U	r value	p value	RP/FLEX_L	r value	p value
COH (%LL)		0.144	0.318		0.514	<0.001*
COH (cm/kg)		0.089	0.540		0.395	0.004*
SEBT						
ANT (%LL)		-0.163	0.258		0.059	0.682
PM (%LL)		0.185	0.199		0.433	0.002*
PL (%LL)		0.249	0.081		0.415	0.003*

Note. RP/FLEX_U–right plank/extension unloaded; RP/FLEX_L –right plank/extension loaded; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

Statistically significant positive correlations were present between the loaded left plank/flexion ratio to the cross-over hop distances, as well as between the loaded left plank/flexion ratio to the posteromedial reach distance and posterolateral reach distances (Table 29, Figures 20-28). No other statistically significant correlations existed for these specific comparisons.

Table 29. Left Plank/Flexion Ratios to Dominant Leg Functional Task Performance

	LP/FLEX_U	r value	p value	LP/FLEX_L	r value	p value
COH (%LL)		0.139	0.335		0.435	0.002*
COH (cm/kg)		0.103	0.475		0.328	0.020*
SEBT						
ANT (%LL)		-0.216	0.132		-0.096	0.509
PM (%LL)		0.186	0.195		0.343	0.015*
PL (%LL)		0.240	0.094		0.340	0.016*

Note. LP/FLEX_U–left plank/extension unloaded; LP/FLEX_L –left plank/extension loaded; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

Statistically significant positive correlations existed between the loaded flexion/extension/BMI ratio and the anterior reach distance (Table 30, Figures 20-28). No other statistically significant correlations existed for these specific comparisons.

Table 30. Flexion/Extension/BMI Ratios to Dominant Leg Functional Task Performance

	FLEXEXT/BMI_U	r value	p value	FLEXEXT/BMI_L	r value	p value
COH (%LL)		-0.044	0.760		-0.217	0.131
COH (cm/kg)		0.007	0.963		-0.078	0.590
SEBT						
ANT (%LL)		0.207	0.149		0.336	0.017*
PM (%LL)		-0.054	0.710		-0.205	0.152
PL (%LL)		-0.084	0.563		-0.172	0.231

Note. FLEXEXT/BMI_U–flexion/extension/BMI unloaded; FLEXEXT/BMI_L –flexion/extension/BMI loaded; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

Figure 20. Correlation of Loaded Core Endurance Ratios to Anterior Reach (Dominant Leg)

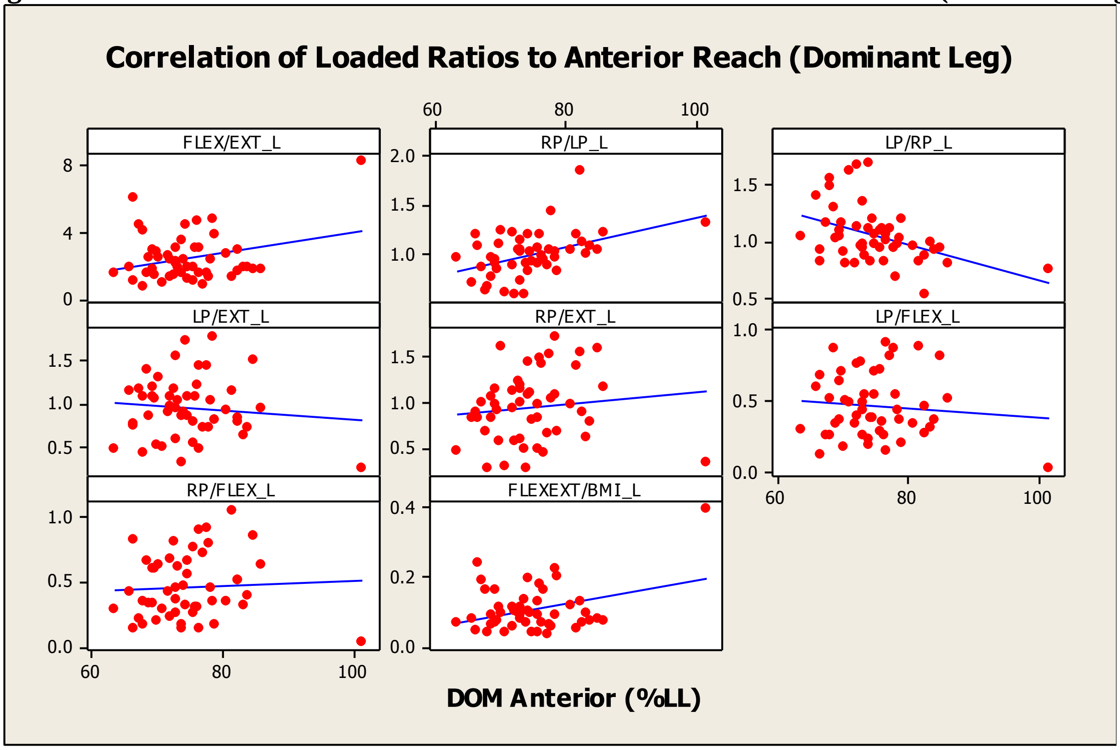


Figure 21. Correlation of Unloaded Core Endurance Ratios to Posterolateral Reach (Dominant Leg)

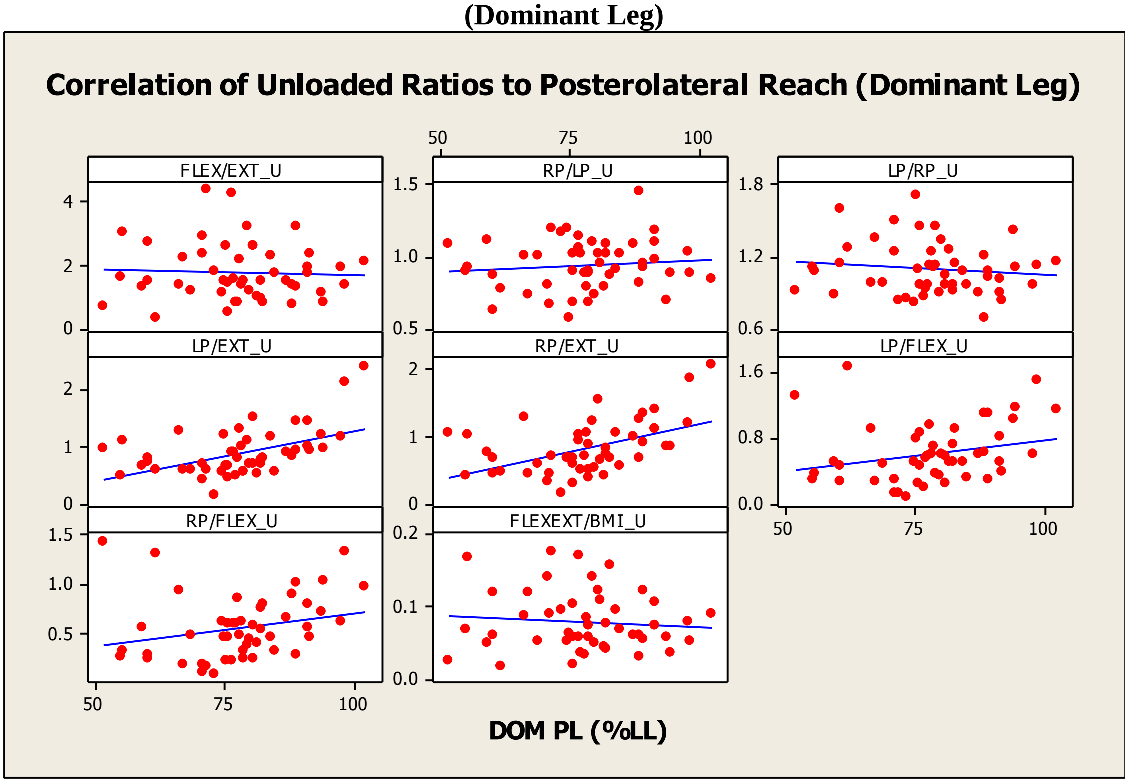


Figure 22. Correlation of Loaded Core Endurance Ratios to Posterolateral Reach (Dominant Leg)

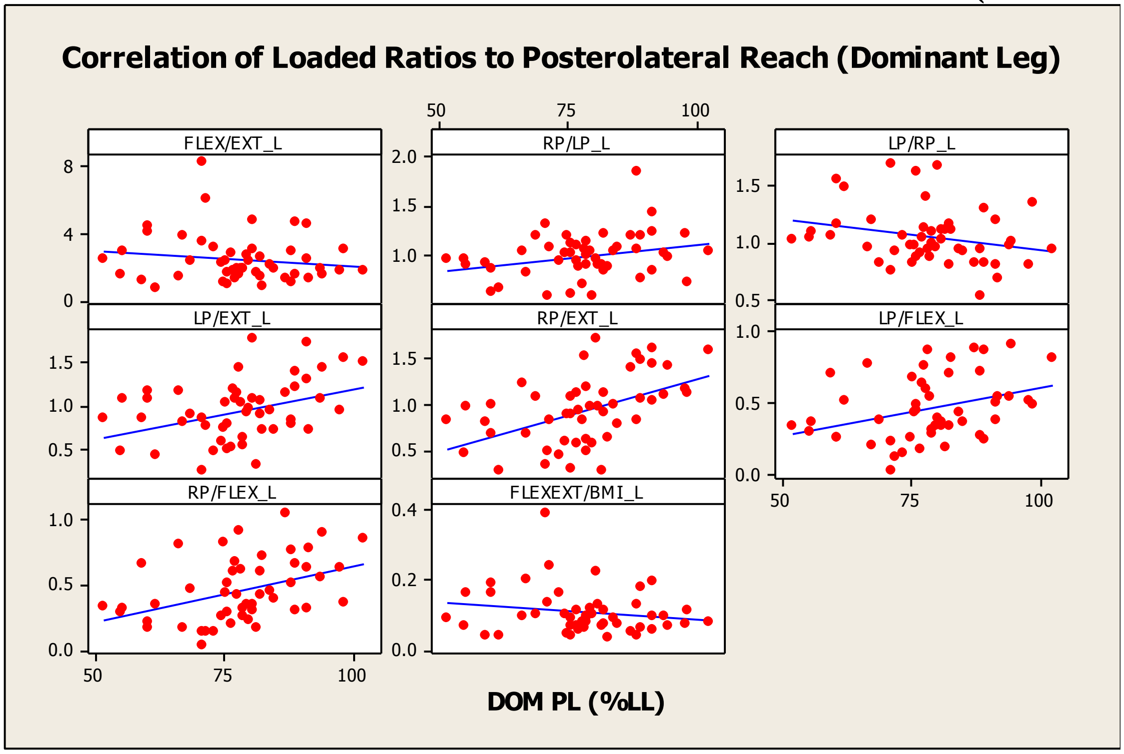


Figure 23. Correlation of Unloaded Ratios to Posteromedial Reach (Dominant Leg)

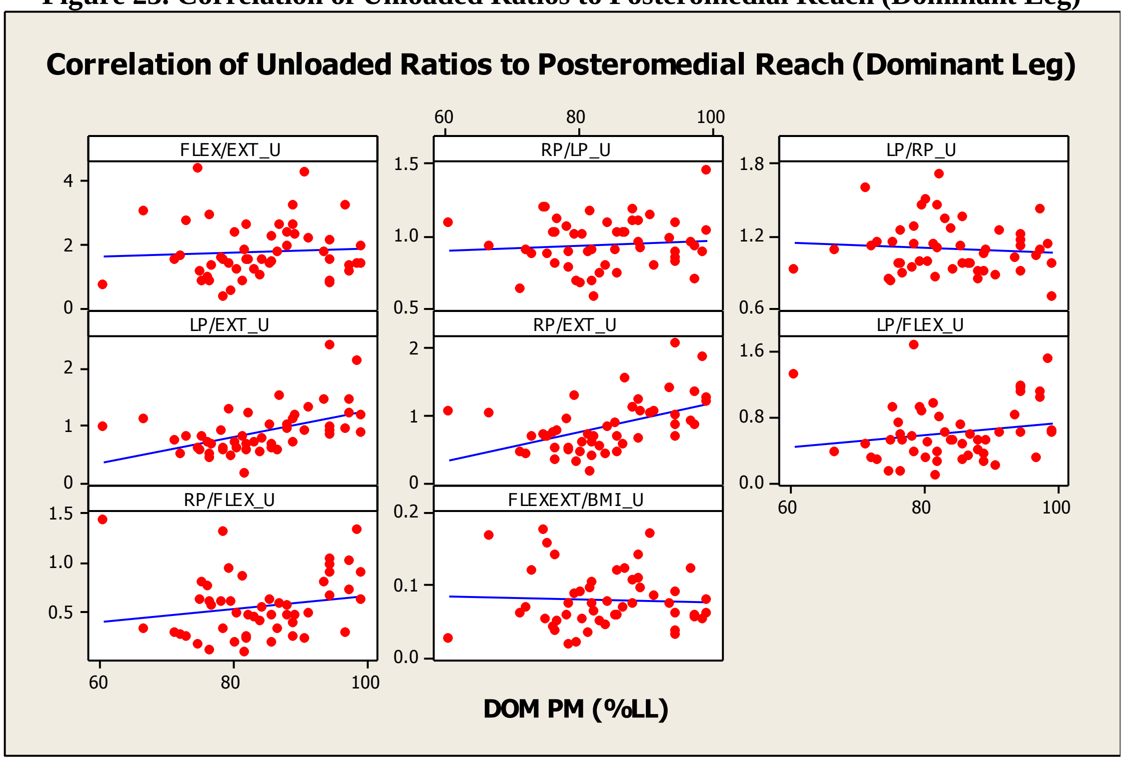


Figure 24. Correlation of Loaded Core Endurance Ratios to Posteromedial Reach (Dominant Leg)

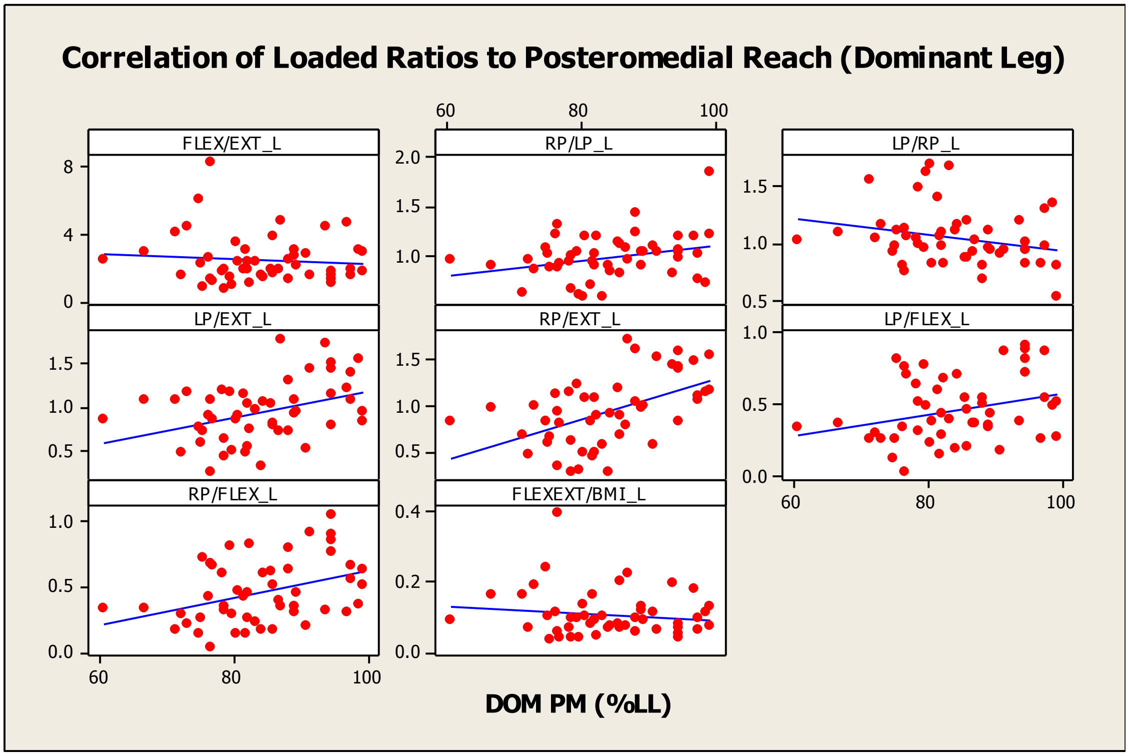


Figure 25. Correlation of Unloaded Core Endurance Ratios to Normalized Cross-Over Hop Distance to Leg Length (%LL) (Dominant Leg)

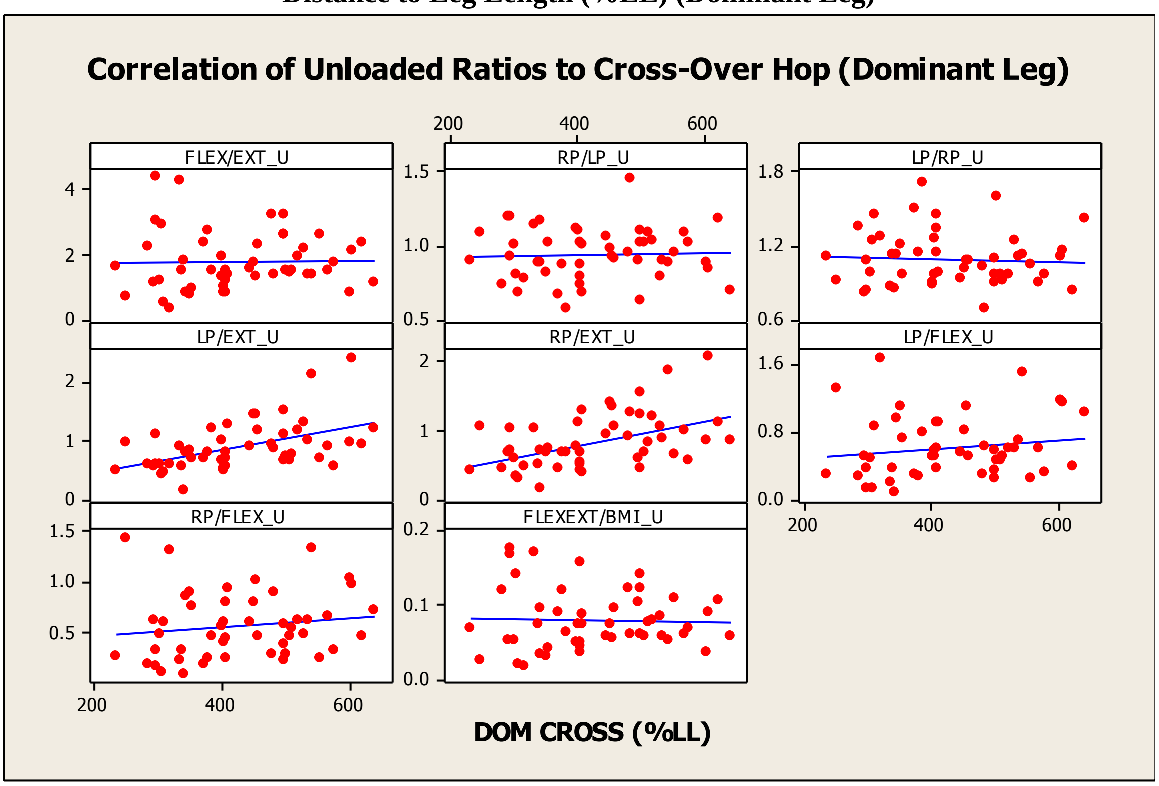


Figure 26. Correlation of Loaded Core Endurance Rations to Normalized Cross-Over Hop Distance to Leg Length (%LL) (Dominant Leg)

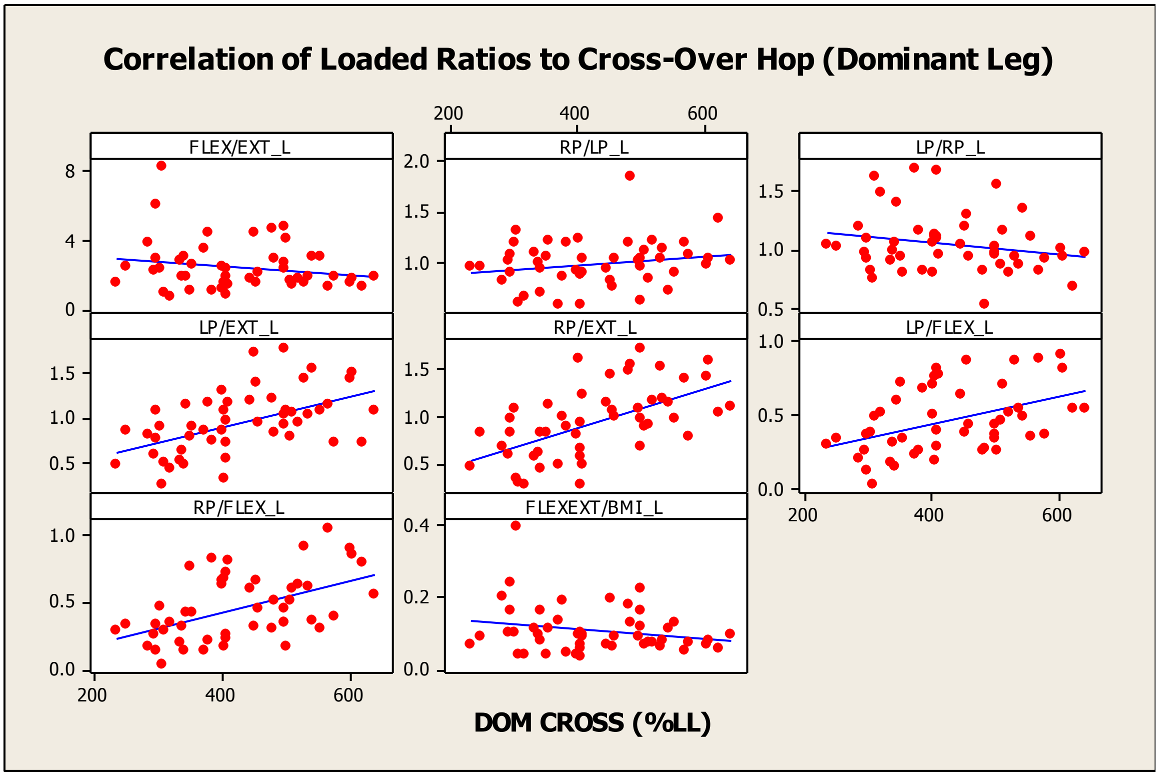
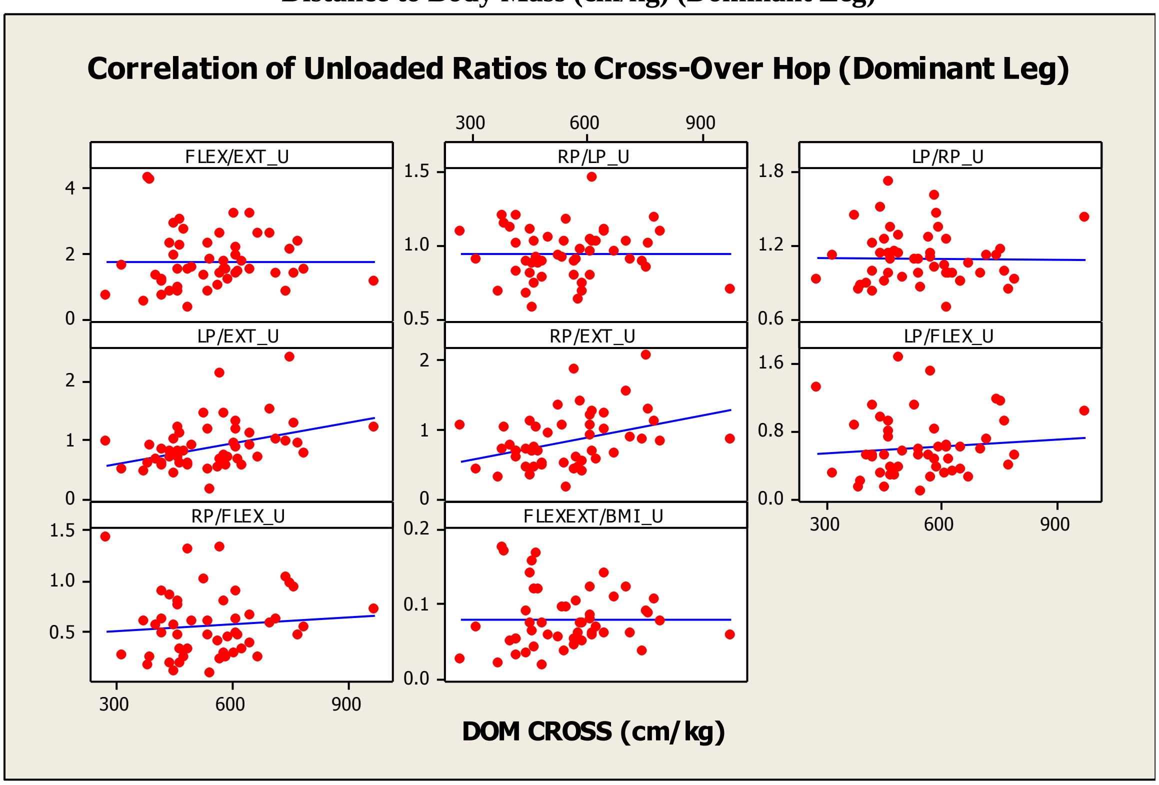
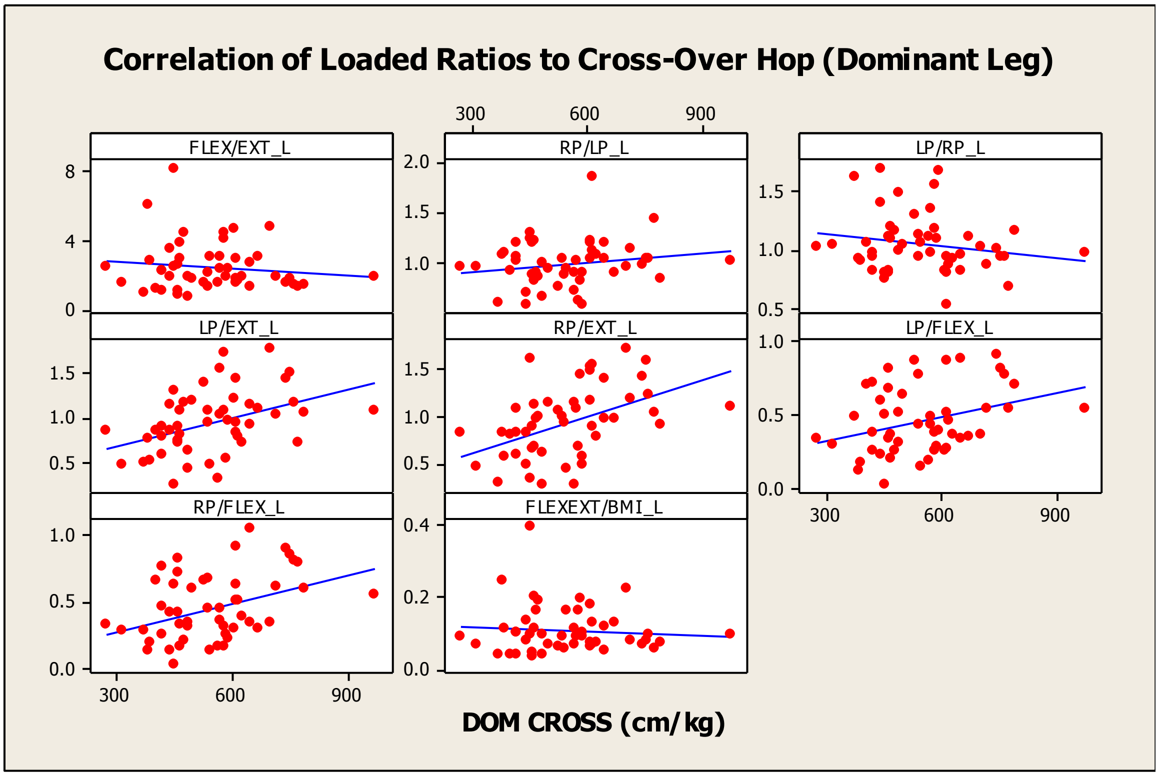


Figure 27. Correlation of Unloaded Core Endurance Ratios to Normalized Cross-Over Hop Distance to Body Mass (cm/kg) (Dominant Leg)



Graph 28. Correlation of Loaded Core Endurance Ratios to Normalized Cross-Over Hop Distance to Body Mass (cm/kg) (Dominant Leg)



Correlation Analyses of Core Endurance Ratios to Functional Tasks

Non-Dominant Leg

No statistically significant correlations were found for these specific comparisons (Table 31, Figures 20-28).

Table 31. Flexion/Extension Ratios to Non-Dominant Leg Functional Task Performance

	FLEX/EXT _U	r value	p value	FLEX/EXT_L	r value	p value
COH (%LL)		-0.032	0.824		-0.234	0.102
COH (cm/kg)		-0.068	0.639		-0.175	0.224
SEBT						
ANT (%LL)		0.074	0.607		-0.114	0.429
PM (%LL)		-0.086	0.551		-0.203	0.158
PL (%LL)		-0.011	0.941		-0.119	0.411

Note. FLEX/EXT_U– flexion/extension unloaded; FLEX/EXT_L – flexion/extension loaded; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

Statistically significant positive correlations were found between the loaded right plank/left plank ratio to the cross-over hop distance, normalized to leg length (%LL), and the loaded right plank/left plank ratio to the anterior reach distance (Table 32, Figures 20-28). No other statistically significant correlations existed for these specific comparisons.

Table 32. Right Plank/Left Plank Ratios to Non-Dominant Leg Functional Task Performance

	RP/LP _U	r value	p value	RP/LP_L	r value	p value
COH (%LL)		0.131	0.364		0.293	0.039*
COH (cm/kg)		0.086	0.554		0.225	0.116
SEBT						
ANT (%LL)		-0.000	1.000		0.351	0.012*
PM (%LL)		-0.031	0.833		0.251	0.079
PL (%LL)		0.027	0.852		0.180	0.210

Note. RP/LP_U– right plank/left plank unloaded; RP/LP_L – right plank/left plank loaded; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

Statistically significant negative correlations were present between the loaded left plank/right plank ratio to the cross-over hop distance, normalized to leg length (%LL), and the loaded left plank/right plank ratio to the anterior reach distance (Table 33, Figures 20-28). No other statistically significant correlations existed for these specific comparisons.

Table 33. Left Plank/Right Plank Ratios to Non-Dominant Leg Functional Task Performance

	LP/RP _U	r value	p value	LP/RP_L	r value	p value
COH (%LL)		-0.131	0.364		-0.298	0.035*
COH (cm/kg)		-0.090	0.534		-0.240	0.093
SEBT						
ANT (%LL)		-0.010	0.946		-0.361	0.010*
PM (%LL)		0.033	0.822		-0.210	0.143
PL (%LL)		-0.032	0.825		-0.103	0.368

Note. LP/RP_U–left plank/right plank unloaded; LP/RP_L – left plank/right plank loaded; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

Statistically significant positive correlations existed between the unloaded and loaded right plank/extension ratios to the cross-over hop distances as well as between the unloaded and loaded right plank/extension ratios to the posteromedial reach and posterolateral reach distances (Table 34, Figures 20-28). A positive correlation also was present between the loaded right plank/extension ratio and the anterior reach distance (Table 34, Figures 20-28). No other statistically significant correlations existed for these specific comparisons.

Table 34. Right Plank/Extension Ratios to Non-Dominant Leg Functional Task Performance

	RP/EXT_U	r value	p value	RP/EXT_L	r value	p value
COH (%LL)		0.430	0.002*		0.583	<0.001*
COH (cm/kg)		0.392	0.005*		0.492	<0.001*
SEBT						
ANT (%LL)		0.257	0.072		0.342	0.015*
PM (%LL)		0.341	0.015*		0.424	0.002*
PL (%LL)		0.360	0.010*		0.361	0.010*

Note. RP/EXT_U–right plank/extension unloaded; RP/EXT_L –right plank/extension loaded; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

Statistically significant positive correlations were found between the unloaded and loaded left plank/extension ratios to the cross-over hop distances as well as between the unloaded and loaded left plank/extension ratios to the anterior reach, posteromedial reach, and the posterolateral reach distances (Table 35, Figures 20-28). No other statistically significant correlations existed for these specific comparisons.

Table 35. Left Plank/Extension Ratios to Non-Dominant Leg Functional Task Performance

	LP/EXT_U	r value	p value	LP/EXT_L	r value	p value
COH (%LL)		0.412	0.003*		0.456	0.001*
COH (cm/kg)		0.390	0.005*		0.400	0.004*
SEBT						
ANT (%LL)		0.268	0.060		0.158	0.275
PM (%LL)		0.383	0.006*		0.323	0.022*
PL (%LL)		0.375	0.007*		0.289	0.042*

Note. LP/EXT_U–left plank/extension unloaded; LP/EXT_L –left plank/extension loaded; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

Statistically significant positive correlations existed between the loaded right plank/flexion ratio and the cross-over hop distances as well as between the loaded right plank/flexion ratio to the anterior reach, posteromedial reach, and the posterolateral reach distances (Table 36, Figures 20-28). No other statistically significant correlations existed for these specific comparisons.

Table 36. Right Plank/Flexion Ratios to Non-Dominant Leg Functional Task Performance

	RP/FLEX_U	r value	p value	RP/FLEX_L	r value	p value
COH (%LL)		0.159	0.269		0.551	<0.001*
COH (cm/kg)		0.169	0.240		0.433	0.002*
SEBT						
ANT (%LL)		-0.098	0.497		0.360	0.010*
PM (%LL)		0.132	0.361		0.433	0.002*
PL (%LL)		0.107	0.458		0.329	0.020*

Note. RP/FLEX_U–right plank/extension unloaded; RP/FLEX_L –right plank/extension loaded; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

Statistically significant positive correlations were present between the loaded left plank/flexion ratio to the cross-over hop distances as well as between the loaded left plank/flexion ratio to the posteromedial reach and posterolateral reach distances (Table 37, Figures 20-28). No other statistically significant correlations existed for these specific comparisons.

Table 37. Left Plank/Flexion Ratios to Non-Dominant Leg Functional Task Performance

	LP/FLEX_U	r value	p value	LP/FLEX_L	r value	p value
COH (%LL)		0.138	0.339		0.430	0.002*
COH (cm/kg)		0.167	0.247		0.340	0.016*
SEBT						
ANT (%LL)		-0.099	0.492		0.210	0.143
PM (%LL)		0.160	0.268		0.343	0.015*
PL (%LL)		0.141	0.330		0.280	0.049*

Note. LP/FLEX_U–left plank/extension unloaded; LP/FLEX_L –left plank/extension loaded; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

No statistically significant correlations were found for these specific comparisons (Table 38, Figures 29-37)

Table 38. Flexion/Extension/BMI Ratios to Non-Dominant Leg Functional Task Performance

	FLEXEXT/BMI_U	r value	p value	FLEXEXT/BMI_L	r value	p value
COH (%LL)		-0.092	0.524		-0.268	0.059
COH (cm/kg)		-0.066	0.651		-0.144	0.318
SEBT						
ANT (%LL)		0.107	0.458		-0.074	0.611
PM (%LL)		-0.169	0.240		-0.205	0.152
PL (%LL)		-0.026	0.858		-0.141	0.329

Note. LP/FLEX_U–left plank/extension unloaded; LP/FLEX_L –left plank/extension loaded; COH – cross-over hop; SEBT – star excursion balance test; ANT – anterior reach; PM – posteromedial reach; PL – posterolateral reach; * Denotes statistical significance

Figure 29. Correlation of Loaded Core Endurance Ratios to Anterior Reach (Non-Dominant Leg)

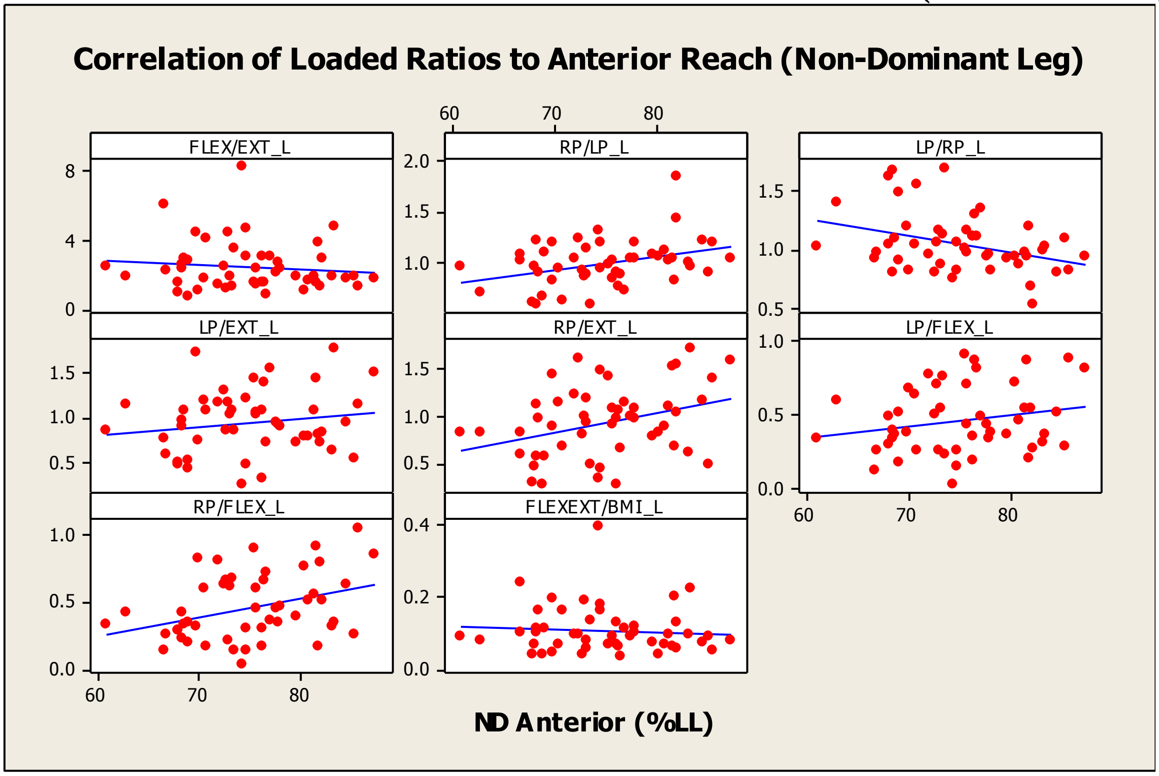


Figure 30. Correlation of Unloaded Core Endurance Ratios to Posterolateral Reach (Non-Dominant Leg)

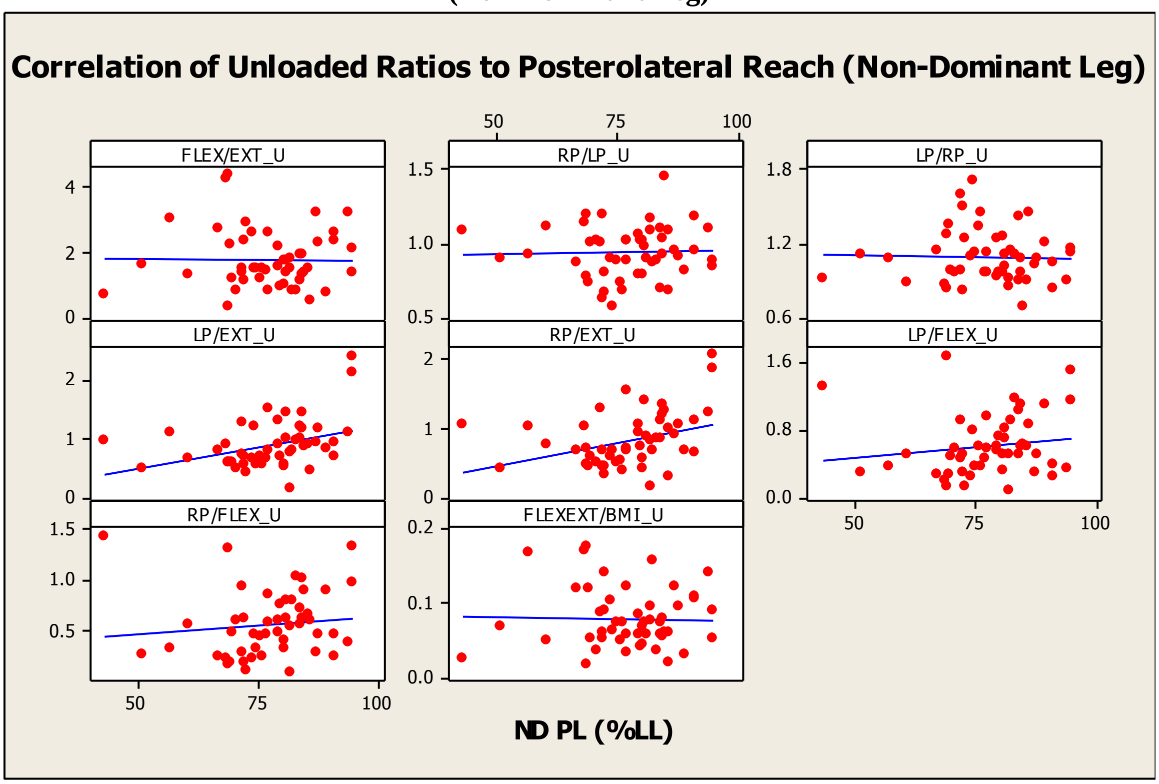


Figure 31. Correlation of Loaded Core Endurance Ratios to Posterolateral Reach (Non-Dominant Leg)

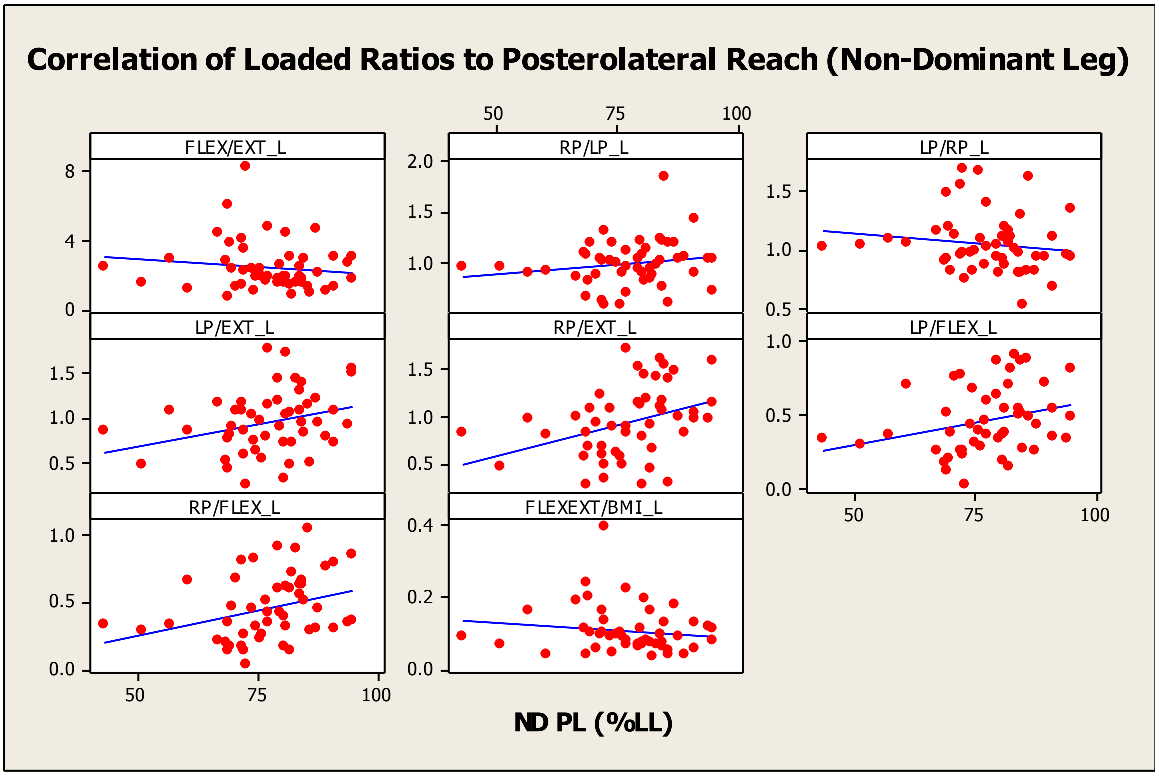


Figure 32. Correlation of Unloaded Core Endurance Ratios to Posteromedial Reach (Non-Dominant Leg)

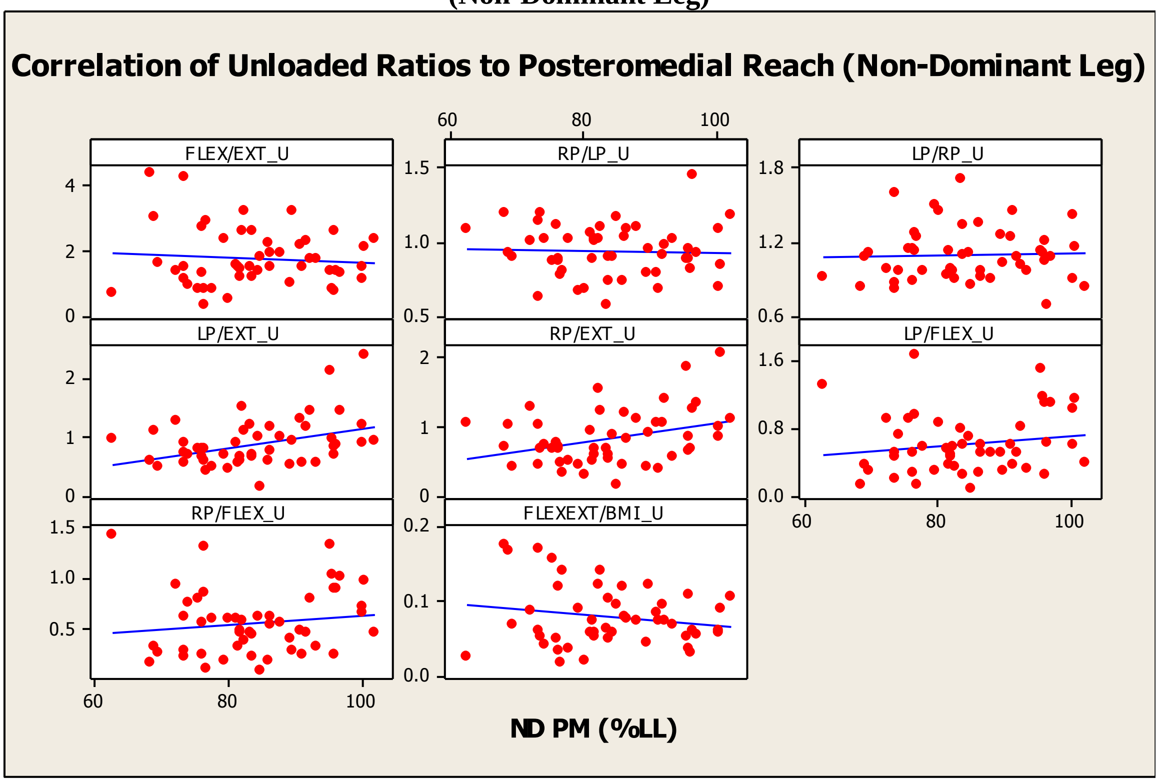


Figure 33. Correlation of Loaded Core Endurance Ratios to Posteromedial Reach (Non-Dominant Leg)

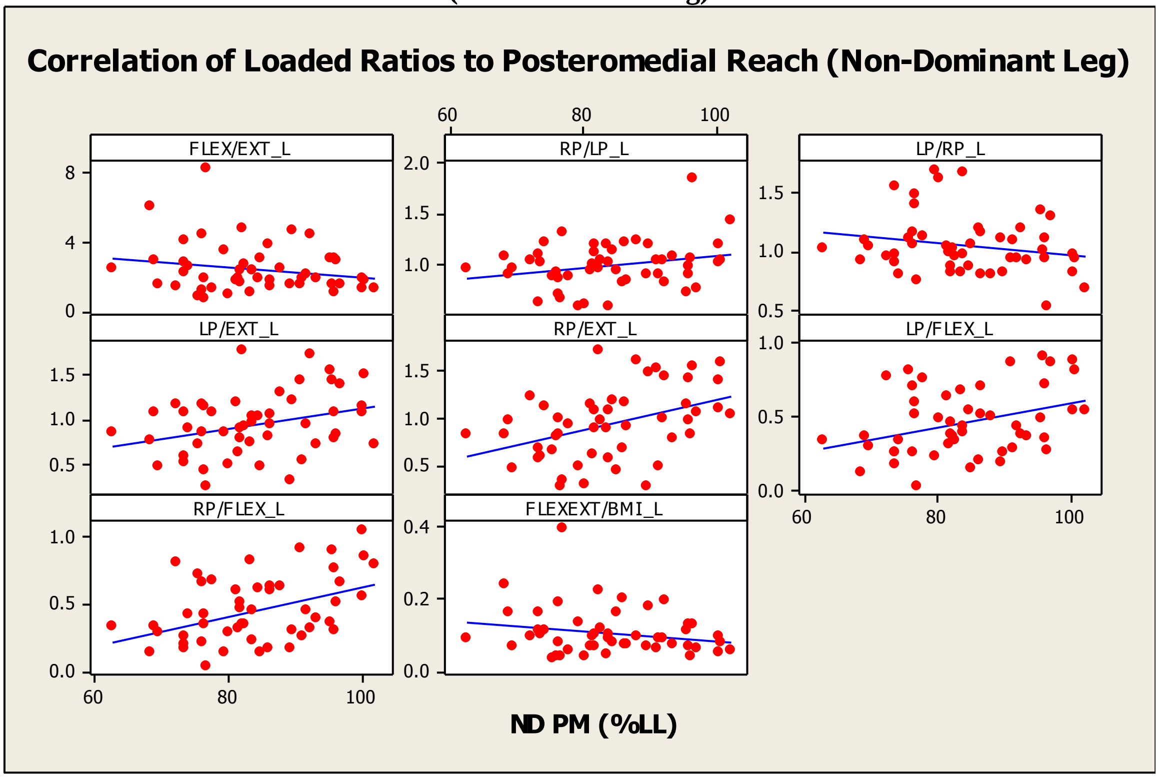


Figure 34. Correlation of Unloaded Core Endurance Rations to Normalized Cross-Over Hop Distance to Leg Length (%LL) (Non-Dominant Leg)

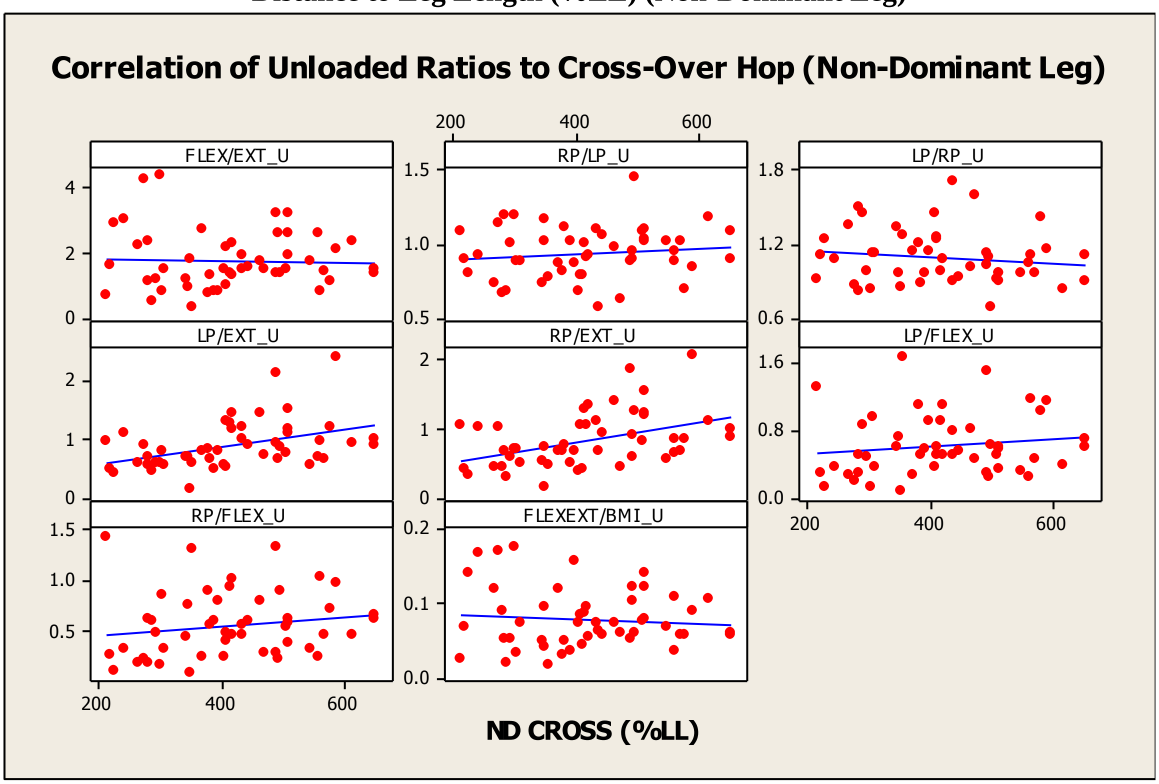


Figure 35. Correlation of Loaded Core Endurance Ratios to Normalized Cross-Over Hop Distance to Leg Length (%LL) (Non-Dominant Leg)

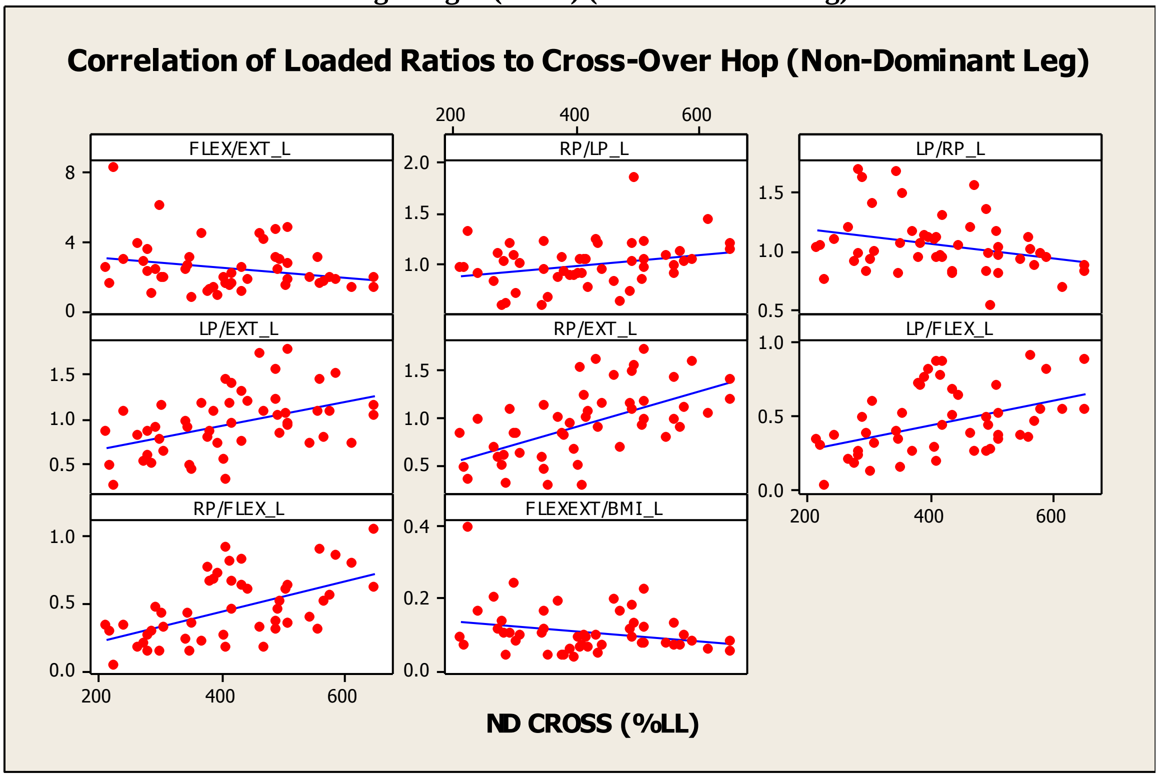


Figure 36. Correlation of Unloaded Core Endurance Ratios to Normalized Cross-Over Hop Distance to Body Mass (cm/kg) (Non-Dominant Leg)

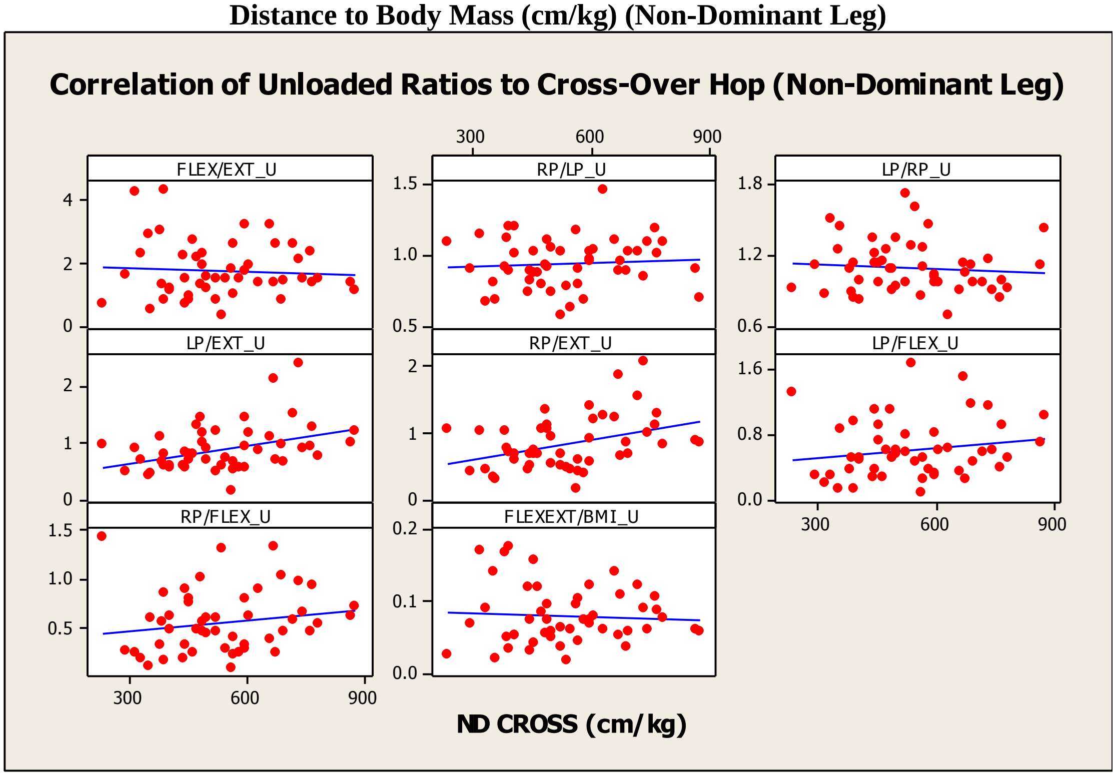
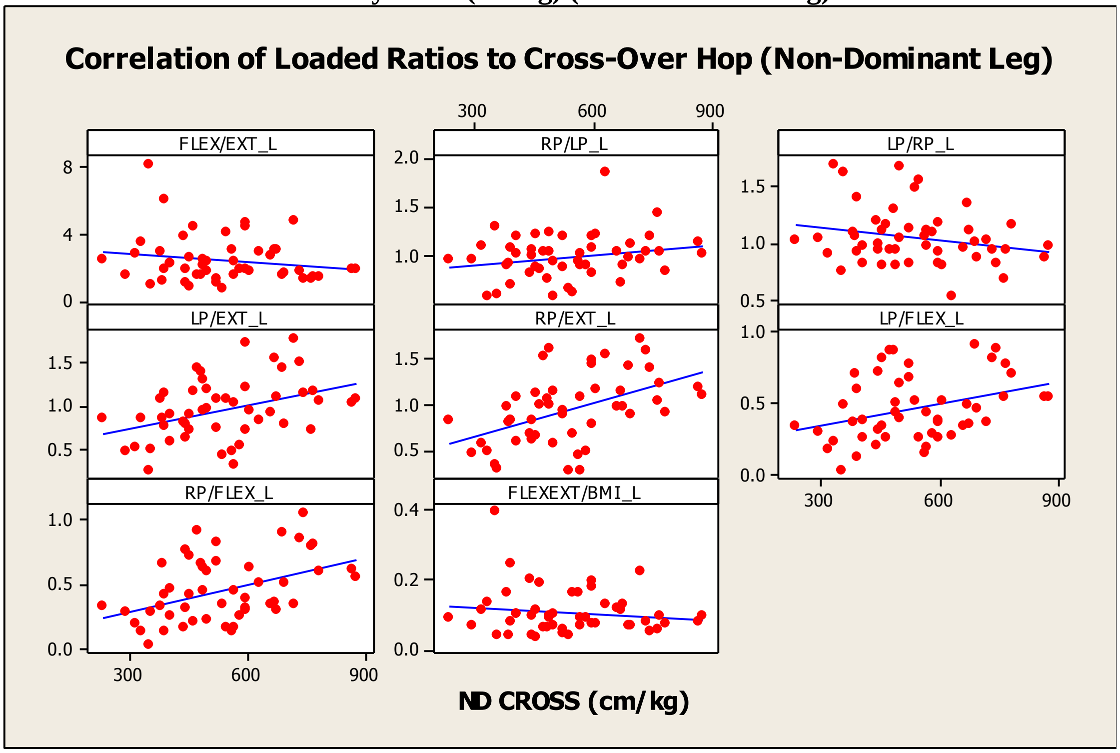


Figure 37. Correlation of Loaded Core Endurance Ratios to Normalized Cross-Over Hop Distance to Body Mass (cm/kg) (Non-Dominant Leg)



CHAPTER 4: DISCUSSION

Core Endurance Measures Between Conditions

The three measures of muscular function are strength, endurance and power. According to McGill[97], the torso flexors, extensor and lateral musculature involved in spine stability and associated with the core are predominately endurance muscles. Hence, McGill et al[12], predicts that the safest, most mechanically justifiable approach to enhance and measure core stability is through exercises emphasizing endurance. Authors[18] have also suggested research be conducted regarding the relationship between endurance measurements of these synergistic muscle groups due the stabilizing effects these muscle groups provide for the spine during essentially all movements.

Within this study, the core musculature was examined under standard methods of isometric testing[11-15] and under a novel method of externally-loaded isometric testing. This loaded condition involved the participant completing the isometric exercises with surplus load symbolizing roughly 10% of their body mass. Previous research[76] has demonstrated that additional loading during an exercise corresponds to increased muscle recruitment to maintain and produce muscle force to compensate for the increased load demand. Therefore, when performing an exercise with an additional load, the body's need to produce force will increase uniformly, allowing for a greater delineation in results if muscle force production capabilities are not adequate to meet the increase demand.[76,77] The aim of this study was to explore the differences and advantages loading during isometric testing may provide for evaluating the core musculature and its relationship to dynamic balance and functional performances.

Previous similar studies have exclusively analyzed core endurance through absolute measures[14,18,62], which limits the application of such observations for comparisons to other investigations. Unique to this study was the analysis and presentation of data as absolute and relative (normalized by body mass, RPI, and BMI). Analyses of normalized data, which take into account the possible influences of anthropometrics, allow for a potential improved means of cohort comparison. For example, it is typical that investigations reporting strength and endurance measures, such as through the use of isokinetic dynamometry, typically use body mass to normalize results[82]. Furthermore, overall the normalized data throughout our study exhibited additional relationships between dynamic balance and functional performance not observed within the non-normalized data comparisons. However, some of these relationships varied between the normalized data.

The difference in results across relative measures may be attributed to the differing calculated dimensions. The RPI calculation utilizes a variable of cubic dimensions for mass and linear dimension of height[79], whereas BMI uses as linear dimension for mass and squared dimension to height. The body mass normalization only accounts for a linear body mass dimension. Hence, due to the RPI model representing a stronger mathematical foundation, the notion is proposed that the relative measure according to RPI may potentially represent an ideal anthropometric measurement.[79] However, this remains to be concluded and requires additional investigation to support or refute this notion. Overall, we recommend that a similar standardized relative measure for isometric core testing be established to allow for improved comparisons among related research studies, especially when taking into account influencing factors such as sex, age and activity level.

The participants examined in this research study demonstrated unique statistically significant differences between the unloaded and loaded conditions for isometric core testing. The non-normalized results comparing core endurance measures between the unloaded and loaded conditions demonstrated a statistically significant difference for all four core-endurance tests. Specifically, the loaded core endurance testing resulted in decreased endurance times when compared to the unloaded core endurance testing. Statistically significant differences also existed for all the core endurance tests when comparing the unloaded and loaded conditions normalized to RPI. Once again, the loaded core endurance testing resulted in decreased endurance times. Comparing the unloaded and loaded conditions when normalized to body mass and BMI only displayed statistically significant differences between the back extension, right lateral plank, and left lateral plank tests. However, the loaded core endurance testing still resulted in decreased endurance times for those measures. Overall, the decrease in isometric hold time in the loaded condition is presumed to be due to the increased difficulty of the task[76].

Relationship of Core Endurance Measures to Functional Task

The correlation analyses of the absolute and relative core endurance measures demonstrated low to moderate positive associations between the right lateral plank and left lateral plank to the cross-over hop, posteromedial reach, and posterolateral reach performances across the unloaded and loaded conditions for both the dominant and non-dominant legs. This compliments previous findings[2] demonstrating that there is a relationship between trunk muscle activity and lower extremity movement. Zazulak & Wilson[2,3] defined core muscle activity as the pre-programmed integration of local, single-joint and multi-joint muscles that provide neuromuscular control to the trunk musculature based on internal and external stimuli of distal portions and segments. Khale [7] defines dynamic postural control as the completion of tasks that displace one's center of mass without compromising their established base of support. This displacement occurs in response to muscular activity during purposeful movements of functional tasks and requires the appropriate integration of proprioception, range of motion and strength [5, 7]

Thus, the positive correlation between the lateral plank measures to the functional and dynamic performances possibly indicates a greater activation of the specific core muscles associated with the lateral planks in maintaining a stable base of support for the completion of the prescribed tasks. The results therefore contradict previous research stating that core stability has no correlation with functional performance.[83,84]

Furthermore all the absolute and relative right lateral plank and left lateral plank measures demonstrated low to moderate positive associations to the anterior reach for the non-dominant leg across unloaded and loaded conditions. This additional right and left plank relationship to the anterior reaching distance may have arisen due to the non-dominant leg creating a more stable stance during the anterior reach. In theory, due to the dominant leg's usage for more mobility and manipulation, the non-dominant leg contributes more to support the actions of the dominant leg.[81] The increased use of the non-dominant leg for stabilization purposes may result in more efficient use of the stabilization muscles of the core during non-dominant leg stance. This would reflect the increased muscle recruitment demonstrated during the non-dominant leg anterior reach in comparison to the dominant leg anterior reach. Furthermore, the raw data of our study displays that 41 of the 50 participants (62%) reached father in the anterior direction when standing on their non-dominant leg. Thus, potentially offering support for such an interpretation.

Based on electromyography research conducted by McGill et al[80], the side plank tests encompass muscle activation of the internal and external obliques, rectus abdominus, transverse abdominus, and the quadratus luborum. These muscles collectively contribute to flexion, extension, and rotary movements involved in trunk stabilizing mechanisms[11,14,18] and have been identified as important core muscles for stabilization in these mechanisms. The cross-over hop test and SEBT challenged our participants ability to produce power in a stable manner and stability in a dynamic balance task.[7,22, 72] Our results demonstrate that a relationship exists between the core musculature and these lower extremity functional performance tests. Although other investigators[83,84] have challenged the presence of this relationship, differences in experimental methods, enrolled participants (elite athletes vs. recreational active individuals) and the influences of age and gender, may account for such inconsistencies in the literature.

The results of prior studies[36,7] have demonstrated that improved performance in core testing yields better results for the anterior and posterolateral reach distances of the SEBT. Similarly, we report positive relations among the back extension, flexion and right lateral plank to dominant leg anterior reach distance for the loaded core endurance condition in non-normalized measures as well as measures normalized to body mass and BMI. The presence of this observation exclusively in the loaded condition is proposed to be indicative of the loaded condition being a more discriminating test for core endurance as a result of its inherent increased difficulty. This signifies loaded testing may be a better mode to more accurately measure core endurance for gauging its potential associations to functional performance. Furthermore, due to the increased difficulty of the tasks, on average, the loaded core endurance testing session was shorter compared to the unloaded core endurance testing session. The ability to test individuals in a timelier manner, under conditions providing potentially stronger associations allow for an improved testing procedure.

Lastly, due the absence of a loaded left lateral plank correlation to the anterior reach distance may again be attributed to the weakness on the dominant side compared to the non-dominant side of the body[81]. We speculate that due to decreased stabilization, it is possible the participants were leaning toward their reaching leg, therefore engaging more right lateral core muscle activation.

The loaded RPI normalized core endurance measures indicated a unique relation among the back extension measure to the normalized cross-over hop and the posterolateral reach distance as well as between the flexion measure to anterior reach distance for the dominant leg. Due to the body positions during the cross-over hop and the posterolateral reach, activation of the extensor muscles is probable. In both dynamic tasks the trunk and hip muscles are controlling a more flexed trunk position that results in an external trunk flexion moment. Therefore, activation of the extensor muscles serves to counteract this external moment by way of an internal trunk extensor moment. Unique to the loaded RPI normalized measures, the back extension and flexion measure did not correlate to the anterior reach. Due to disparities among different anthropometric normalization techniques, variations among the comparative measures are expected.[79]

The non-normalized and RPI normalized loaded core endurance measures demonstrated positive associations among extension to cross-over hop, as well as to the anterior and posteromedial reach distances for the non-dominant leg. The relationship between the extensor muscles to the cross-over hop and posteromedial reach distances coincides with the previously noted explanation of the muscles controlling a more flexed trunk position. The extensor muscle relationship to the anterior reach may be attributed to a stronger, more stable non-dominant leg. If the non-dominant leg provided a more stable stance, less hip/trunk extension and a more upright posture may have resulted.[81] Thus, higher activation of extensor muscles occurred as oppose to flexor muscles.

Prior studies have demonstrated statistically significant associations between quadriceps isokinetic strength and lower extremity function as measured by performance in single-legged hop[86,87], the cross-over hop[87], and functional stability tests[88]. The results of our study demonstrate equal or greater associations between core endurance and lower extremity functional performance than have previously been found between quadriceps strength and similar lower extremity functional test performance. The association between core endurance and lower extremity functional performance is particularly strong with regard to right and left plank measures and cross-over hop performance. These results suggest that core endurance may be suggested as an equal or possibly greater indicator of lower extremity dynamic functional performance. With this in mind, clinicians may opt for simple low cost core endurance testing instead of high cost isokinetic testing of the lower extremities when looking for relationships between strength and functional performance. Additional research gauging the extent of core endurance and quadriceps strength as predictors of lower extremity functional performance should be conducted to gain a greater understanding of this potential relation. Combing core and lower extremity strength measures may add strength to the association between muscle strength/endurance and functional performance.

Core Endurance Ratios Between Conditions

Statistically significant differences were present between the loaded and unloaded conditions for the FLEX/EXT, RP/EXT, RP/FLEX, LP/FLEX and FLEX/EXT/BMI ratios. The evaluative technique of core measures through ratios provides a comparative measure of strength between muscle groups.[69] Hence, the presence of statistically significant differences between the unloaded and loaded conditions for the core endurance ratios reinforces our novel suggestion that analyzing core endurance measures under a loaded condition may be a better testing method due to decrease time to test. The lack of significance of the LP/EXT ratio may be related to side to side imbalances in the core muscle endurance as measured by the plank measures.

Relationship of Core Endurance Ratios to Functional Tasks

The unloaded and loaded RP/EXT and LP/EXT ratios demonstrated positive associations to cross-over hop performance, posterolateral reach and posteromedial reach distances on both the dominant and non-dominant legs. The loaded RP/FLEX and LP/FLEX ratios also demonstrated positive associations to cross-over hop performance, posterolateral reach and posteromedial reach distances on both the dominant and non-dominant leg. These results demonstrate additional support for the previously made predictions that the right and left plank tests are significant predictors of functional performance within the cross-over hop test, and the posterolateral and posteromedial SEBT measures. Furthermore, the additional associations present only within the loaded analyses further supports that loaded testing conditions may provide a better mode to more accurately measure core endurance associations to functional performance.

Additionally, the relationships between core endurance and function in our study demonstrate support for previous findings that the stabilization of the core is accomplished through the synergistic activity of flexor, extensor and oblique muscles and working together as a unit they contribute to functional stability[18,11,14, 89]. Overall the plank tests had greater associations with functional test performance than with the flexors or extensors alone. It is also apparent that the relationship between muscles contributing to plank test performance and those contributing to back extensor or flexor performance is important with regard to lower extremity functional test performance. Our data suggests that plank tests may better measure the endurance of individual muscles or muscle synergies important in lower extremity function. Flexion and extension tests may not adequately require activation of more laterally positioned muscles, such as the obliques and quadrates lumborum, that may play a significant role in functional task performance (McGill guy wire theory) whereas plank tasks may not only activate the more laterally positioned musculature, but also the more centrally located flexors and extensors.[80]

The absence of consistent statistically significant correlations between the flexion and extension tests to functional performance, once again may be attributed to the flexion and extension tests not adequately requiring activation of more laterally positioned muscles possibly more significant to functional task performance. Therefore, due to their analysis in a ratio with the right and left plank exercises, the significance of their relationship to the functional movements may now be more prominent.

The inverse associations between the loaded RP/LP ratio and the loaded LP/RP ratio to the anterior reaching distance on the dominant leg demonstrates that stronger right lateral musculature correlated with better performance on those functional tasks. The inverse association between loaded RP/LP ratio and the loaded LP/RP ratio to the cross-over hop distance and anterior reach distance on the non-dominant leg further supports this finding. Panjabi[89] suggested that muscle activity helps compensate for a loss of passive stability. Additional research has shown that muscles can contribute to stability of the trunk through co-contraction.[90] Individuals will increase their co-contraction in response to conditions that threaten spinal stability. Ideally, McGill[62] states all surrounding trunk muscles would increase their activation levels together to ensure a coordinate bracing effort. Therefore, co-contraction demonstrates an association between the stability of the upper and lower extremities via the abdominal fascial system.

Our results demonstrate that the participant's performance increased with more right side co-contraction activation during the prescribed functional movements. According the cut-offs established by McGill[85], a RLP/LLP ratio >0.05 suggests unbalanced endurance. This distinction indicated that only 11 of 50 participants within this study fell within the balanced parameter. Therefore, this right side co-contraction pattern may be attributed to a relatively large unbalanced participant population sample. Additionally, McGill et al[90] only analyzed RP/LP ratio for plank measures, which limits our capability to compare and contrast our findings accordingly. Hence, based on these results there is an apparent disparity present between the ratios that future research should address. Furthermore, research should also be conducted testing different patterns of balance between core endurance muscles to gauge whether different co-contraction profiles may exist.

Limitations

The lack of controlling for influences of gender, age, and sport participation in our study is a threat to the interval validity of our results and may account for some of the discrepancies addressed in comparison to similar previous studies[82, 83]. However, our results are more generalizable compared to research conducted on competitive and elite athletes.[82] Furthermore, due to the prominent differences observed between dominant and non-dominant leg evaluations, it is recommended that future research implement more sophisticated instrumentation, such as motion analysis and electromyography in order to profile neuromechanical contributions that underpin the observed performance measures.

Another considerable limitation stems from the arbitrarily selected 10% body mass load as the additional weight for the loaded condition. However, with a scarcity of literature studying the influence of adding a load to the core endurance test, we cannot state whether this was a suitable load. In future testing it is recommended that methods such as a percentage of peak trunk flexion, extension and plank moments be used as a more appropriate means to select external load for the respective tests.

Lastly, based on feedback from various participants' modifications of the endurance flexion test and the right and left lateral plank test are recommended. During the endurance flexion test, the position held placed additional stress to some of the participant's neck muscles affecting their ability to hold the test to true abdominal flexion fatigue. It is recommended a neck brace be worn to alleviate this possible contributing factor. Also, during the right and left lateral plank tests some participants claimed the stress impacted on the shoulder during the test affected their ability to hold the plank until true fatigue. To eliminate this possible external factor it is recommended that the screening process include medical history surrounding shoulder injuries or a modification be made for the actual test.

A suggested modified test would be to have the participants lie on a BOSU Ball™ with their torso extended beyond the support of the ball, in a manner similar to the back extension test. There feet would need to be secured either by straps or with the help of assisted hands. The test would measure the amount of time the participant could maintain the position and/or the amount of time taken to reach their limit of tolerance, yielding fatigue. These modified versions relieve the additional stresses that possibly affect results and would therefore provide a more accurate measure of the intended muscle group. Obviously, the reliability and validity of these stated amended techniques would need to be determined before their implementation in comparative cohort studies.

Despite these limitations, the data gathered in this study is unique due to the scarcity in research examining the relationship of core endurance to functional performance and the implementation of loaded conditions as well as the application of various data normalization techniques yielding relative measures.

CHAPTER 5: CONCLUSION

The results of our study demonstrated the association between core endurance and lower extremity functional performance is particularly strong with regard to right and left plank measures to cross-over hop performance and posterior reaching distances within the SEBT. The results indicated equal or greater associations between core endurance and lower extremity functional performance than have previously been found between quadriceps strength and similar lower extremity functional test performance. Additional research gauging the extent of core endurance and quadriceps strength as predictors of lower extremity functional performance should be conducted to gain a greater understanding of this potential relation. Furthermore, loaded testing may be a better mode to more accurately measure core endurance when gauging its potential associations to functional performance. The loaded testing provides a more discriminating testing procedure. Therefore, the results of our study demonstrated greater delineation through the presence of additional associations within the loaded data in comparison to the unloaded data. Lastly, the novel method of relative measures for core endurance exhibited a possibly greater interpretation of the relationships between dynamic balance and functional performance. Additional relationships were observed within the relative measures therefore, we recommend that a standardized relative measure for isometric core testing be established to allow for improved comparisons among related research studies.

REFERENCES

1. Willson JD, Dougherty CP, Ireland ML, Davis IM. Core stability and its relationship to lower extremity function and injury. *J Am Acad Orthop Surg.* Sep 2005;13(5):316-325.
2. Zazulak BT, Hewett TE, Reeves NP, Goldberg B, Cholewicki J. The effects of core proprioception on knee injury: a prospective biomechanical-epidemiological study. *Am J Sports Med.* Mar 2007;35(3):368-373.
3. Kibler WB, Press J, Sciascia A. The role of core stability in athletic function. *Sports Med.* 2006;36(3):189-198.
4. Zazulak BT, Hewett TE, Reeves NP, Goldberg B, Cholewicki J. Deficits in neuromuscular control of the trunk predict knee injury risk: a prospective biomechanical-epidemiologic study. *Am J Sports Med.* Jul 2007;35(7):1123-1130.
5. Herrington L, Hatcher J, Hatcher A, McNicholas M. A comparison of Star Excursion Balance Test reach distances between ACL deficient patients and asymptomatic controls. *Knee.* Mar 2009;16(2):149-152.
6. Karatas M, Cetin N, Bayramoglu M, Dilek A. Trunk muscle strength in relation to balance and functional disability in unihemispheric stroke patients. *Am J Phys Med Rehabil.* Feb 2004;83(2):81-87.
7. Khale N. Core Stability Training in Dynamic Balance Testing Among Young, Healthy Adults. *Athletic Training and Sports Health Care.* January 30, 2009 2009;1(2):65-73.
8. Horak FB. Clinical measurement of postural control in adults. *Phys Ther.* Dec 1987;67(12):1881-1885.
9. Oliver G. Implementation of a Core Stability Program for Elementary School Children. *Athletic Training and Sports Health Care.* 2010;2(6):261-266.
10. Cholewicki J, Silfies SP, Shah RA, et al. Delayed trunk muscle reflex responses increase the risk of low back injuries. *Spine (Phila Pa 1976).* Dec 1 2005;30(23):2614-2620.
11. Ito T, Shirado O, Suzuki H, Takahashi M, Kaneda K, Strax TE. Lumbar trunk muscle endurance testing: an inexpensive alternative to a machine for evaluation. *Arch Phys Med Rehabil.* Jan 1996;77(1):75-79.
12. Chan RH. Endurance times of trunk muscles in male intercollegiate rowers in Hong Kong. *Arch Phys Med Rehabil.* Oct 2005;86(10):2009-2012.
13. Kankaanpaa M, Laaksonen D, Taimela S, Kokko SM, Airaksinen O, Hanninen O. Age, sex, and body mass index as determinants of back and hip extensor fatigue in the isometric Sorensen back endurance test. *Arch Phys Med Rehabil.* Sep 1998;79(9):1069-1075.
14. McGill SM, Childs A, Liebenson C. Endurance times for low back stabilization exercises: clinical targets for testing and training from a normal database. *Arch Phys Med Rehabil.* Aug 1999;80(8):941-944.
15. Paalanne NP, Korpelainen R, Taimela SP, Remes J, Salakka M, Karppinen JI. Reproducibility and reference values of inclinometric balance and isometric trunk muscle strength measurements in Finnish young adults. *J Strength Cond Res.* Aug 2009;23(5):1618-1626.
16. Smith SS, Mayer TG, Gatchel RJ, Becker TJ. Quantification of lumbar function. Part 1: Isometric and multispeed isokinetic trunk strength measures in sagittal and axial planes in normal subjects. *Spine (Phila Pa 1976).* Oct 1985;10(8):757-764.
17. Hertel J, Olmsted-Kramer LC. Deficits in time-to-boundary measures of postural control with chronic ankle instability. *Gait Posture.* Jan 2007;25(1):33-39.

18. McGill S. *Low back disorders: evidence-based prevention and rehabilitation*. Champaign, IL: Human Kinetics; 2002.
19. Biering-Sorensen F. Physical measurements as risk indicators for low-back trouble over a one-year period. *Spine (Phila Pa 1976).* Mar 1984;9(2):106-119.
20. Latimer J, Maher CG, Refshauge K, Colaco I. The reliability and validity of the Biering-Sorensen test in asymptomatic subjects and subjects reporting current or previous nonspecific low back pain. *Spine (Phila Pa 1976).* Oct 15 1999;24(20):2085-2089; discussion 2090.
21. Boyd BS, Wanek L, Gray AT, Topp KS. Mechanosensitivity during lower extremity neurodynamic testing is diminished in individuals with Type 2 Diabetes Mellitus and peripheral neuropathy: a cross sectional study. *BMC Neurol.* 2010;10:75.
22. Hertel J, Braham RA, Hale SA, Olmsted-Kramer LC. Simplifying the star excursion balance test: analyses of subjects with and without chronic ankle instability. *J Orthop Sports Phys Ther.* Mar 2006;36(3):131-137.
23. Hertel J, Miller, J, Deneger, C. Intratester and Intertester Reliability during Star Excursion Balance Tests. *J Sport Rehabil.* 2000;9:136-142.
24. Robinson RH, Gribble PA. Support for a reduction in the number of trials needed for the star excursion balance test. *Arch Phys Med Rehabil.* Feb 2008;89(2):364-370.
25. McKeon PO, Ingersoll CD, Kerrigan DC, Saliba E, Bennett BC, Hertel J. Balance training improves function and postural control in those with chronic ankle instability. *Med Sci Sports Exerc.* Oct 2008;40(10):1810-1819.
26. Blackburn T GK, Petschauer MA, Prentice WE. Balance and joint stability: the relative contributions of proprioception and muscular strength. *J Sport Rehabil.* 2000;9:315–328.
27. Lin W, Lee AJY. The relationship between ankle inversion/eversion strength and balance ability. *Bull phys Educ.* 2003;34:55–64.
28. Le Clair K RC. Postural stability measures: what to measure and for how long. *Clin Biomech (Bristol, Avon).* 1996;11:176-178.
29. Palmieri RM IC, Stone MB, Krause BA. Center-of-pressure parameters used in the assessment of postural control. *J Sport Rehabil.* 2002;11:51-66.
30. Booher L, Hench, K., Worrell, T., Stikeleather, J. Reliability of Three Single-Leg Hop Tests. *J of Sports Rehabilitation.* 1993;2:165-170.
31. Daniel D, Stone, ML., Riehl, B., Moore, M.,. The One Leg Hop For Distance. *A Measurement of Lower Limb Function.*212-213.
32. Reid A, Birmingham TB, Stratford PW, Alcock GK, Giffin JR. Hop testing provides a reliable and valid outcome measure during rehabilitation after anterior cruciate ligament reconstruction. *Phys Ther.* Mar 2007;87(3):337-349.
33. Liebenson C. *Rehabilitation of the spine: a practitioner's manual*. 2nd ed. Philadelphia: Lippincott Williams & Wilkins; 2007.
34. Madigan ML, Davidson BS, Nussbaum MA. Postural sway and joint kinematics during quiet standing are affected by lumbar extensor fatigue. *Hum Mov Sci.* Dec 2006;25(6):788-799.
35. Smith M, Coppieters MW, Hodges PW. Effect of experimentally induced low back pain on postural sway with breathing. *Exp Brain Res.* Sep 2005;166(1):109-117.
36. Tsukagoshi T, Shima Y, Nakase J, et al. Relationship between core strength and balance ability in high school female handball and basketball players. *Br J Sports Med.* Apr 2011;45(4):378.

37. Myer GD, Ford KR, Palumbo JP, Hewett TE. Neuromuscular training improves performance and lower-extremity biomechanics in female athletes. *J Strength Cond Res.* Feb 2005;19(1):51-60.
38. Alentorn-Geli E, Myer GD, Silvers HJ, et al. Prevention of non-contact anterior cruciate ligament injuries in soccer players. Part 2: a review of prevention programs aimed to modify risk factors and to reduce injury rates. *Knee Surg Sports Traumatol Arthrosc.* Aug 2009;17(8):859-879.
39. Barber-Westin SD, Noyes FR, Smith ST, Campbell TM. Reducing the risk of noncontact anterior cruciate ligament injuries in the female athlete. *Phys Sportsmed.* Oct 2009;37(3):49-61.
40. Myer GD, Chu DA, Brent JL, Hewett TE. Trunk and hip control neuromuscular training for the prevention of knee joint injury. *Clin Sports Med.* Jul 2008;27(3):425-448, ix.
41. Vrbanic TS, Ravlic-Gulan J, Gulan G, Matovinovic D. Balance index score as a predictive factor for lower sports results or anterior cruciate ligament knee injuries in Croatian female athletes--preliminary study. *Coll Antropol.* Mar 2007;31(1):253-258.
42. Gottlob CA, Baker CL, Jr. Anterior cruciate ligament reconstruction: socioeconomic issues and cost effectiveness. *Am J Orthop (Belle Mead NJ).* Jun 2000;29(6):472-476.
43. Gottlob CA, Baker CL, Jr., Pellissier JM, Colvin L. Cost effectiveness of anterior cruciate ligament reconstruction in young adults. *Clin Orthop Relat Res.* Oct 1999(367):272-282.
44. Herman DC, Weinhold PS, Guskiewicz KM, Garrett WE, Yu B, Padua DA. The effects of strength training on the lower extremity biomechanics of female recreational athletes during a stop-jump task. *Am J Sports Med.* Apr 2008;36(4):733-740.
45. Lohmander LS, Englund PM, Dahl LL, Roos EM. The long-term consequence of anterior cruciate ligament and meniscus injuries: osteoarthritis. *Am J Sports Med.* Oct 2007;35(10):1756-1769.
46. Meunier A, Odensten M, Good L. Long-term results after primary repair or non-surgical treatment of anterior cruciate ligament rupture: a randomized study with a 15-year follow-up. *Scand J Med Sci Sports.* Jun 2007;17(3):230-237.
47. Neuman P, Englund M, Kostogiannis I, Friden T, Roos H, Dahlberg LE. Prevalence of tibiofemoral osteoarthritis 15 years after nonoperative treatment of anterior cruciate ligament injury: a prospective cohort study. *Am J Sports Med.* Sep 2008;36(9):1717-1725.
48. Myer GD, Ford KR, Hewett TE. Rationale and Clinical Techniques for Anterior Cruciate Ligament Injury Prevention Among Female Athletes. *J Athl Train.* Dec 2004;39(4):352-364.
49. Delfico AJ, Garrett WE, Jr. Mechanisms of injury of the anterior cruciate ligament in soccer players. *Clin Sports Med.* Oct 1998;17(4):779-785, vii.
50. Bendjaballah MZ, Shirazi-Adl A, Zukor DJ. Finite element analysis of human knee joint in varus-valgus. *Clin Biomech (Bristol, Avon).* Apr 1997;12(3):139-148.
51. Hewett TE, Myer GD, Ford KR, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am J Sports Med.* Apr 2005;33(4):492-501.
52. Hewett TE, Zazulak BT, Myer GD, Ford KR. A review of electromyographic activation levels, timing differences, and increased anterior cruciate ligament injury incidence in female athletes. *Br J Sports Med.* Jun 2005;39(6):347-350.

53. Markolf KL, Burchfield DM, Shapiro MM, Shepard MF, Finerman GA, Slauterbeck JL. Combined knee loading states that generate high anterior cruciate ligament forces. *J Orthop Res.* Nov 1995;13(6):930-935.
54. Zazulak BT, Ponce PL, Straub SJ, Medvecky MJ, Avedisian L, Hewett TE. Gender comparison of hip muscle activity during single-leg landing. *J Orthop Sports Phys Ther.* May 2005;35(5):292-299.
55. Sitler M, Ryan J, Hopkinson W, et al. The efficacy of a prophylactic knee brace to reduce knee injuries in football. A prospective, randomized study at West Point. *Am J Sports Med.* May-Jun 1990;18(3):310-315.
56. Hultman G, Nordin M, Saraste H, Ohlsen H. Body composition, endurance, strength, cross-sectional area, and density of MM erector spinae in men with and without low back pain. *J Spinal Disord.* Apr 1993;6(2):114-123.
57. Nicolaisen T, Jorgensen K. Trunk strength, back muscle endurance and low-back trouble. *Scand J Rehabil Med.* 1985;17(3):121-127.
58. Suzuki N, Endo S. A quantitative study of trunk muscle strength and fatigability in the low-back-pain syndrome. *Spine (Phila Pa 1976).* Jan-Feb 1983;8(1):69-74.
59. Adams RD. Recent developments in cerebrovascular diseases. *Br Med J.* Apr 5 1958;1(5074):785-788.
60. Bohannon RW. Lateral trunk flexion strength: impairment, measurement reliability and implications following unilateral brain lesion. *Int J Rehabil Res.* 1992;15(3):249-251.
61. Coorevits P, Danneels L, Cambier D, Ramon H, Vanderstraeten G. Assessment of the validity of the Biering-Sorensen test for measuring back muscle fatigue based on EMG median frequency characteristics of back and hip muscles. *J Electromyogr Kinesiol.* Dec 2008;18(6):997-1005.
62. McGill S. *Low back disorders: evidence-based prevention and rehabilitation*. 2nd ed. Champaign, IL: Human Kinetics; 2007.
63. Verhagen E, Bobbert M, Inklaar M, et al. The effect of a balance training programme on centre of pressure excursion in one-leg stance. *Clin Biomech (Bristol, Avon).* Dec 2005;20(10):1094-1100.
64. Gribble PA, Hertel J. Considerations for normalizations of measures of the star excursion balance test. *Meas Phys Educ Sci.* 2007;42(1):35-41.
65. Evans T, Hertel J, Sebastianelli W. Bilateral deficits in postural control following lateral ankle sprain. *Foot Ankle Int.* Nov 2004;25(11):833-839.
66. Garn SN, Newton RA. Kinesthetic awareness in subjects with multiple ankle sprains. *Phys Ther.* Nov 1988; 68(11):1667-1671.
67. Hertel J, Olmsted-Kramer LC, Challis JH. Time-to-boundary measures of postural control during single leg quiet standing. *J Appl Biomech.* Feb 2006; 22(1):67-73.
68. Fitzgerald GK, Lephart SM, Hwang JH, Wainner RS. Hop tests as predictors of dynamic knee stability. *J Orthop Sports Phys Ther.* Oct 2001; 31(10):588-597.
69. Fisler A, Miller S, Vairo G. Core strength and its relationship to static dynamic balance. 2001.
70. Lee Joon-Hee, Hoshino, Yuichi MD, et al. Trunk Muscle Weakness as a Risk Factor for Low Back Pain: A 5-Year Prospective Study. *Spine.* 1999; 24(1):54-57
71. Hopper DM, Goh SC, Wentworth LA et al. Test-retest reliability of knee rating scales and functional hop tests one year following anterior cruciate ligament reconstruction, *Phys Ther Sport.* 2002; 3:10-18.

72. Clark NC, Gumbrell CJ, Rana S et al. Intratester reliability and measurement error of the adapted crossover hop for distance, *Phys Ther Sport.* 2002; 3:143-151..
73. Reid A, Birmingham T, Stratford P, et al. Hop Testing Provides a Reliable and Valid Outcome Measure During Rehabilitation After Anterior Cruciate Ligament Reconstruction. *Phys Ther.* 2007; 87:337-349.
74. Bandy WD, Rusche KR, Tekulve FY. Reliability and limb symmetry for five unilateral functional tests for the lower extremities, *Isokinetics Exerc Sci.* 1994; 4:108-111.
75. Fitzgerald G. Kelley, Lephart S, Hwang J et al. Hop Tests as Predictors of Dynamic Knee Stability. *J Orthop Sports Phys Ther*. 2001; 31(10): 558-597.
76. Driss T, Vandewalle H, Quievre J, et al. Effects of external loading on power output in a squat jump on a force platform: A comparison between strength and power athletes and sedentary individuals. *J Sports Sci.* 2010; 19(2): 99-105.
77. Ozkaya O, Colakoglu M, Kuzucu E, et al. Mechanically Braked Elliptical Wingate Test: Modification Considerations, Load Optimization and Reliability. *J Strength Cond Res,* 2011.
78. Vuk S, Markovic G, Jaric S. External loading and maximum dynamic output in vertical jumping: The role of training history. *Human Movement Science*. 2011.
79. Ricardo DR, Araujo C. Body Mass Index: A Scientific Evidence-Based Inquiry. *Arq Bras Cardiol.* 2002; 79: 70-80.
80. Sone T, Imai Y, Joo Y, et al. Side-to-side differences in cortical bone mineral density of tibiae in young male athletes. *Bone.* 2006; 38(5): 708-713.
81. Vairo GL, Myers BJ, Sell T, et al. Neuromuscular and biomechanical landing performance subsequent to ipsilateral semitendinosus and gracilis autograft anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc.* 2008; 16:2–14.
82. Nesser TW, Lee WL. The relationship between core strength and performance in division I female soccer players. *J Exercise Physiology*. 2009; 12(2): 21-28.
83. Tomoko, O, Huxel KC, Nesser TW. Relationship between core stability, functional movement, and performance. *J Strength Cond Res.* 2011; 25(1): 252-261.
84. Miller SJ, Challis JH, Denegar CR. Influence of knee extensor strength deficits on anterior balance reach test performance. *J Athl Train.* 2002; 37(2): S-52.
85. Wilk KE, Romaniello WT, Soscia SM, et al. The relationship between subjective knee scores, isokinetic testing, and functional testing in the ACL-reconstructed knee. *J Orthop Sports Phys Ther.* 1994; 20(2): 60-73.
86. Keays SL, Bullock-Saxton JE, Newcombe P, et al. The relationship between knee strength and functional stability before and after anterior cruciate ligament reconstruction. *J Orthop Res.* 2003; 21: 231-237.
87. Tse MA, McManus AM, Masters RS. Trunk muscle endurance tests: effect of trunk posture on test outcome. *J Strength Cond Re.* 2010; 24(12): 3464-3470
88. Waldhelm A. Assessment of core stability: developing practical models. Nova Southeastern University. May 2011.

LITERATURE REVIEW

Injuries Related to Core Instability and Balance

Some of the most common injuries occurring within active individuals of the present day surround issues with the lower extremities of the body. [4, 38-41] Lack of adequate trunk and core strength can impair postural control and the balance and functions of the lower extremities, causing poor task mechanics and inevitably injuries to occur.[4, 9] One of the most common injuries is a torn anterior cruciate ligament (ACL)[.4, 38-41] Annually, 30,000 women and girls suffer from non- contact ACL injuries, with costs exceeding $17,000 in surgical cost and more than $650 million in rehabilitative costs [2, 48]. Furthermore, soccer, the most commonly played sport, reports an incidence rate between 0.06 to 3.7 in ACL injuries per 1,000 hours of active playing [38, 49]. Anterior cruciate ligament ruptures carry extensive recovery times and effect patients in multiple ways; greatly diminishing activity levels as well as quality of life and can cause further medical and health issues later in life[38, 42-44]

The specific mechanism of ACL injuries explained by Zazulak et al[4] involves the combination of a valgus positioning of the lower extremities, a derived extension occurring during unbalanced weight distribution, and the plantar surface of the foot being fixed in a position directed away from the body's center of mass. This mechanism may differ from males to females due to the greater valgus angle created in a female's coronal plane [4]. However, overall, the dynamic stability of an athlete's knee relies on the accuracy of the sensory input creating the appropriate motor response to meet the demands of the rapid changes in trunk position, provoked by the movements such as cutting, stopping, or landing movements [4].

Research focusing on the reduction of ACL injuries through the design and implementation of specific injury prevention programs and/or strategies has been a growing source of interest. Sitler et al[55] found the use of a prophylactic knee to provide profound preventative protection for certain football players, while others have provided strong support around training programs as the best preventative measure. Alentorn-Geli et al[38] discussed successful training components to encompass a focus around dynamic balance and strength, lower body plyometrics, stretching, trunk control, and decision-making based on body awareness. Neuromuscular retraining programs have also been studied and have shown high success rates in the reduction of noncontact ACL injury. Success of these programs involves teaching athletes control techniques for upper body, trunk, and lower body positions, implementing effective training practices that increase hip and knee flexion, in turn, lowering the center of gravity, and focusing on performance to develop muscular strength and skill for landing with decreased ground reaction forces [39.]

Due to the activation of core musculature preceding the activation of lower extremity function, programs focusing on improving dysfunctions of the core and trunk also have been documented as preventative measures for other injuries. Oliver et al[9] concluded that improved core stability could enhance the functions of the kinetic chain, therefore reducing deficits that result in injuries and dysfunctions. Some other injuries benefiting from core related rehabilitative techniques include low back pain (LBP) and patients recovering from unihemispheric strokes, with a resulting limited balance.[6, 19] The development of LBP can result from excessive fatigability of lumbar paraspinal muscles and weaknesses in the trunk flexor and extensor muscles.[13, 20, 56-58] Unihemispher strokes typically affect the systems involved with balance and severely impact the functions of trunk musculature.[6, 59] Furthermore, due to the effects of neurological and eurological diseases, such as lumbar discectomy, multiple sclerosis and amyotrophic lateral sclerosis, on balance, core stability has been defined as a prognostic clinical tool for their functional recovery.[69]

Core Stability and Balance

The musculoskeletal portion of the body responsible for functional stabilization and force generation produced by motion encompasses the structures of the central core.[3] Core muscle activity can be understood as the pre-programmed integration of local, single-joint muscles and multi-joint muscles that provide neuromuscular control to the trunk muscles through the integration of internal and external stimuli of distal portions and segments. [2, 3] It is known as the stabilizing unit of the body and comprises muscles of the thoracolumbar spine, hips and pelvis, acting with proximal lower limb and abdominal structures.[1-3]

This stabilizing factor has been defined as the foundation for trunk control based on its production, transfer, and control of force and motion to distal segments of the kinetic chain. [3-4] and more specifically is essential for the perpetuation of body positions, stabilizing of the body during movements, and sustainment of mobility for our everyday activities. [6, 60] Biomechanically, when body weight is shifted into a plane, the trunk serves to counteract the movement in order to restore the center of balance, therefore, also serving as a key component for balance, transfer of weight, and gait.

The complexity of balance involves the interaction of several body systems; vestibular, visual, proprioceptive, musculoskeletal and cognitive and can be characterized as either static or dynamic. [5-6] Static postural control involves maintenance of a base of support in conjunction with the minimization of movement through one's center of mass or body segments or more simply, is one's ability to maintain position while standing in a unilateral or bilateral stance.[5, 7] A popular form of assessment involves the measurement of pressure changes or sway area.[5] Dynamic postural control explains the completion of tasks that displace one's center of mass without compromising their established base of support. This displacement occurs in response to muscular activity during purposeful movements of functional tasks and requires the appropriate integration of proprioception, range of motion and strength.[5, 7] Examples include running, jumping and cutting.

Measurements of Core Musculature

The three measures of muscular function associated with core stability are strength, endurance and power. McGill et al[12] identified endurance-based exercises as the safest testing approach and the most mechanically justifiable for core stability enhancement when combined with neutral spine posture during load exercises (which avoid end-range positions) and when abdominal contraction and bracing are performed in a functional mode. Furthermore, isometric endurance testing recruits trunk muscles commonly associated with injuries, therefore acting as a preeminent method in measuring core strength.[11-15] Various resources have also validated isometric endurance measurements as a reliable method to assess trunk muscle strength.[14-18]

Current studies have suggested research be conducted regarding the relationship between endurance measurements of the torso flexors, extensors and lateral musculature due the stabilizing effects these muscles groups provide for the spine during essentially all movements.[18] Research conducted by McGill & Cholewicki[11, 14] concluded the quadratus lumborum acts as the major stabilizer of the lumbar spine based on high activity levels produced by the motor control system during tasks utilizing substantial flexor and extensor moment development. Various exercises have been designed and implemented to assess the quadratus lumborum and one of the best exercises is the isometric lateral flexion endurance test or side bridge test.[14] Progression towards isometric endurance test for rehabilitative purposes developed as the side bridge technique gained credibility, and further assessments aimed to measure normal values for flexor, extensor and lateral flexion endurance times and ratios were developed.[69] The three most validated and highly reproducible stabilizing core endurance exercises for trunk functionality assessment are the following: the Biering-Sorensen Back Extension, isometric flexion, and lateral flexion tests.[21]

Biering-Sorensen Test

Fin Biering-Sorensen first developed the Biering-Sorensen test in 1983 during a longitudinal study focusing on the standardization of physical examinations for low-back problems.[19] Roughly 900 participants were tested over the course of one year and anthropometric measurements were utilized in conjunction with flexibility of the back and hamstrings, and strength and endurance testing of trunk muscles.[19] This specific back extensor isometric test involved placing the subjects in a prone position with their ankles fixed to a table via a strap and their arms folded across the chest. The subjects were required to maintain the unsupported upper portion of their body, designated from the anterior superior iliac spine, parallel to the floor. The amount of time the subjects could maintain the position or the amount of time taken to reach fatigue was evaluated.[19] The results yielded that females possessed higher endurance rates than men across all age groups. Furthermore, it was established that all participants unable to complete the test complained of low-back pain and pain within legs and abdomen.[19]

Several cross-studies have been completed for validation purposes of the Biering-Sorensen's method. Nicholaisen & Jorgensen[25] produced parallel results, also linking lower isometric endurance with lower-back pain in comparison to controls representing normal individuals with significantly higher isometric endurance. Latimer et al[20] also found comparable results after completing the exact test performed in 1983, in which again patients presenting lower-back pain correlated with decreased performance on the endurance test in comparison to the healthy controls.

Coorevits et al[61], examined hip and back extensor muscles through the Beiring-Sorensen test by combining the test with electromyography analysis. This allowed for a normalized median frequency slope to be determined (NMFslope). The NMFslope established correlations between fatigue of both back and hip muscles and endurance times. However, although correspondences were seen in both back and hip muscles, it was found that the thoracic portion of the iolocostalis lumborum muscle was ultimately responsible for the limiting performance with endurance times in the Beiring-Sorensen test.[61] Overall, these studies validate the back extensor musculature as the sole reciprocator and limiting factor when performing the Biering-Sorensen isometric core endurance exercise.[69]

Intraclass correlation coefficient (ICC) defines the reproducibility of measures and was performed by Paalanne, et al. on the Beiring-Sorensen test.[15] The test was repeated 30 minutes following the completion of the first test and revealed an ICC of 0.93, indicating high reproducibility for isometric extension endurance.[15] Latimer et al[20], also tested the Beiring-Sorensen test and yielded an ICC of 0.83. These studies represent a high degree of validity and strong reproducibility for the Biering-Sorensen test in testing the back extensor strength.

Isometric Flexion Endurance

The isometric flexion endurance test begins with the subject in a sit-up position and the back resting on a wedge angled at 60^{o} from the floor.[69] The knees are flexed at a 90^{o} angle and the arms are crossed against the chest. The subject begins the timed isometric test once the wedge is moved 10cm back and ends once the subject fatigues beyond comfort or when the body falls below 60^{o}. Men tend to demonstrate greater amounts of flexion compared to women during the testing.[69] Paalanne et al[14], tested the reliability of the isometric flexion endurance test and found an ICC of 0.87 and a reliability coefficient of 0.93 for an 8-week 5-day period. Overall, the isometric flexion test produces reliable measure of trunk flexor strength.

Isometric Lateral Flexion

The isometric lateral flexion endurance test begins with subjects lying on their side, with both legs extended.[69] The top foot is placed in front of the lower foot. The hips are then lifted upward off the matt and the body is supported with one elbow and their feet; essentially creating a straight line over their full body length.[14] The non-supporting arm is held across the chest and the hand is placed on the opposite shoulder. The test ends when the subject fatigues beyond comfort or when the hips fall back to the matt. Both arms are tested as bases of support. Paalanne et al[14, 15] found an ICC of 0.84 and a reproducibility coefficient of 0.96 for the right side bridge and 0.99 for the left side bridge for the isometric lateral flexion test during a 8-week 5-day period of repeated sessions

Endurance Ratios

The trunk extension-flexion ratio provides a useful analysis of the trunk muscles and is a common parameter for trunk muscle balance assessment.[70] This evaluative technique provides a comparative measure of strength between muscle groups.[69] Several cross-sectional studies have revealed strong correlations between patients with LBP and low extension-flexion ratios and McGill et al[62] supports the inference that individuals with lower-back problems exhibit weaker extensor endurance relative to flexor endurance. Overall, greater support surrounds muscle strength imbalances as a reliable indicating factor compared to strength deficits in any one test.[62]

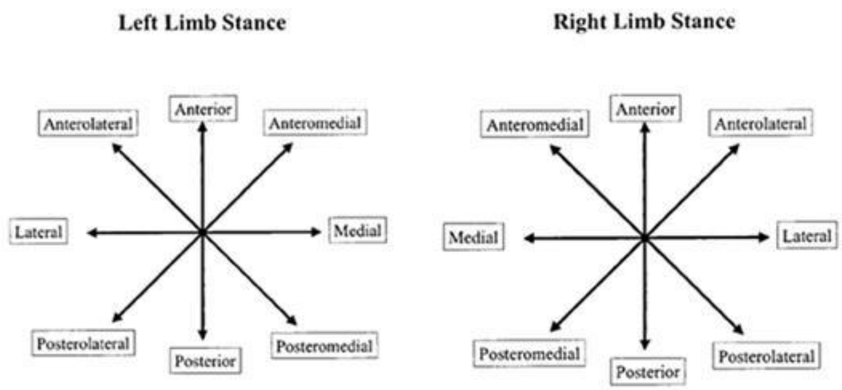
Quantifying Dynamic Balance

Measurements of dynamic balance can be conducted through the usage of functional performance testing (FPT). The importance of FPT, in relation to clinical settings, surrounds the dynamic assessment completed through the FPT measures. Although functional tests are unable to identify specific abnormalities, they allow for a general measure of lower extremity function to be calculated in relation to joint stability, pain, muscle strength and power.[72] Furthermore, elements of neuromuscular coordination and coactivation, proprioception and agility are also measured.[72] These combined measures comprise the essentialities for performance of dynamic movement. Two specific tests yielding valid and reproducible results are the Star Excursion Balance Test and the Cross-Over Hop test.

Star Excursion Balance Test

The Star Excursion Balance Test (SEBT) has long been recognized for its reliability in measurements of dynamic balance with an ICC = 0.81-0.86.[22] The test entails the completion of 8 directional reaching tasks, spaced 45^{o} apart as depicted in Figure 1.

Figure 1: Left and Right limb view of 8 directions performed during SEBT



The SEBT requires the subjects to stand on one leg and then reach, with the non-weight bearing leg, in the specified directions. They are instructed to place their hands on their hips to minimize transfers in body weight. The goal is to reach the leg out without compromising the base of support and then return the leg back to the starting position.[5, 7, 23-24] For accuracy in results, the positions are marked by the same examiner each time. Recent work has identified that the 8 directions may be minimized to 3 tested directions based on redundancy and correlations found between the reach directions.[7, 22] Kinematic patterns in the stance limb also showed redundancy between the reach directions, further downplaying the necessity for utilizing all 8 directions to measure dynamic postural control.[7, 24] Therefore, for this study, only anterior, posteromedial, and posterolateral directions were tested.

Several studies[7,22] have also found 3 reach trials to demonstrate sufficient evidence. Kahle et al[7], evaluated 3 trials for the production of maximum excursion distances in accordance with practice trials and Robinson et al[24], utilized 4 practice trials to produce reliable reach distances. Overall, the conclusion can be made that when utilizing the SEBT in accordance with evaluation of dynamic balance, movements in three different directions and the completion of four practice trials will provide valid and reliable data.[22]

In order to quantify the results between the subjects' in a measurable and comparable manner, the results were normalized with respect to the subjects' leg length. The 3 maximal reaches were averaged for each subject and then divided by their leg length. This value was expressed as %LL allowing the maximal reaches to easily be compared among participants as a percentage.[64]

Recent work completed by Tsukagoshi et al[36] discovered that an increased performance in the SEBT was observed in participants demonstrating greater core endurance in the front and side bridge planks. Therefore, a conclusion can be drawn between similar SEBT task performance and the increased core strength effects towards the functionality of the lower limbs.

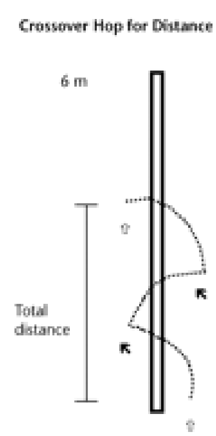
Cross-Over Hop

Hop testing is a form of FPT that serves as a quantitative measure for defining function and or outcome and have become popular testing forms by clinicians during rehabilitative processes.[72] The information gathered during hop testing evaluates the integration of several physical parameters with functional performance such as joint laxity, muscle extensibility, muscle power and strength, proprioception, neuromuscular control, balance, and agility.[72] Previous hop test studies have provided information relating to measurement reliability, hop test measurements in relation to other physical impairments (such as muscle weakness), deficits within passive joint proprioception, and implementation of hop tests to indicate the capacity of functional performance in patients with ACL injury.[77] However, little research has been conducted to explore the relationship core strength shares with the performance of cross-over hop performance. Movements such as directional change, speed, acceleration, deceleration and rebounding demand dynamic knee stabilization, ultimately related to strong core stabilization.[32]

Therefore, research surrounding core stabilization paired with methods such as cross over hop testing would be progressively beneficial and should produce newfound knowledge.

The cross over hop test requires subjects perform three consecutive single leg hops, aiming for maximum distance, while crossing a line 15 cm wide and 6 m long, as depicted in Figure 2.[71, 73] The distance between the starting line and the toe of the tested leg, preceding the third hop, is measured.[71] The jumps were classified successful only if the landing was maintained for 2 seconds. An unsuccessful hop involved the occurrence of any of the following: the touch down of contralateral lower extremities or of either upper extremity, loss of balance, or performance of an additional hop upon landing.[71]

Figure 2: Hop testing layout



Body Loading During Dynamic Quantifications

The concept of body loading in testing surrounds the understanding of muscle activation in regards to forces acting on or within the body. When additional weight is added during an exercise, muscle recruitment will occur to maintain and produce activity and compensate for the increases in force being applied. Therefore, when performing an exercise with additional body weight, the body's internal reactions will increase uniformly, allowing for a greater delineation in results.

Studies have tested this concept through analyzing various activities of individuals with no load and individuals carrying additional, pre-determined loads. Ozkaya et al[77], concluded that a workload of 18% body mass was optimal for measuring maximal and reliable anaerobic power outcomes during elliptical training. Test and retest of the peak power, average power, minimum power, power drop, fatigue index ratio, and delta lactate responses were also analyzed in regards to the additional workload and all demonstrated high correlations.[77] Driss et al[76], examined external loading on the power output during squat jumps and discovered the force corresponding to peak instantaneous power increased and the velocity corresponding to peak instantaneous power decreased with external loading. The loading ranged from 0-10 kg worn in a special vest.[76]

The above studies tested all subjects utilizing a vest containing the additional load and had the subjects perform the prescribed activities. No research was found incorporating body loads for measurements of core strength, however, based on the findings of previous studies the presence of additional body load should allow for greater determinants in weakness of the core.

Conclusion

Although research is available demonstrating the weaknesses in core strength to lower extremity injuries, minimal research surrounds to the relationship between core strength to dynamic balance and functional hop task performance. Furthermore, no current research exists measuring these relationships in the presence of additional loading. The relationship between core strength and functional performance needs to be further evaluated in order develop a more knowledgeable understanding of their correlations and utilizing methods of additional body loads should produce greater understanding of these concepts.

APPENDIX A: (RECRUITMENT)

Title of Project:	The Relationship of Core Strength to Dynamic Balance and Functional Hop Task Performance
Principal Investigator:	Sayers John Miller, PhD, PT, ATC
Project Coordinator:	Giampietro L Vairo, MS, ATC
Research Support:	Sarah M Lopez
Script:	Healthy College-Aged Participants (18-35 years old)

Hello, my name is John Miller and I work with the Athletic Training Research Laboratory at Penn State. I am currently looking for research volunteers and was wondering if you would be interested in participating or at least hearing more about this study. I am looking for a group of participants who are 18 to 35 years old, have no history of lower body or low-back injury in the past six months and no related surgeries. Participants in this research study should be in good general health, not overweight and non-smokers. Participants cannot be pregnant at the time of the study. If you are undergoing physical therapy or sports rehabilitation under the supervision of a physical therapist or athletic trainer you will not be eligible to participate. I will be examining how core strength relates to balance. If you are interested in participating, you would be required to come to the Athletic Training Research Lab in 21D & E Recreation Building for three testing sessions. The first one would last approximately 45 minutes and the remaining two approximately 20 minutes. During the testing session we will measure core strength through three tests and your postural control abilities as you will be asked to perform two balancing exercises. As a participant we will be happy to provide you with your specific data results. If you have any questions or need to get in touch with me for any reason, my phone number is 814-865-6782 and my e-mail is sjm221@psu.edu. Thank you.

PENNSTATE

Athletic Training Research Laboratory

Research Volunteers Needed

Are you interested in learning more about core strength and balance performance?

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

Measurements: Core strength, static and dynamic balance as well as distance for a single-leg cross-over hop

Purpose: To study the relationship between core strength and balance under a loaded condition

Three sessions in the Athletic Training Research Laboratory in 21 D & E Recreation Building. The first session will last approximately 45 minutes and the remaining two sessions will last approximately 20 minutes.

Requirements:

- Men and women ages 18 – 35 years old
- Good general health
- Non-smoker or consumer of nicotine products
- Not overweight

Dr S John Miller, John Vairo and Sarah Lopez
Department of Kinesiology

For more information, contact John Miller at
sjm221@psu.edu or 814-865-6782

APPENDIX B: (QUESTIONAIRE)

PENNSTATE

1855

Title of Project: The Relationship of Core Strength to Dynamic Balance and Functional Hop Task Performance

Principal Investigator: Sayers John Miller, PhD, PT, ATC

Project Coordinator: Giampietro L Vairo, MS, ATC

Research Support: Sarah Lopez

Screening Checklist: Healthy College-Aged Participants (18-35 years old)

Participant Identification Number:______________________________

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

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

2. Do you speak English? **Yes** **No**

3. Are you generally healthy (BMI[1] under 30 and a non-smoker or non-consumer of nicotine products)?
   Yes **No**

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

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

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

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

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

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

7. Do you currently have any lower body joint swelling? **Yes** **No**

8. Are you pregnant? **Yes** **No**

[1]United States Government. (2010) Defining Overweight and Obesity. Center for Disease Control and Prevention. June.

APPENDIX C: (INFORMED CONSENT)

ORP OFFICE USE ONLY
DO NOT REMOVE OR MODIFY
IRB# 35177 Doc. #1001
The Pennsylvania State University
Office for Research Protections
Institutional Review Board
Approval Date: 10/17/2011 – J. Mathieu
Expiration Date: 10/16/2012 – J. Mathieu

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

Title of Project:	The Relationship of Core Strength to Dynamic Balance and Functional Hop Task Performance
Principal Investigator:	S John Miller, PhD, PT, ATC Assistant Professor of Kinesiology Department of Kinesiology 146 Recreation Building, University Park PA 16802 sjm221@psu.edu; 814-865-6782
Project Coordinator:	Giampietro "John" L Vairo, MS, ATC Instructor of Kinesiology – PhD Candidate (ABD) in Kinesiology Department of Kinesiology 146 Recreation Building, University Park PA 16802 glv103@psu.edu; 814-865-2725
Research Support:	Sarah M Lopez Schreyer Honors College Undergraduate Student Department of Kinesiology 21E Recreation Building, University Park PA 16802 sml5248@psu.edu; 717-805-2098

1. **Purpose of the study:** The purpose of this research is to study the effects of core strength and endurance on balance both dynamic and static performance with additional body weight loading. A total of 50 people between the ages of 18-35 years old will be taking part in this study.

2. **Criteria for inclusion of participants:** You are being invited to participate in this research study because you are healthy, physically active and between the ages of 18-35 years old. You have no history of lower body or back injuries within the last six months and have never undergone surgeries for injuries to these areas. You are also not diagnosed with diabetes, peripheral neuropathy or epilepsy.

3. **Procedures to be followed:** If you chose to participate in this research study, you will be asked to perform the following procedures:

Procedures

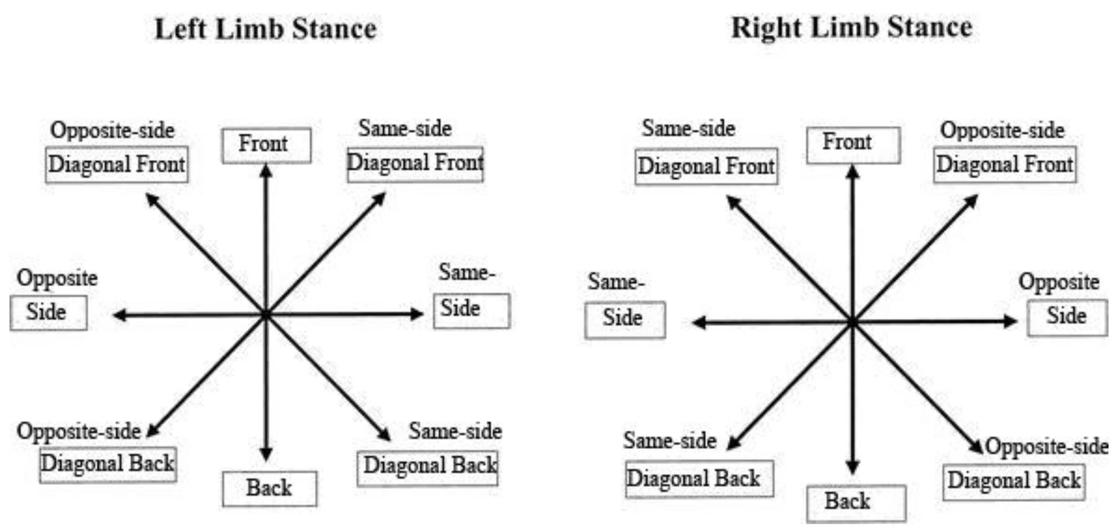
A. We will begin the study by measuring your height, weight, and length of one leg. We will also determine your dominate leg by asking you to kick a soccer ball.

B. We will also ask you to perform three abdominal exercises thereafter. One exercise will require you to do static sit-up, another will require back extension and lastly, you will be asked to do a lateral plank. All will be measured to maximum hold and rests will be held between each measurement.

C. Following the warm-up, we will fit you with a vest that is worn over your body. The vest is held to your trunk with Velcro straps. The vest will weight 20% of your overall body weight.

D. You will then be asked to perform a single-leg balance stance task. You will be standing barefoot on one leg with your arms crossed over your chest while bending your knee on the opposite leg. You will be asked to keep balance for 10 seconds. We will ask that you complete three trials with your eyes open and then three trials with your eyes closed. Your balance performance will be measured by a force platform, which stays still on the floor and is electronically hooked up to a computer. You will be asked to perform the single-leg balance stance task for both of your legs.

E. You will then be asked to perform a single-leg balance reach task. You start the single-leg balance reach task by standing in place on one leg in the middle of an asterisk drawn on the floor. You then reach as far as possible with your other leg in each of the following directions: front, opposite-side diagonal back, same-side diagonal back. A picture of the single-leg balance reach task is below.



You will be asked to complete three trials in each direction. You will be given practice trials and rest between each trial. You will be asked to perform the single-leg balance reach task for both of your legs.

F. For your last measurement, you will be asked to do a maximum cross over hop test. You will perform three consecutive single leg hops, aiming for maximum distance, while crossing a line 15 cm wide between each hop. You will be given practice and then three hops will be measured with the best hop recorded into the data.

4. **Discomforts and risks:** The discomforts and risks with participation in this type of research study are minimal. The tests used are within expected ranges for physically active people. To lessen the chance of injury, you will also be shown how to properly perform every task in the experiment. Possible discomfort may consist of delayed onset muscle soreness 48 to 72 hours following testing. As with any research study, it is possible that unknown harmful effects may happen. However, the chance for injury in this type of research study is minimal and includes muscle strains, ligament

sprains and bone fractures. We will take every possible effort to watch for and help prevent against any discomforts and risks.

5. **Benefits:** There is no direct benefit to you from participating in this research study. The benefits to society include recognizing potential advantages core strength training on balance performance in healthy college age people.
6. **Duration/time of the procedures and study:** The testing session will last about one hour and will include taking height and weight measures, trunk strength tests, balance tests and a single-leg hop test. All testing takes place in the Athletic Training Research Laboratory in 21E Recreation Building on Penn State's University Park Campus.

7. **Statement of confidentiality:** Your participation in this research study is strictly confidential. All research records from your participation in this study will be kept confidential similar to medical records at your doctor's office or hospital. All records will be secured in locked file cabinets at the Athletic Training Research Laboratory. A unique case number will indicate your identity on research records. In the event of any publication resulting from this research study, no personally identifiable information will be disclosed. Penn State's Office for Research Protections, the Institutional Review Board and the Office for Human Research Protections in the Department of Health and Human Services may review records related to this research study. Federal regulations require research records be kept for a minimum period of three years at the end of the study. Three years following the end of this research study all records will be appropriately destroyed.

8. **Right to ask questions:** Please contact S John Miller at (814) 865-6782 with questions, complaints or concerns about this research. You can also call this number if you feel this study has harmed you. If you have any questions, concerns, problems about your rights as a research participant or would like to offer input, please contact Penn State University's Office for Research Protections at (814) 865-1775. The Office for Research Protections cannot answer questions about research procedures. Questions about research procedures can be answered by the research team. Referral information for those who wish to seek additional assistance includes the following:

   Penn State University Health Services
   Student Health Center
   University Park PA 16802
   814-863-0774

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

10. **Injury Clause:** In the unlikely event you become injured as a result of your participation in this research study, medical care is available. If you become injured during testing procedures the investigators listed on this informed consent form will provide you with appropriate first aid care and instruct you on proper steps for follow-up care. If you were to experience any unexpected pain or discomfort from participating in this research study after leaving the Athletic Training Research Laboratory please contact S John Miller immediately at (814) 865-6782. If you cannot reach S John Miller please leave him a voicemail and contact your doctor.

    If you are a Penn State student and cannot reach S John Miller or your doctor, please leave them voicemails and contact Penn State University Health Services at:

Student Health Center
University Park PA 16802
814-863-0774

It is the policy of this institution to provide neither financial compensation nor free medical treatment for research-related injury. By signing this document, you are not waiving any rights that you have against The Pennsylvania State University for injury resulting from negligence of the University or its investigators.

You must be 18 years of age or older to take part in this research study. If you agree to take part in this research study and the information outlined above, please sign your name and indicate the date below.

You will be given a copy of this signed and dated consent form for your records.

____ ______________________

Participant Signature Date

____ ______________________

Person Obtaining Consent Date

APPENDIX D: (DATA COLLECTION)

Participant ID ____________________________

Age ______

Height __________________ in

Weight __________________ lbs

BMI _______________

RPI _________________

Right Leg Length __________________ cm

Left Leg Length ____________________ cm

Dominant Leg _____________________

CORE STRENGTH TESTS

Exercise	Back Extension	Endurance Flexion	Left Lateral Plank	Right Lateral Plank
Time				

CORE STRENGTH TESTS WITH 10% WEIGHT

Exercise	Back Extension	Endurance Flexion	Left Lateral Plank	Right Lateral Plank
Time				

STAR EXCURSION BALANCE TEST

	Dominant Foot			Best	Non-dominant Foot			Best
Anterior								
Posterolateral								
Posteromedial								

CROSS-OVER HOP TEST

Dominant Leg			Best	Non-dominant Leg			Best

APPENDIX E: (LOAD CALCUATION SHEET)

Weight	10%	Weight	10%	Weight	10%
90	9	**132**	13	**174**	17
91	9	**133**	13	**175**	18
92	9	**134**	13	**176**	18
93	9	**135**	14	**177**	18
94	9	**136**	14	**178**	18
95	10	**137**	14	**179**	18
96	10	**138**	14	**180**	18
97	10	**139**	14	**181**	18
98	10	**140**	14	**182**	18
99	10	**141**	14	**183**	18
100	10	**142**	14	**184**	18
101	10	**143**	14	**185**	19
102	10	**144**	14	**186**	19
103	10	**145**	15	**187**	19
104	10	**146**	15	**188**	19
105	11	**147**	15	**189**	19
106	11	**148**	15	**190**	19
107	11	**149**	15	**191**	19
108	11	**150**	15	**192**	19
109	11	**151**	15	**193**	19
110	11	**152**	15	**194**	19
111	11	**153**	15	**195**	20
112	11	**154**	15	**196**	20
113	11	**155**	16	**197**	20
114	11	**156**	16	**198**	20
115	12	**157**	16	**199**	20
116	12	**158**	16	**200**	20
117	12	**159**	16	**201**	20
118	12	**160**	16	**202**	20
119	12	**161**	16	**203**	20
120	12	**162**	16	**204**	20
121	12	**163**	16	**205**	21
122	12	**164**	16	**206**	21
123	12	**165**	17	**207**	21
124	12	**166**	17	**208**	21
125	13	**167**	17	**209**	21
126	13	**168**	17	**210**	21
127	13	**169**	17	**211**	21
128	13	**170**	17	**212**	21
129	13	**171**	17	**213**	21
130	13	**172**	17	**214**	21
131	13	**173**	17	**215**	22

ACADEMIC VISTA for Sarah M. Lopez

Sarah M. Lopez
218 W. Fairmount Ave
State College, PA 16801
sml5248@psu.edu

Education:

Bachelor of Science Degree in Movement Science, Pennsylvania State University, Spring 2012
Honors in Kinesiology
Thesis Title: The Relationship of Core Strength to Dynamic Balance and Functional Hop Task Performance
Thesis Supervisor: Dr. S. John Miller

Related Experience:

Teaching Assistant for Anatomy & Physiology
Pennsylvania State University
Supervisor: Dr. John Waters
Fall 2011-Spring 2012
Internship with Hershey Medical Center
Supervisor: Marie Poppe
Summer 2011
Internship with Fit For Play Physical Therapy
Supervisor: Jim Bennett
Fall 2009

Awards:

Schreyer Honors College Academic Excellence Scholarship
Dean's List (Fall 2008, Spring 2009, Fall 2009, Spring 2010, Fall 2011)

Activities:

Relay For Life Spirit Captain – Mission Liaison
Atlas THON Student Organization Member
Kinesiology Club Member
Pre-Physical Therapy Club Member