LEVERAGING LIMB LOADING METRICS TO INFORM CLINICAL DECISION MAKING AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

A Dissertation

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By

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ABSTRACT

Following anterior cruciate ligament reconstruction (ACLR) many individuals are faced with barriers hindering their ability to successfully return to unrestricted physical activity (RTA). Two primary barriers to individuals following ACLR are physical recovery (i.e., strength and functional performance) and psychological recovery (i.e., kinesiophobia, lack of knee self-efficacy, confidence to RTA, etc.). The point-of-care Lower Extremity Assessment Protocol (LEAP) program utilizes a battery of quadriceps and hamstring strength and symmetry metrics, patient reported outcomes, bilateral bodyweight squatting performance and symmetry metrics to highlight any deficits while tracking patient's progress throughout rehabilitation. Manuscript I used data from assessments conducted approximately five months post-ACLR to determine the influence of sex on limb loading performance and to determine if a relationship is present between limb loading and patient reported outcomes. We found that females underload their surgical limb more than their male counterparts. Additionally, we found that at five months post-ACLR, individuals have a decreased perception of their ability to complete activities of daily living and lower subjective knee function when their limb loading is asymmetrical. The focus of manuscript II was to assess how limb loading and lower extremity strength (i.e., quadriceps and hamstrings) change between five- and eight-month assessments. We found that there was an increase in loading on the ACLR limb over time as well as improvements in lower extremity strength. However, there was no relationship between the rate of change in limb loading and lower extremity strength. The focus of manuscript

III was to determine if limb loading, quadriceps strength, and ACL Return to sport after injury (ACL-RSI) scores at an interim stage of recovery are associated with jump landing performance at a clearance to RTA. We found that unilateral ACLR limb loading and ACL-RSI scores are prognostic of performance during a jump landing. The utilization of limb loading performance throughout early, mid, and late stages of recovery can be used to guide clinical decision making in rehabilitation interventions early to circumvent the potential adoption of poor movement patterns that can increase and individual's risk of reinjury.

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APPROVAL OF THE DISSERTATION

This dissertation, “Leveraging Limb Loading Metrics to Inform Clinical Decision Making After Anterior Cruciate Ligament Reconstruction” has been approved by the Graduate Faculty of the School of Education and Human Development in partial fulfillment for the degree of Doctor of Philosophy.

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SECTION II: MANUSCRIPT I

Comparison of Limb Loading Characteristics and Subjective Functional Outcomes Between Sexes Following ACLR

Abstract:

Introduction: Following anterior cruciate ligament reconstruction (ACLR), many individuals experience maladaptive biomechanical movement patterns; that if left untreated, could place individuals at an increased risk for reinjury. Limb loading characteristics during functional tasks, like a bilateral bodyweight squat, can be a way to highlight poor movement quality. Therefore, the aims of this study were to (1) compare limb loading metrics during a bilateral bodyweight squatting task across sexes following ACLR and (2) describe the relationship between limb loading characteristics and subjective patient reported outcomes (PROs).
Methods: Participants consisted of 142 individuals (71 males and 71 females) who were on average, 24.4±11.1yrs, 5.2±1.40 months post-surgery who participated in a single return to activity assessments in a controlled laboratory setting. Limb loading peak force normalized to body mass (N/kg) and unilateral cumulative load (%) of the ACLR and contralateral limbs were collected. Limb symmetry index (%) was also calculated for the normalized peak force limb loading. Patient reported outcomes (PROs) were also recorded. Limb loading differences (ACLR vs contralateral) and sex differences were analyzed via an analysis of covariance, and relationships between limb loading metric and PROs were determined via a Spearman Rho correlation.
Results: The majority of individuals (91/142, 64.1%) offloaded their ACLR limb (6.6±1.56 N/kg) compared to their contralateral limb (7.3±1.61 N/kg, $p<0.001$). Females significantly offloaded their ACLR limb (6.3±1.38 N/kg) more than their contralateral limb (7.2±1.62 N/kg, $p<0.001$) where males did not significantly off load their ACLR limb (6.98±1.65 N/kg) compared to their contralateral limb (7.4±1.60, $p=0.07$). Weak relationships were observed (ρ-value range: -0.23 to 0.19) across limb loading metrics and PROs with the strongest relationships observed for with the KOOS ADL subscale.
Conclusion: In individuals less than 9-months following ACLR, on average the ACLR limb was underloaded compared to the contralateral limb. Limb loading recovery was influenced by sex. The presence of a relationship between limb loading metrics and PROs indicate that regardless of limb, patients who load their limbs disproportionately have a lower perception in their capability to completed activities of daily living and lower subjective knee function.

Introduction

Injury to the anterior cruciate ligament (ACL) is one of the most common musculoskeletal injuries and subsequent surgical reconstruction (ACLR) is the most frequented courses of treatment[1,2]. After surgical intervention, many individuals struggle to return to pre-injury levels of physical activity participation. Approximately 35% of athletes are not able to return to their previous level of sport.[3] Of those who are able to return to their previous sporting activity, 45% are not able to return to competitive sport.[3] Physical and psychological barriers contribute to a person's ability to successfully return-to-activity (RTA).[4,5] These individuals who are not able to return to their previous level of activity, particularly adults, may have an increased risk of morbidities such as coronary artery disease, certain cancers, and Type 2 diabetes.[6] There is also evidence that following ACLR, patients exhibit altered biomechanics and abnormal limb loading which is a major contributor to the development of early onset osteoarthritis (OA).[7,8] Early onset OA develops in around 50% of patients following ACLR. Symptoms of early onset OA, such as pain, can deter physical activity and decrease patients' overall quality of life.[9,10]

Individuals following ACLR also may experience altered biomechanics during landing and walking.[11–13] The quality of movement, such as during gait or squatting, can be compromised due to an unconscious underloading of the ACLR limb compared to the contralateral limb.[14,15] Underloading of the ACLR limb, when compounded overtime, could increase the risk of developing early onset OA.[16] Determining a patient's capacity to evenly distribute their weight across limbs during a functional task is critical for tailoring an optimal rehabilitation intervention following ACLR. If maladaptive offloading patterns from the ACLR limb to the contralateral limb persist throughout rehabilitation, it could exacerbate poor movement patterns during high-risk ballistic activities (i.e., jumping) potentially increasing the risk of reinjury to the ipsilateral or contralateral ACL.

Movement compensations following ACLR are common and can be assessed with a variety of techniques[17,18]. The gold standard of movement pattern assessment is through the use of cost prohibitive 3D motion capture equipment.[19] A bilateral bodyweight squat is a movement that is simple, safe, low impact, low cost, used during a multitude of activities of daily living (ADLs), and easily modified during rehabilitation to increase the demands (e.g., adding an external weight, increasing sets and repetitions, increasing the tempo, etc.) on the patient.[18] Bilateral squats can be performed in a cyclic fashion that can aid in skill acquisition and once performed correctly may be used to develop optimal motor patterns that can be transferred to more intensive functional skills or activities (i.e. jump landings).[20–22]

Limb loading during a simple and functional, bilateral squatting task can be a way to identify sources of movement compensations early in the post-operative recovery period that may be indicative of long-term consequences (e.g., early onset OA) following ACLR. Bilateral squatting is a safe and easy maneuver that can be implemented early following ACLR, while limiting patient's exposures to overly demanding and risky tasks (i.e., jump landings). Therefore, the aims of this study were to: (Aim 1) compare limb loading during a body weight bilateral squatting task between limbs and across sexes and (Aim 2) describe the relationship between limb loading metrics and subjective function described through patient reported outcomes (PROs) in patients less than 9-months post-ACLR. We hypothesized that females would exhibit more asymmetric loading during the bilateral squatting task compared to their male counterparts, and that overall patients would have asymmetric loading during the squatting task as indicated by an underloading of the ACLR limb compared to the contralateral limb. Additionally, we hypothesized that patients who have more symmetric loading during the squatting task would also have greater subjective knee function, psychological readiness to RTA, and would report participation in higher levels of physical activity.

Methods

Study Design

This observational cohort study was a part of a larger point-of-care, collaborative research program in a single academic health system. This study was conducted in a controlled university laboratory setting and approved by the university's institutional review board for health science research. For the first aim, the independent variables were limb (ACLR vs contralateral) and sex (male vs female). The dependent variables were normalized peak force (N/kg) and unilateral cumulative load (UCL) (%). For the second aim, the variables on interest were the scores from the PROs (i.e., International Knee Documentation Committee subjective knee evaluation[23], Knee Injury and Osteoarthritis Score[24], Anterior Cruciate Ligament Return to Sport after Injury[25], and Tegner Activity Scale[26]) and limb symmetry index that was calculated from limb loading during the bilateral body weight squat. Sample size was based on identifying sex differences in limb loading using data collected in our lab as a variability estimate in limb loading. We determined that at least 104 (52 male and 52 female) patients were necessary to identify a moderate effect (Cohen's d = 0.5) between sexes with an $\alpha \leq 0.05$ and power (1-beta) of 0.80.

Participants

A total of 142 patients (50% female) volunteered to participate and were enrolled after providing written informed consent prior to enrollment. Patients were included if they had a primary, uncomplicated, unilateral, isolated ACLR surgery. Patients were excluded if they had a history of prior ACLRs, multi-ligament reconstruction, contralateral ACL injury, graft failure, sustained other lower extremity injuries or concussions within six months of study participation and or any time throughout the study, and or if they had a history of neurological disorders.

Table M1-1: Participant Demographics (Mean±SD)

	Total Participants	**Males**	**Females**
Sample (n)	142	71	71
Age (yrs)	24.42±11.09	23.83±9.66	25.02±12.39
Mass (kg)*	78.28±17.53	84.40±17.79	72.16±15.07
Height (cm)*	172.83±10.01	178.41±8.56	167.25±8.09
Time post-surgery (months)	5.17±1.40	5.03±1.35	5.32±.144
Surgical limb = Dominant limb (n[%])**	58 (40.8%)	33 (46.5%)	25 (35.2%)
Surgical limb = Nondominant limb (n[%])**	84 (59.2%)	38 (53.5%)	46 (64.8%)
Graft Type (n[%])**			
Patella Tendon	113 (79.6%)	57 (80.3%)	56 (78.9%)
Hamstring Tendon	17 (12%)	7 (9.9 %)	10 (14.1%)
Quadriceps Tendon	11 (7.7%)	7 (9.9 %)	4 (5.6 %)
Allograft	1 (0.7%)	0 (0%)	1 (1.4%)

*Significant difference between males and females determined by independent samples *t*-test (p<0.01); **Limb dominance and graft type is listed as the number of participants followed by the cumulative percentage.

Procedures

Limb loading during a bilateral body weight squat and PRO scores were measured during the same visit. Limb dominance was also recorded and self-defined as the limb that a patient would use to kick a soccer ball with.

Body Weight Squatting Task

Patients were instructed to complete three sets of three repetitions of a squatting task with rest periods as needed between trials. Patients were instructed to stand with their feet shoulder width apart and to perform a squat with approximately 90-degrees of knee flexion or to the "height of a chair" and to return to their upright standing position (Figure M1-1) at a pace set by a metronome (40 beats per minute where patients should be at maximum knee flexion i.e., at the "bottom of the squat" or at maximum knee extension i.e., the "top of the squat" at each beep of the metronome). Patients were given the opportunity to practice the squatting protocol until they felt comfortable performing the task. Vertical force was continuously measured from each limb individually using a pressure mat (SB Mat, Tekscan Inc., Boston, MA, USA) and software (FootMat Research ver. 7.10-14) sampled at 60Hz was used during data collection.

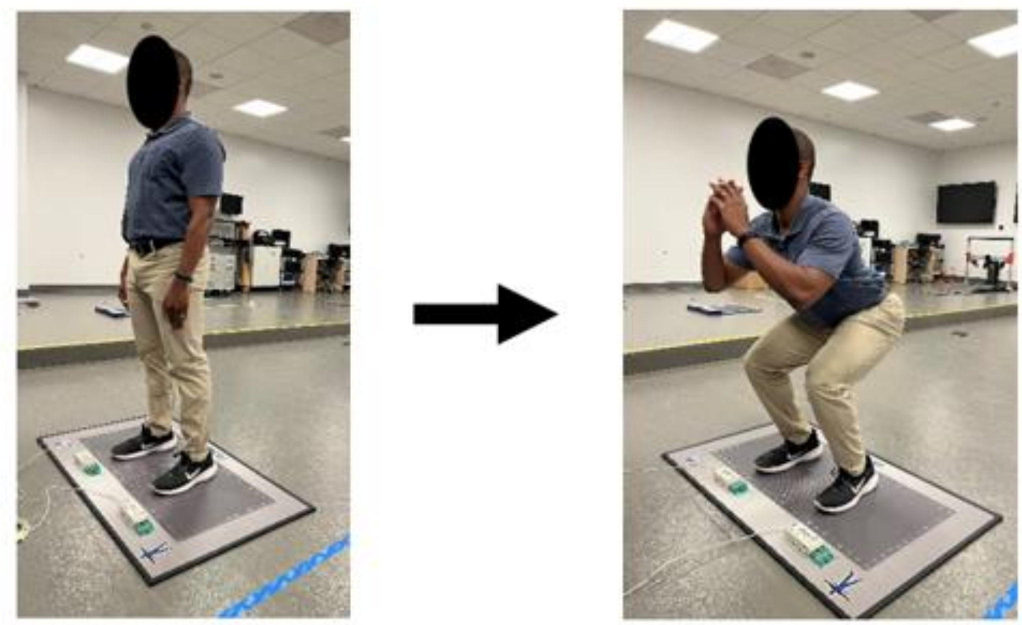

Figure M1-1. Data Collection set up during the bilateral squatting task. Patients were instructed to squat to approximately the height of a chair then return to their starting position three consecutive times to the rhythm of a metronome set to 40 beats per minute.

Patient-Reported Outcomes (PROs)

Each participant completed a series of PROs during the visit. The International Knee Documentation Committee (IKDC) was recorded determining subjective knee function.[23] The Knee Injury and Osteoarthritis Outcome Score (KOOS; Subscales include Symptom, Pain, Activities of Daily Living (ADL), Sport, and Quality of Life (QOL)) assessed the severity of the knee symptoms and functional disabilities experienced by the patient.[24] The Anterior Cruciate Ligament Return to Sport after Injury (ACL- RSI) was collected to assess the patient’s confidence, risk appraisal, and emotions related to resuming sport related activities.[25] The Tegner Activity Scale (TAS) was recorded to determine patients’ activity level that is based on work and sports activities.[26] All PROs have been found to be valid and reliable measures of their respective constructs.[23–27]

Data Processing

All data was processed using a custom MATLAB (MATLAB R2022a, ver 9.12.0, The MathWorks Inc, Natick MA, USA) code. Average peak loading force was calculated using the force (N) metrics derived from the FootMat software during the patient's squatting task. The peak force (N) was calculated individually for each limb by recording the largest single force output over each of the three sets and then averaging those values across the three sets. Once the peak loading was calculated for each individual, it was then normalized to each patient's body mass (N/kg). The UCL was calculated as the percentage (%) of each individual limb's contribution throughout the squat trial, then averaged across the three trials. A 50% UCL value for each limb is indicative of symmetry loading from each limb. Limb symmetry index (LSI) of the peak force produced by the ACLR limb divided by the contralateral limb was also calculated as a percentage (%), then averaged across the three trials. An LSI value of 100% is indicative of the ACLR limb producing the same or equal peak force value as the contralateral limb. The absolute value of LSI was also calculated by conducting: $1 - |LSI_{PeakForce}|$. An absolute value LSI score of 0 is indicative of equal peak force loading from each limb. A positive absolute value LSI score is indicative of higher peak force LSI loading from the ACLR limb while a negative value is indicative of higher peak force LSI loading from the contralateral limb.

Statistical Analysis

An independent samples *t*-test was conducted to determine the influence of sex on LSI of normalized limb loading peak force. The influence of sex on bilateral loading during squat tasks was evaluated using a 2x2 (limb-by-sex) analysis of covariance

(ANCOVA) while covarying for whether the surgical limb was the self-identified as the dominant or non-dominant limb. *Post hoc t*-tests were performed as appropriate. Paired-samples *t*-tests were used to compared normalized peak force limb loading values and UCL values between males and females and between the ACLR and contralateral limb. Cohen's *d* effect sizes were calculated and used to interpret pooled standardized mean differences, which are representative of the magnitude of observed differences. Effect size values were classified as small: ≤0.29, weak: 0.30-0.49, moderate: 0.50-0.79, or strong: >0.80.[28]

The relationship between the non-normally distributed PROs and limb loading metrics were calculated using Spearman's correlation coefficients. Correlation coefficients were determined to be classified as: weak: ≤0.35, moderate: 0.36-0.67, and strong: 0.68-1.00[29]. Positive correlations are indicative of as an individual increases their limb loading or symmetry value their PRO measures also improve. Negative correlations indicate that as an individual offloads their limb or decreases their limb symmetry their PRO outcome will improve.

SPSS v. 28.0 (IBM SPSS 244 Inc., Chicago, IL) was used for all statistical calculations. All analyses were performed with *a*≤0.05 determined *a priori.*

Results

Of the 142 participants, 91 exhibited peak force LSI values less than 1 indicating the majority of participants (64.1%) underloaded their ACLR limb. For those individuals who had an LSI value less than 1, the mean and standard deviation for their LSI value for peak force loading was 76.8±17.1%. Whereas 51 individuals (35.9%) had an LSI value for peak loading greater than or equal to 1 indicating greater loading of the ACLR limb compared to the contralateral limb during the squatting task. (Figure M1-2). Of these 51 individuals who exhibited an LSI value greater than or equal to 1 the mean and standard deviation LSI value for peak force limb loading was 127.3±21.4%. The percent difference between individuals who had an LSI value less than 1 compared to those whose LSI value was greater than or equal to 1 was 23.2% and 27.3% respectively. Across males, 25 individuals, or 35.2% of males, had an LSI value greater than or equal to 1, and 46 or 64.8% of males had an LSI values less than 1. For females, 26 individuals, or 36.6%, had an LSI value greater than or equal to 1, while 45 or 63.4%, of females had an LSI value less than 1. The independent samples *t*-test identified no significant differences between males and females peak force LSI values (t=1.54, p=0.06, Cohen's d=0.26).

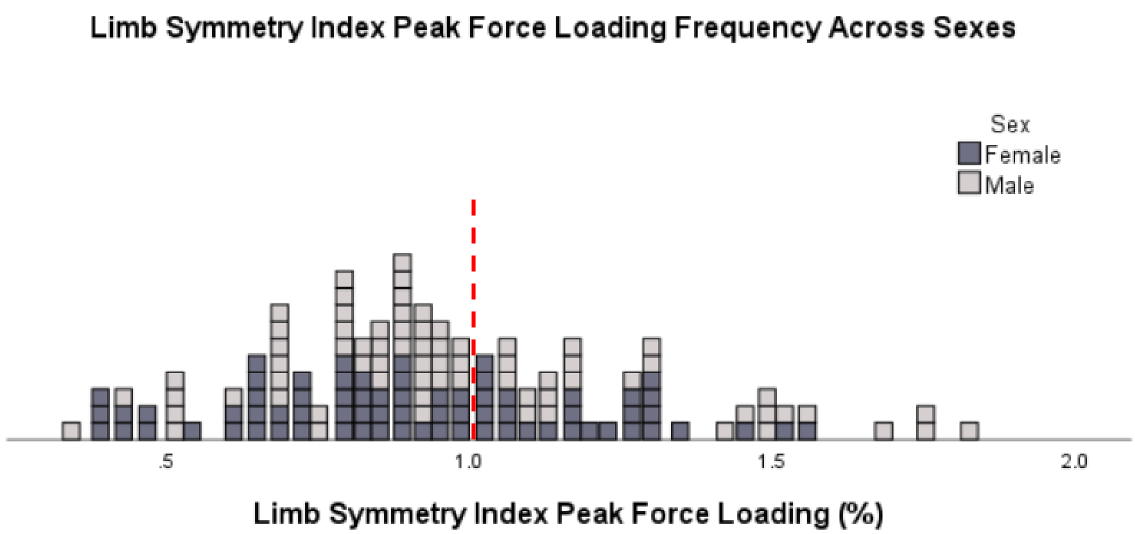

Figure M1-2. Limb symmetry index frequency distribution. Dashed line represents the split between individuals who had an LSI value greater than or equal to 1 (n=51) and less than 1 (n=91). LSI ≥ 1: Males (n=25), Females (n=26); LSI < 1: Males (n=46), Females (n=45)

A significant limb-by-sex interaction for normalized limb loading peak force ($F_{(1,139)}$=5.71, p=0.02, Figure M1-3) was observed. *Post hoc* analysis revealed females underloaded their ACLR limb compared to their contralateral limb (t=3.55, p<0.001, Cohen's d=0.42, Table M1-2). Males in general did underload their ACLR limb compared to their contralateral limb, however this finding was not statistically significant (t=1.49, p=0.07, Cohen's d=0.18, Table M1-2).

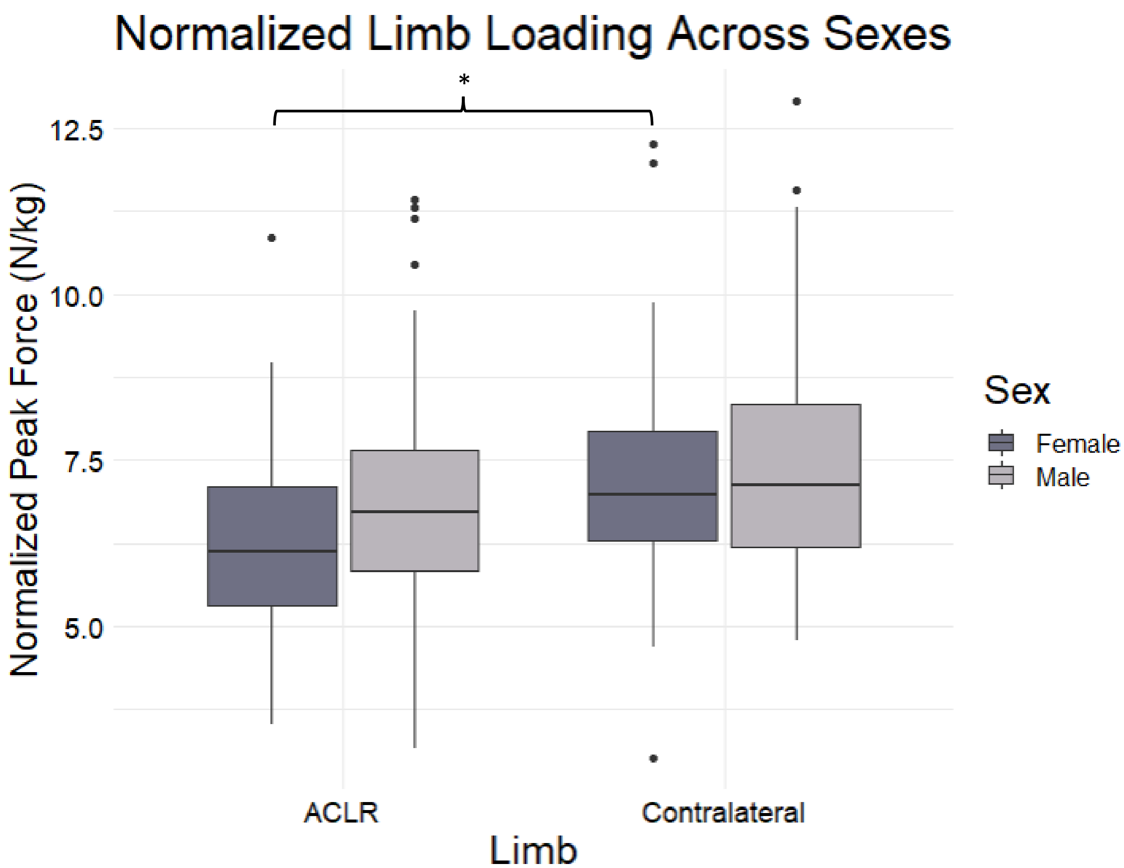

Figure M1-3. Limb loading normalized peak force differences between males and females following ACLR. * Indicates significant difference between limb loading between the ACLR and contralateral limb in females (p<0.05).

No limb-by-sex interaction was observed for UCL ($F_{(1,139)}$=2.48, p=0.12). However, there was a main effect for limb, where the UCL of the ACLR limb (48.8±10.0%) was loaded significantly less than the contralateral limb (51.2±9.0%; $F_{(1,139)}$=11.84, p<0.001, Cohen's d=0.22). There was no difference in UCL across sexes ($F_{(1,139)}$=0.032, p=0.86).

Table M1-2: Limb loading metrics across limbs and sexes (n=142)

	ACLR: Normalized Peak Force (N/kg)	**Contralateral: Normalized Peak Force (N/kg)**	**Effect Size: Cohen's *d***	***p*-value**	**95% Confidence Interval**
Male	7.0±1.65	7.4±1.60	0.18	0.07	-0.41, 0.06
Female	6.3±1.38	7.2±1.62	0.42	<0.001*	-0.66, -0.18
Combined	6.6±1.56	7.3±1.61	0.31	<0.001*	0.14, 0.47
	ACLR: UCL (%)	**Contralateral: UCL (%)**	**Effect Size: Cohen's *d***	***p*-value**	**95% Confidence Interval**
Male	49.3±10.0	50.7±9.5	0.07	0.272	-0.31, 0.16
Female	48.4±9.1	51.6±9.1	0.18	0.07	-0.42, 0.05
Combined	48.8±9.28	51.2±9.28	0.13	0.06	-0.04, 0.29

***Indicates significant differences between the ACLR and contralateral limbs (*p<0.05)**

There were weak, yet significant negative relationships between the contralateral limb for normalized limb loading peak force and UCL and PROs (p<0.05) (Table M1-3). There were weak significant positive relationships between the ACLR limb for normalized limb loading peak force and UCL and PROs (p<0.05) (Table M1-3).

Table M1-3. Spearman rho correlation coefficient values for limb loading metrics and PROs across ACLR and contralateral limbs

		PROs						
	Limb Loading Metric	**IKDC**	**KOOS Sym**	**KOOS ADL**	**KOOS Sport**	**ACL RSI**	**TAS Pre**	**TAS Current**
ACLR Limb	**Norm Peak Force**	0.10	0.03	0.11	0.03	0.03	0.11	**0.18***
	UCL	0.11	**0.17***	**0.19***	-0.10	0.08	0.15	0.09
Cont. Limb	**Norm Peak Force**	-0.16	**-0.23****	**-0.17***	-0.13	**-0.18***	-0.07	0.02
	UCL	-0.11	**-0.17***	**-0.19***	-0.10	-0.08	-0.15	-0.09
Abs. Value	**Peak Force LSI**	-0.003	-0.06	-0.04	-0.01	-0.01	-0.04	-0.04

International Knee Documentation Committee Subjective Knee Form (IKDC), Knee Injury and Osteoarthritis Score (KOOS), Symptom (Sym), Activities of Daily Living (ADL), ACL Return to Sport after Injury (ACL RSI), Tegner Activity Scale (TAS), Contralateral (Cont.), and Absolute (Abs.), Normalized (Norm.), Unilateral Cumulative Load (UCL). (*p<0.05, **p<0.01)

Discussion

The goals of this study were to compare side-side limb loading metrics during bilateral, body weight squatting and determine relationship with perceived function in patients recovering from a unilateral ACLR. In the current study, we observed patients who are approximately five months post-ACLR, on average, offload their ACLR limb compared to their contralateral limb during a bilateral bodyweight squat. It was also observed that females offloaded their ACLR limb more than their male counterparts (Figure M1-3) during the bilateral body weight squatting task. Finally, when evaluating limb loading metrics and PROs, weak relationships were observed in individuals following ACLR.

In the current study, we observed patients, on average, offloading their ACLR limb compared to their contralateral limb during a bilateral squatting task, which aligns with previously conducted research.[15,18,30,31] The magnitude of differences between limb loading discrepancies for the ACLR versus the contralateral limb in previously conducted studies were larger than the ones observed in this study. This difference in magnitude could be due to differences in methodologies and instrumentation, however, the results are all in congruence with each other. The offloading from the ACLR limb observed in individuals during an easy and safe bilateral squatting activity is cause for concern. If this movement pattern adaptation is not corrected this could perpetuate long-term when patients are participating in more dynamic and ballistic activities like running, jumping, and cutting maneuvers.[13,32,33] Poor biomechanics during these high demand activities that could increase one's risk for reinjury and catalyze the progression towards the development of early onset knee osteoarthritis.[11,14,30]

It is also important to note that when examining LSI values for the limb loading metrics that 51 individuals out of the 142 participants or 36% of our sample in the current study had an LSI value of 1 or greater. It is currently unclear as to which physical or psychological characteristics these patients might have allowed them to evenly distribute or even overload their ACLR limb during this squatting task. A recent study found that following three conditions, natural, instructed, and feedback, patients following ACLR went from being asymmetric in their loading during the natural condition to symmetrically loaded with the instructed and feedback conditions.[15] This finding indicates that with the proper training and instruction individuals following ACLR evenly distribute their weight across their limbs. Additionally, another previously conducted study found that time was a factor contributing to loading distribution, where individuals who were >24 months post-ACLR overloaded their surgical limb compared to their contralateral limb.[34] One additional possible explanation could be that these patients in the current study, were in a controlled laboratory setting doing a variety of lower extremity assessments on their surgical limb that could potentially altered their focus during the task and changed their natural kinematics by increasing their loading on their ACLR limb.

To our knowledge, this is the first study to examine the effect of sex on limb loading metrics during a bilateral squat in patients recovering from ACLR. In the current study, we observed that females offloaded their ACLR limb more and were more asymmetric during the bilateral squatting task compared to their male counterparts. Our results align with those of related studies that have investigated the influence of sex on 3D kinematic and kinetic variables during a variety of tasks such as walking and jump landings.[35–37] These studies, evaluating explosive tasks were suggestive that females had worse movement quality and decreased muscle activity compared to their male counterparts following ACLR.[35,36] However, during a mild walking task the opposite conclusion was made. Males with a non-contact mechanism of injury were found to underload their ACLR limb more than their female counterparts and males who sustained a contact mechanism of injury.[38] A bilateral squatting task could be an intermediary between an explosive task and leisure walking. Where a squat is not as physically demanding as a jump landing explosive task, however, it can be more demanding than leisure walking when progressed appropriately. Given the nature of a bilateral squatting task, it could have utility in highlighting loading asymmetries between sexes.

Additionally, it is possible that females following ACLR cope differently in their biomechanical movement patterns compared to their male counterparts. In the current study, the presence of sex differences for limb loading metrics at approximately 5-months post-ACLR indicates that clinicians have the opportunity to intervene whilst patients are attending structured ACLR rehabilitation. The impact of the observed sex differences in limb loading on post operative rehabilitation, return to sports decision making and re-injury risk is an area of future research.

Weak relationships found between limb loading metrics and PROs indicate that as a patient becomes more symmetric their subjective knee function improves. One significant relationship was observed for the limb load normalized peak force variable where patients applied less force on the contralateral their KOOS symptom score improved. This finding is similar to previous studies that found individuals following ACLR, who were considered symptomatic via KOOS scores, underloaded their ACLR limb compared to their contralateral limb during a walking task.[34,39] We also observed while the UCL coming from the contralateral limb decreased, the UCL from the ACLR limb increased, KOOS symptom and activity of daily living subscale scores improved. The KOOS activities of daily living subscale questions addresses the degrees of difficulty when preforming everyday tasks (e.g., rising from sitting, getting in/out of a car, getting on/off the toilet) which frequently mimic the motion of a bodyweight bilateral squat.[24] These relationships indicate that regardless of limb, patients who load their limbs more unevenly have a lower perception of their ability to complete activities of daily living. A similar relationship was found where individuals who had greater normalized peak force limb loading from their ACLR limb were currently participating in higher levels of physical activity determined by the TAS. A significant negative relationship was only observed for the ACL-RSI questionnaire and the normalized peak force from the contralateral limb. This is somewhat contradictory to a previous study's finding where no relationship was observed between limb loading during walking and kinesiophobia determined by the Tampa Scale for Kinesiophobia.[40]

A bilateral bodyweight squat is a commonly used exercise during rehabilitation sessions and when performing activities of daily living. The ability to objectively and precisely measure limb loading during a commonly performed movement (i.e., bilateral squat) gives clinicians tools to practice personalized medicine. Personalizing a patient's rehabilitation protocol to fit their individualized needs using a translatable clinical measure allows for more targeted interventions and ultimately better outcomes. During traditional RTA testing batteries that clinicians commonly use strength measures, functional tasks, and subjective patient reported functional outcomes.[41,42] Limited previous research has incorporated a squatting task variation in a RTA protocol, and few have utilized a bilateral body weight squat in their arsenal of tests.[21,43–46] Many researchers have suggested that the optimal time for individuals to RTP can be anywhere between nine to twelve months following surgery.[1,42,44,47] The average time following ACLR for the individuals in the current study is approximately five months, indicating that patients may need to be re-examined closer to the time of their clearance to return-to-play. It is currently unclear whether these loading asymmetries persist past five months following ACLR. The evidence provided in the current study highlights the need to further investigate the influence of limb loading metrics following ACLR during serial assessment and explore the feasibility of implementing a squatting task into an RTA protocol.

Limitations

Participants in this study underwent rehabilitation with their preferred clinician therefore we did not control post operative rehabilitation. Additionally, rehabilitation plans were not recorded nor was compliance to complete their recommend protocol. The current study required one visit to the laboratory at a time point when rehabilitation may not have been complete, therefore the findings of this study should be considered an interim functional analysis as patients are recovering from ACLR. A single testing session may not be representative of overall patient function following ACLR, the importance of repeat testing to tracking progress, evaluating the efficacy of exercise interventions and making informed healthcare decisions is immeasurable. Throughout the testing session we standardized squat pace using a metronome, which could have influenced preferred squatting pace and may be less generalizable to functional scenarios during activity or sport. However, it has been observed that there is a moderate to strong relationship between the biomechanical movement profiles during a bilateral squatting task and a drop landing task in individuals following ACLR.[30] This relationship suggests that movement patterns during a squatting task could carry over during a high demand dynamic jump landing task, indicating that a squatting task could be a useful proxy to evaluate the quality of movement patterns in a safe manner.

Conclusions

Approximately five months post-surgery, patients recovering from ACLR were observed offloading their ACLR limb to their contralateral limb. Females underloaded their ACLR limb more than their male counterparts. Additionally, the relationship, albeit small, between limb loading metrics and PROs, may indicate individuals who are asymmetrically loading their limbs during a bodyweight bilateral squatting task perceive a decreased ability to perform their activities of daily living. The evidence provided in this study highlights the need to further investigate the influence of limb loading metrics following ACLR and explore the feasibility of implementing a bilateral squatting task into an RTA protocol.

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SECTION II: MANUSCRIPT II

Analysis of Lower Extremity Strength and Limb Loading Recovery Across Time Following Anterior Cruciate Ligament Reconstruction

Abstract:

Introduction: Common goals following anterior cruciate ligament reconstruction (ACLR) throughout recovery is to regain lower extremity strength and ensure good movement quality strategies in order to mitigate reinjury risk and successfully return to unrestricted activity (RTA). Limb loading characteristics during bilateral bodyweight squats and isokinetic quadricep and hamstring peak torque are items of interest to assess movement quality and strength. Therefore, the aims of this study were to (1) describe how limb loading and strength change from early to late-stage recovery and (2) analyze the relationship between the change in limb loading performance and the change in quadriceps and hamstring strength metrics.
Methods: Participants consisted of 60 individuals (28 males and 32 females) who were on average 22.5±9.35yrs, Months post-ACLR: Visit 1: 4.9±1.44, Visit 2: 8.0±1.90, participated in two laboratory visits to assess limb loading and strength across recovery. Limb loading peak force (N) and unilateral cumulative load (%) of the ACLR and contralateral limbs were recorded. Quadriceps and hamstring isokinetic peak torque (Nm) values were also collected at 90º/sec for both the ACLR and contralateral limbs. Limb symmetry index (%) was calculated for both limb loading metrics and strength metrics. Change scores were calculated from the change in limb loading and strength outcomes from visit 1 to visit 2. Two separate analysis of variance was conducted to compare limb loading metric and lower extremity strength metrics across limbs and time. A Pearson's *r* correlation was conducted to examine any relationship between limb loading and strength change scores.
Results: A significant limb-by-time interaction was observed for limb loading peak force (N) ($F_{(1,59)}$=5.71, p=0.02) where the ACLR limb was significantly underloaded at visit 1 compared to the contralateral limb (t=2.42, p<0.01, Cohen's d=0.31). However, the ACLR limb significantly improved across visits (t=1.83, p=0.04, Cohen's d=0.24). Additionally a limb-by-time interaction for quadriceps peak torque (Nm) ($F_{(1,59)}$=36.40, p<0.001) was observed where the ACLR significantly increased the peak torque value across visits (t=9.69, p<0.001, Cohen's d=1.25), however strength deficits persisted at both visit 1 (t=14.69, p<0.001, Cohen's d=1.90) and visit 2 (t=11.23, p<0.001, Cohen's d=1.45). There was no significant relationship observed between change scores for limb loading metrics and strength metrics.
Conclusion: From early to late-stage recovery following ACLR, limb loading peak force on average increased for the ACLR limb and decreased on the contralateral limb during a bilateral squatting task. Quadriceps and hamstring peak torque also on average increased across visits. No relationship was observed between the change in limb loading metrics and lower extremity strength. This could indicate strength and motor control determined via limb loading, recover independently of each other. Future research should further investigate the influence of strength and neuromuscular control throughout the recovery process following ACLR and the potential impact on longer term prognosis and outcomes.

Introduction

Anterior cruciate ligament (ACL) injury and subsequent elective reconstructive surgery is a common musculoskeletal injury and course of treatment in physically active individuals.[1] Many patients who opt for an ACL reconstruction (ACLR) after injury do so with the goal to return to their prior level of physical activity or sport. However, neuromuscular adaptations are common in patients who undergo ACLR and can lead to persistent quadriceps weakness, abnormal movement patterns, and muscle activation deficits.[2] Persistent quadriceps muscle weakness is a barrier for many patients when trying to return to their previous level of activity.[3,4] Strength has been observed to gradually improve from four to six months following ACLR.[5] Unfortunately, these strength and movement pattern deficits have been seen to persist anywhere from one to seven years post-surgery.[3,5–9] The individualized nature of muscle recovery highlights the need for repeated patient assessment providing objective benchmarks in order to inform clinical decision making throughout the rehabilitation process[5]. The ability to track changes and highlight neuromuscular deficits described via limb loading as well strength recovery over time will aid clinicians in adapting an individualized rehabilitation program and guiding decision making as patients are returning to pre-injury activities.

The presence of strength deficits may also lead to poor biomechanical movement patterns that can subsequently increase an individual's risk for reinjury following ACLR.[6,10–12] Many clinicians incorporate precise measures of patients' physical performance including strength and biomechanical function with testing protocols to guide the timing for release from care and return to unrestricted activity (RTA)[5]. During traditional RTA testing batteries, clinicians will utilize a variety of strength measures, functional tasks, and subjective patient reported outcomes in order to determine a patient's readiness to RTA[13,14]. Limited research has incorporated a squatting task (e.g., single leg squat[1,8,15]) in an RTA protocol, and few have utilized a bilateral bodyweight squat in their arsenal of tests[16]. The most common time for researchers and clinicians to test ACLR patients is as the individual is attempting to RTA[8], however, to our knowledge no previously conducted study has assessed squatting technique over time throughout the rehabilitation process. A bilateral squatting task is a multi-joint exercise that individuals need to be able to independently perform many activities of daily living (e.g., getting in/out of a car, sitting/standing on the toilet, rising from bed, picking up an object from the floor). Advanced motion capture techniques have been validated and commonly used to assess movement quality; however, these methods can be time and cost inefficient.[17] Therefore, a simple assessment that can be instrumented that is clinically accessible is an optimal solution for objective movement quality testing. Adding the objectivity of implementing an instrumented pressure mat during the bilateral squat to determine the amount an individual might offload the involved ACLR limb reduces the subjectivity associated with a clinician's visual inspection.

Determining how limb loading characteristics during a simple, easy, safe, cost-effective task (i.e., a bilateral squat) change from early to late-stage recovery can be clinically impactful. Serial assessments of movement quality can glean information on a patient's progression allowing for early intervention from clinicians to correct poor movement patterns and thereby lowering the risk of reinjury.[5] Over the course of post operative rehabilitation, it is essential to identify poor motor function during common maneuvers and activities of daily living. Precision measurements of bilateral loading during squatting tasks is a safe and easy approach for clinicians to provide patient feedback and guide impairment-based exercise progressions. Therefore, the aims of this study are to: (1) describe how limb loading during a bilateral squatting task and quadriceps extension strength changes over two time points during recovery following ACLR and (2) to analyze the relationship between the change in limb loading symmetry during a bilateral squatting task over time, compared to the change in quadriceps and hamstring strength symmetry over time between testing visits. We hypothesize that limb loading during squatting will improve over time and will be related to improvements in quadriceps and hamstring strength recovery.

Methods

Study Design

This observational cohort study was part of a larger point-of-care collaborative research program in a single academic health system and was approved by our university's institutional review board for health science research. All testing was conducted in a controlled laboratory setting. The independent variable was time post-surgery (Visit 1: approximately four to six months post-surgery, Visit 2: approximately six to eight months post-surgery) for the two patient visits. The dependent variables for limb loading were peak force (N) and unilateral cumulative load (UCL) (%). The dependent variable for quadriceps strength was knee extension peak torque (Nm).

Participants

A total of 60 patients (53% female) volunteered to participate and enrolled in the current study following written informed consent (Table M2-1). Patients who had an isolated, primary, uncomplicated ACLR surgery were included in the study. Patient were excluded if they had a history of prior ACLRs, multi-ligament reconstruction, a contralateral ACL injury, graft failure, sustained other lower extremity injuries, sustained a concussion within the last six months, or had a history of neurological disorders.

Table M2-1. Participant Demographics (Mean±SD)

	Total Participants (n=60)
Sex (Male/Female)	28M/32F
Age (yrs)	22.55±9.35
Mass (kg)	76.95±15.42
Height (cm)	172.05±9.51
Time post-surgery (months)	Visit 1: 4.85±1.44 Visit 2: 7.96±1.90
Surgical limb = Dominant limb (n[%])*	23 (38.3%)
Surgical limb = Nondominant limb (n[%])*	37 (61.7%)
Graft Type (n[%])*	
Patella Tendon	49 (81.7%)
Hamstring Tendon	8 (13%)
Quadriceps Tendon	3 (5%)

***Limb dominance and graft type is listed as the number of participants followed by the cumulative percentage.

Procedures

Limb loading during a functional task, as well as quadriceps strength was measured during visit 1 and visit 2.

Double Leg Squatting Task

Limb loading was measured during a bilateral body weight squat using an instrumented pressure mat (SBmat, Tekscan Inc., Boston, MA, USA) and associated software (FootMat Research ver. 7.10-14). Patients were instructed to stand with their feet shoulder width apart and to squat down at approximately 90-degrees or to the "height of a chair" and to return to their upright standing position (Figure M2-1). Patients were asked to complete three sets of three repetitions of the squatting task with rest provided between sets upon request. Patients were also given the opportunity to practice the squatting task to the metronome until they felt comfortable performing the task. Data were collected at 60Hz with patients moving to a set metronome of 40 beats per minute. The average peak force (N) and UCL (%), were computed using a custom written code (MATLAB R2022a, ver 9.12.0, The MathWorks Inc, Natick, MA, USA) code.

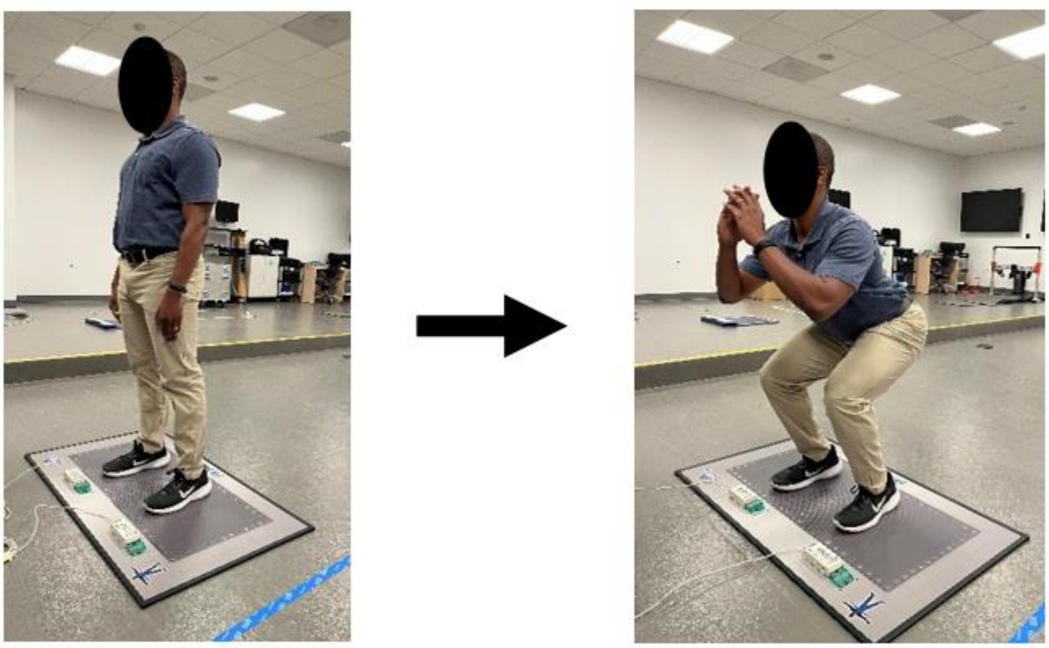

Figure M2-1. Data collection set up during the bilateral squatting task. Patients were instructed to squat to approximately the height of a chair then return to their starting position three consecutive times to the rhythm of a metronome set to 40 beats per minute. This was repeated across three trials.

Quadriceps and Hamstring Strength Assessment

Isokinetic quadriceps and hamstring peak torque were measured bilaterally during isokinetic testing at 90º/s using a multimodal dynamometer (Systems IV, Biodex Medical Systems Inc, Shirley, NY). All patients were instructed to sit on the dynamometer chair, which was then adjusted so that their hips and knees were set to 85-degrees 90-degrees of flexion respectively (See Figure M2-2). All patients were instructed to kick out “as hard and fast as possible” until they reach full extension followed by an immediate pull back in “as hard and fast as possible” until they reach full flexion. Patients were instructed to complete eight consecutive repetitions of the isokinetic task[18]. All patients tested their contralateral limb first, then followed with their ACLR limb.

Figure M2-2. Patient set up for the quadriceps and hamstring strength assessment. Patients were positioned with their hip and knees flexed at 85° and 90° respectively. Patients were instructed to extend and flex their knee as fast as possible using only their lower extremity musculature. Patients completed eight repetitions total per limb and always started the testing session with the contralateral limb.

Data Processing

The average peak force (N) was calculated individually for both the ACLR and Contralateral limbs of each patient. The peak force recorded for each limb for each of the three trials were averaged together. The UCL (%) was calculated as the percentage of each individual limb's contribution throughout the squatting trial, then averaged across the three trials. Limb loading symmetry was calculated as the force of the ACLR limb divided by the force of the contralateral limb averaged across the three trials. The quadriceps peak torque was recorded as the largest value obtained during the testing session.

Statistical Analysis

A 2x2 limb-by-time analysis of variance (ANOVA) was used to determine how limb loading metrics (i.e., peak force (N) and UCL (%)) from the ACLR and contralateral limb change over the course of two laboratory visits. An additional 2x2 limb-by-time ANOVA was conducted to determine how quadriceps and hamstring isokinetic strength to body mass (Nm) at 90º/s changed from visit 1 to visit 2. *Post hoc t*-tests performed where appropriate. Paired samples *t*-test was used to compare peak force, UCL, quadriceps strength, and hamstring strength across visit 1 and visit 2.

Pearson's *r* correlation coefficient was utilized to examine the relationship between quadriceps and hamstring strength symmetry change scores and limb loading symmetry change scores, quadriceps and hamstring peak torque change scores, and limb loading peak force changes scores. Correlation coefficients were determined to be classified as: no relationship: 0-0.25, fair: 0.26-0.50, moderate: 0.51-0.75, and excellent: >0.76[19].

All statistical analysis was conducted using version 28 of SPSS (IBM SPSS 244 Inc., Chicago, IL). An *a priori* alpha level was set to ≤0.05 for all analyses.

Results

There was a significant limb-by-time interaction for peak force (N) ($F_{(1,59)}$=5.71, p=0.02) but not for UCL (%) ($F_{(1,59)}$=1.76, p=0.19) (Figure M2-3). There was no main effect for limb ($F_{(1,59)}$=0.19, p=0.67) nor time ($F_{(1,59)}$=0.16, p=0.69) for the UCL. For the limb-by-time interaction for peak force, *post hoc* paired *t*-tests indicated for limb loading peak force, individuals increased the loading on their ACLR from their visit 1 (502.79±142.64 N) to visit 2 (527.02±159.41 N**,** t=1.83, p=0.04, 95% CI [-0.02, 0.49], Cohen's d=0.24). For the limb loading peak force, individuals significantly underloaded their ACLR limb (502.79±142.64 N) compared to their contralateral limb at visit 1 only (560.32±149.58 N, t=2.42, p<0.01, 95% CI [0.05, 0.57], Cohen's d=0.31). Additionally, individuals decreased the loading on their contralateral limb (560.32±149.58 N) from visit 1 to visit 2 (547.30±152.56 N), however, this decrease in limb loading was not significantly different across visits (t=-0.81, p=0.21, 95% CI [-0.36, 0.15], Cohen's d=-0.10).

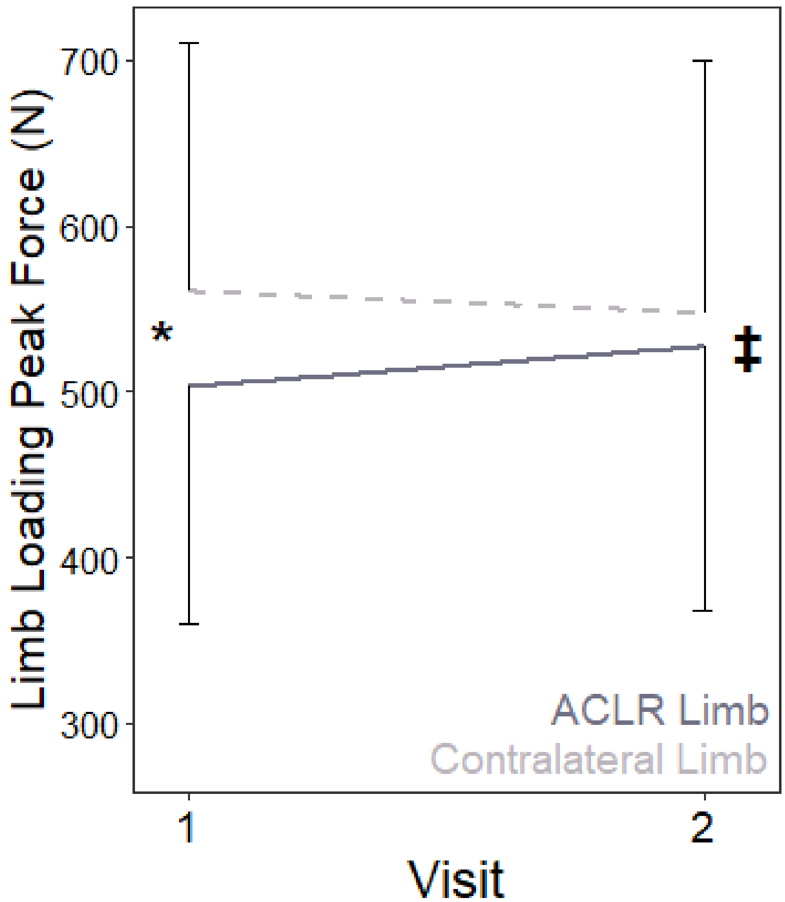

Figure M2-3. Mean limb loading peak force changes across Visit 1 and Visit 2. (*Significant differences at Visit 1 between limbs, $p<0.05$; **Significant differences between Visit 1 and Visit 2 for the ACLR limb)

There was a significant limb-by-time interaction for quadriceps peak torque (Nm) ($F_{(1,59)}=36.40$, $p<0.001$) (Figure M2-4). For this interaction, *post hoc* paired *t*-tests indicated that the ACLR limb peak torque increased from visit 1 (99.24±37.80 Nm) to visit 2 (123.36±43.46 Nm, $t=9.69$, $p<0.001$, 95% CI [0.91, 1.59], Cohen's $d=1.25$). Additionally, quadriceps peak torque for the ACLR limb at visit 1 ($t=14.69$, $p<0.001$, 95% CI [1.47, 2.32], Cohen's $d=1.90$) and visit 2 ($t=11.23$, $p<0.001$, 95% CI [1.08, 1.81], Cohen's *d*=1.45) was significantly lowered compared to the contralateral limb (Visit 1:169.38±47.29 Nm, Visit 2: 173.29±48.84 Nm).

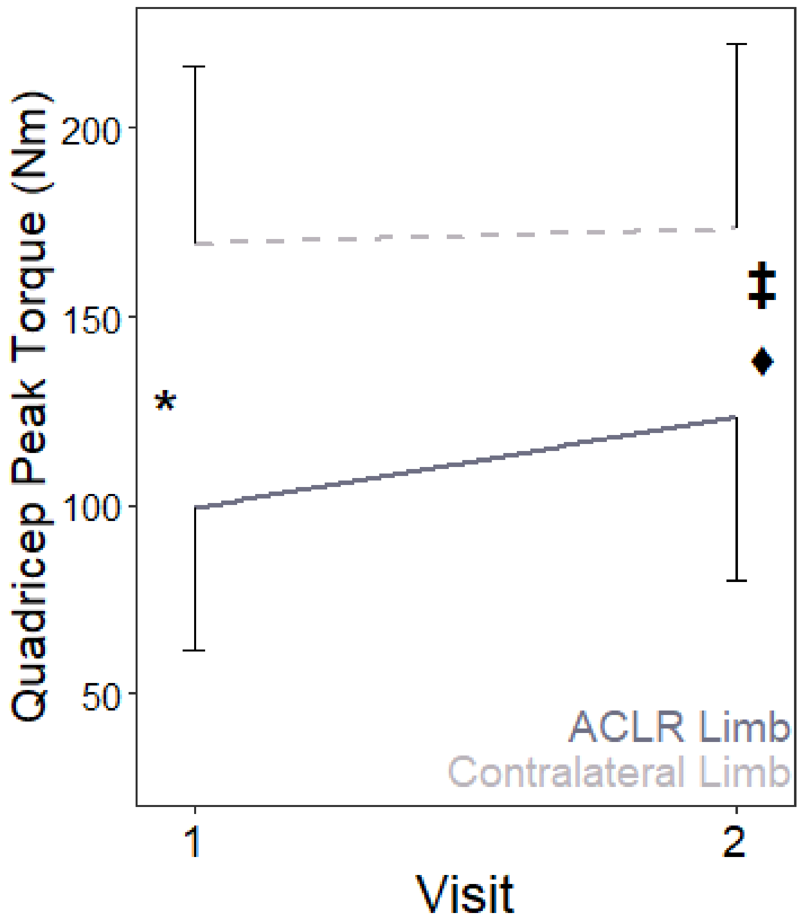

Figure M2-4. Mean quadriceps peak torque changes across Visit 1 and Visit 2. (*Significant differences at Visit 1 between limbs, $p<0.05$; ‡Significant differences between Visit 1 and Visit 1 for the ACLR limb, $p<0.05$; ♦Significant differences at Visit 2 between limbs, $p<0.05$)

No significant limb-by-time interaction was found for hamstring peak torque (Nm) ($F_{(1,59)}=1.60$, $p=0.21$) (Figure M2-5). There was a main effect for limb ($F_{(1,59)}=5.32$, $p=0.03$) for hamstring peak torque, where the ACLR limb produced less torque than the contralateral limb. Additionally, there was a main effect for time ($F_{(1,59)}=41.50$, $p<0.001$)

for hamstring peak torque, where hamstring torque increased from visit 1 to visit 2 (Visit 1: ACLR: 68.61±21.75 Nm Contralateral: 72.87±18.37 Nm; Visit 2: ACLR: 78.21±20.33 Nm, Contralateral: 80.15±18.99 Nm).

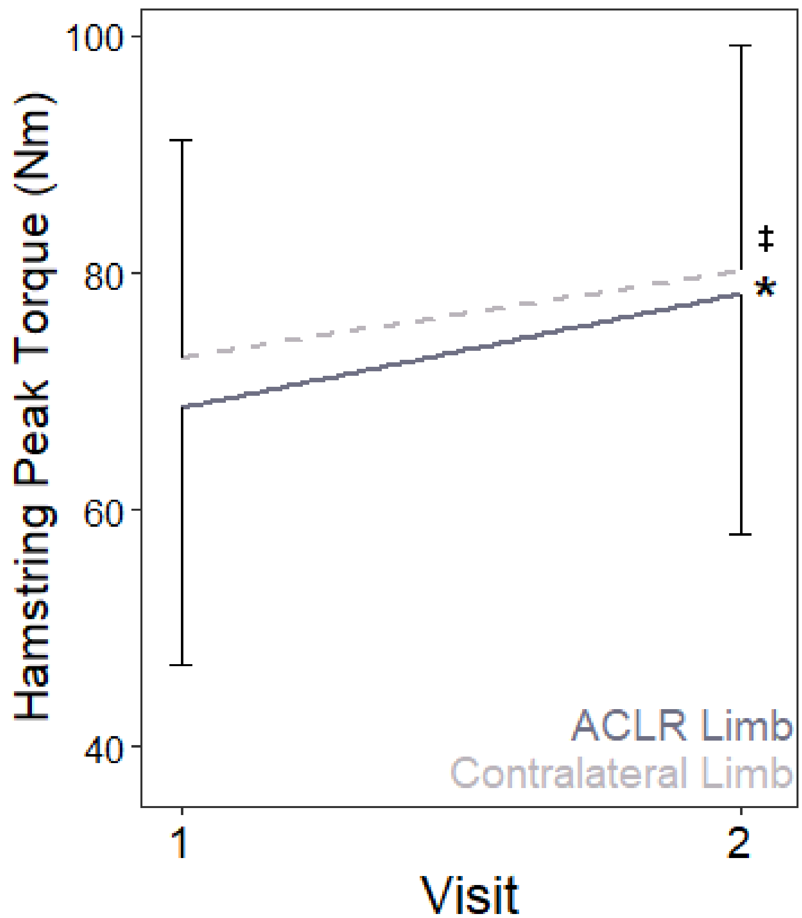

Figure M2-5. Mean hamstring peak torque changes across Visit 1 and Visit 2. (*Time main effect, significant difference from Visit 1 to Visit 2, $p<0.05$; ‡Limb main effect, significant difference between the ACLR and contralateral limb, $p<0.05$)

No significant relationships were observed for the person's correlations across limb loading symmetry and lower extremity changes scores. There were also no significant relationships between limb loading peak force and UCL and lower extremity strength peak torque.

Discussion

The primary goal of the current study was to compare limb loading during a bilateral squatting task over time in patients rehabilitating after primary, unilateral ACLR and to examine the relationship with quadriceps and hamstring strength recovery. In the current study we observed patients with ACLR, on average exhibit increased loading on their ACLR limb and decreased loading on their contralateral limb between visits approximately four to eight months following ACLR. Based on the findings of this study, this change in loading was not related to strength changes in quadriceps and hamstring muscle groups over the same time period.

The side-to-side difference in limb loading at visit 1 agrees with previous research highlighting an underloading of the ACLR limb compared to the contralateral limb during functional tasks (e.g., walking, squatting, jump landing) following ACLR.[20–25] In the current study we observed patients offloading the ACLR limb early in recovery agrees with a previous finding where individuals offloaded their ACLR compared to their contralateral limb at earlier stages of recovery following ACLR.[22] However, at later stages of recovery patients were found to not underload their ACLR limb compared to their contralateral limb. This increase in limb loading for the ACLR limb is a promising clinically relevant finding due to the increased risk patients have for developing early onset osteoarthritis. A recent study found that underloading the ACLR limb during gait was associated with negative adaptations in the tibiofemoral cartilage composition as early as six months post-surgery.[26] In the present study, the concurrent reduced loading of the contralateral limb, while not statistically significant, suggests that individuals are starting to more symmetrically distribute their bodyweight across both limbs during a functional task like a bodyweight squat. This finding is promising given traditionally rehabilitation specialists have the ultimate goal for their patients to achieve symmetry across strength, hopping and functional tasks (i.e., gait, jump landings, etc.) in order to RTA.[27–30]

Additionally, the finding of an increase in quadriceps and hamstring strength over the course of visit 1 and visit 2 has been observed in previously conducted studies.[3,5,31,32] This finding of an increase in lower extremity strength across recovery is expected due to the participation in rehabilitation programs where one of their primary goals is for patients to recover lower extremity strength.[1,30] It is of note that even with improvements of quadriceps strength over time, there were still significant deficits in peak torque output compared to the contralateral limb at late-stage recovery. The presence of strength deficits near the point of RTA, is cause for concern where individuals may begin, or continue, to implement alternative movement strategies of shifting their loading to adjacent joints or musculature to adapt to the demands of their activity (e.g., sporting competition).[33]

Many rehabilitation programs are structured to have the vast majority of patient visits with a rehabilitation specialist to occur by 16-weeks, or three months, post-surgery.[34] However, if patients are exhibiting poor motor functions around six months following ACLR surgery, they likely will have already attended the majority of their rehabilitation visits, limiting their access to rehabilitation specialists to correct their negative movement patterns. The present study, to our knowledge, is the first study to examine how limb loading metrics during a bilateral squatting and lower extremity strength concurrently change over time from mid- to late-stage recovery following ACLR. Previous studies have examined limb loading asymmetries during gait and jump landings following ACLR during recovery and up to two years following ACLR.[7,28,35–39] Due to previously conducted research the finding of limb loading discrepancies at early stages of recovery and the improvement of lower extremity strength over time were not surprising.[5,22,40] Following a ligamentous injury there is evidence of a reorganization of the motor cortex that can induce reduced neuroplastic changes that can negatively modify sensory feedback leading to altered motor output.[2] Following these neuroplastic changes, a greater demand is placed on the neuromuscular system potentially resulting in poor biomechanical movement patterns.[2] Many individuals have been investigating the influence of neuromuscular training following ACLR across a rehabilitation and injury prevention lens for several years.[12,41–45] Following ACLR, each patient received standard-of-care guidelines that incorporates neuromuscular training tasks starting between four to six months post-surgery.[34] The potential implementation of neuromuscular training during these individual's rehabilitation starting at four months post-ACLR could be why limb loading deficits between the ACLR and contralateral limbs were observed at visit 1 and not at visit 2.

The lack of a relationship between the change in limb loading and lower extremity strength was contrary to our hypothesis and an unexpected finding. Resistance training is a large part of rehabilitation following ACLR.[32,46,47] Resistance training has been observed as integral factor when causing positive adaptations to the neuromuscular system.[48–51] Following ACLR, there have been previously observed negative effects on the neuromuscular system leading to strength deficits and poor neuromuscular control even after surgical reconstruction.[52–54] With the previously described evidence of the positive influence of strength training on the neuromuscular system it was hypothesized that as patients' strength improves as would their limb loading metrics. However, in this study it appears that improvements in lower extremity strength and neuromuscular control, determined by limb loading performance, are independently recovering from each other following ACLR. A similar finding of no relationship between isokinetic quadriceps peak torque and gait metrics was observed in individuals six months following ACLR.[55] It was also found in healthy female collegiate athletes, landing mechanics improved following a brief instruction and technique cueing, however, strength was not a predictor of landing mechanics performance.[56] This finding reinforces the notion that strength and functional performance may not influence each other in healthy individual, which could be further exacerbated in individuals following ACLR because of their predisposition to altered strength and motor control. Outside factors may be influencing the recovery of strength and limb loading performance over time, suggesting that strength and motor control may need to be separately addressed throughout rehabilitation programs. ACLR.

A bilateral squat can be used to potentially lay a foundation of good quality motor patterns and is easily modifiable due to the controlled nature of the task.[20,57] The 3D kinematic assessment of bilateral squatting technique has been shown to be a motor skill that will have transferable kinematic effects to dynamic hopping tasks.[57,58] However, a vast majority of patients who suffer from an ACLR do not have access to research grade equipment or 3D kinematic assessments. Many patients are also challenged with the barrier of accessibility to physical therapy visits that are covered by health insurance.[34] Without proper access to rehabilitation specialists/scientists, identifying maladaptive loading patterns following ACLR could become challenging. Patients who exhibit poor movement patterns at later stages following ACLR surgery most likely have also exhausted their number of rehabilitation visits covered by insurance.[34] This limited access to rehabilitation specialists/scientists to analyze and correct their maladaptive movement patterns could have negative consequences on patients' ability to return to their previous level of physical activity. The utilization of a simple, easy, safe, cost-effective task such as a bilateral squat requiring less expenses (i.e., equipment, employee training, etc.) could allow for early intervention from clinicians in order to correct poor movement patterns and lowering the risk of reinjury.

Limitations

Study participants underwent rehabilitation with their preferred rehabilitation specialist, therefore limiting our ability to control any aspect of patients' post operative rehabilitation protocol or rehabilitation compliance. Throughout the testing sessions participants were instructed to squat to a standardized metronome beat which could have influenced the way individuals naturally distributed their body weight during the task due to the potential novelty of the task. However, participants were provided with ample practice trials to familiarize themselves with the study procedures. Additionally, patients were wearing preferred footwear during testing instead of a standardized shoe which could have influenced squatting performance.

Participants completed the squatting task under a rested state, future studies may evaluate the role of fatigue on loading and loading recovery. Additionally, the laboratory setting in conjunction with the nature of the squatting task being a low impact task that they complete during their everyday activities could possibly not have been rigorous enough to elicit the full magnitude of maladaptive movement patterns. However, the bilateral squatting task has been described a safe low impact maneuver to be performed early during recovery following ACLR and is described as one fundamental movement involved in participation of activities of daily living, sport specific training, and sporting competitions.[20,29,59]

Conclusions

In patients following primary, unilateral ACLR, limb loading during a bilateral body weight squat, on average, increased on the ACLR limb and decreased on the contralateral limb over time. Quadriceps and hamstring strength also on average increased across visits. There was no relationship observed between the change in limb loading metrics and lower extremity strength potentially indicating that strength and limb loading recover independently of one another. Future research should further investigate the influence of strength and neuromuscular control throughout the recovery process following ACLR and the potential impact on longer term prognosis and outcomes.

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SECTION II: MANUSCRIPT III

An Exploratory Analysis of the Predictability of Limb Loading on Functional Performance Outcomes After ACLR

Abstract

Introduction: Bilateral bodyweight squats are a multi-joint exercise that are safe, easy, and cost-effective assessment that can be completed early during recovery to evaluate movement quality. Many return to unrestricted activity (RTA) assessments are not conducted until 6-month or later following surgery due to safety concerns when completing dynamic jump landing tasks. The primary goals of this study were to determine if limb loading and lower extremity strength metrics and subjective function at an interim stage of recovery is associated with LESS jump landing performance at a later stage of recovery.
Methods: Participants consisted of 203 individuals (107M/96F) who were on average 21.8±7.77 years old and 8.8±6.71 months post-anterior cruciate ligament reconstruction (ACLR). Data from all participants was used for an exploratory factor analysis (EFA) of LESS item errors. From the EFA, factor scores were generated using three unique methods: summation, weighted, and binary method. Of those, 45 individuals (51.1%, 22 males and 23 females, 20.4±7.11 years old) participated in an RTA assessment in a controlled laboratory across two visits (Visit 1: 5.1±1.42 months post-ACLR; Visit 2: 8.3±1.81 months post-ACLR). Limb loading peak force (N), quadriceps peak torque (Nm), and ACL-RSI assessments were administered at visit 1. Limb symmetry index (%) was calculated for limb loading peak force and quadriceps peak torque. The LESS was administered at visit 2. Multiple linear regressions and binary logistic regressions were completed using the three factor scoring methods and incorporated limb loading, quadriceps strength, and ACL-RSI score as predictors for analysis.
Results: An exploratory factor analysis across LESS scores grouped together into 2 factors evaluating (1) foot and body segment positioning during landing and (2) knee valgus and landing stiffness. Multiple linear regressions found a significant model ($F_{(3,39)}$=3.20, p=0.03, R^2=0.20) for the weighted method, indicating ACL-RSI scores were a significant predictor of errors being committed in factor 2 (β=0.02, p=0.01). A significant binary logistic regression (p<0.01, Nagelkerke R^2=0.34, AUC=0.86, 95% CI [0.74, 0.97]) also found unilateral limb loading peak force (N) (OR=0.99, 95% CI[0.985, 0.9998], p=0.04) was a significant predictor of errors being committed in factor 2.
Conclusion: Limb loading peak force (N) on the ACLR limb assessed via bilateral bodyweight squats around 5-month post-surgery was found to be predictive of the potential adoption of risky biomechanical movement patterns (i.e., knee valgus and stiff landings) during a jump landing task at approximately 8-months following ACLR.

Introduction

A common goal of individuals following anterior cruciate ligament reconstruction (ACLR) is for patients to return to participating in physical activity.[1,2] Due to the majority of ACL injuries happen during a sporting activity or fast-paced dynamic task, it is important to ensure that individuals are able to safely reintegrate into sport participation with proper biomechanical form.[3–5] Following initial injury and subsequent reconstruction, many people face strength and functional movement deficits which can increase these individuals risk for reinjury.[6,7] The odds of reinjury following an ACLR after returning to competitive sport has been reported to be as high as five times that of those who did not return to competitive sports.[8,9] It is of utmost importance to ensure that individuals following ACLR are able to safely return to unrestricted activity (RTA) with the highest quality movement patterns.

Movement patterns during activity are modifiable factors that rehabilitation specialists can target during rehabilitation to decrease an individual's reinjury risks. A common test for clinicians to evaluate a patient's movement patterns following ACLR is the landing error scoring system (LESS) test. The LESS is commonly used because it is a dynamic task that has translatable characteristics to typical motion seen during sporting activities. The LESS is a reliable and valid clinical tool that is used to evaluate high-risk landing mechanics associated with bilateral limb loading that can aid in assisting clinicians in RTA decision making[10–12]. The LESS test is comprised of a 17-item error scoring system that a trained evaluator is assessing during a drop jump from a box.[10] The assessment that trained investigators are conducting is evaluating a diverse set of biomechanical movement errors in order to determine if someone is at an increased risk for an ACL injury.[11] Due to the initial purpose of the LESS, being identification of risk factors for ACL injury, further evaluation is necessary to determine its utility in patients recovering from ACLR and identifying risk for reinjury.

Additionally, dynamic tasks, like jump landings performed in the LESS, are traditionally not performed until approximately six months following ACLR.[10,13,14] Although there is utility in conducting the LESS, the six-month delay in being able to conduct it might leave a large amount of time for individuals to learn poor motor patterns and ingrain them into their everyday practice. Previous studies have found that the ability to retrain both gait and jump landing motor patterns can happen in as little as four to six weeks and can be further ingrained over a subsequent two-to-three-month timespan.[15,16] If individuals following ACLR are at an increased neuroplastic state and they adopt poor movement patterns during these early stages of recovery, it could exacerbate and lengthen their recovery process.[17]

A bilateral squatting assessment also evaluates loading patterns during a functional test, like the LESS.[6,7,18] However, unlike the LESS, a bilateral squatting assessment may be performed early during a patient's rehabilitation due to the safety and minimal demands of the task on the ACLR patient. Bilateral bodyweight squats are a multi-joint exercise that allows the knee and surrounding musculature to be loaded and strengthened while also facilitating motor learning during the cyclic task.[7,19] It is unclear if bilateral squat symmetry and lower extremity strength assessed at a mid-recovery timepoint could be associated with functional abilities during a dynamic ballistic LESS test. A strong association between bilateral squatting performance and strength and LESS assessment functional task could allow clinicians to assess an individual's loading patterns earlier during rehabilitation and intervene early by redirecting any rehabilitation plan in order to correct any mechanical deficits. The purpose of this study was threefold: 1) determine how different components of the LESS load together, 2) determine how limb loading symmetry and lower extremity strength symmetry at mid-stage recovery is associated with LESS performance at a late-stage of recovery, and 3) determine to what extent does limb loading and lower extremity strength at mid-stage recovery influence LESS performance at a late-stage of recovery.

Methods

Study Design

This study was an observational cohort study that was part of a larger point-of-care collaboration between an academic research program and a single academic health system. The university's institutional review board for health sciences research approved this study to be conducted in a laboratory setting. Outcome variables included the total LESS error score and LESS error clusters determined by an exploratory factor analysis at visit 2. Predictor variables included limb loading and strength symmetry (%), limb loading peak force (N), quadriceps peak torque (Nm) and the score for the Anterior Cruciate Ligament Return to Sport after Injury (ACL-RSI)[20] questionnaire.

Participants

Participants consisted of 203 (51.1% female) individuals who volunteered to enroll and participate in the current study after providing written informed consent. Patients were included if they sustained an ACLR and completed a LESS assessment. All 203 patients were included in the exploratory analysis of this study. Patients were excluded if they had a history of a previously sustained ACLR, a contralateral ACLR injury, a multi-ligament reconstruction, graft failure, had sustained other lower extremity injuries, had a history of neurological disorders, or had a concussion in the last six months. Of the 203 participants who enrolled, 45 individuals were included in the main analysis (Table M3-1). This subgroup of 45 patients, these individuals were included if they sustained a primary, isolated, and uncomplicated ACLR surgery.

Table M3-1. Participant Demographics (Mean±SD)

	Exploratory Analysis Sample Participants (n=203)	Main Analysis Sample Participants (n=45)
Sex (Male/Female)	107M/96F	22M/23F
Age (yrs)	21.81±7.77	20.43±7.11
Mass (kg)	77.55±16.12	76.93±14.22
Height (cm)	172.60±15.97	172.95±9.59
Time post-surgery (months)	8.82±6.71	Visit 1: 5.09±1.42 Visit 2: 8.27±1.81
Surgical limb = Dominant limb (n[%])*	99 (48.8%)	18 (40%)
Surgical limb = Nondominant limb (n[%])*	104 (51.2%)	27 (60%)

*****Limb dominance is listed as the number of participants followed by the cumulative percentage.

Procedures

The exploratory analysis sample of 203 individuals completed one visit assessing the LESS test. For the 45 individuals who were included in the main analysis, they completed the all of the following assessments: Visit 1: Limb loading, quadriceps strength, and ACL-RSI; Visit 2: Jump landing assessments via the LESS.

Bilateral Squatting Task

Patients were instructed by trained investigators to stand with their feet shoulder width apart and to squat down at approximately 90-degrees and then immediately return to their upright standing position to the beat of a metronome set to 40 beats per minute (Figure M3-1). At the initial metronomes, patients were instructed to lower themselves to the “height of a chair”. Patients were instructed as soon as they heard a second beep of the metronome they were to immediately move upwards to return to their starting position. Patients repeated this cycle for three repetitions and for three sets with rest provided between sets. Patients were given the opportunity to practice the squatting task until they felt comfortable performing the task. During the squatting task, data was collected at 60Hz. A bilateral body weight squat was used to measure limb loading on an instrumented pressure mat (SBmat, Tekscan Inc., Boston, MA, USA) and associated software (FootMat Research ver. 7.10-14).

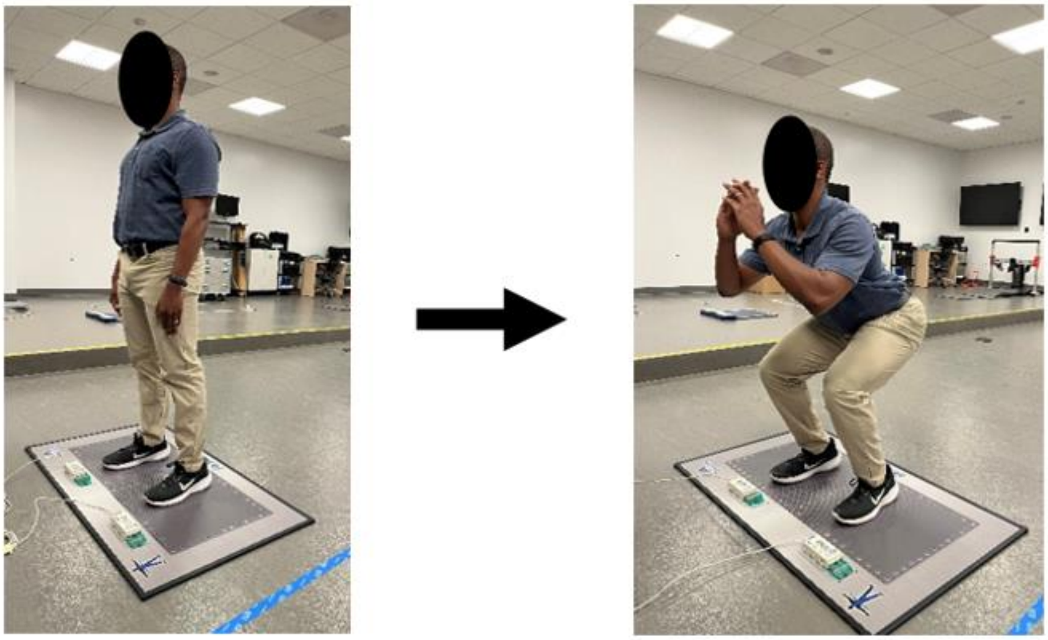

Figure M3-1. Data collection set up during the bilateral squatting task. Patients were instructed to squat to approximately the height of a chair then return to their starting position three consecutive times to the rhythm of a metronome set to 40 beats per minute. This was repeated across three trials.

Lower Extremity Strength Assessment

Isokinetic quadriceps peak torque was measured bilaterally during isokinetic testing at 90º/s using a multimodal dynamometer (Systems IV, Biodex Medical Systems Inc, Shirley, NY) with a universal data export to a data acquisition system (MP150, Biopac Inc, Goleta, CA). All patients were instructed to sit on the dynamometer chair and adjusted with their hips and knees secured at 85-degrees and 90-degrees of flexion respectively (Figure M3-2). All patients were instructed to kick out "as hard and fast as possible" until they reach full extension followed by an immediate pull back in "as hard and fast as possible" until they reach full flexion. Patients were instructed to complete eight consecutive repetitions of the isokinetic task[21]. All patient's contralateral limb was tested first, then followed with their surgical limb.

Figure M3-2. Patient set up for the quadriceps strength assessment. Patients were positioned with their hip and knees flexed at 85° and 90° respectively. Patients were instructed to extend and flex their knee as fast as possible using only their lower extremity musculature. Patients completed eight repetitions total per limb and always started the testing session with the contralateral limb.

Landing Error Scoring System (LESS) Assessment

The landing error scoring system assessment was conducted as previously described[11]. Patients were instructed to stand on top of a 30-cm plyometric box and jump out horizontally with both feet to a target on the ground that was measured out to 50% of the patients' height. Once the patients landed on the ground, they were told to immediately complete a maximal vertical jump. Patient completed three jump trials while handheld video cameras were positioned on 1-m high tripods at 3-m in the frontal and sagittal plane from the landing zone. Patients were given the opportunity to complete practice jumps until they felt confident in performing the task. The video recorded from the LESS trials were uploaded to Kinovea software (version 0.8.15, available for download at http://www.kinovea.org) and scored by a trained investigator. A mode score of the three trials was recorded for each individual error item. A summation of all the individual item error scores was used as the patient's overall LESS total score.

Patient Report Outcome (PRO)

Each participant completed a PRO during visit 1. The ACL-RSI was collected to assess each patient's confidence, emotion, and risk appraisal related to RTA.[20]

Data Processing

The peak force (N) was computed using a custom written code (MATLAB R2022a, ver 9.12.0, The MathWorks Inc, Natick, MA, USA) code. The peak force output for each individual limb was recorded for each squat trial and averaged across the three trials. Limb loading symmetry was calculated as the peak force recorded from the ACLR limb divided by the peak force from the contralateral limb multiplied by 100. The peak torque for quadriceps strength was recorded as the largest torque value obtained during the isokinetic testing session. Limb loading peak force (N) and quadriceps peak torque limb symmetry index (LSI) values were calculated using the following equation: $LSI = \frac{ACLR\ Limb}{Contralateral\ Limb} * 100\%$.

Statistical Analysis

A preliminary analysis was conducted to determine how limb loading, strength, and patient perceived confidence influence total LESS error score performance. A multiple linear regression was conducted using the statistical software SPSS (version 28, IBM SPSS 244 Inc., Chicago, IL). Predictor variables were entered into the model starting with limb loading metric, quadriceps strength metric, and ACL-RSI.

Exploratory factor analysis (EFA) was then conducted within the exploratory analysis sample of 203 participants to determine how individual error items from the LESS test group together into factors (e.g., stiffness, knee valgus, etc.) using an open-sourced statistical software jamovi (The jamovi project (2022). *jamovi* (Version 2.3) [Computer Software]). The EFA was conducted including each itemized error score determined by the LESS scoring. Factors were retained when they had an eigenvalue greater than 1.0.

LESS Factor Identification

The EFA highlighted two distinct factor groupings with eigenvalues greater than 1 (Table M3-2 for factor loadings and error item descriptions). Factor 1 had an eigenvalue of 1.6012 and included errors 6, 7, and 8 in the sagittal plane as well as error 12 in the frontal plane which includes errors evaluating hip and trunk flexion, joint displacement, and placement of the foot with respect to shoulder width. Factor 2 had an eigenvalue of 1.0098 and included errors 14 and 15 in the frontal plane which primarily focuses on knee valgus motion and landing stiffness. Factor 1 will be referred to as the Biplanar Factor and Factor 2 will now be referred to as the Frontal Factor for the remainder of the study.

Table M3-2. Exploratory Factor Analysis: Factor Loadings

Error Items	EFA Factor Loadings – Factors: Biplanar	Frontal	Description – Segment of jump landing task:	Error Committed – No	Error Committed – Yes
Sagittal Camera View					
6	0.701		From initial contact to max knee flexion	Hip of test leg flexes more on trunk	Hip of test leg does not flex more or extends
7	0.638		From initial contact to max knee flexion	Trunk flexes more	Trunk does not flex more or extends
8	0.584		Joint Displacement	Large displacement of trunk, hips, and knees	Some or very little displacement of the trunk, hips, and knees
Frontal Camera View					
12	0.392		Once the entire foot is in contact with the ground	Medial heel of test leg is in line with shoulder width	Medial heel of test leg is wider or narrower than shoulder width
14		0.719	At the time of max knee flexion	Center of patella is lateral to great toe	Center of patella is inline or medial to great toe
15		0.807	Overall impression	Displays soft landing and no frontal plane motion at the knee	Displays easy to stiff landing and large frontal plane motion at the knee

LESS Factor Scores

LESS item errors were grouped together based on their strength within the Biplanar and Frontal factors characterized by factor loadings with the higher the loading being indicative of a greater relationship. Factors were then further examined and differentiated into three unique scoring methods (Table M3-3). First, we created factor sums where if an individual committed any errors within each factor those items would be summed together to get a sum score for that specific factor. The second approach was conducted using the Thurstone method[22,23] where each LESS item error in each factor utilized their weighted loadings from the EFA in order to calculate unique factor scores. Lastly, a binary factor score was created where if an individual committed any error in the itemized list for each respective factor, they were scored with a binary yes (1) or no (2) score.

Table M3-3. Factor Scoring Methods

Method	Summation of LESS score	Weighted Sum of Less score using Thurstone method [22,23]	Binary LESS score
Description	Factor score is calculated based on the sum of all committed errors included within a specific factor	Factor score is calculated based on the weighted loading determined by the EFA. Where committing an error for an item with a higher loading will elicit a higher factor score. Each error committed is weighted based on the EFA analysis to derive the total sum score for this variable.	Factor score is calculated where if a person commits any of the errors included within a specific factor, they will be given a binary outcome of yes (1). If a person does not commit any error for the items within each respective factor, they will be given a binary outcome of no (0).

Multiple linear regressions were conducted on the 45 participants from the main analysis sample using the statistical software SPSS to determine whether limb loading LSI, quadriceps peak torque LSI, and ACL-RSI scores are associated with Biplanar and Frontal factors determined from the EFA using the summation and weighted Thurstone scores (Figure M3-3). Separate multiple linear regressions were conducted to determine whether limb loading from the ACLR limb, quadriceps peak torque from the ACLR limb, and ACL-RSI scores are associated with LESS factors determined from the EFA using the summation and weighted Thurstone scores. The change in R^2 and standardized Beta coefficient (β) were calculated and reported explaining the variance in each model. Beta coefficient values were interpreted as weak (≤0.49), moderate (0.5 to 0.69) and strong (≥0.7). The α level was determined *a priori* as 0.05 or less.

Binary logistic regression was also conducted on the 45 participants from the main analysis sample (Figure M3-3) using the statistical software SPSS. The first binary logistic regression was conducted to determine whether limb loading LSI, quadriceps peak torque LSI, and ACL-RSI scores are associated with the Biplanar and Frontal factors using the binary factor scores. A separate binary logistic regression was also conducted to determine whether limb loading from the ACLR limb, quadriceps peak torque from the ACLR limb, and ACL-RSI scores are associated with the Biplanar and Frontal factors using the binary factor scores. Each binary logistic regression, with the associated adjusted odds ratios, was conducted using the enter method to determine the association between predictor variables (i.e., limb loading, strength, and ACL-RSI) and dependent variable (i.e., binary factor for LESS performance). For all logistic regression models, a receiver operator characteristic (ROC) curve and associated area under the curve (AUC) was conducted to determine the strength of the model in predicting if patients commit an error in their respective factor. The AUC values were interpreted as no discrimination (0.5), acceptable (0.7 to 0.8), excellent (0.8 to 0.9), and outstanding (>0.9).[24] All analysis had an α level determined *a priori* and set to 0.05 or less.

All regressions utilized the following equations with their respective factor scoring method (i.e., Summation, Weighted Thurstone, Binary) as the dependent variable for each factor (i.e., Biplanar and Frontal):

Equation 1-Symmetry Predictors: $\widehat{Factor\ Scoing\ Method_i} = \beta_0 + \beta_1 * Limb\ Loading\ Symmetry_i + \beta_2 * Quadriceps\ Strength\ Symmetry_i + \beta_3 + ACL - RSI_i$

Equation 2-Unilateral Predictors: $\widehat{Factor\ Scoring\ Method_i} = \beta_0 + \beta_1 * ACLR\ Limb\ Loading\ Peak\ Force_i + \beta_2 * ACLR\ Quadriceps\ Peak\ Torque_i + \beta_3 + ACL - RSI_i$

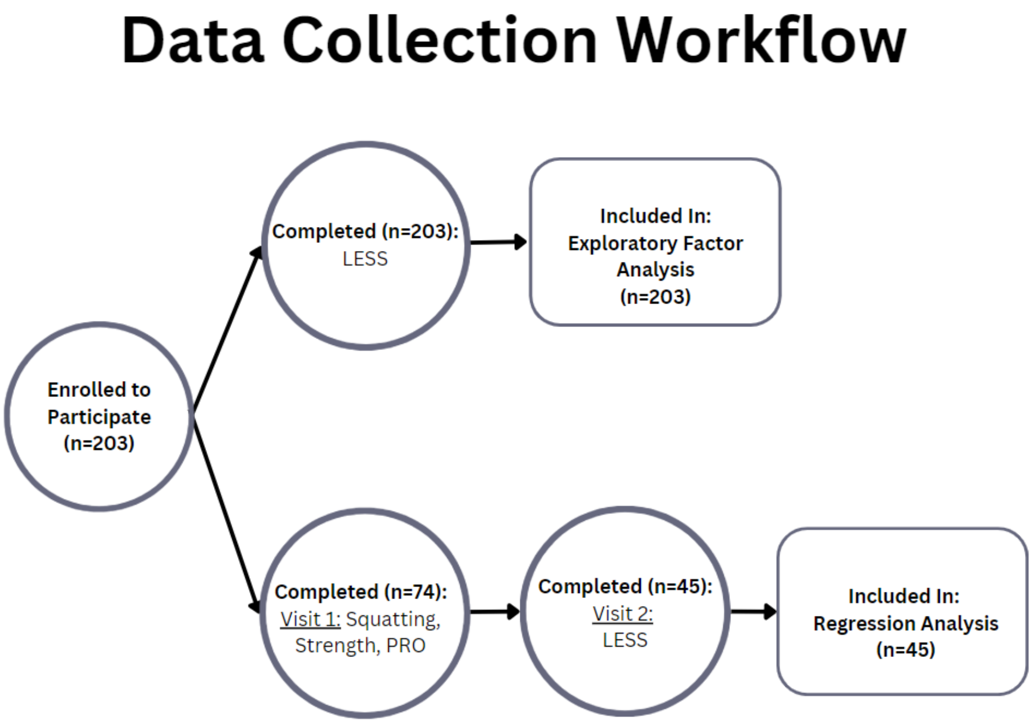

Figure M3-3. Analysis Decision Tree for all patients screened and enrolled into the study.

Results

LESS Total Score Preliminary Analysis

The multiple regression evaluating the association between the LESS total error score and limb loading peak force, quadriceps isokinetic peak torque, and ACL-RSI score found that quadriceps peak torque was the only predictor variable that had a significant association ($F_{(3,39)}$=3.39, p=0.03, R^2=0.21). There was a weak association between quadriceps peak torque and LESS total error score (β=-0.02, p=0.02).

Prediction of Summated and Weighted Factor Scores

Overall results indicated that neither the combined predictors for limb loading symmetry, quadriceps strength LSI, and ACL-RSI model ($F_{(3,39)}$=2.05, p=0.12, R^2=0.14) nor the limb loading peak force, quadriceps peak torque, and ACL-RSI model ($F_{(3,39)}$=1.55, p=0.22, R^2=0.11) were statistically associated with sum Biplanar factor scores. Additionally, results indicated that neither the combined predictors for limb loading symmetry, quadriceps strength LSI, and ACL-RSI model ($F_{(3,39)}$=1.59, p=0.21, R^2=0.11) nor the limb loading peak force, quadriceps peak torque, and ACL-RSI model ($F_{(3,39)}$=2.59, p=0.06, R^2=0.17) were statistically associated with sum Frontal factor scores.

Overall results indicated that neither the combined predictors for limb loading symmetry, quadriceps strength LSI, and ACL-RSI model ($F_{(3,39)}$=1.97, p=0.14, R^2=0.13) nor the limb loading peak force, quadriceps peak torque, and ACL-RSI model ($F_{(3,39)}$=1.44, p=0.25, R^2=0.10) were statistically associated with weighted Thurstone Biplanar factor scores. Additionally, results indicated that the combined predictors for limb loading symmetry, quadriceps strength LSI, and ACL-RSI model ($F_{(3,39)}$=2.41, p=0.08, R^2=0.16) were not statistically associated with weighted Thurstone Frontal factor scores. Lastly, results indicated that limb loading peak force, quadriceps peak torque, and ACL-RSI model were statistically associated with weighted Thurstone Frontal factor scores ($F_{(3,39)}$=3.20, p=0.03, R^2=0.20). Limb loading peak force (β=-0.001, p=0.58) and quadriceps peak torque (β=-0.005, p=0.19) were not significantly associated with weighted Thurstone Frontal factor scores. Scores from the ACL-RSI were associated with weighted Thurstone Frontal factor scores (β=0.02, p=0.01; Table M3-4)

Table M3-4. Multiple linear regression results

	Predictor	Unstandardized β coefficient	*t* statistic	*p*-value
	Unilateral Predictors			
Frontal Factor: Weighted Thurstone	ACLR Limb Loading Peak Force	-0.001	-0.56	0.58
	ACLR Limb Quadriceps Peak Torque	-0.01	-1.33	0.19
	ACL-RSI	0.02	2.63	0.01*

*Indicates significant unilateral predictor (p<0.05)

Prediction of Binary Factor Scores

The binary logistic regression evaluating the association between limb loading symmetry, quadriceps strength LSI, and ACL-RSI with binary Biplanar factor score was not statistically significant (p>0.05, AUC=0.70). The binary logistic regression evaluating the association between ACLR limb loading peak force, ACLR limb quadriceps peak torque, and ACL-RSI with binary Biplanar factor score was not statistically significant (p>0.05, AUC=0.59).

The binary logistic regression evaluating the association between limb loading symmetry, quadriceps strength LSI, and ACL-RSI with binary Frontal factor scores was statistically significant (p<0.05, Nagelkerke R^2=0.17, AUC=0.74, 95% CI [0.57, 0.91]). Neither limb loading symmetry nor quadriceps strength symmetry were significant predictors in this model (Table M3-5). The ACL-RSI score variable was also not a significant predictor either, however it was close to reaching significance (p=0.052). The binary logistic regression evaluating the association between limb loading peak force, quadriceps peak torque, and ACL-RSI with binary Frontal factor scores was statistically significant (p<0.01, Nagelkerke R^2=0.34, AUC=0.86, 95% CI [0.74, 0.97]). Limb loading peak force (p=0.04) was the only significant predictor of an individual committing an error in the LESS binary Frontal factor. The overall results of the binary logistic regressions for factor 1 can be found in Table M3-5.

Table M3-5. Binary logistic regression results

	Predictor	β coefficient	Wald Statistic	*p*-value	Odds Ratio	95% CI Lower	95% CI Upper
	Symmetry Predictors						
Frontal Factor: Binary (Yes/No) Any Error Committed	Limb Loading Symmetry	-1.13	0.94	0.33	0.32	0.03	3.18
	Quadriceps Strength LSI	0.95	0.16	0.69	2.59	0.02	298.01
	ACL-RSI	0.03	3.76	0.052	1.03	0.9996	1.07
	Unilateral Predictors						
Frontal Factor: Binary (Yes/No) Any Error Committed	ACLR Limb Loading Peak Force	-0.01	4.10	0.04*	0.99	0.985	0.9998
	ACLR Limb Quadriceps Peak Torque	-0.01	0.72	0.40	0.99	0.97	1.01
	ACL-RSI	0.04	3.81	0.051	1.04	0.9998	1.09

*Indicates significant predictor (p<0.05)

Discussion

The initial goal of this study was to determine if limb loading symmetry, strength symmetry, and ACL-RSI scores at an early stage of recovery predict functional landing performance at late-stage recovery determined via LESS errors. Our secondary goal was to see if unilateral outcomes of limb loading peak force, quadriceps peak torque, and ACL-RSI scores at an early stage of recovery predict functional performance at late-stage recovery determined via LESS error factors. In the current study we observed that symmetry predictors were not associated with any factor scores, however unilateral limb loading peak force and ACL-RSI were significant predictors of errors committed in the Frontal factor using the binary factor scoring method. The Frontal Factor was comprised of frontal plane knee motion, or knee valgus, and landing stiffness from the jump landing task. The presence of a significant association with unilateral limb loading and the Frontal Factor supports the notion that not only does ACLR limb loading have similar characteristics, but it is also potentially predictive of knee valgus and landing stiffness during a jump landing task. Therefore, ACLR limb loading during a bodyweight squat can be possibly used as prognostic clinical assessment for the adoption of risky biomechanical movement patterns.

We observed the preliminary regression model validated that quadriceps strength at around 5-months post-ACLR, predicted performance on the LESS total score assessed around 8-months following surgery. This finding corresponds to a previously conducted study that found worse performance on the LESS was related to lower quadriceps peak torque normalized to body mass.[25] The LESS is made up of a variety of unique error items, some of which (i.e. knee valgus during landing) have been objectively measured with 3D motion capture techniques and found to be associated with increased risk of reinjury.[7,11,26] We aimed to build upon this finding by reducing the amount of overall LESS error items by using an EFA to highlight error items that are most highly associated with each other. By conducting this EFA, we potentially are able to also discern error items that might be most clinically meaningful in this patient population following ACLR. It is important to distinguish different unique errors in this sample of ACLR individuals compared to the original intent of the LESS to screen non-injured individuals for risk of initial ACL injury.[11]

The EFA produced two unique factors of LESS error items. The first factor comprised of three error items in the sagittal camera view and one error item from the frontal camera view. These errors are primarily evaluating body segment (i.e., hip, trunk, and feet) positioning during the jump landing task. The second factor was made up of two error items from the frontal camera view that are assessing knee valgus and landing stiffness from the jump landing task. Each of these factors included error items with cohesive constructs that the error items were assessing. A previous study conducted a factor analysis on LESS item errors and found five distinct groups of related errors.[27] The previous study was conducted on over 2,700 healthy cadets entering into military academies, assessing for high-risk landing characteristics for sustaining a future musculoskeletal injury.[27] The difference between the previously conducted EFA and the current EFA factor groupings suggest that the LESS has unique clinical utilities for healthy versus ACLR populations that should be further explored.

The primary finding from the current study was the observation that limb loading during a squat around five months post ACLR was a significant predictor of frontal plane knee positioning and landing stiffness at approximately eight months. The presence of a significant association for the Frontal factor, which focuses on knee valgus and landing stiffness, is of importance due to the known associated increased risk of reinjury with the presence of knee valgus and stiff landing during dynamic tasks.[26,28] The AUC from the ROC analysis from the Frontal factor models indicated that limb loading from the ACLR limb during a bilateral squat assessment has an 86%, or “excellent”[24], chance of determining whether that same patient is going to have knee valgus during a jump landing task at a later stage of recovery.

An unexpected finding was none of the factor models (i.e., Biplanar, Frontal), across any of the methods (i.e., summation, weighted Thurstone, binary) used to create the factor scores, found quadriceps strength metrics significantly associated with the present of LESS errors committed in either factor. Given the preliminary validation regression, indicating that quadriceps strength was associated with overall LESS error total score, and previously conducted research also showing a relationship between strength and LESS performance[25], it was expected that quadriceps strength might be a significant predictor in the regression factor models.

Additionally, it was observed that ACL-RSI was also a significant predictor of whether patients committed an error within the Frontal factor. The weighted Thurstone factor scoring method using unilateral predictors found an association between overall ACL-RSI scores and committing errors in the Frontal factor. There have been previous studies stating the more confidence patients have, measured via the ACL-RSI, the higher the odds of them returning to sport at 12-months post-surgery.[29,30] One study found that ACL-RSI scores and time from injury to assessment were predictors for individuals returning to preinjury sport or recreational activity participation.[30] The aforementioned studies and our current finding share a similar clinical impact. However, given the very small β value from the linear regression suggests this finding should be considered with caution.

The ability to predict functional performance at approximately eight months following surgery using a safe, easy, and cost-effective bilateral squatting assessment at approximately five months post-ACLR, highlights the prognostic ability for early detection and correction of risky biomechanical motor patterns that may put patients at increased risk for reinjury. Traditionally, functional tasks have been used to observe deficits between the ACLR and contralateral limb to aid in the decision making process when clinicians are programming an individual's rehabilitation plan or determining a patient's readiness to RTA.[13,31] From our findings, and those findings that suggest that biomechanical movement patterns are transferable to dynamic jump landing tasks[7], limb loading performance during a bilateral bodyweight squat at an early stage in recovery can inform clinicians on their patient's potential ability to adopt poor motor patterns. Previous research has found that upon visual inspection during a drop landing task, with good inter- and intra-rater reliability and high sensitivity, clinicians and allied health professionals can reliably identify knee valgus.[32,33] This gives clinicians an opportunity for early intervention and alteration of specific patient's rehabilitation plan without the need for high-tech expensive biomechanical equipment.

Limitations

Patient participants underwent rehabilitation with their preferred rehabilitation specialist, limiting our ability to control for post-operative rehabilitation protocol and patient compliance. During each testing session, patients were wearing their preferred footwear instead of standardized footwear, which could have influenced their performance during the squatting task and jump landings. During the squatting task, individuals were asked to squat to the beat of a standardized metronome which could have influenced their biomechanical approach to the task. Additionally, patients were asked to complete a standardized jump landing task. The novelty of both the squatting and jump landing tasks could have altered their performance on each task, however, patients were given opportunities to practice both tasks to familiarize themselves with the novel task. More precise measurements of biomechanical movement profiles could be obtained using 3D motion capture techniques. However, the utility of the current methodology is the accessibility to the testing tools for clinicians with minimal cost and ease of implementation, unlike the 3D motion capture systems.

Conclusions

Limb loading assessed via bilateral bodyweight squats approximately five months post-surgery was found to be predictive of the potential adoption of risky biomechanical movement patterns (i.e., knee valgus and stiff landings) during a jump landing task at approximately eight months following ACLR. There is some evidence that subjective outcomes from the ACL-RSI questionnaire could also add insight to this implementation of poor movement patterns, however this should be interpreted with caution. The evidence from this study suggests that rehabilitation specialists can utilize a simple, easy, safe, and cost-effective assessment of limb loading during a bodyweight bilateral squat to gauge patient's potential to develop poor motor patterns and redirect patient's rehabilitation protocols to fit their individualized needs.

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APPENDIX A

Problem Statement/Significance

Anterior cruciate ligament injury is one of the most common sports injuries in physically active individuals with an annual incidence rates ranging from 80,000 to 250,000 per year.[40,102] This sheer volume of injuries with all the associated anterior cruciate ligament reconstruction (ACLR) surgeries, doctors' visits, and rehabilitation therapy visits can elicit an economic impact of up to $3 billion in the United States healthcare system per year.[63] It has been observed that after surgery 81% of individuals returned to some form of sport, 65% were able to return to a previous level of sport, and 55% of athletes, who opt for ACLR, returned to a competitive level of sport following an ACLR.[4] Additionally, one in three or 33% of individuals will experience reduced levels of physical activity, potentially affecting health, well-being, and overall quality of life.[4,14] Previous research has found that a reduction in participation of physical activity may serve as a catalyst for more chronic diseases such as obesity, diabetes, cardiovascular diseases, and/or cancers.[9] A previously established barrier for many individuals to successfully RST is persistent lower extremity muscle weakness.[44] After an ACLR, patients can experience persistent strength and functional deficits that can linger anywhere from two to five years after surgery.[29,71] Patients can also develop early onset of knee osteoarthritis, that can further their overall health related quality of life.[1,29,59,75,82]

Most individuals who undergo an ACLR are prescribed a structured rehabilitation program that plays a critical role in restoring strength and optimal movement quality with the goal of successfully returning patients to their previous level of physical activity or level of competitive sport while minimizing risk of reinjury.[19] During rehabilitation, the primary focus is treating weakness on the ACLR limb compared to the contralateral limb. Strength deficiencies following ACLR can translate to movement compensations during functional tasks such as a bilateral squat or a jump landing task.[81,92] For example these compensations can include offloading their ACLR limb by putting more of their weight on their contralateral limb.[81] These compensations compounded over time are cause for concern with asymmetric loading patterns have been associated with future ACL reinjury as well as the degeneration of cartilage.[76,91]

Bilateral (double leg) body weight squats are a multi-joint exercise that are frequently utilized by clinicians early and progressed throughout an individual's rehabilitation.[89] This movement allows the knee and surrounding musculature to be loaded and strengthened in a safe manner while also facilitating motor learning during the cyclic task, potentially minimizing the risk of reinjury.[81,89] However, many individuals post-ACLR will experience persistent muscle weakness and may shift their bodyweight to an adjacent joint or to the contralateral limb.[92] This shift in a patient's bodyweight to the contralateral limb could be an attempt to offload the ACLR limb suffering from weakness. Offloading is a result from compensatory movement that may lead to maladaptive movement patterns later in the rehabilitation phase or after clearance to return-to-sport (RTS).[92] Allowing this offloading movement compensation to persist could lead to larger maladaptive movement patterns, potentially becoming detrimental during a fast paced practice or game setting for athletes, thereby increasing an individual's risk for reinjury.[92] Previous studies have found compensatory movement patterns in ACLR patients during walking, squatting, and jumping.[81,92,93] These studies have theorized that strength deficits could be a large contributing factor to these tasks that are associated with activities of daily living. These poor loading adaptations have been implicated in increasing the rate of cartilage degeneration and therefore accelerating the development of osteoarthritis.[93] The addition of an easy, safe, and quick functional bilateral squatting task paired with the information from a traditional battery of clinical tests may enhance clinical decisions and interventions early in the recovery phase following ACLR.

Functional tasks such as hopping or jumping typically are not incorporated into a patient's rehabilitation programming until the later stages of recovery.[66] Traditionally, these tasks are utilized to observe limb symmetry between distance hopped across limbs to aid in the decision-making process of clinicians.[55,66] Conversely, the functional task of a bilateral squat can be completed early after surgery and is assessing similar outcomes to hopping and jumping tasks. The ability to use the bilateral squat in a safe manner to assess symmetry would allow for early detection of potential maladaptive movement patterns that over time, if not corrected, could manifest as poor movement strategies in dynamic ballistic activities such as hopping during a game-like setting that could result in injury.[81]

Knee loading post-ACLR if not identified early and corrected could lead to maladaptive movement patterns and potentially increasing the likelihood of reinjury and early onset osteoarthritis[65,92]. Therefore, in order to address the problem of early and safe identification of poor loading strategies post-ACLR, I propose to evaluate limb loading during a bilateral bodyweight squat. This assessment can compare across limbs and sexes, compare how limb loading changes over time, and determine if this functional assessment conducted early in rehabilitation can predict functional outcomes at later stages of rehabilitation during a jump landing task.

Research Question(s) and Experimental Hypotheses

Manuscript I: Comparison of Limb Loading Characteristics and Subjective Functional Outcomes Between Sexes Following ACLR

Aim 1 Research Question:

To compare limb loading (Peak force distribution (N) and Unilateral cumulative load (%)) during a bilateral squatting task between limbs (i.e., ACLR vs Contralateral) and across sexes (i.e., Male vs Female) in individuals less than 9-months post-ACLR.

Aim 1 Research Hypothesis 1: Patients will have asymmetric squat loading with the ACL limb having lower values for the following variables compared to the contralateral limb:

- Normalized peak force distribution (N/kg)
- Unilateral cumulative load (%)

Aim 1 Research Hypothesis 2: Men will load their ACLR limb more than their female counterparts during the bilateral squatting task compared to women for the following variables:

- Normalized peak force distribution (N/kg)
- Unilateral cumulative load (%)

Aim 2 Research Question:

To describe the relationship between limb symmetry (LSI (%)) and subjective function described through patient reported outcomes (IKDC, KOOS, ACL-RSI, and Tegner Activity Scale)

Aim 2 Research Hypothesis 1: Patients with greater limb loading symmetry will have greater subjective patient report function determined by the International Knee Documentation Committee (IKDC) and Knee Injury and Osteoarthritis Outcome Score (KOOS).

Aim 2 Research Hypothesis 2: Patients with greater limb loading symmetry will have more confidence in their knee function determined by the Anterior Cruciate Ligament Return to Sport after Injury (ACL-RSI).

Aim 2 Research Hypothesis 3: Patients with greater limb loading symmetry will report participating in higher levels of physical activity determined by the Tegner Activity Scale (TAS).

Project and Design

Manuscript I

Aim 1

a) **Experimental Design**
    - Descriptive study

  Independent Variables:

    - Limbs (ACLR vs Contralateral)
    - Sex (Males vs Females)

  Dependent Variables:

    - Normalized Limb Loading Peak Force (N)
    - Unilateral cumulative load (%)

Aim 2

b) **Experimental Design**
    - Descriptive study

  Independent Variables:

  Function

    - International Knee Documentation Committee (IKDC)

  Symptom Severity

    - Knee Injury and Osteoarthritis Outcome Score (KOOS)

  Psychological Readiness

    - Anterior Cruciate Ligament Return to Sport after Injury (ACL-RSI)

  Physical Activity Level

    - Tegner Activity Scale (TAS)

  Dependent Variables:

    - Limb Loading Symmetry (%)

Manuscript II: Analysis of Lower Extremity Strength and Limb Loading Recovery Across Time Following Anterior Cruciate Ligament Reconstruction

Aim 1 Research Question:

To describe how limb loading (Peak force distribution (N) and Unilateral cumulative load (%)) during a bilateral squatting task and lower extremity strength (isokinetic knee extension and flexion peak torque (Nm)) metrics change over two time points during recovery following ACLR.

Aim 1 Research Hypothesis

We hypothesize that in patients post-ACLR, the following changes will occur from their visit 1 to their visit 2 post-ACLR:

Hypothesis 1: Isokinetic quadriceps and hamstring strength will increase from visit 1 to visit 2 in the ACLR limb for the following variable:

- Isokinetic knee extension peak torque at 90º/s (Nm)
- Isokinetic knee flexion peak torque at 90º/s (Nm)

Hypothesis 2: Limb loading during a bilateral squatting task will increase from visit 1 to visit 2 for the following variables:

- Limb loading peak force (N)
- Unilateral cumulative load (%)

Aim 2 Research Question:

To analyze the relationship between the change (Visit 2-Visit1) in limb loading symmetry (LSI (%)) during a bilateral squatting task from Visit 1 to Visit 2, compared to the change (Visit 2-Visit1) in quadriceps and hamstring strength symmetry (LSI (%)) during an isokinetic strength test from visit 1 to visit 2.

Aim 2 Research Hypothesis:

We hypothesize that the change in bilateral squat limb loading symmetry and quadriceps and hamstring strength symmetry in patients post-ACLR, the following changes will occur from their visit 1 to their visit 2 post-ACLR:

Hypothesis 1: As quadriceps strength symmetry improves from visit 1 to visit 2, limb loading during the bilateral squat will also improve (moving closer to 100% symmetry) from visit 1 to visit 2 for the following variables:

- Isokinetic knee extension symmetry (%)
- Isokinetic knee flexion symmetry (%)
- Squat limb loading Symmetry (%)

Project and Design

Manuscript II

Aim 1

a) **Experimental Design**
   - Descriptive Study

Independent Variables:

- Time post-surgery (Visit 1: 5-months; Visit 2: 8-months)

Dependent Variables:

- Limb Loading Peak Force (N)
- Unilateral cumulative load (%)
- Knee Extension Peak Isokinetic Torque (Nm)
- Knee Flexion Peak Isokinetic Torque (Nm)

Aim 2

b) **Experimental Design**
   - Descriptive Study

Independent Variables:

- Lower Extremity Strength Symmetry Change Scores:
  - Knee extension isokinetic peak torque symmetry at visit 2 minus knee extension isokinetic peak torque symmetry at visit 1.
  - Knee flexion isokinetic peak torque symmetry at visit 2 minus knee flexion isokinetic peak torque symmetry at visit 1.
- Lower Extremity Strength Change Scores
  - ACL limb knee extension isokinetic peak torque at visit 2 minus knee extension isokinetic peak torque at visit 1.
  - ACL limb knee flexion isokinetic peak torque at visit 2 minus knee flexion isokinetic peak torque at visit 1.
  - Contralateral limb knee extension isokinetic peak torque at visit 2 minus knee extension isokinetic peak torque at visit 1.
  - Contralateral limb knee flexion isokinetic peak torque at visit 2 minus knee flexion isokinetic peak torque at visit 1.

Dependent Variables:

- Limb Loading Symmetry Change Scores:
    - Limb Loading Symmetry at visit 2 minus limb loading symmetry at visit 1.
- Limb Loading Change Scores:
    - ACL limb loading peak force at visit 2 minus limb loading peak force at visit 1.
    - ACL limb unilateral cumulative load at visit 2 minus unilateral cumulative load at visit 1.
    - Contralateral limb loading peak force at visit 2 minus limb loading peak force at visit 1.
    - Contralateral limb unilateral cumulative load at visit 2 minus unilateral cumulative load at visit 1.

Manuscript III: An Exploratory Analysis of the Predictability of Limb Loading on Functional Performance Outcomes After ACLR

Aim 1 Research Question:

To determine if different errors scored during the LESS task have qualities that cluster together using an exploratory factor analysis in patients recovering from ACLR.

Aim 1 Research Hypothesis:

We hypothesize that there will be three distinct latent grouping categories for errors that are scored:

Hypothesized Latent Grouping Categories:

- Frontal Plane
- Sagittal Plane
- Overall Movement Quality

Aim 2 Research Question:

To determine if limb loading symmetry during a bilateral squatting task, quadriceps isokinetic strength symmetry, and patient reported confidence at Visit 1, approximately 5-months post-ACLR, is predictive of functional performance determined by errors committed during the LESS task at Visit 2, approximately 8-month post-ACLR.

Aim 2 Research Hypothesis:

We hypothesize that patients, following ACLR, who have lower limb loading symmetry, lower quadriceps strength, and worse patient reported confidence will have a presence of errors committed within at least one of the landing error scoring system error groupings.

Aim 3 Research Question:

To determine if limb loading of the ACLR limb during a bilateral squatting task, ACLR limb quadriceps peak torque, and patient reported confidence at Visit 1, approximately 4-months post-ACLR, is predictive of unilateral errors committed during the landing error scoring test.

Aim 3 Research Hypothesis:

We hypothesize that the ACLR limb loading (Peak force distribution (N)) at Visit1 approximately 4-months post-ACLR will predict errors indicative of unilateral function (Errors: 9, 11, 14) that will be committed during the landing error scoring task at Visit 2 approximately 6-months post-ACLR.

Project and Design

Manuscript III

Aim 1

a) Experimental Design

- Descriptive Study

Independent Variables:

- 17 Errors from the LESS test

Dependent Variables:

- Latent Groups

Aim 2

b) Experimental Design

- Descriptive Study

Independent Variables:

- Factor Scoring Methods
  - Summation Method
  - Weighted sum of LESS scores using the Thurstone method[39,99]
  - Binary Method

Dependent Variables:

- Limb Loading Symmetry (%)
- Quadriceps Strength Symmetry (%)
- Anterior Cruciate Ligament Return to Sport after Injury (ACL-RSI)

Aim 3

c) Experimental Design

- Descriptive Study

Independent Variables:

- Factor Scoring Methods
  - Summation Method
  - Weighted sum of LESS scores using the Thurstone method[39,99]

  - Binary Method

Dependent Variables:

- Limb Loading Peak Force (N)
- Quadriceps Peak Torque (Nm)
- Anterior Cruciate Ligament Return to Sport after Injury (ACL-RSI)

Inclusion Criteria

- 12-64 years of age
- History of primary, isolated, unilateral, & uncomplicated ACL injury reconstruction

Exclusion Criteria

- Multiple ligament reconstruction or a prior history of graft rupture prior to the time of the initial visit.
- Prior history of lower extremity surgery or lower extremity injury within the past 6-months.
- Any injury event that occurred between initial STEP visit (4-months) and LEAP visit (6-months).
- Referral from outside the University of Virginia health systems medical network.
- Patients who are known to be pregnant
- Patients diagnosed with malignancy
- Patients with serious skin infection near the lower limb
- Patients with known muscular abnormalities
- History of cardiopulmonary disorder
- History of stroke
- History of neurological or psychiatric disorders including poorly controlled migraine headaches, seizure disorders, history or immediate family history of seizures and/or epilepsy
- Patients with any type of neuropathy
- Patients with a clinical diagnosis of multiple sclerosis (MS)
- Implanted biomedical device (active or inactive implants (including device leads), including deep brain stimulators, cochlear implants, and vagus nerve stimulators)
- History of skull fracture
- Patients taking any medications, which may influence cortical excitability, which could influence neurophysiologic measures and affect objective clinical data (e.g., antispastics, anxiolytics, hypnotics, anti-epileptics)

Study Assumptions

- Participants will provide accurate information regarding lower-extremity injury and surgical history
- Participants will participate to the best of their abilities exerting maximal effort and attention during all exercises
- Limb symmetry collected is normally distributed
- Knee extension tasks are representative of peak quadriceps function

Delimitations

- Performed at a single-site academic institution
- Primary, unilateral, isolated, and uncomplicated ACL reconstruction
- Timing of Strength and Endurance Protocol (STEP) (4-months) and Lower Extremity Assessment Protocol (LEAP) (6-months) tests may vary (±2 months) due to patient referral patterns

Limitations

There are no known limitations at this time

Operational Definitions & Equations

1. ACL reinjury – A subsequent tear of the ACL following an initial ACLR. The subsequent tear could be of the ipsilateral or contralateral ACL. All injuries were verified by chart review from follow-up clinic visits, verbal confirmation through phone calls, or written confirmation through email.
2. Base of Support – the area beneath a person's feet that includes every point of contact the person has with the ground.
3. Center of Force – point of application of the ground reaction forces over a person's base of support.
4. Isokinetic strength – The peak torque during a maximal effort task where the velocity of the movement is predetermined to a set speed.
5. Kinematics – Describing and measuring human movement by focusing on the type of motion, the direction, and the quantity of the motion without regard for the forces that my produce that movement; further subdivided into osteokinematics and arthrokinematics[46].
6. Kinetics – The science that deals with forces that produce, stop, or modify motion of bodies as a whole or of individual body segments. The study of forces acting on the body[46].

7. Landing Error Scoring System (LESS) – A bilateral jump landing task evaluating how a person lands from a jump. This is comprised of 17 possible movement errors[74].
8. Limb symmetry – A comparison of the surgical (ACLR) limb's capacity to the non-surgical (contralateral) limb. Limb symmetry index is calculated as the following $\left(\frac{ACLR\ Limb}{Contralateral\ Limb}\right) * 100\%$
9. Maladaptive movement patterns – movement patterns that prevent a patient from participating in movement in a safe manner (e.g., offloading, quadriceps avoidance during hopping, etc.)
10. Movement Error – A movement that a patient does that may put them in a dangerous position to injure themselves (e.g., knee valgus).
11. Neuromuscular control – The unconscious activation of dynamic restraints occurring in preparation for and in response to joint motion and loading for the purpose of maintaining and restoring functional joint stability[88].
12. Offloading – The shifting of a patient's mass from being equally distributed across both limbs, to putting more of their mass on one limb compared to the other. This movement can be considered a compensational movement pattern or an asymmetric movement pattern.
13. Patient Report Outcomes (PROs) – The subjective evaluation measuring how an individual perceives an injury or illness to their overall function, lifestyle, and well-being.
14. Persistent muscle weakness – strength deficits that are reported following injury or surgical intervention and fail to improve following prescribed treatments and rehabilitions[47].
15. Post-traumatic osteoarthritis (PTOA) – the presence of an osteoarthritic progression of joint cartilage degeneration after joint trauma[107].
16. Return to Unrestricted Activity (RTA) – The ability of the patient to successfully return to prior levels of physical activity or sport following ACLR. This is verified through patient medical chart reviews, follow-up visits, and/or questionnaires administered over the phone directly with the patient or caretaker.

Innovation

Limited research has incorporated a squatting task variation in a RTS protocol, and few have utilized a bilateral body weight squat in their arsenal of tests[25,35,36,67,82]. If there is a difference in limb loading during a bilateral squatting task in males compared to females this would allow for clinicians to utilize a simple, easy, safe, cost-effective task that they are already implementing in their practice in order to alter their treatment plans according to the individual needs of their patients. Additionally, a bilateral squatting task is something that clinicians can use throughout both early and late stages of rehabilitation. The ability to track changes in patient squat loading with an easy, safe, and quick functional task paired with a quadriceps strength task over time will help aid clinicians in adapting a rehabilitation regiment based on how each individual patient is progressing overtime and intervene if their patient is starting to offload their ACLR limb.

The presence of a relationship between a bilateral squat limb loading symmetry and the LESS assessment functional task would allow clinicians to assess an individual's loading patterns earlier during rehabilitation. The ability to determine a patient's ability to evenly distribute their weight across both limbs could be crucial for intervention. If these maladaptive offloading patterns persist throughout rehabilitation, this could exacerbate functional abilities to perform tasks when the demands of the tasks are ballistic and in a less controlled setting potentially increasing their risk for reinjury. The 3D kinematic assessment of bilateral squatting technique has been shown to be motor skill that will have transferable kinematic effects to dynamic hopping tasks[36,50]. If we are able to elucidate that kinetic assessment of squat loading patterns are predictive of kinematic outcomes during a hopping task later during a patient's rehabilitation phase, this would allow clinicians to intervene early in order to correct poor movement patterns as well as assess patients without the need of expensive 3D kinematic analysis equipment.

APPENDIX B

Literature Review

Introduction

Injuries to the anterior cruciate ligament (ACL) is one of the most common musculoskeletal injuries amongst young active populations.[35] A common treatment option following this injury is the surgical reconstruction (ACLR), with the goal being for patients being able to successfully return-to-unrestricted physical activities (RTA).[71] Following injury and subsequent reconstruction, many individuals experience muscle dysfunction (i.e. strength deficits, motor control deficits, etc.)[24,29,61,71] and psychological consequences (i.e. kinesiophobia, lack of knee self-efficacy, lack of confidence in the knee when returning to physical activity)[5,12,42] that can negatively impact the patient's overall health related quality of life. Muscular deficits have been previously evaluated, however, alterations in limb loading during functional tasks and repercussions to these alterations have yet to be thoroughly discussed and evaluated. The purpose of this literature review is to describe and interpret current peer-reviewed literature surrounding the impact of ACLR, adaptations to the musculature, limb loading alterations following ACLR, and traditional RTA decision making process in individuals following ACLR.

Epidemiological Impact and Patient Resilience post-ACLR

Anterior cruciate ligament (ACL) injuries are common active populations with an incidence rate of 3%-15% yearly depending on a variety of factors (e.g., sport participation, competition level, gender, etc.).[35,71] Additionally, following an initial injury, individuals have a 33% chance on sustaining a reinjury within 2 years of the initial injury.[71] A previous study found when examining high school girls' lacrosse seasons from 2008/209-2016/17 that 65% of knee ligamentous injuries was made up of ACL injuries. Whereas medial cruciate ligament (24%), lateral cruciate ligament (9%), posterior cruciate ligament (<0.01%), and meniscal (39%) injuries made up a smaller percentage of injuries across eight lacrosse seasons.[95] This injury is most prevalent in physically active individuals between 15-25, with an incidence rate of approximately 350,000 in the United States and 1 million worldwide per year.[25,35] Many individuals after injury will opt for a reconstructive surgery (ACLR) in order to return to sport or physical activity.[41,102] The large volume of individuals experiencing this injury and ultimate reconstruction along with the cost of a structured rehabilitation program, and individuals who reinjure has proven to have an enormous economic burden on the United States healthcare system of up to $1 billion per year.[35] Furthermore, many individuals who undergo this injury and reconstruction will have a high likelihood of developing other knee decrements such as meniscal damage, early onset knee osteoarthritis (OA), and early total knee replacement; further exacerbating the economic toll on healthcare systems and those individual's health related quality of life (HRQOL).[41,51,65]

Many of these individuals post-ACLR will have limited and varying amounts of success in fully returning to their previous pre-injury competitive level of physical activity. A structured form of rehabilitation can greatly influence this likelihood of successfully RTA.[105] A study found that of the patients who were fully compliant to the rehabilitation regimen 86% successfully RTA to their preinjury level, compared to 67% who were moderately compliant, 50% who were scarcely compliant, and 45% RTA at their preinjury level who were non-compliant.[105] However, many people do not RTA to their previous level and up to 30% of individuals will sustain a retear.[41] Of the individuals who retear, 74% endure the secondary injury within two years of the initial injury[110]. Graft failure is also a concern with a 5.8% incidence rate of retearing and 11.8% incidence rate of tearing the contralateral side.[71] Additionally, for individuals who RTA within one year are up to 15x more likely to have a secondary reinjury than their healthy control counterparts; this risk of reinjury decreases to 6x for individuals who return within two years.[71] The ability to mitigate the amount of reinjuries that occurred would potentially enhance the quality of life for many individuals who have already sustained their first injury and alleviate future economic burdens that are associated with reinjuries.

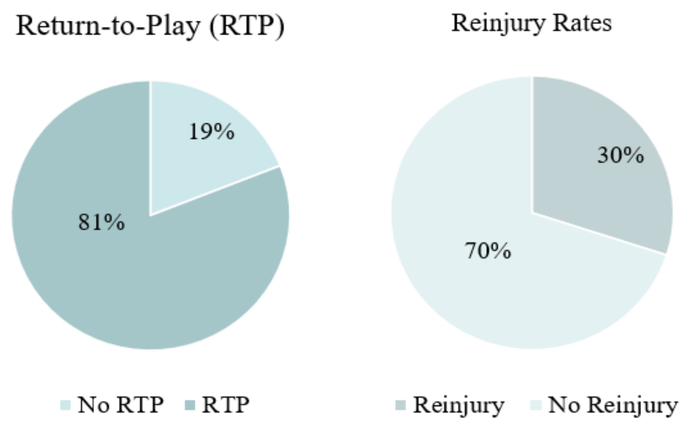

Figure 1: Return-to-play and reinjury rates after ACL reconstruction.[4,41]

Previous research has had conflicting guidelines of when is the optimal time to RTA, ranging from 12 weeks, 6-12 months, and to up to 2 years following ACLR, with no agreed gold standard of RTA criteria or protocol.[12,13,30,35,41,71,109] A previously conducted study narrowed down RTA to be comprised of three constructs: biological healing, physical readiness, and psychological readiness.[12,34] It is important to take into consideration the biological healing timeline of the graft itself which can last up to two years to fully assimilate and complete the "re-ligamentization" process depending on the surgical technique utilized.[12,35,71,78,111] This healing process requires the graft to repopulate and proliferate cells, initial re-vascularization, and re-innervation to restore native properties of the ligament.[71] For example, individuals

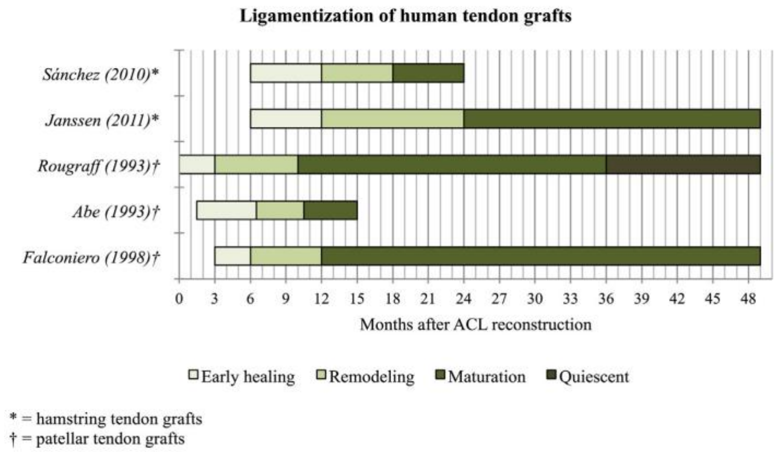

Figure 2. Average ligamentization healing timeline for hamstring and patellar tendon grafts.[78]

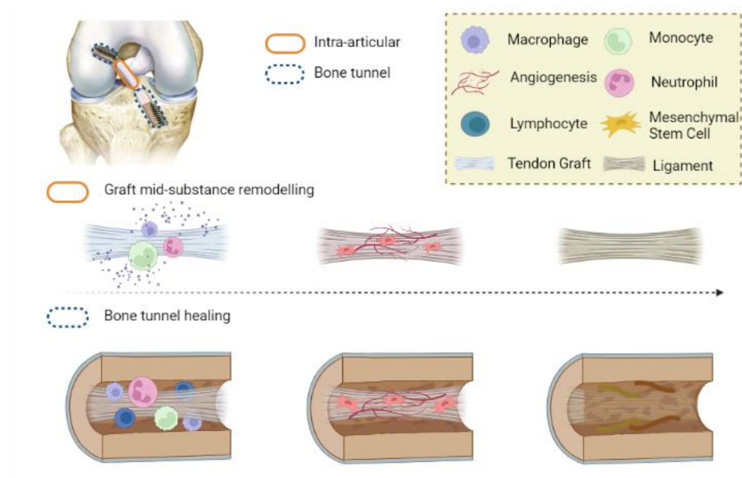

Figure 3. ACL graft healing process after graft-to-bone tunneling schematic diagram.[111]

who undergo a hamstring graft that requires tendon graft-to-bone healing where the tendon graft changes material characteristics to a more stiff material mimicing that of bone.[111] This transition to of the tendon to a bone like matieral requries the formation of tissues called “enthesis” that aid in the following transition: tendon to uncalcified fibrocartilage then to calcified fibrocartilage and lastly to bone.[111] Whereas individuals who undergo a patella bone-tendon-bone graft, allows for a rigid fixation of the graft in the bone tunnel.[97] This type of healing is differ than that of the hamstring graft, in the a patella bone-tendon-bone graft mimics the healing process of a fractured bone allowing for a more stable fixation of the graft within the bone tunnels which facilitates early osteointegration.[97]

Many clinicians and researchers have assessed the physical and psychological readiness of patients; however, the actual assessment can vary widely across healthcare teams and patients. The most common assessment themes that researchers and clinicians have accepted are various iterations of functional tests, movement quality evaluation, strength, power, stability assessments, and psychological subjective patient readiness.[5,16,35]

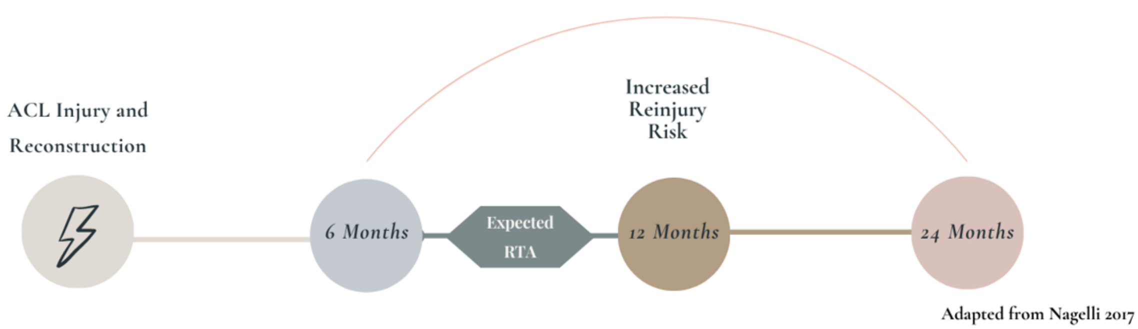

Figure 4: Recovery timeline following ACL injury and subsequent reconstruction.[71]

Muscular Adaptations post-injury

After a traumatic injury and surgery, like an ACLR, there are extensive barriers that patients must overcome. After the traumatic event of the injury itself with the surgery, the neuromuscular system undergoes adaptations that can lead to clinical deficits such as, persistent muscle weakness, abnormal movement patterns, and muscle activation deficits.[72] Persistent muscle weakness, in particular, is a large contributor to hindering patients' ability to successfully RTA.[64,98] Muscle strength is most commonly used to make healthcare decisions when releasing a patient to unrestrictive activity due to the role it plays controlling dynamic stability during functional movement and to lessen any progression of chronic sequelae, such as early onset knee osteoarthrisits.[98]

The most commonly discussed muscle groups are comprised of the thigh musculature, more specifically the quadriceps and hamstrings. These quadriceps deficits can range from 5-40% compared to the non-surgical limb and can persist for up to seven years post-surgery.[98] Hamstring strength deficits can also range from 9-27% lasting up to three years post-surgery.[98] Weakness of these two groups have been observed through the lens of eliciting an increased reinjury risk, decreased movement quality, and decreased muscle activation post-ACLR.[57,75]

Hip weakness has also been previous discussed following ACLR and the complications that can stem from weakness.[24,31,52] Hip weakness, specifically in the gluteus medius, can lead to altered biomechanics such as knee valgus during functional tasks.[24] The inability of the hip musculature to stabilize the pelvis and femoral movement during a dynamic task, such as jump-landing, by allowing the knee lose its postural stability and displace in a valgus position places an increased reinjury risk on those individuals especially with repeated exposures.[24,52] Additionally, hip abductor weakness can result in a Trendelenburg stance or movement pattern where the contralateral pelvis is elevated and a possible trunk lean to the ipsilateral limb causing less demands to be placed at the hips.[84] This reallocation of functional demands can have a negative effect by further increasing the demands placed on the ACLR knee.[84]

The core musculature is also influenced after an ACL injury. The core is a set of muscles that stabilize the spine and pelvis and aid in generating and transferring energy to distal segments, such as limbs, of the body.[53] Without the core the body would not be able to operate effectively by providing proximal stabilization while the distal limbs perform the desired function.[53] This possible instability of the trunk or core during dynamic tasks could also lead to increased knee injury risks.[48,112] A previous study observed an increased amount of trunk displacement during a large perturbation in individuals who had sustained and ACL injury compared to their uninjured counterparts.[112] This finding suggests that increased instability at the trunk and the core musculature is associated with an increase in knee injury risk.[112]

There is an array of ways in which rehabilitation specialists are able to capture and measure these deficits. A common barrier for many rehabilitation specialists is the cost of precise measurement tools.[12,96] The gold standard for measuring strength and movement deficits include instrumentation such as 3D motion capture devices and isokinetic dynamometers, however the vast majority of clinics, and thereby patients, do not readily have access to these tools. There are more cost effective alternatives that are more clinically accessible to rehabilitation specialists, such as 2D video recording, handheld dynamometry, instrumented insoles, etc. to assess kinematic and kinetic variables following ACLR.[12,96] For example, a common way that rehabilitation specialists and researchers have examined kinematic performance during a jump landing task, like the one completed during the landing error scoring system (LESS) test, is by using 3D motion capture technologies. However, it has been observed that there is moderate to excellent validity and excellent interrater reliability of the LESS measured using 2D video analysis, to accurately assess 3D kinematic performance.[73] When developing the scoring criteria for the LESS, authors identified high-risk movement patterns, termed "errors", that could be visually identified via 2D video recordings. Furthermore, this test was originally developed as a screening tool to assess healthy individual's risk of initial non-contact ACL injury.[74]

Repercussions of ACLR on biomechanical loading

The process of regaining strength can be a slow multifaceted process for many individuals.[44] Overall muscle weakness can lead to functional deficits and altered movement patterns that can place individuals at risk of reinjury.[8,76] Not only can these barriers lead to decreased performance, but also can be detrimental to a person's long-term health by increasing joint degeneration.[30,60,98] Movement adaptations and abnormal loading of the medial tibiofemoral compartment can increase that rate of joint degeneration by increasing the rate of cartilage thinning.[3,33,107] Side-to-side asymmetric kinetic loading patterns have been observed in functional tasks such as a drop vertical jump during both the take-off and landing phases of the tasks.[77,81,86] This off-loading pattern is theorized as a protection mechanism in order to minimize the demands of the ACLR limb by eliciting an interlimb compensation.[86] This interlimb compensation can be attributed to several different factors such as neuromuscular function, muscle weakness, limited range of motion, pain, and kineiophobia.[86]

From a kinematic perspective, poor landing mechanics during functional tasks post-ACLR can pose increased reinjury risks if not corrected. High speed dynamic functional tasks such as jump landings are commonly used as RTA criteria due to the nature of the movements being akin to active real-time sport participation.[26,27,77] These tasks are able to highlight poor movement patterns, such as valgus collapse, which is a primary predictor of an ACL injury.[45] A previous study found that healthy women showed an upwards of 4º more knee valgus displacement than their male counterparts.[49] This increase in frontal plane displacement could potentially increase the valgus loadings on the knee by up to 200% for women.[49] It is unclear as to whether the 4º increase in knee valgus carries over to an ACLR population or whether it is exacerbated. Additionally, a reduction in knee flexion moment has also been observed in individuals post-ACLR compared to healthy controls.[27,28,77,101] This lack of knee flexion of the ACLR limb can further exacerbate the load that the ACL graft must sustain during a ballistic movement.[28,48,87,101] A decrease in knee extension moment was also observed in individuals post-ACLR during the takeoff phase and initial contact during a single leg vertical jump.[27,77] This movement compensation strategy is thought to be an attempt by individuals to protect their soft tissues at the knee; however these strategies could be detrimental overtime by facilitating poor landing patterns that inadvertently lead to reinjury.[27]

Rehabilitation specialists are able to use an array of tools to measure loading following ACLR. The most commonly used tool to measure limb loading is through inground force plates.[21] This instrumentation allows for precise measurement of vertical ground reaction force measurement during low impact activities, such as walking or doing a sit-to-stand, as well as higher impact dynamic activities, like countermovement jumps and drop jumps.[21,76,83] Other similar devices that are more cost effective have been utilized to measure balance and loading performance, such as the Nintendo Wii Balance Board and Tekscan MobileMat.[18,23] A newer technology that is being implemented are instrumented insoles. These insoles allow patients to take them outside of the lab and collect data longitudinally in a non-laboratory setting creating a more accurate representation of how patients are participating in everyday activities with regard to whether they are underloading the surgical limb.[96]

Clinically accepted Return to Unrestricted Activity Testing

Currently there is no gold standard accepted for the RTA testing battery criteria. Many clinicians and researchers have similar variations of tests but testing procedures are not universal across all rehabilitation teams.[34,35,54,58,67] The process of recovery with the goal of returning to a previous level of physical activity can be multi-faceted. Traditionally, rehabilitation protocols have been more time-based, however it is becoming more acceptable to have a goal-based criteria when going through the rehabilitation process.[67] These goal-based criteria are comprised of both physical and psychological components.[34,35,67] Previous research highlighted that being purposeful in determining which RTA tests are used minimizes redundancy and increases efficiency during testing to give clinicians unique information on the patient's performance and limb symmetry.[29] Serial assessments should be considered when adopting a RTA testing battery. Serial assessments allow clinicians to track progress and guide clinical decision making, starting approximately 4-months following ACLR. These assessments, particularly evaluating strength increases, should be performed with at least 2-months between testing in order to observe clinically meaningful changes.[11]

There are generally two scenarios in which patients undergo an RTA testing battery. First, is in research setting with laboratory grade instrumentation. This setting generally has access to expensive equipment such as isokinetic dynamometers or 3D motion capture video analysis systems that require trained personnel to operate the devices and fluent in data processing techniques to derive meaningful conclusions.[2,26,56,71,85] These measurements are very precise; however, the overall general ACL population likely will not have financial or geographical access nor time to participate in these types of testing settings.

A more commonly setting is in clinic, such as a physical therapy or athletic training facility, that is more easily accessible to a large number of individuals.[26] These settings are more cost effective for many clinics and as more research is conducted more devices will become more affordable and accessible to more individuals. Kinetics can be objectively measured using handheld dynamometers or strain gauges which are much cheaper than the isokinetic dynamometer alternatives.[2,32,43] Many clinics are also able to utilize 2-dimensional video analysis by exporting the data to open access software for kinematic analysis.[6,26] These low expense options are more affordable for many clinics and have been proven to have test-retest reliability and are valid.[2,6,79,80]

The primary purpose when conducting RTA assessments is to determine how that individual is functioning and to highlight any deficits that the ACLR limb is presented compared to the contralateral limb that should be addressed before clearance to unrestricted physical activity.[41] These RTA tests, however, are not always used to determine whether a patient is ready for full clearance.[10] These RTA tests have the most utility in being able to track progress throughout the rehabilitation process while pinpointing deficits that clinicians should consider intervening on prior to returning to unrestricted activity.[10] Limb symmetry or limb symmetry index (LSI) is a commonly used metric that assess these between limb deficits.[41,75] This metric is defined as: $LSI = \frac{ACLR\ Limb}{Contralateral\ Limb} * 100\%$ with a value of 100% representing perfect symmetry.[75] A LSI value of 90% or greater however has been accepted by the research community as a successful test.[66,67]

This metric can be used to assess a variety of physical tests, it is quick and easy to calculate, and is able to highlight any deficits between limbs. When evaluating strength many individuals, if they have access, will utilize isokinetic dynamometry. These assessments in a ACL population has most commonly been conducted during a concentric knee extension and flexion task.[38,54,94,98] A few previous studies did utilize both concentric and eccentric strength evaluations, however, this is not as commonly utilized.[22,103] For functional dynamic tasks, LSI can be used to determine any differences in limbs during tasks such as the single leg hop, triple hop, or 6-meter timed hop. These hoping tasks are easy to administer and have little to no cost associated with administering them.[82] A discrepancy in distance for the single leg and triple hop or time during the 6-meter timed hop will allow clinicians to alter their rehabilitation program to work of functional deficits.[66] Hoping and jumping tasks are good tool to use in evaluating the readiness of an individual to RTA, however, these tests generally are conducted toward the end of the rehabilitation process.[34,55,66,68] Additionally, some RTA tests include the landing error scoring system (LESS) test.[29,57] There has been a relationship observed between quadriceps strength and performance of the LESS. Where the lower a person's quadriceps strength is the worse the performance is during the LESS test (i.e., the more error someone commits during the LESS).[57]

An alternative option for clinicians to utilize LSI during a functional task could be through a double leg body weight squatting task. Previous research has evaluated double and single leg stance squats however it has been through the lens of motor control strategies, muscle activation, and the effects of fatigue, not as a RTA test.[89,108,113] An increase in research studies have been recently conducted evaluating double leg bilateral squatting tasks and loading symmetry.[20,21,81,92] Rehabilitation specialists have been traditionally familiar with incorporating squats within their typical ACLR rehabilitation protocol for a variety of reasons. The nature of the task requiring multiple joints to be loaded in a synchronous fashion forcing the patients to practice their motor control as well as strengthen the surrounding musculature.[81,89] Bilateral squats are very safe to perform early after reconstruction due to the reduction of anterior shear forces placed on the knee.[92,108] The easy accessibility of a bilateral squatting task and minimal if any cost associated allows for clinicians to test their patients in a functional task early in the rehabilitation process compared to waiting 6-months to assess functional hopping tasks.[89,92] It has also been theorized that bilateral squatting techniques will have a "carryover" effect to more dynamic ballistic tasks such as during a jump landing task.[81]

Traditional Continuum of Care for Recovery

The process to return from an ACLR is multilayered with many factors to consider as well as multiple constituents playing a role in the decision-making process.[106] There are three main broad factors that are accounted for when assessing the readiness of an individual to RTA: 1) biological readiness of the graft itself to withstand forces during physical activity[30,34,70]; 2) physical readiness and capacity of the individual to safely engage in physical activity[13,34]; 3) psychological readiness by diminishing any fear or apprehension of the individual to participate in physical activity without concern of reinjury.[13,34] Even with these three broad factors, time post-surgery has been, and is still the largest contributing factor influencing RTA decision making.[13] Ensuring the graft is fully healed before returning to unrestricted activity, tangentially measured via time following surgery, is of utmost importance. If a patient is cleared to return to unrestricted activity prematurely, this can increase the likelihood of the patient's graft failing.[100]

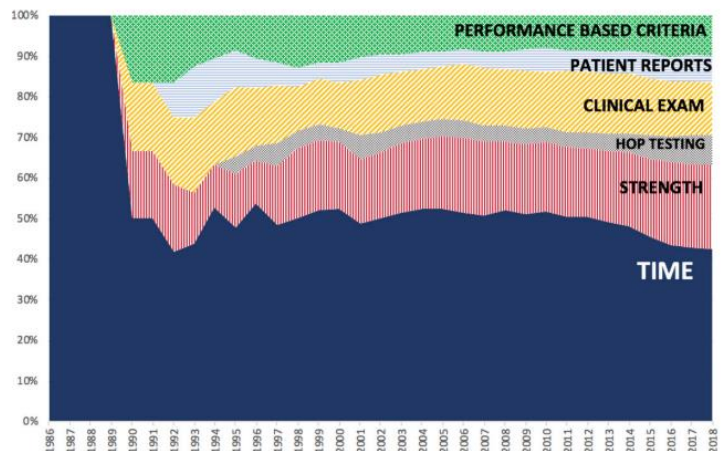

Figure 5. Proportion of RTA criteria factors described in published research from 1986 to 2018.[13]

The ability to be able to successfully collaborate across all stakeholders involved in a person's rehabilitation process, such as physicians, physical therapists, athletic trainers, strength and conditioning specialist, sport psychologist, and/or coaching staff, can also be difficult.[25,35,69] The communication between the healthcare constituents is important, however, communication with the patient is even more crucial for the success of the patient.

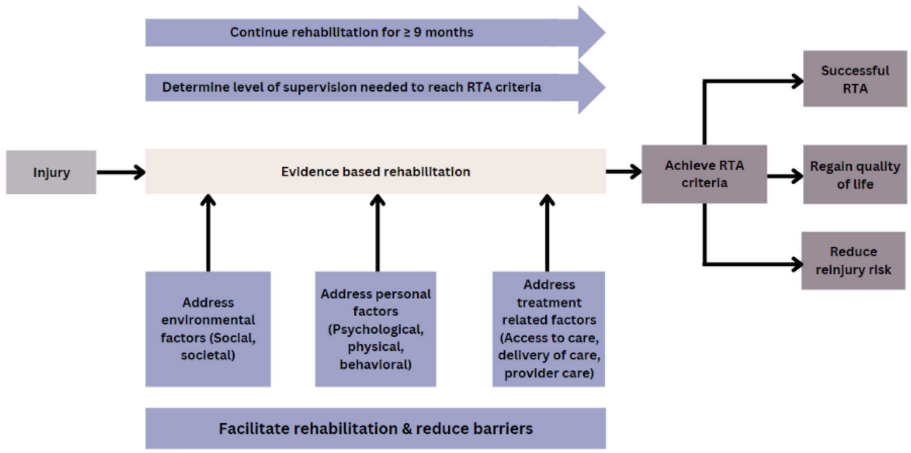

Figure 6. Return-to-play continuum post-ACLR.[106]

Ensuring from the beginning of the rehabilitation process that patients have clear realistic expectations and goals for progressing but also as a timeline to clearance to unrestricted physical activity.[12,34,104] Patients also can experience psychological barriers that can hinder their ability to fully RTA at the same pre-injury level of rigor.[5,69] Psychological factors can include fear of injury or kinesiophobia, expectations, motivation, sports confidence, and optimism could be predictive of self-reported function like pain, functional ability, and RTA.[12,25,69,104] Ensuring that patients have a support system in place is crucial in facilitating confidence in their progress during rehabilitation.[15]

This injury does have long-term consequences that should be taken into consideration. This injury is an anatomy changing injury not only to the knee structures and musculature but also from a neurological perspective.[37,60,62,72] The loss of the ligament itself with the multitude of mechanoreceptors, such as Golgi tendon organs, Ruffini endings, Pacinian corpuscles, and free nerve endings, as well as the muscle atrophy makes it very challenging to expect patients to return full to unrestricted activity before 6-months after surgery.[37,114] These decrements in the individual's functional capacity from a muscular and neurological perspective can hinder a patient's health related quality of life. Individuals post-ACLR can have a decrease in the amount of physical activity they participate in, which could also cause an increased risk of early onset knee osteoarthritis, early total knee replacement surgery, cardiovascular disease, obesity, and cancers.[5,7,9,51] Any preventative measures that can be utilized to diminish the risks of individuals incurring these comorbidities should be explored.

The post-operative rehabilitation and recovery can last 6-months or up to over a year which can become challenging for patients and their rehabilitation team.[71] Many individuals can also experience financial hardships and constraints from insurance companies that may greatly limit the amount of visits to a rehabilitation specialist.[17,69,90] This is can be a real issue in the later phase of rehabilitation which can be a crucial time to develop neuromuscular training and develop optimal movement patterns and strength necessary for high demand activities such as plyometrics and agility tasks that are needed to return to high performance in their sport or activity.[17] The ability to identify injury risk factors

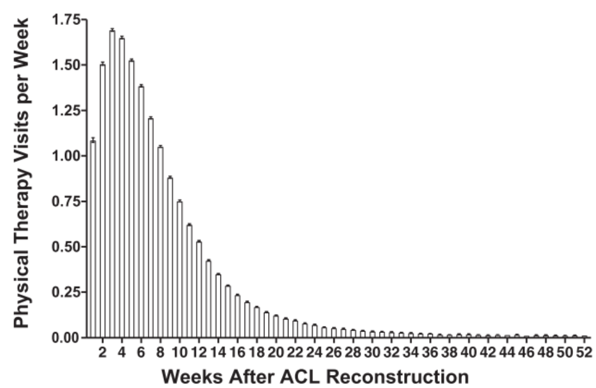

Figure 7. Mean number of weekly physical therapy visits after ACLR.[17]

through a moment assessment, like a squat, early in the rehabilitation phase would allow for clinicians to address those movement compensations quickly while the patient is still attending rehabilitation to potentially mitigate their reinjury risk when they are no longer in a structured rehabilitation program.

Conclusion

Injury and subsequent reconstruction to the ACL can negatively impact a patient's quality of life due to numerous factors (i.e., financial burden, strength deficits, increased reinjury rate, early onset osteoarthritis, etc.). Patients have to overcome three primary recovery processes, 1) biological healing, 2) psychological healing, and 3) physical healing.[34] Many individuals experience deficits to their muscular strength and limb loading which if left untreated could increase one's risk for reinjury or other consequences such as the development of early onset osteoarthritis. A way to measure patients' progress while also highlighting deficits that may need additional intervention is through serial RTA assessments. Currently, minimal RTA assessments include a measurement of limb loading performance during a functional task. It is unclear as to how biological sex may influence movement patterns during a bilateral squatting task, or if limb loading recovery is related to lower extremity strength recovery. Previous research has also highlighted the relationship between similar movement characteristics during a squatting task and a jump landing. However, it is unclear as to the prognostic ability of a limb loading squatting task during an initial RTA visit to predict functional performance at a later RTA assessment timepoint. The following study will present with aims to address these gaps in the current literature.

APPENDIX C

Additional Methods

Table C1. Overall Study Procedures

1. Attend Visit 1 (V1) at the Student Health and Wellness Center, Room 329. Strength and Endurance Protocol (STEP)
    a. Obtain informed consent
    b. Complete Patient Screening
        i. Assess eligibility criteria
    c. Obtain anthropometric measures and patient demographics
        i. Take patient's body mass (kg)
        ii. Take patient's body height (cm)
        iii. Determine the "involved" surgical limb (ACL-Reconstructed Limb)
        iv. Determine limb dominance
    d. Complete patient reported outcomes
    e. Warm-up
    f. Assess quadriceps and hamstring isokinetic torque at 90º/sec
    g. Assess double-leg squat
    h. Dismiss patient for Visit 1
2. Attend Visit 2 (V2) at the Student Health and Wellness Center, Room 329. Lower Extremity Assessment Protocol (LEAP)
    a. Obtain anthropometric measures and patient demographics
        i. Take patient's body mass (kg)
        ii. Take patient's body height (cm)
    b. Complete patient reported outcomes
    c. Warm-up
    d. Assess quadriceps and hamstring isokinetic torque at 90º/sec
    e. Assess double-leg squat
    f. Complete the Landing Error Scoring System (LESS)
    g. Dismiss patient from Visit 2

Table C2. Patient Consenting Process

When a participant first arrives in the lab, they should be given the current consent form with an explanation of its contents, time to review and the opportunity to ask questions. The process of documenting the informed consent process differs depending on the participant:

- ACLR adult signs the adult knee consent
- ACLR child 14- 18 signs the adult knee consent and a guardian must sign the consent
- ACLR child 12-14 signs the child assent form and the guardian must sign the consent
- ACLR Spanish speaking participant signs the Spanish short form while the translator signs the consent form after verbally translating it to the participant
- Healthy participant signs the healthy adult consent

After the participant has provided informed consent and signed the correct form the person obtaining the consent must also sign the form.

Figure C2: Informed Consent For IRB-HSR # 17399

IRB-HSR # 17399: Return to Activity Following Injury
Subjects with Knee Injury

Consent of an Adult to Be in a Research Study

In this form "you" means a person 18 years of age or older who is being asked to volunteer to participate in this study.

Parents' or Guardians' Permission for Your Child to be in a Research Study

Agreement of a Child (15-17 years of age) to Be in a Research Study

In this form "you" means the child in the study *and* the parent or guardian.

- ✓ If you are the parent or guardian, you are being asked to give permission for your child to be in this study.
- ✓ If you are the child, you are being asked if you agree to be in this study.

In this form "we" means the researchers and staff involved in running this study at the University of Virginia.

In this form "you" means the person (your child) who is being asked to be in this study. As the parent or guardian, you are being asked to give permission for your child to be in this study.

Participant's Name________________________________

Principal Investigator: Joseph Hart, PhD, ATC
Human Services, Curry School of Education
PO Box 400407
Charlottesville, VA 22904-4407 Telephone: (434) 924-6187

What is the purpose of this form?

This form will help you decide if you want to be in the research study. You need to be informed about the study, before you can decide if you want to be in it. You do not have to be in the study if you do not want to. You should have all your questions answered before you give your permission or consent to be in the study.

This consent form may contain words or information you do not understand. The Principal Investigator, Joseph Hart, PhD, ATC (Assistant Professor in Sports Medicine/Athletic Training), and the research Study Coordinators, (Doctoral students, Sports Medicine) who are familiar with the study will explain anything that you do not clearly understand. Please ask as many questions as you need to make sure that you understand this study and why you are being asked to participate.

Please read this form carefully. If you want to be in the study, you will need to sign this form. You will get a copy of this signed form.

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Version Date: 10/12/21

IRB-HSR # 17399: Return to Activity Following Injury
Subjects with Knee Injury

Who is funding this study?

There will be no funding for this study.

Why is this research being done?

The purpose of this study is to learn more about leg function after joint injury of the knee.We know that leg function may change after an injury occurs. The goal of this study is to determine whether the quality of leg function, levels of pain, or levels of strength may help predict how well someone will do after an injury or surgery. Overall, we hope to get information that may improve health care and quality of life for patients.

You are being asked to be in this study because you have recently had a joint injury of your knee requiring medical treatment and you were physically active before your injury.

Up to 5,000 people will be enrolled in this study at UVA.

What will happen if you are in the study?

If you choose to participate in this study, you will sign this consent form before any study related procedures take place.

We will then review your medical history with you, including your medications, to make sure it is safe for you to participate.

STUDY PROCEDURES (will take approximately one and a half hours to complete):

If you are a participant with a knee injury, you will be asked to complete the following:

1. **Gait Motion Collection; approximately 10 minutes**
   You will wear 5 Motion Tracking devices, one on each wrist, one on each ankle, and one on your back plus flat pressure sensing inserts in your shoes (similar to the insole of your shoe). The devices do not directly attach to your body skin, because we use comfortable wearable fabrics or bands to wrap the devices.
   You will exercise on a treadmill at varying speeds for up to 10 minutes in order to "warm up" prior to testing.

2. **Questionnaires; approximately 15 minutes total to complete**
   You will complete several questionnaires. These questionnaires ask about:
   a. How you are feeling
   b. Your lifestyle habits
   c. Medicine use

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d. Daily activities
e. Your leg function
f. Your pain during daily activities
g. Physical therapy
    - You will be asked to complete this questionnaire in-person and may receive a follow-up phone call within 12 months of completing your assessment to complete the questionnaire again.

3. **Isokinetic strength; about 10 minutes**

This test measures the force you produce with your leg.

- You will be asked to sit in a stationary chair with your knees bent at 90 degrees (a right angle).
- Your hips will be secured with Velcro straps. Your ankle will be secured to a padded strap below the chair. This strap is connected to a device which will measure how much force you can produce.
- You will be asked to kick out and pull back your leg up to10 times. This will be repeated at two different levels of resistance.
- You will be asked to complete this trial as fast as you can
- You will be asked to complete one trial at each level of resistance.
- This will be performed on both legs.

4. **Isometric strength and fatigue; about 10 minutes**

This test will measure the force you are producing with your leg.

- You will be seated in a stationary chair. The chair has handles on each side.
- Your hips will be secured with Velcro straps. Your ankle will be secured to a padded strap below the chair. This strap is connected to a device designed to measure how much force you can produce.
- You will be asked to kick out and pull back as hard as you can several times in order to estimate the most force you can produce with your leg. We will ask you to do this three times. You will rest for 2 minutes between each time.
- You will then be asked to kick out and pull back at your maximum effort and hold your leg out for 30-60 seconds to measure how quickly your muscles become tired, also called motor fatigue. We will ask you to try to keep the same amount of force for as long as you can.
- This will be performed on both legs.

5. Postural Control (Balance); about 5 minutes

- We will ask you to stand with both legs on a large plate, which measures force.
- Once balanced, you will be asked to pick one leg up, and balance on the other with your eyes closed. Each trial will last for 20 seconds.
- We will ask you to do this four times on each leg, 2 with your eyes open, 2 with your eyes closed.

6. Landing Error Scoring System (jump landing task); about 5 minutes

IRB-HSR # 17399: Return to Activity Following Injury
Subjects with Knee Injury

- You will be asked to stand on a raised platform (about 12 inches high)
- You will then be asked to step down and then jump straight up
- We will ask you to do this three times
- Video cameras will be used to record this activity from the front and side views.

7. **Single leg hop tests; about 15 minutes**

- You will be asked to lie down on a treatment table so that the length of your leg can be measured.
- You will then be asked to hop as far as you can on each leg multiple times in different directions.
- The distance you hop will be measured along a tape measure.
- We will also ask you to hop as quickly as possible over a distance of about 20 feet.
- You will be given 4 practice hop trials in order to practice before testing begins.
- Once testing begins, three hop trials will be measured for each hop test.
- This will be performed on both legs.

8. **Single leg vertical hop; about 5 minutes**

- You will be asked to stand on a mat with one leg and hop straight up 4 consecutive times.
- You will be asked to perform this task twice on each limb.

9. **Double leg squat; about 5 minutes**

- You will be asked to stand on a mat with both feet.
- You will then be asked to squat down as far as you can and then return back to your standing position.
- You will be asked to perform this 3 times.

10. **Hip strength assessment, about 10 minutes**

- You will be asked to lie on your back with your knees bent in between the dynamometer (a device used to measure force), which will be on both sides of each knee.
- You will be asked to push in and out as hard as you can for three separate trials.
- You will have the opportunity to practice pushing out and pushing in as many times as you would like.

11. EMG sensors

- **Delsys Trignio wireless Surface EMG sensors will be placed on both thighs at the beginning of the test and will be worn throughout all procedures listed above**
- **The electrodes are secured using a wrap so they do not move and do not require shaving the skin**

12. Follow-up Phone Call or Postage Mail; about 15 minutes

- You may be contacted within 12 months to complete the Physical Therapy Questionnaire and injury history form. You will complete these questionnaires both in-person at your strength and functional assessment, at any follow-up visits, and via the follow-up phone call.

- You may also be contacted through postage mail with the same follow-up questionnaire. A pre-paid return mail will be provided to return the competed questionnaire to the lab.

WHAT ARE YOUR AND YOUR PARENT/LEGAL GUARDIAN'S RESPONSIBILITIES IN THE STUDY?

You and your parent/legal guardian have certain responsibilities to help ensure your safety.
These responsibilities are listed below:

- Your parent/legal guardian must bring you to each study visit.
- You and your parent/legal guardian must be completely truthful about your health history.
- Follow all instructions given.
- You or your parent/legal guardian should tell the study doctor or study staff about any changes in your health or the way you feel.
- Answer all of the study-related questions completely.

Inform the study doctor or study staff as soon as possible if you have to take any new medications, including anything prescribed by a doctor or those that you can buy without a prescription (over-the-counter), including herbal supplements and vitamins.

How long will this study take?

You will return to Exercise and Sports Injury Lab (EASIL) in Memorial Gym yearly or twice a year for ten years, depending on your doctor's instructions and the results of your initial exam in this study. You will complete up to 3 visits within 6 months of your surgery: one prior to your surgery and 2 withing 6 months after your surgery. Then you will have the option to return another 2-3 times over the next 6 months from your surgery (depending on the recommendations from the study team and your doctor) and then yearly thereafter. The study session will be a repeat of the sessions described above. Each visit will last about 1½ hours.

If you want to know about the results before the study is done:

During the study you are having an investigational test done. The purpose of the test is NOT to diagnose any disease or abnormality you may have. Because the test is investigational there is no way for the study leader to understand if the results are "normal" or "abnormal." However, IF any test results are concerning, your study leader will let you know.

In addition, as the research moves forward, your study leader will keep you informed of any new findings about the research itself that may be important for your health or may help you decide if you want to continue in the study.

You will be provided with a personalized report based on the information gathered during your assessment. With your permission, a copy will also be shared with your referring physician (if your doctor is within the University of Virginia medical system).

<u>Other unexpected risks:</u>
You may have side effects that we do not expect or know to watch for now. Call the study leader if you have any symptoms or problems.

Could you be helped by being in this study?

You may or may not benefit from being in this study. Possible benefits include learning more about how your joint injury is doing. In addition, information researchers get from this study may help others in the future.

What are the risks of being in this study?

Risks and side effects related to the study procedures include:
<u>Less Likely</u>

- You may have temporary soreness of your knee and/ or thigh muscles after the strength and movement exercises.
- There is a very small risk of falling during the jumping, squatting and hopping tasks
- There is a very small risk of lower leg joint sprain such as ankle or knee, and mild muscle soreness

If soreness occurs, it will very likely resolve on its own, with no further problems.

<u>Other unexpected risks:</u>
You may have side effects that we do not expect or know to watch for now. Call the study leader if you have any symptoms or problems.

What are your other choices if you do not join this study?

You do not have to be in this study to be treated for your illness or condition. You can get the usual treatment even if you choose not to be in this study. The usual treatment would include continuing to be followed and treated with traditional rehabilitation as prescribed by your treating physician. Participation in this study does not take the place of treatment for your injury.

If you are an employee of UVa your job will not be affected if you decide not to participate in this study.

If you are a student at UVa, your grades will not be affected if you decide not to participate in this study.

Will you be paid for being in this study?

You will not get any money for being in this study.

Will being in this study cost you any money?

All of the procedures in this study will be provided at no cost to you or your health insurance. You will be responsible for the cost of travel to come to any study visit and for any parking costs.

What if you are hurt in this study?

If you are hurt as a result of being in this study, there are no plans to pay you for medical expenses, lost wages, disability, or discomfort. The charges for any medical treatment you receive will be billed to your insurance. You will be responsible for any amount your insurance does not cover. You do not give up any legal rights, such as seeking compensation for injury, by signing this form.

What happens if you leave the study early?

You can change your mind about being in the study any time. You can agree to be in the study now and change your mind later. If you decide to stop, please tell us right away. You do not have to be in this study to get services you can normally get at the University of Virginia.

Even if you do not change your mind, the study leader (Dr. Joe Hart) can take you out of the study. Some of the reasons for doing so may include

a) Your study physician is concerned about your health
b) Your injury gets worse
c) The side effects of the study procedures are too dangerous for you
d) You do not follow instructions
e) The study sponsor closes the study for safety, administrative or other reasons

If you decide to stop being in the study, we will ask you to please notify Dr. Joe Hart in writing at 210 Emmet Street South, P.O. Box 400407, Charlottesville, VA 22904-4407.

How will your personal information be shared?

The UVa researchers are asking for your permission to gather, use and share information about you for this study. If you decide not to give your permission, you cannot be in this study, but you can continue to receive regular medical care at UVA.

If you sign this form, we may collect any or all of the following information about you:

- Personal information such as name, address, date of birth, medical record number.
- Social Security number ONLY IF you are being paid to be in this study.
- Your health information. If required for this study, this may include a review of your medical records and test results from before, during and after the study from any of your doctors or health care providers (if required for this study, this may include mental health care records, substance abuse records, and/or HIV/AIDS records).

Who will see your private information?

- The researchers to make sure they can conduct the study the right way, observe the effects of the study and understand its results.
- People or groups that oversee the study to make sure it is done correctly.
- The sponsor(s) of this study, and the people or groups it hires to help perform or review this research.

- Insurance companies or other organizations that may need the information in order to pay your medical bills or other costs of your participation in the study.
- Tax reporting offices (if you are paid for being in the study).
- People who evaluate study results, which can include sponsors and other companies that make the drug or device being studied, researchers at other sites conducting the same study, and government agencies that provide oversight such as the Food and Drug Administration (FDA) if the study is regulated by the FDA.

Some of the people outside of UVa who will see your information may not have to follow the same privacy laws that we follow. They may release your information to others, and it may no longer be protected by those laws.

The information collected from you might be published in a medical journal. This would be done in a way that protects your privacy. No one will be able to find out from the article that you were in the study.

What if you sign the form but then decide you don't want your private information shared?

You can change your mind at any time. Your permission does not end unless you cancel it. To cancel it, please send a letter to the researchers listed on this form. Then you will no longer be in the study. The researchers will still use information about you that was collected before you ended your participation.

The information collected about you will be kept confidential by UVa as required by the federal Privacy Rule. Your information will not be released outside of UVa unless it is permitted by law.

Please contact the researchers listed below to:

- Obtain more information about the study
- Ask a question about the study procedures or treatments
- Report an illness, injury, or other problem (you may also need to tell your regular doctors)
- Leave the study before it is finished
- Express a concern about the study

Joseph Hart, PhD, ATC
Human Services, Curry School of Education
PO Box 400407
Charlottesville, VA 22904-4407
Telephone: (434) 924-6187

What if you have a concern about a study?

You may also report a concern about a study or ask questions about your rights as a research subject by contacting the Institutional Review Board listed below.

University of Virginia Institutional Review Board for Health Sciences Research
PO Box 800483

Charlottesville, Virginia 22908 Telephone: 434-924-9634

When you call or write about a concern, please give as much information as you can. Include the name of the study leader, the IRB-HSR Number (at the top of this form), and details about the problem. This will help officials look into your concern. When reporting a concern, you do not have to give your name.

Signatures

What does your signature mean?

Before you sign this form, please ask questions about any part of this study that is not clear to you. Your signature below means that you have received this information and all your questions have been answered. If you sign the form it means that you agree to join the study. You will receive a copy of this signed document.

Consent From Adult

___________________	___________________	______
PARTICIPANT (SIGNATURE)	PARTICIPANT (PRINT)	DATE

To be completed by participant if 18 years of age or older.

Person Obtaining Consent

By signing below, you confirm that you have fully explained this study to the potential subject, allowed them time to read the consent or have the consent read to them, and have answered all their questions.

___________________	___________________	______
PERSON OBTAINING CONSENT (SIGNATURE)	PERSON OBTAINING CONSENT (PRINT)	DATE

Assent from Child

Consent from the parent/guardian MUST be obtained before approaching the child for their assent.

___________________	___________________	______
PARTICIPANT (SIGNATURE)	PARTICIPANT (PRINT)	DATE

Person Obtaining Assent of the Child (less than 18 years of age)

Consent from the parent/guardian MUST be obtained before approaching the child for their assent.

By signing below you confirm that the study has been explained to the child (less than 18 years of age), all questions have been answered and the child has voluntarily agreed to participate.

___________________	___________________	______
PERSON OBTAINING ASSENT (SIGNATURE)	PERSON OBTAINING ASSENT (PRINT)	DATE

Parental/ Guardian Permission

By signing below, you confirm you have the legal authority to sign for this child.

___________________	___________________	______
PARENT/GUARDIAN (SIGNATURE)	PARENT/GUARDIAN (PRINT NAME)	DATE

Person Obtaining Parental/Guardian Permission

By signing below you confirm that you have fully explained this study to the parent/guardian, allowed them time to read the consent or have the consent read to them, and have answered all their questions.

___________________	___________________	______
PERSON OBTAINING PARENTAL/ GUARDIAN PERMISSION (SIGNATURE)	PERSON OBTAINING PARENTAL/GUARDIAN PERMISSION (PRINT NAME)	DATE

Signature of Impartial Witness

If this consent form is read to the subject because the subject is blind or illiterate, an impartial witness not affiliated with the research or study doctor must be present for the consenting process and sign the following statement. The subject may place an X on the Participant Signature line above.

I agree the information in this informed consent form was presented orally in my presence to the **identified individual(s)** who has had the opportunity to ask any questions he/she had about the study. I also agree that the **identified individual(s)** freely gave their informed consent to participate in this trial.
Please indicate with check box the identified individual(s):

☐ Subject
☐ Parent(s)/Guardian of the subject

___________________	___________________	______
IMPARTIAL WITNESS (SIGNATURE)	IMPARTIAL WITNESS (PRINT)	DATE

Interpreter

If the study is explained to a potential subject in a language other than English, the signature of the interpreter is required and signatures are required on separate forms depending on the language spoken by each individual. See table below for additional information.

INDIVIDUAL	***SIGN***

Subject/Surrogate	*Translated Short Form OR translated Full Consent*
Interpreter	*EITHER* • *Translated Short Form AND English Version of Full Consent* • *Translated Full Consent*
Person Obtaining Consent	*English Version of Full Consent*
Parent/Guardian	*Applicable form in language they understand (sign one of the following)* • *English Version of Full Consent,* • *Translated Full Consent* • *Translated Short Form*

The study was explained to the following individuals in a language other than English.
Check all that apply.
☐ Subject
☐ Parent(s)/Guardian of the subject

Interpreter
By signing below you confirm that the study has been fully explained in a language the person understood and that all of their questions have been answered.

INTERPRETER (SIGNATURE)	INTERPRETER (PRINT)	DATE

If an interpreter was used via an outside phone service such as Cyracom, enter the interpreters ID# on the signature line above and document in the consenting process note that an outside interpreter via phone service was used to obtain consent/assent.

Table C3. Patient Demographics

1. Take patient's mass & height on standing scale and stadiometer (Health O Meter #500KL)

   Figure C3. Health O Meter #500KL device used to measure height and weight

2. Determine the patient's involved or surgical limb by asking "which leg did you have surgery on?"
3. Determine the patient's dominant limb by asking "which leg would you kick a soccer ball with for distance?"
4. Administer patient demographic and health history form

Table C4. Patient Reported Outcome Measures

Following the consenting process and demographics, Figures C4.1 through Figure C4.5. were completed

Figure C4.1. General Health History Form

General Health History Form
UVA Exercise and Sports Injury Laboratory

Name: ______________________
Date of Visit: ________________

Height	Weight	Sex	Age	Date of Birth
				/ /

Please check below if you have had any of the following and explain checked items on line.

General Medical

- ☐ Allergies/Sensitivities (Latex, cold, medications, etc.)
- ☐ Asthma
- ☐ Cancer
- ☐ Biomedical devices (Implants, pacemaker, etc.)
- ☐ Diabetes
- ☐ Pregnant or nursing
- ☐ Recent illness (Cold, flu, infection, etc.)
- ☐ Surgery
- ☐ Other: _______________

Please Explain: ____

Neurological

- ☐ Epilepsy/Seizures
- ☐ Anxiety disorder
- ☐ ADHD
- ☐ Diabetic neuropathy
- ☐ Multiple Sclerosis
- ☐ Parkinson disease
- ☐ Cerebral Palsy
- ☐ Vertigo
- ☐ Balance disorder
- ☐ Concussion or Traumatic brain injury
- ☐ Other: _______________

Please Explain: ____

Cardiovascular

- ☐ High blood pressure
- ☐ Shortness of breath
- ☐ Heart attack
- ☐ Heart disease
- ☐ Stroke
- ☐ Heart murmur
- ☐ Thrombosis or Embolism
- ☐ Marfan's Syndrome
- ☐ Sickle cell trait
- ☐ Cardiac Arrhythmia (irregular heart beat)
- ☐ Other:

Please Explain: ____

General Orthopaedic

- ☐ Surgery
- ☐ Previous fracture
- ☐ Sprains or Strains (ligament/muscle/tendon)
- ☐ Osteoarthritis
- ☐ Rheumatoid arthritis
- ☐ Assistive devices (crutches, braces, etc.)
- ☐ Gout
- ☐ Osteoporosis/Osteopenia
- ☐ Other: _______________

Please Explain: ____

Other

❖ Have you taken any prescription or over-the-counter medications within the last 24-hours?
☐ YES ☐ NO *If yes, please list:* ________________________________

❖ Have you consumed any of the following stimulants or depressants in the last 12-hours?
☐ Caffeine ☐ Alcohol ☐ Tobacco
If yes, please explain: ________________________

❖ Do you exercise regularly? ☐ YES ☐ NO
If yes, what type and for how long? ________________________________

❖ Are you currently experiencing physical pain? ☐ YES ☐ NO
If yes, please indicate location, severity, and currently treatments for you pain:
____

Figure C4.2. Tampa Scale for Kinesiophobia (TSK-17)

TAMPA SCALE FOR KINESIOPHOBIA

	CIRCLE THE NUMBER THAT BEST DESCRIBES YOUR BELIEF FOR EACH STATEMENT BELOW:	STRONGLY DISAGREE	DISAGREE	AGREE	STRONGLY AGREE
1	I'm afraid that I might injure myself if I exercise	1	2	3	4
2	If I were to try to overcome it, my pain would increase	1	2	3	4
3	My body is telling me I have something dangerously wrong	1	2	3	4
4	My pain would probably be relieved if I were to exercise	1	2	3	4
5	People aren't taking my medical condition seriously enough	1	2	3	4
6	My accident has put my body at risk for the rest of my life	1	2	3	4
7	Pain always means I have injured my body	1	2	3	4
8	Just because something aggravates my pain does not mean it is dangerous	1	2	3	4
9	I am afraid that I might injure myself accidentally	1	2	3	4
10	Simply being careful that I do not make any unnecessary movements is the safest thing I can do to prevent my pain from worsening	1	2	3	4
11	I wouldn't have this much pain if there weren't something potentially dangerous going on in my body	1	2	3	4
12	Although my condition is painful, I would be better off if I were physically active	1	2	3	4
13	Pain lets me know when to stop exercising so that I don't injure myself	1	2	3	4
14	It's really not safe for a person with a condition like mine to be physically active	1	2	3	4
15	I can't do all the things normal people do because it's too easy for me to get injured	1	2	3	4
16	Even though something is causing me a lot of pain, I don't think it's actually dangerous	1	2	3	4
17	No one should have to exercise when he/she is in pain	1	2	3	4

Figure C4.3. Knee Injury and Osteoarthritis Outcome Score (KOOS)

Please complete the survey below.

Thank you!

1) Date of Visit ____________________

INSTRUCTIONS: This survey asks for your view about your knee. This information will help us keep track of how you feel about your knee and how well you are able to perform your usual activities.
Answer every question by ticking the appropriate box, only one box for each question. If you are unsure about how to answer a question, please give the best answer you can.

Symptoms
These questions should be answered thinking of your knee symptoms during the last week.

2) S1. Do you have swelling in your knee?
- ○ Never
- ○ Rarely
- ○ Sometimes
- ○ Often
- ○ Always

3) S2. Do you feel grinding, hear clicking or any other type of noise when your knee moves?
- ○ Never
- ○ Rarely
- ○ Sometimes
- ○ Often
- ○ Always

4) S3. Does your knee catch or hang up when moving?
- ○ Never
- ○ Rarely
- ○ Sometimes
- ○ Often
- ○ Always

5) S4. Can you straighten your knee fully?
- ○ Always
- ○ Often
- ○ Sometimes
- ○ Rarely
- ○ Never

6) S5. Can you bend your knee fully?
- ○ Always
- ○ Often
- ○ Sometimes
- ○ Rarely
- ○ Never

Stiffness
The following questions concern the amount of joint stiffness you have experienced during the last week in your knee. Stiffness is a sensation of restriction or slowness in the ease with which you move your knee joint.

7) S6. How severe is your knee joint stiffness after first wakening in the morning?
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

8) S7. How severe is your knee stiffness after sitting, lying or resting later in the day?
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

Pain

9) P1. How often do you experience knee pain?
- ○ Never
- ○ Monthly
- ○ Weekly
- ○ Daily
- ○ Always

What amount of knee pain have you experienced the last week during the following activities?

10) P2. Twisting/pivoting on your knee
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

11) P3. Straightening knee fully
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

12) P4. Bending knee fully
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

13) P5. Walking on flat surface
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

14) P6. Going up or down stairs
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

15) P7. At night while in bed
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

16) P8. Sitting or lying
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

17) P9. Standing upright
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

Function, daily living
The following questions concern your physical function. By this we mean your ability to move around and to look after yourself. For each of the following activities please indicate the degree of difficulty you have experienced in the last week due to your knee.

18) A1. Descending stairs
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

19) A2. Ascending stairs
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

For each of the following activities please indicate the degree of difficulty you have experienced in the last week due to your knee.

20) A3. Rising from sitting
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

21) A4. Standing
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

22) A5. Bending to floor/pick up an object
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

23) A6. Walking on flat surface
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

24) A7. Getting in/out of car
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

25) A8. Going shopping
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

26) A9. Putting on socks/stockings
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

27) A10. Rising from bed
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

28) A11. Taking off socks/stockings
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

29) A12. Lying in bed (turning over, maintaining knee position)
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

30) A13. Getting in/out of bath
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

31) A14. Sitting
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

32) A15. Getting on/off toilet
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

For each of the following activities please indicate the degree of difficulty you have experienced in the last week due to your knee.

33) A16. Heavy domestic duties (movign heavy boxes, scrubbing floors, etc)
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

34) A17. Light domestic duties (cooking, dusting, etc)
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

Function, sports and recreational activities
The following questions concern your physical function when being active on a higher level. The questions should be answered thinking of what degree of difficulty you have experienced during the last week due to your knee.

35) SP1. Squatting
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

36) SP2. Running
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

37) SP3. Jumping
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

38) SP4. Twisting/pivoting on your injured knee
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

39) SP5. Kneeling
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

Quality of Life

40) Q1. How often are you aware of your knee problem?
- ○ Never
- ○ Monthly
- ○ Weekly
- ○ Daily
- ○ Constantly

41) Q2. Have you modified your life style to avoid potentially damaging activities to your knee?
- ○ Not at all
- ○ Mildly
- ○ Moderately
- ○ Severely
- ○ Totally

42) Q3. How much are you troubled with lack of confidence in your knee?
- ○ Not at all
- ○ Mildly
- ○ Moderately
- ○ Severely
- ○ Totally

43) Q4. In general, how much difficulty do you have with your knee?
- ○ None
- ○ Mild
- ○ Moderate
- ○ Severe
- ○ Extreme

Figure C4.4. International Knee Documentation Committee Subjective Knee Form (IKDC)

Please complete the survey below.

Thank you!

2000 IKDC SUBJECTIVE KNEE EVALUATION FROM

1) Date of Visit ____________________

SYMPTOMS*:

***Grade symptoms at the highest activity level at which you think you could function without significant symptoms, even if you were not actually performing activities at this level.**

2) 1. What is the highest level of activity that you can perform without significant knee pain?

○ Very strenuous activities like jumping or pivoting as in basketball or soccer
○ Strenuous activities like heavy physical work, skiing or tennis
○ Moderate activities like moderate physical work, running or jogging
○ Light activities like walking, housework or yard work
○ Unable to perform any of the above activities due to knee pain

3) 2. During the past 4 weeks, or since your injury, how often have you had pain?
(0 = Never and 10 = Constant)

○ 0 ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

4) 3. If you have pain, how severe is it?
(0 = No pain and 10 = worst pain imaginable)

○ 0 ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

5) 4. During the past 4 weeks, or since your injury, how stiff or swollen was your knee?

○ Not at all
○ Mildly
○ Moderately
○ Very
○ Extremely

6) 5. What is the highest level of activity you can perform without significant swelling in your knee?

○ Very strenuous activities like jumping or pivoting as in basketball or soccer
○ Strenuous activities like heavy physical work, skiing or tennis
○ Moderate activities like moderate physical work, running or jogging
○ Light activities like walking, housework or yard work
○ Unable to perform any of the above activities due to knee swelling

7) 6. During the past 4 weeks, or since your injury, did your knee lock or catch?

○ Yes ○ No

8) 7. What is the highest level of activity you can perform without significant giving way in your knee?

○ Very strenuous activities like jumping or pivoting as in basketball or soccer
○ Strenuous activities like heavy physical work, skiing or tennis
○ Moderate activities like moderate physical work, running or jogging
○ Light activities like walking, housework or yard work
○ Unable to perform any of the above activities due to giving way of the knee

SPORTS ACTIVITES:

9) 8. What is the highest level of activity you can participate in on a regular basis?

○ Very strenuous activities like jumping or pivoting as in basketball or soccer
○ Strenuous activities like heavy physical work, skiing or tennis
○ Moderate activities like moderate physical work, running or jogging
○ Light activities like walking, housework or yard work
○ Unable to perform any of the above activities due to giving way of the knee

9. How does your knee affect your ability to:

	Not difficult at all	Minimally difficult	Moderately difficult	Extremely difficult	Unable to do
10) a. Go up stairs	○	○	○	○	○
11) b. Go down stairs	○	○	○	○	○
12) c. Kneel on the front of your knee	○	○	○	○	○
13) d. Squat	○	○	○	○	○
14) e. Sit with your knee bent	○	○	○	○	○
15) f. Rise from a chair	○	○	○	○	○
16) g. Run staight ahead	○	○	○	○	○
17) h. Jump and land on your involved leg	○	○	○	○	○
18) i. Stop and start quickly	○	○	○	○	○

FUNCTION:

10. How would you rate the function of your knee on a scale of 0 to 10 with 10 being normal, excellent function and 0 being the inability to perform any of your usual daily activities which may include sports?

19) FUNCTION PRIOR TO YOUR KNEE INJURY:
(0 = Cannot perform daily activites and 10 = No limitation in daily activities)

○ 0 ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

20) CURRENT FUNCTION OF YOUR KNEE:
(0 = Cannot perform daily activites and 10 = No limitation in daily activities)

○ 0 ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

Figure C4.5. ACL- Return to Sport after Injury

Please complete the survey below.

Thank you!

1) Date of Visit ____________________

2) Are you confident that you can perform at your previous level of sport participation?
(0 indicates "Not at all confident" 100 indicates "Fully confident")

○ 0 ○ 10 ○ 20 ○ 30 ○ 40 ○ 50 ○ 60 ○ 70 ○ 80 ○ 90 ○ 100

3) Do you think you are likely to re-injure your knee by participating in your sport?
(0 indicates "Extremely likely" 100 indicates "Not likely at all")

○ 0 ○ 10 ○ 20 ○ 30 ○ 40 ○ 50 ○ 60 ○ 70 ○ 80 ○ 90 ○ 100

4) Are you nervous about playing your sport?
(0 indicates "Extremely nervous" 100 indicates "Not nervous at all")

○ 0 ○ 10 ○ 20 ○ 30 ○ 40 ○ 50 ○ 60 ○ 70 ○ 80 ○ 90 ○ 100

5) Are you confident that your knee will not give way by playing your sport?
(0 indicates "Not at all confident" 100 indicates "Fully confident")

○ 0 ○ 10 ○ 20 ○ 30 ○ 40 ○ 50 ○ 60 ○ 70 ○ 80 ○ 90 ○ 100

6) Are you confident that you could play your sport without concern for your knee?
(0 indicates "Not at all confident" 100 indicates "Fully confident")

○ 0 ○ 10 ○ 20 ○ 30 ○ 40 ○ 50 ○ 60 ○ 70 ○ 80 ○ 90 ○ 100

7) Do you find it frustrating to have to consider your knee with respect to your sport?
(0 indicates "Extremely frustrating" 100 indicates "Not at all frustrating")

○ 0 ○ 10 ○ 20 ○ 30 ○ 40 ○ 50 ○ 60 ○ 70 ○ 80 ○ 90 ○ 100

8) Are you fearful of re-injuring your knee by playing your sport?
(0 indicates "Extremely fearful" 100 indicates "No fear at all")

○ 0 ○ 10 ○ 20 ○ 30 ○ 40 ○ 50 ○ 60 ○ 70 ○ 80 ○ 90 ○ 100

9) Are you confident about your knee holding up under pressure?
(0 indicates "Not at all confident" 100 indicates "Fully confident")

○ 0 ○ 10 ○ 20 ○ 30 ○ 40 ○ 50 ○ 60 ○ 70 ○ 80 ○ 90 ○ 100

10) Are you afraid of accidentally injuring your knee by playing your sport?
(0 indicates "Extremely afraid" 100 indicates "Not at all afraid")

○ 0 ○ 10 ○ 20 ○ 30 ○ 40 ○ 50 ○ 60 ○ 70 ○ 80 ○ 90 ○ 100

11) Do thoughts of having to go through surgery and rehabilitation prevent you from playing your sport?
(0 indicates "All of the time" 100 indicates "None of the time")

○ 0 ○ 10 ○ 20 ○ 30 ○ 40 ○ 50 ○ 60 ○ 70 ○ 80 ○ 90 ○ 100

12) Are you confident about your ability to perform well at your sport?
(0 indicates "Not at all confident" 100 indicates "Fully confident")

○ 0 ○ 10 ○ 20 ○ 30 ○ 40 ○ 50 ○ 60 ○ 70 ○ 80 ○ 90 ○ 100

13) Do you feel relaxed about playing your sport?
(0 indicates "Not at all relaxed" 100 indicates "Fully relaxed")

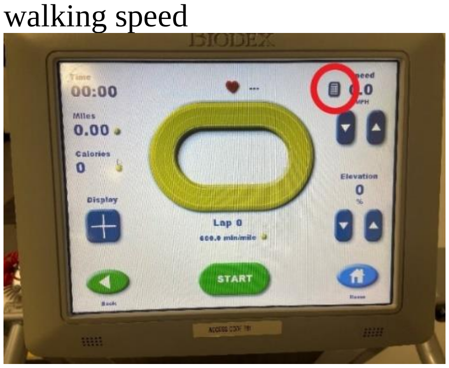
○ 0 ○ 10 ○ 20 ○ 30 ○ 40 ○ 50 ○ 60 ○ 70 ○ 80 ○ 90 ○ 100

Table C5. Warm-up Protocol

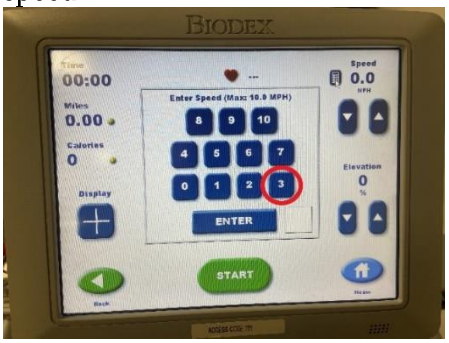
The participant will warm up on the Biodex Gait Trainer 3 treadmill for 5 minutes. To set up the treadmill:

1. Tap “Treadmill”
   Figure C5.1. Treadmill screen showing where to click the “Treadmill” option
   

2. Tap “Quick Start”
   Figure C5.2. Treadmill screen showing where to click the “Quick Start” option
   

3. Tap the calculator icon next to speed
   Figure C5.3. Treadmill screen highlighting where to find the screen to enter the walking speed
   

4. Tap “3” for 3 MPH then tap “Enter”
Figure C5.4. Treadmill screen highlighting where to enter in 3 as the walking speed



5. Have the participant walk until the time gets to 5:00 then tap “STOP”
Figure C5.5. Treadmill screen with time and “STOP” button highlighted

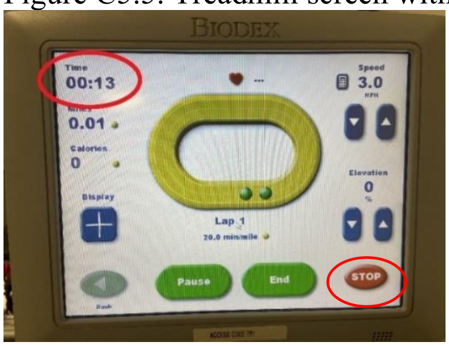


Figure C5.6. Patient Set-up on the treadmill

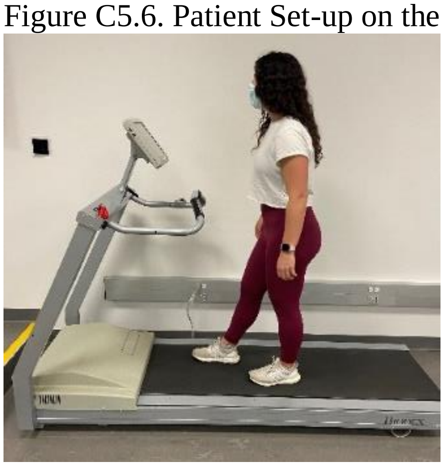


Table C6. Lower Extremity Strength Set-up and Procedures

Table C6.1. Biodex Set-up – Biodex Systems IV Multi-Modal Dynamometer

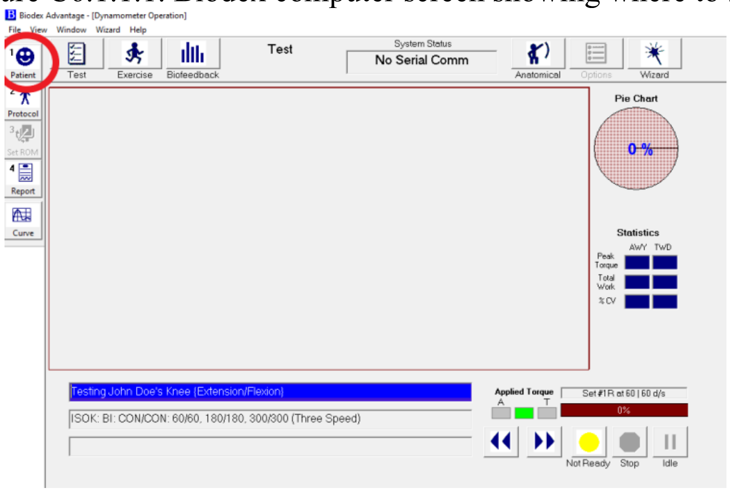
Figure C6.1. Biodex Systems IV Multi-Modal Dynamometer

Table C6.1.1. Create Patient Profile

To create a participant profile in Biodex:

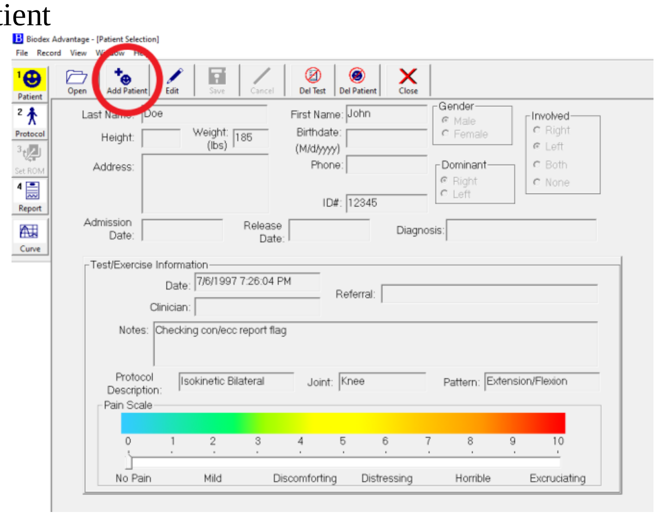
1. Click “Patient”

Figure C6.1.1.1. Biodex computer screen showing where to select “Patient”



2. Click “Add Patient”

Figure C6.1.1.2. Biodex computer screen showing where to select to add a new patient



3. Enter the participant’s:
   a. Last name
   b. First name
   c. LEAP ID
   d. Weight (lbs)
   e. Gender
   f. Surgical Limb for “Involved”

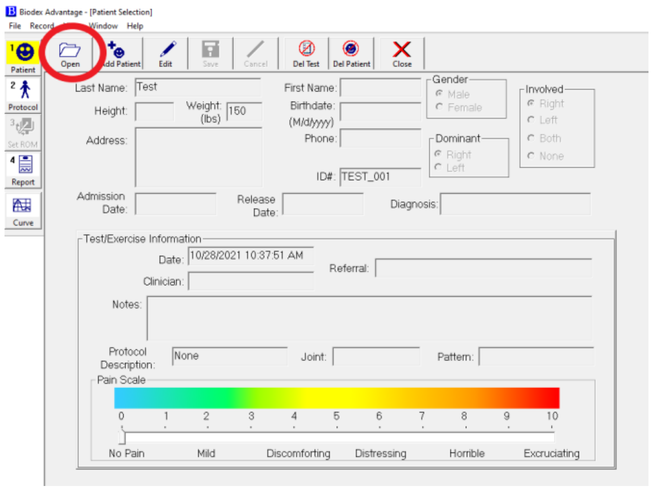
4. Click “Save”

Figure C6.1.1.3. Biodex computer screen showing where to select “Save”

Table C6.1.2. Open New Isokinetic Trial

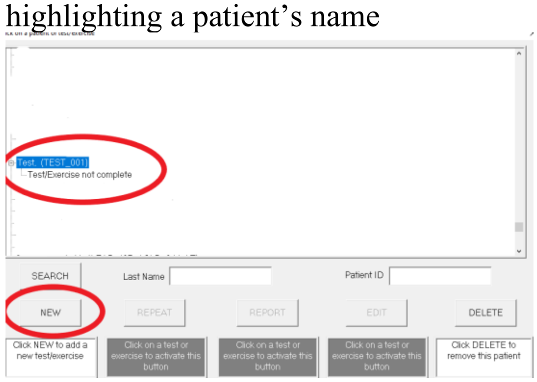
1. Click “Open”

   Figure C6.1.2.1. Biodex computer screen showing where to select “Open” to open a new trial

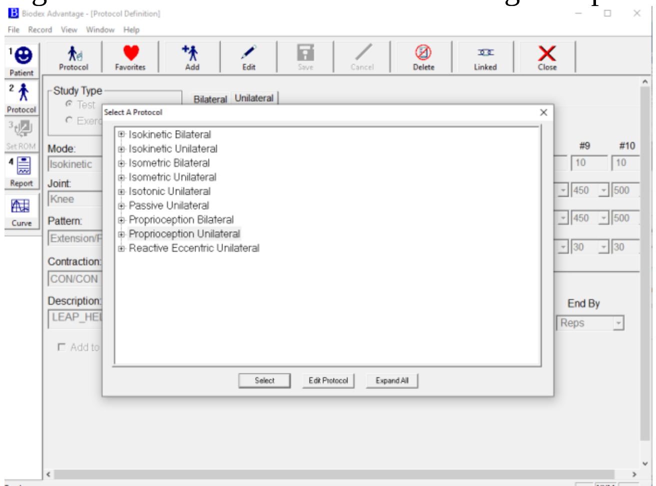


2. Click the participant’s name
3. Click “New”

   Figure C6.1.2.2. Biodex computer screen showing where to click “New” after highlighting a patient’s name



4. Expand the “Isokinetic Unilateral” protocol
Figure C6.1.2.3. Biodex screen showing the options for testing protocols



5. Click “LEAP_Isokinetic_90_180”
Figure C6.1.2.4. Biodex screen showing the appropriate isokinetic testing protocol used for this study

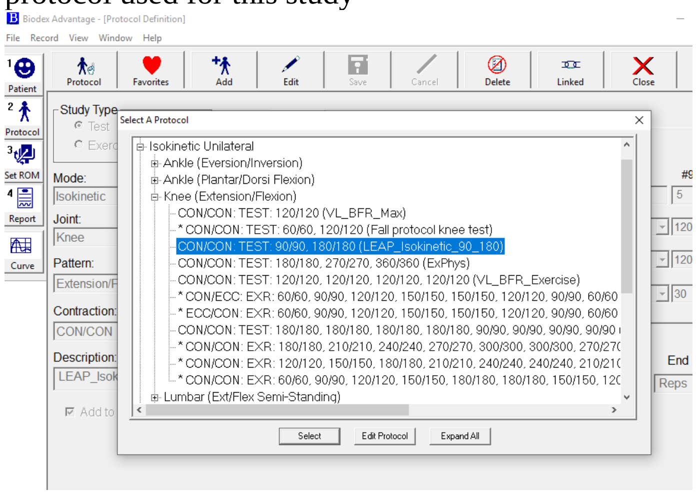


Table C6.1.3. Patient Biodex Set-up

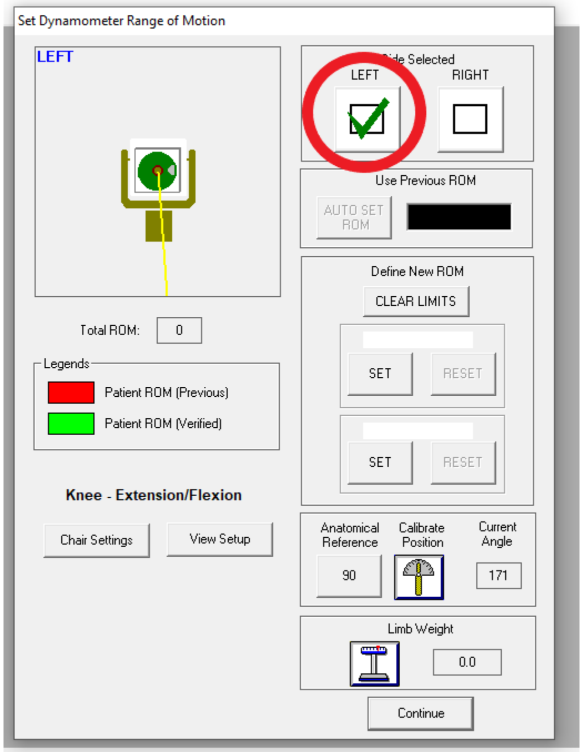
Adjusting the Biodex to the participant's measurements:

1. Seat the participant in the chair with their hips all the way back
2. Move the back of the chair so that approximately 5cm of the participant's thigh overhand the edge of the chair
3. Strap the participant in using the seatbelt
4. Adjust the chair forward/backward and up/down so that that the lateral epicondyle aligns with the axis of rotation of the Biodex
5. Adjust the length of the Biodex arm so that the strap is 2cm above the lateral malleolus
6. Use the Velcro to strap in the participant's leg

Table C6.1.4 Setting Range of Motion

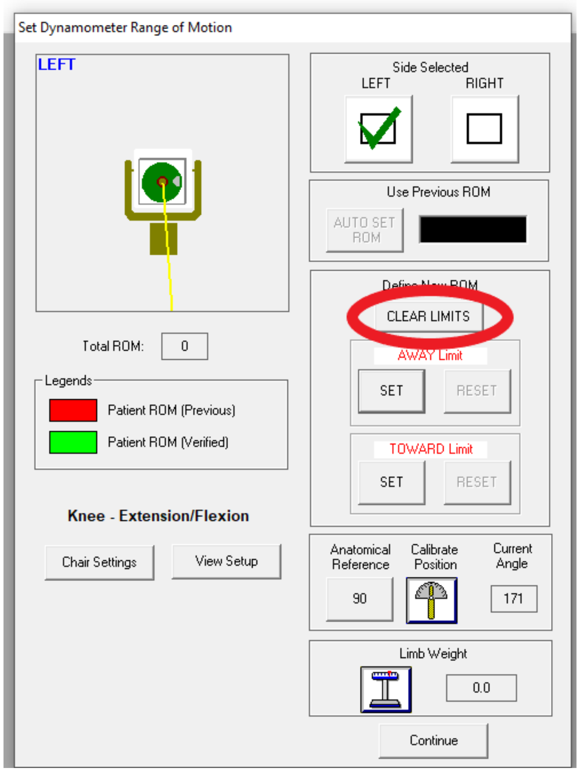
To set up the range of motion:

1. Select the proper limb side (Left/Right) for the uninvolved/non-surgical limb Figure C6.1.4.1. Biodex screen used to select the respective limb for being currently tested (Left/Right)



2. Click “Clear Limits”

Figure C6.1.4.2. Biodex screen showing which button to click in order to clear the default range of motion limits.



3. Bring the Biodex arm to full extension (0 degrees of knee flexion) then click the black hold/resume button on the Biodex

Figure C6.1.4.3. Biodex arm positioning to set the “AWAY” limit where the knee should be fully extended

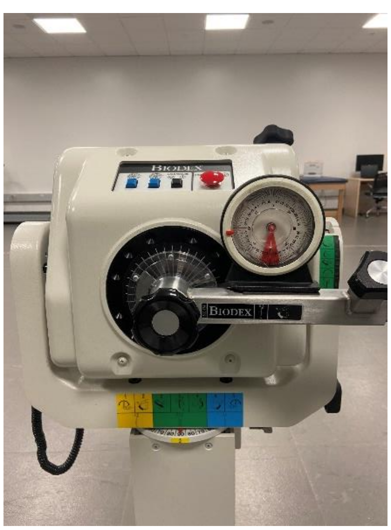
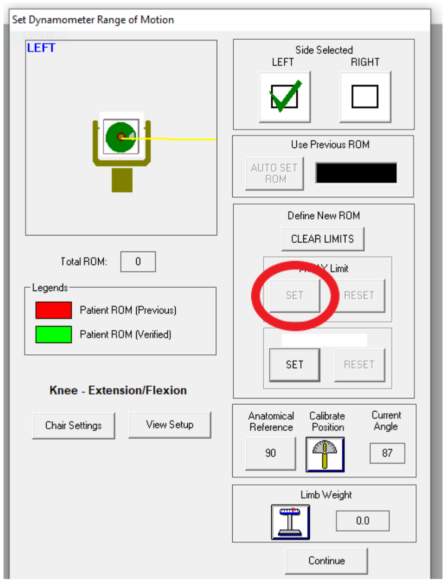


Figure C6.1.4.3.1. Biodex "Hold/Resume" button used to lock the arm in the current position.

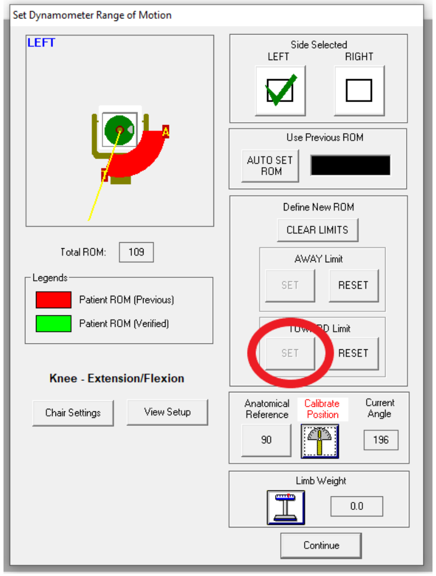
4. Click the "Set" button under the AWAY limit
   Figure C6.1.4.4. Biodex screen showing which button to click when the arm is fully extended (0 degrees of knee flexion) in order to set the "AWAY" range of motion limit.



5. Click the hold/resume button on the Biodex
   Figure C6.1.4.5. Biodex motor with the highlighted “Hole/Resume” button used to unlock the arm attachment from being in a fully extended position.
   

6. Bring the Biodex arm to 110 degrees of flexion then click the black hold/resume button on the Biodex
   Figure C6.1.4.6. Biodex arm positioning in order to set the “TOWARDS” range of motion limit
   

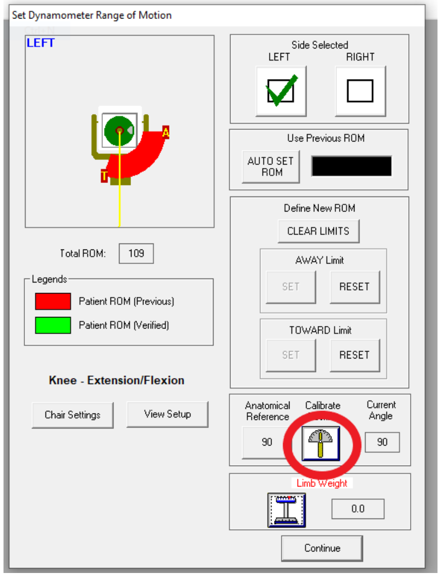
7. Click the “Set” button under the TOWARD limit
Figure C6.1.4.7. Biodex screen showing which button to click to set the “TOWARD” range of motion limit



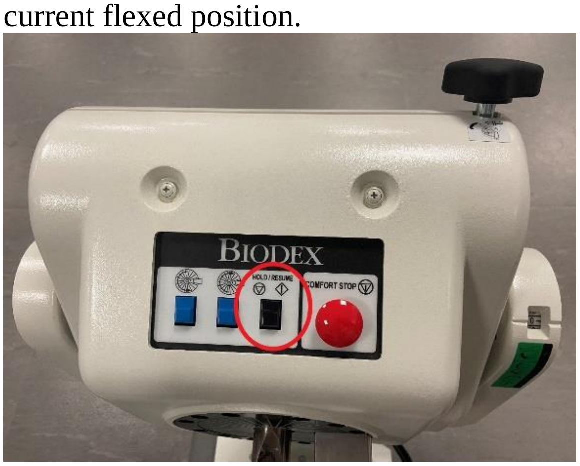
8. Click the hold/resume button on the Biodex
Figure C6.1.4.8. Biodex “Hold/Resume” button used to unlock the arm in the current flexed position.

9. Bring the Biodex arm to 90 degrees of knee flexion then click the black hold/resume button on the Biodex

10. Click the "Calibrate" button
    Figure C6.1.4.10. Biodex screen showing which button to click once the arm is set to 90 degrees of knee flexion



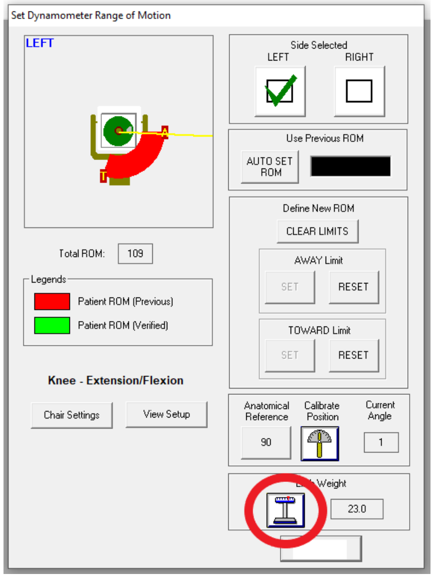
11. Click the hold/resume button on the Biodex
    Figure C6.1.4.11. Biodex "Hold/Resume" button used to unlock the arm in the current flexed position.



12. Bring the Biodex arm up to 10 degrees of flexion then click the black hold/resume button on the Biodex
13. Tell the participant to relax their leg

14. Click the limb weight icon multiple times

Figure C6.1.4.14. Biodex screen showing the button to click when measuring the weight of the lower limb/shank



15. Click "Continue"

Figure C6.1.4.16. Final patient set-up prior to starting the strength testing trial

Table C6.2. Biodex Data Collection

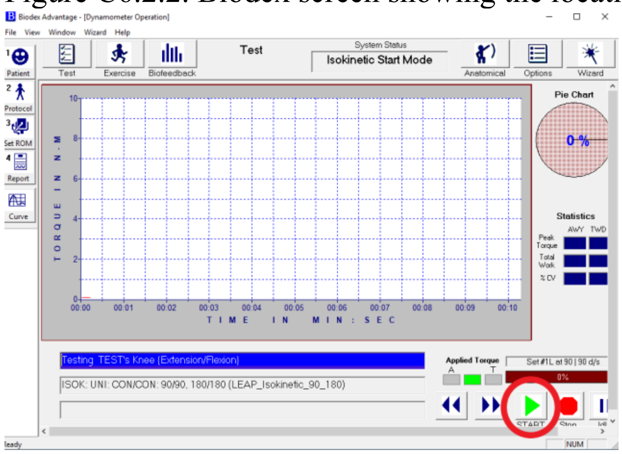
Data Collection – Isokinetic 90°/second

All tests begin with the non-surgical limb*

Explain to the participant that this task will be testing their quadriceps and hamstrings strength by having them kick out and pull in as hard and as fast as they can.

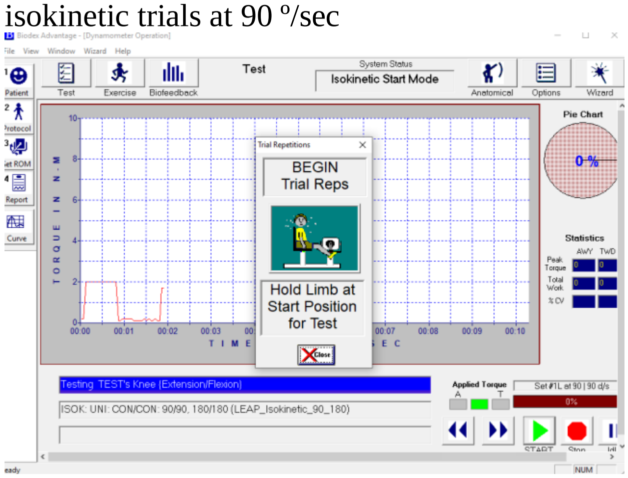
1. Instruct them to:
   a. "Sit up straight with your back against the backrest"
   b. "Do not rotate or arch your back"
   c. "Cross your hands on your chest"
   d. "Focus on kicking out and pulling back in as fast and as hard as possible only using your thigh muscles"
2. Click the "Start" button

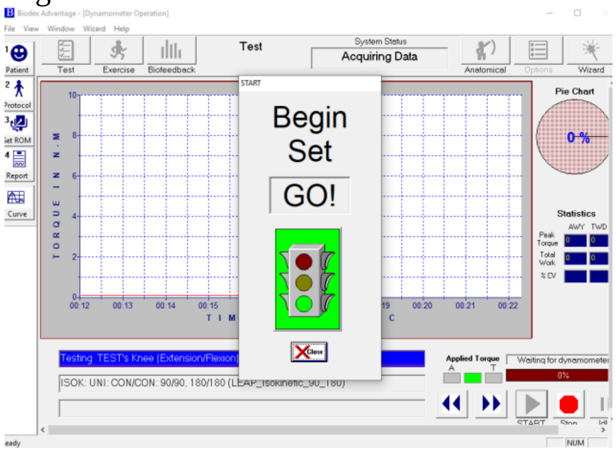
   Figure C6.2.2. Biodex screen showing the location of the "Start" button



3. Let the participant perform as many practice reps as needed until they are familiar with the task

   Figure C6.2.3. Biodex screen that is displayed while patients are practicing their isokinetic trials at 90 °/sec



4. Ask the participant to hold their leg still at the starting position until they see the "GO!" screen
   Figure C6.2.4. Biodex screen displayed when indicating that the strength trial has begun
   

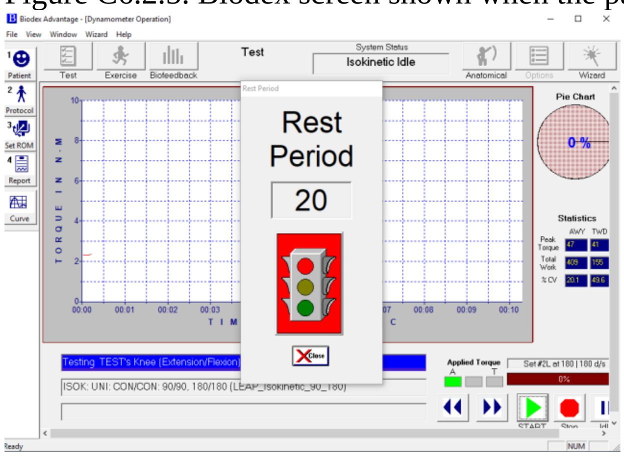
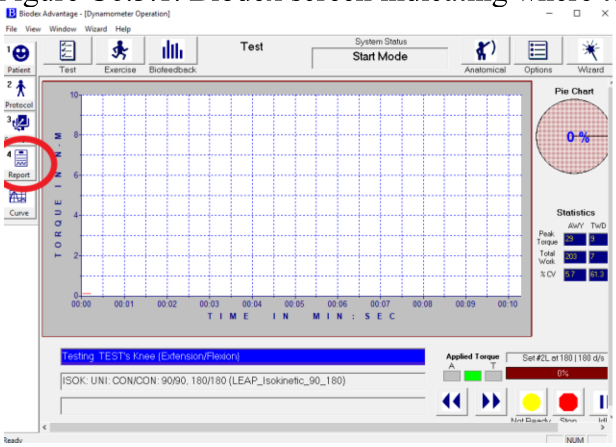
5. Participant will perform 8 repetitions
   Participant will rest for 30 seconds before repeating this task on the involved/surgical limb
   Figure C6.2.5. Biodex screen shown when the patient is resting between sets
   

Table C6.3. Saving Biodex Data

Saving Isokinetic Data

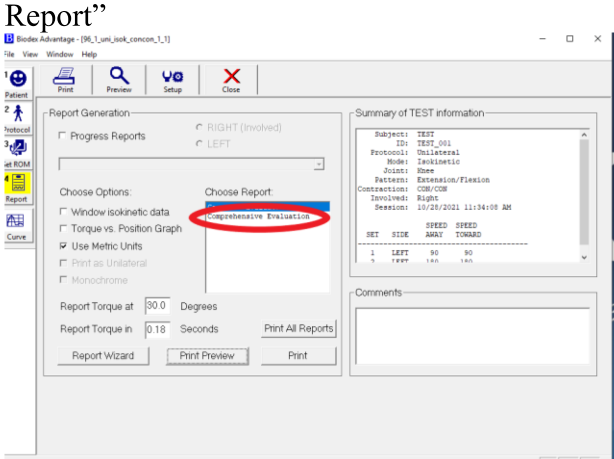
1. Click “Report”

Figure C6.3.1. Biodex screen indicating where to click to get to the “Report” page



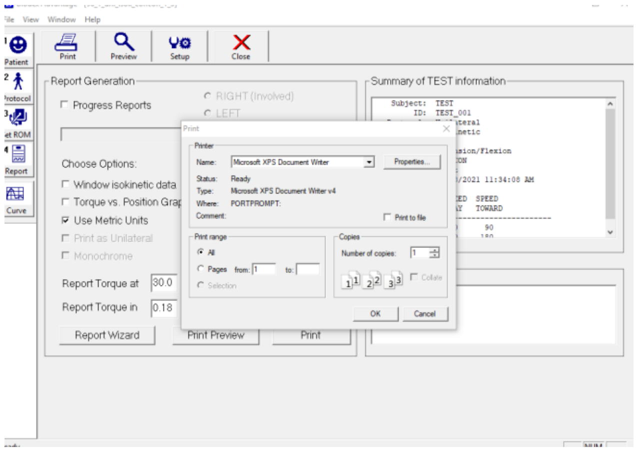
2. Choose “Comprehensive Report”

Figure C6.3.2. Biodex screen showing where to click to export the “Comprehensive Report”

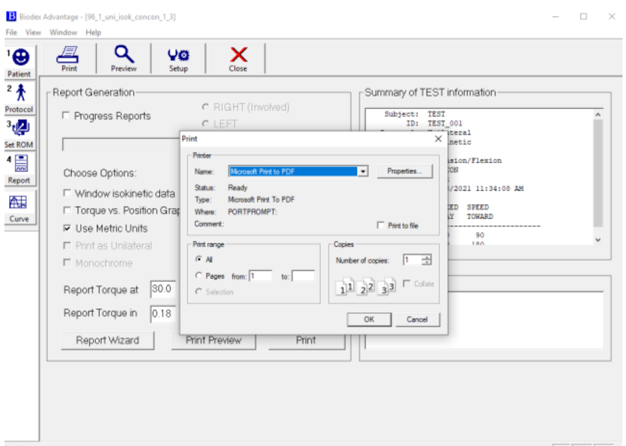


3. Click “Print”

4. Save as “Microsoft XPS Document Writer” titled “[LEAP_ID]_uninv”
   Figure C6.3.4 Biodex screen showing where to save the file as a “Microsoft XPS Document Writer” file



5. Save as “Microsoft Print to PDF” titled “[LEAP_ID]_uninv”
   Figure C6.3.5 Biodex screen showing where to save the file as a “Microsoft Print to PDF” file



***Repeat steps 1-5 to save files for the involved/surgical limb.**
***For steps 4-5 the naming convention will be the same except having “_uninv” at the end of the file, “_inv” will replace it.**

Table C7. Bilateral “Double-leg” Squat Set-up and Procedures

Table C7.1 Tekscan Set-up – Tekscan SB Mat

Figure C7.1.0.1 Tekscan SB Mat

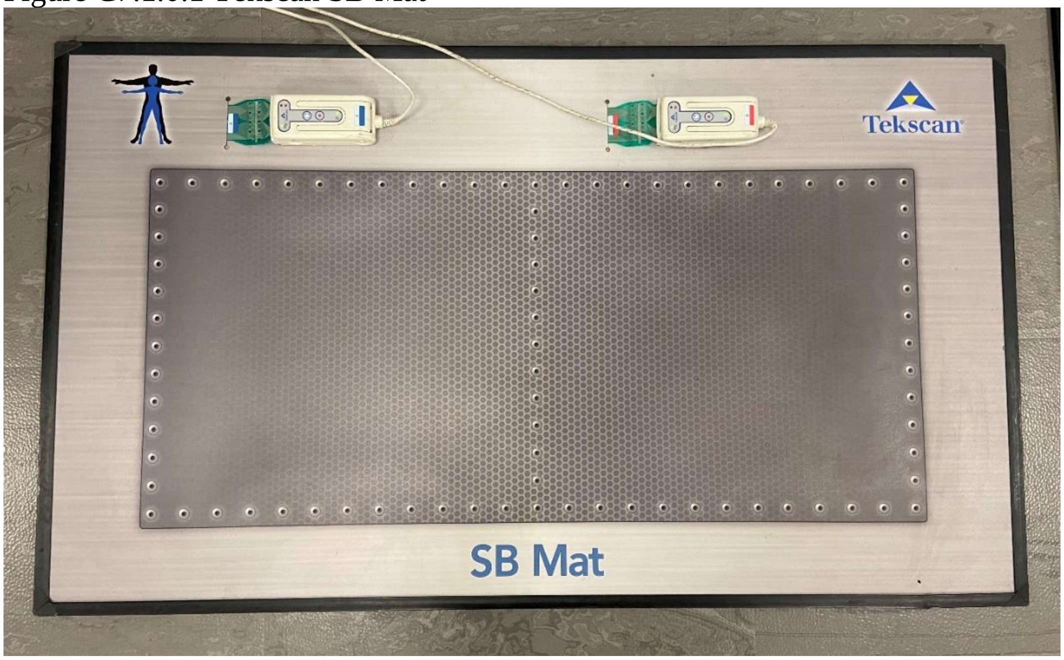
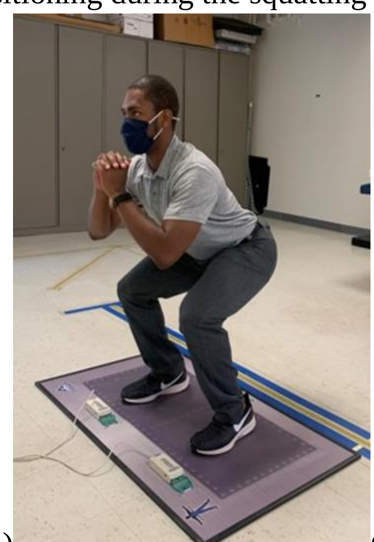


Figure C7.1.0.2. Patient positioning during the squatting trials

(A)  (B)  (C) 

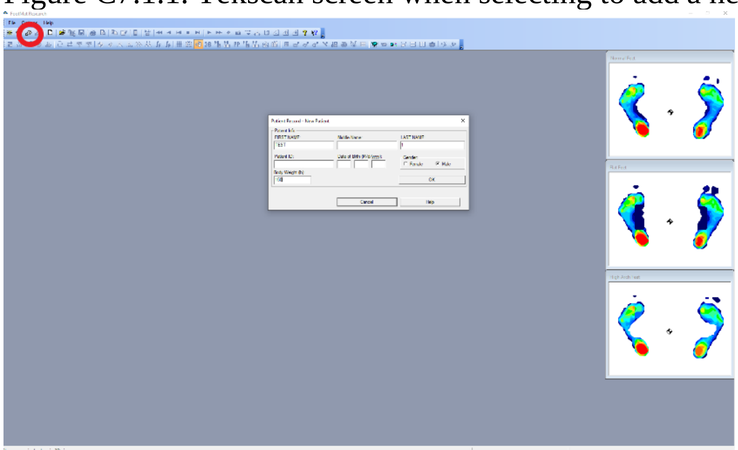
(A) Patient starting position. (B) Patient position at the bottom of the squatting task. (C) Patient ending position.

Table C7.1.1. Create Tekscan Patient Profile

To create a participant profile in Tekscan software FootMat Research 7.10 Application:

1. Click “Patient”

   Figure C7.1.1. Tekscan screen when selecting to add a new patient

2. Fill in
   a. First Name
   b. Last Name
   c. Patient ID
3. Click “Ok”

Table C7.1.2 Create New Squatting Trial

1. Open the patient file and click “New Movie”
   Figure C7.1.2.1. Tekscan screen indicating where to click “Open Patient”

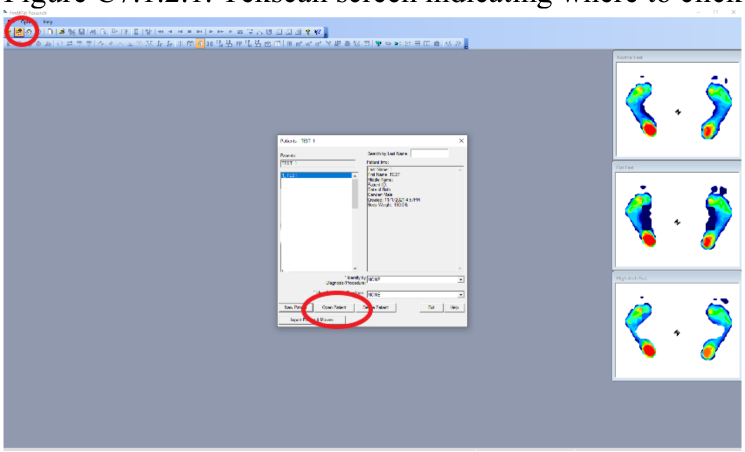


   Figure C7.1.2.2. Tekscan screen indicating where to click “New Movie”

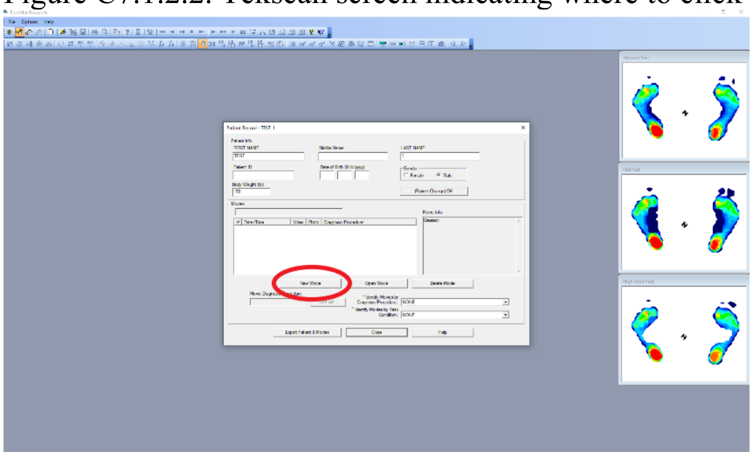
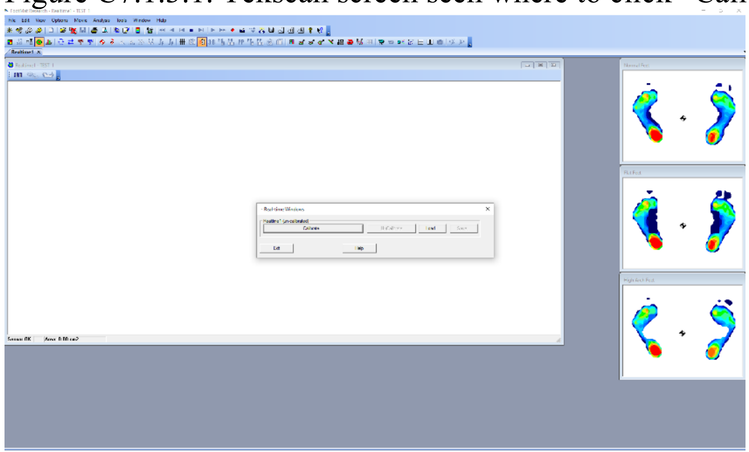
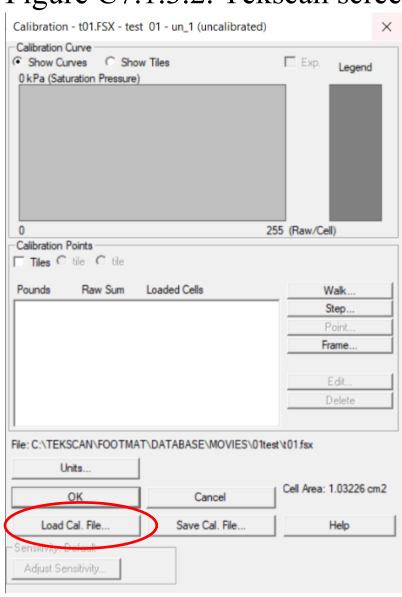


Table C7.1.3. Calibration of Tekscan SB Mat

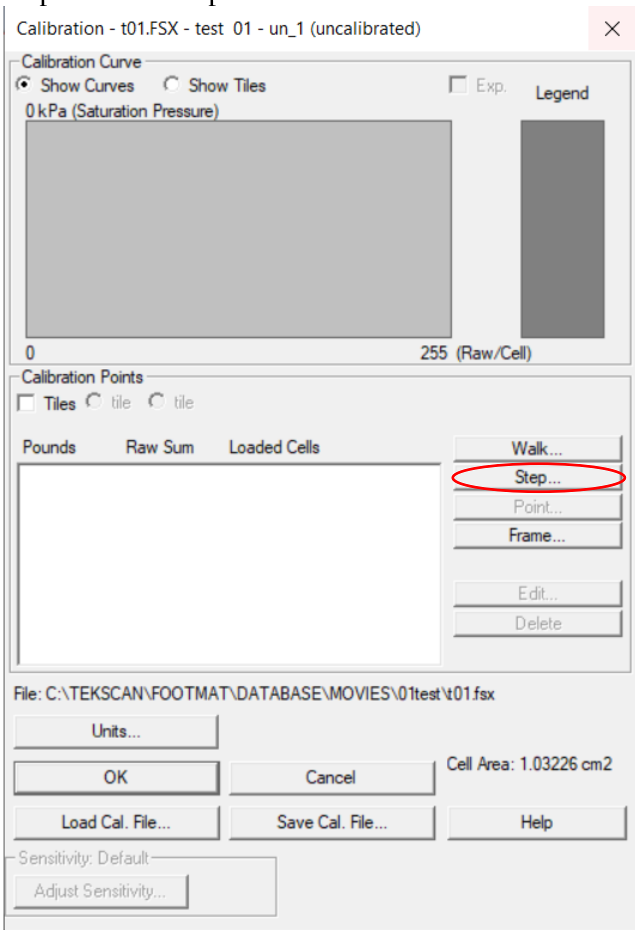
SB Mat Calibration Procedure:

1. Select “Tools” -> “Calibration”
   Figure C7.1.3.1. Tekscan screen seen where to click “Calibration”
   

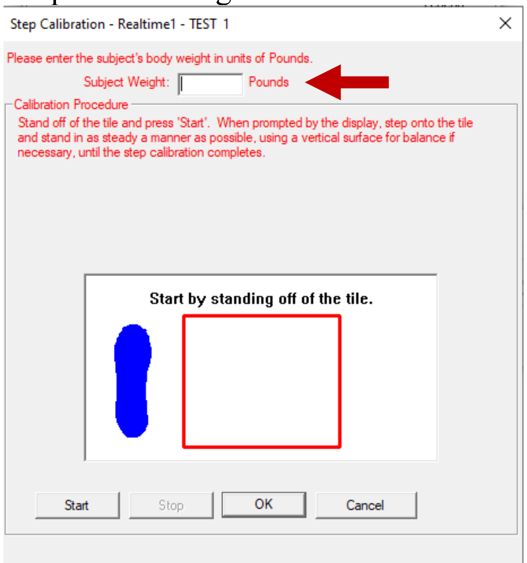
2. Select “Load Cal. File…” if there is a calibration file already created with the participant’s weight
   Figure C7.1.3.2. Tekscan screen showing where to click “Load Cal. File…”
   

3. If there is a file named with the participant’s associated weight, load the respective STEP calibration file associated with that weight.

4. If there isn't a file already created select "Step"
Figure C7.1.3.4. Tekscan screen showing where to click "Step" to start the step calibration process.

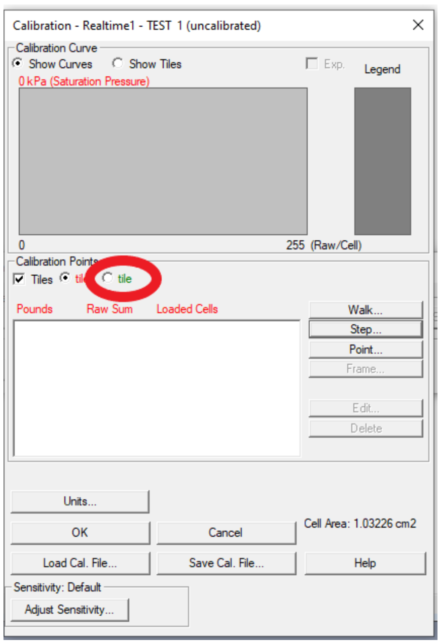


5. Enter the participant's weight in pounds
Figure C7.1.3.5. Tekscan screen shown with the location of where to enter in the patient's weight in lbs.

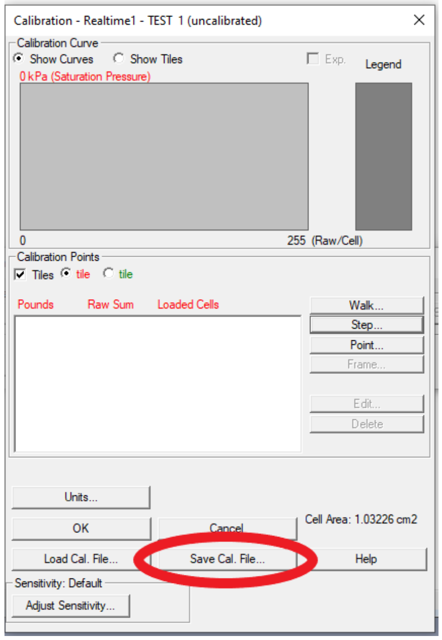


6. Then follow the onscreen instructions having the participant step onto the singular tile on the right side first with one foot and holding as still as possible when prompted at the sound of a ding.

7. Once completed, then select the other tile and repeat on the left foot
Figure C7.1.3.7. Tekscan screen indicating the green "tile" icon that should be clicked in order to calibrate the left sensing area of the SB mat



8. Save the new calibration file with the weight
Figure C7.1.3.8. Tekscan screen indicating where to click to save that calibration file



9. Once a calibration file is created for that patient's weight, repeat steps 1 & 2 to make sure the SB mat is calibrated correctly to the patient's weight.

Table C7.2. Tekscan SB Mat Data Collection Protocol

Data Collection – Bilateral Squat 3 sets of 3 repetitions

Instruct patients to:

1. Stand shoulder width apart
2. During the test, squat down to the "height of a chair"
3. Follow the beat of a predetermined metronome setting of 40 beats per minute

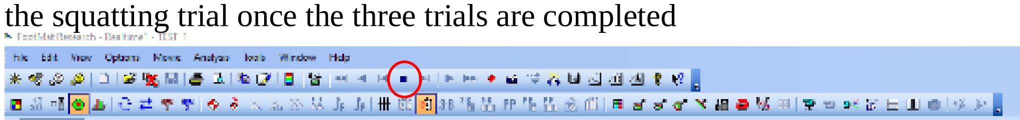

Pro Metronome App used to create the tempo of 40 beats per minute.

4. Once a "new movie" is open and ready and the patient is ready to start the trial click the red record button seen below

Figure C7.2.4. Tekscan screen highlighting where to click the "Record" button for the squatting trial

5. Complete three squatting repetitions
6. After completing the third squat remain standing in place until instructed by investigator to relax.
7. Once the repetitions are complete, click the stop button seen below

Figure C7.2.7. Tekscan screen highlighting where to click the "Stop" button for the squatting trial once the three trials are completed



***Repeat steps 4 through 7 until three sets are successfully completed**

Table C7.3 Visit 1 Completion

Once patients have completed the following tasks, they may be dismissed from visit 1.

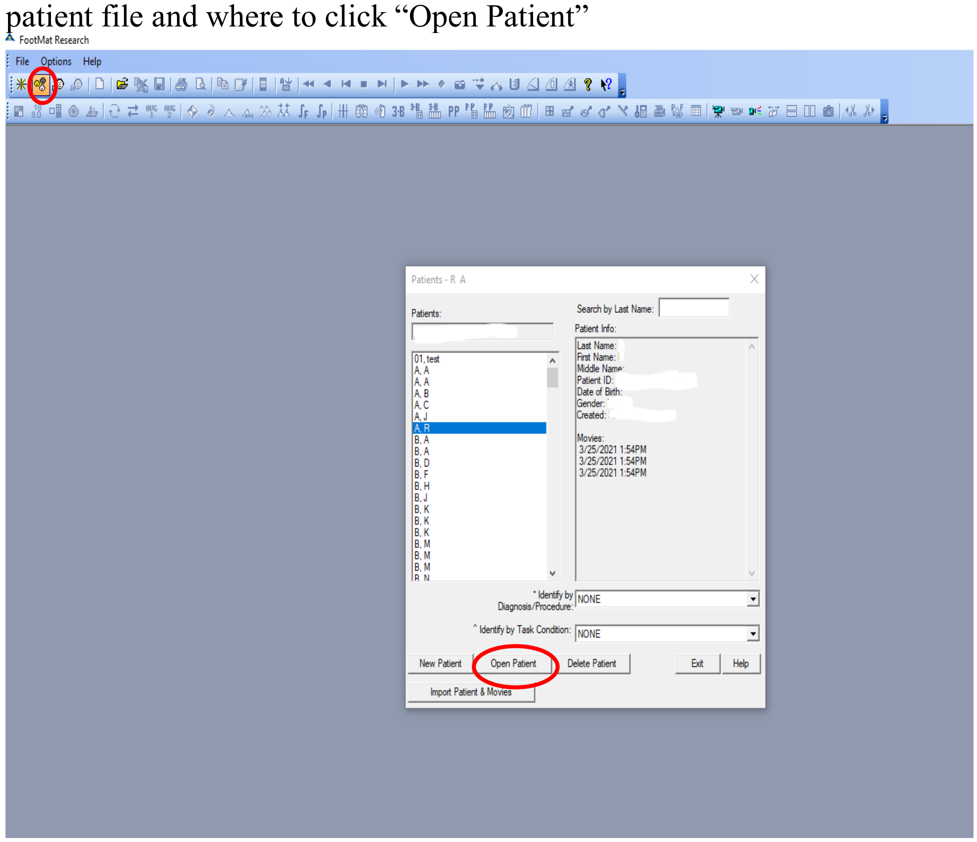
1. Consent form
2. Patient reported outcomes (Figures C2-C6)
3. Biodex Strength Assessment
4. Tekscan SB Mat Squatting Assessment

Table C8. Tekscan SB Mat Data Processing

Data Processing

1. Open Patient file

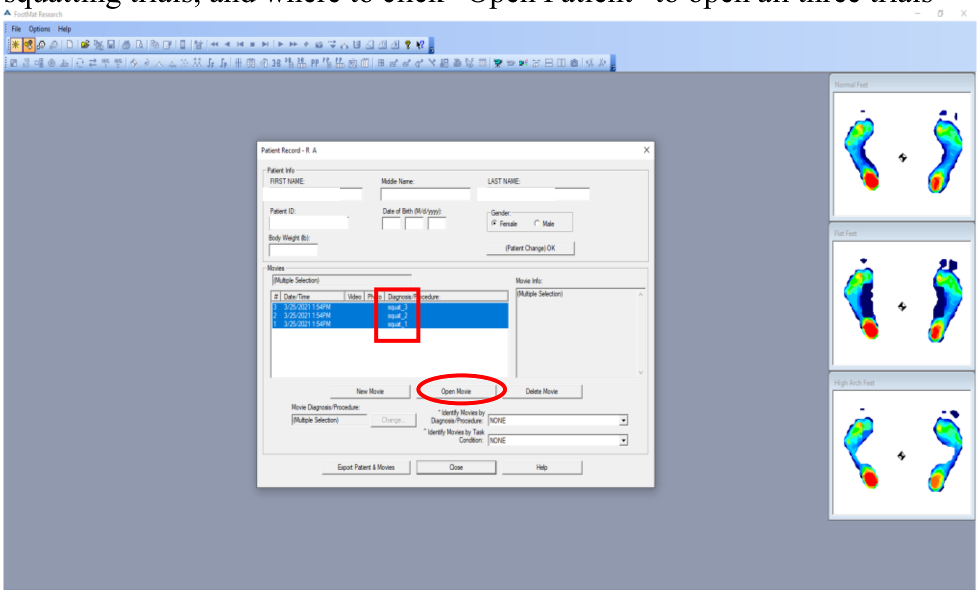
   Figure C8.1. Tekscan screen that is seen when trying to select the appropriate patient file and where to click “Open Patient”



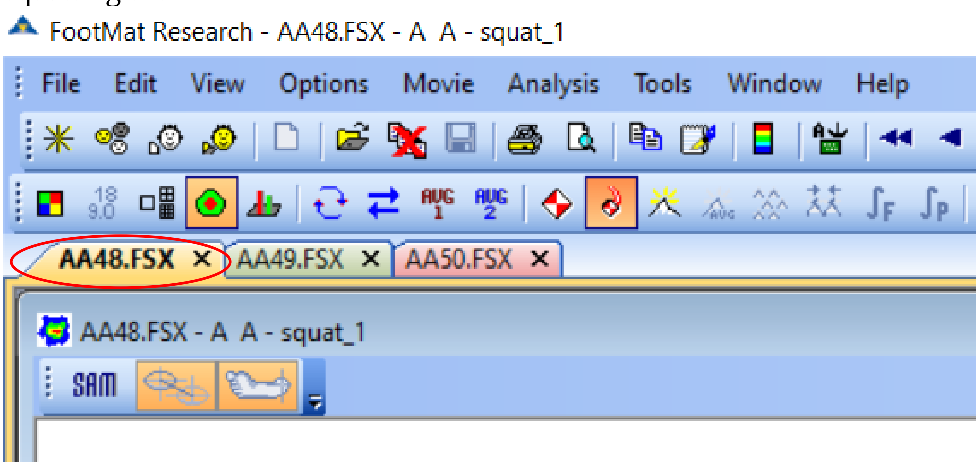
2. Select all three squatting trials labeled “Squat_1, Squat_2, Squat_3”

3. Select “Open Movie”

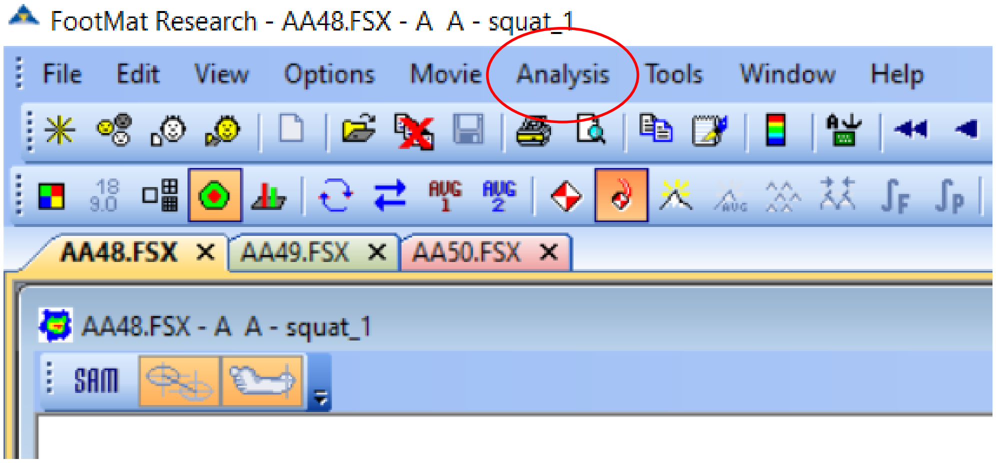
Figure C8.3. Tekscan screen showing where to highlight the respective squatting trials, and where to click “Open Patient” to open all three trials



4. Click on the first trial tab at the top of the page.
Figure C8.4. Tekscan screen showing where to click to select the first squatting trial

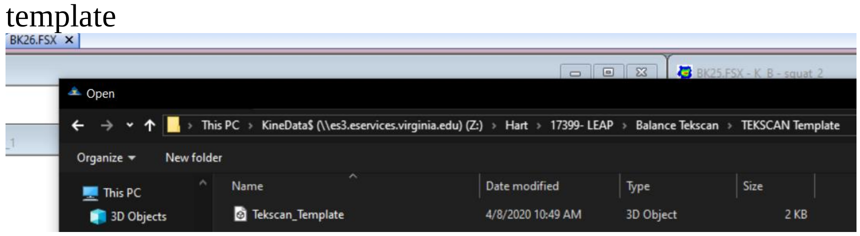


5. Select “Analysis” option at the top of the page.
   Figure C8.5. Tekscan screen showing where to click the “Analysis” button



6. Select “Load Object File”
7. Open the “Tekscan_Template.fbx” file that is located on the high security VPN on ES3 within the following folders:
   1. Hart -> 17399- LEAP -> Balance Tekscan -> TEKSCAN Template

   Figure C8.7. Folder screen and path of where to find the Tekscan template



8. 3 Graphs will populate seen below.
    1. Green = Total mat pressure distribution
    2. Cyan = Left foot pressure distribution
    3. Red = Right foot pressure distribution

Figure C8.8. Tekscan screen once the three graphs are generated from the first squatting trial encompassing the total mat, left foot, and right foot pressure distribution

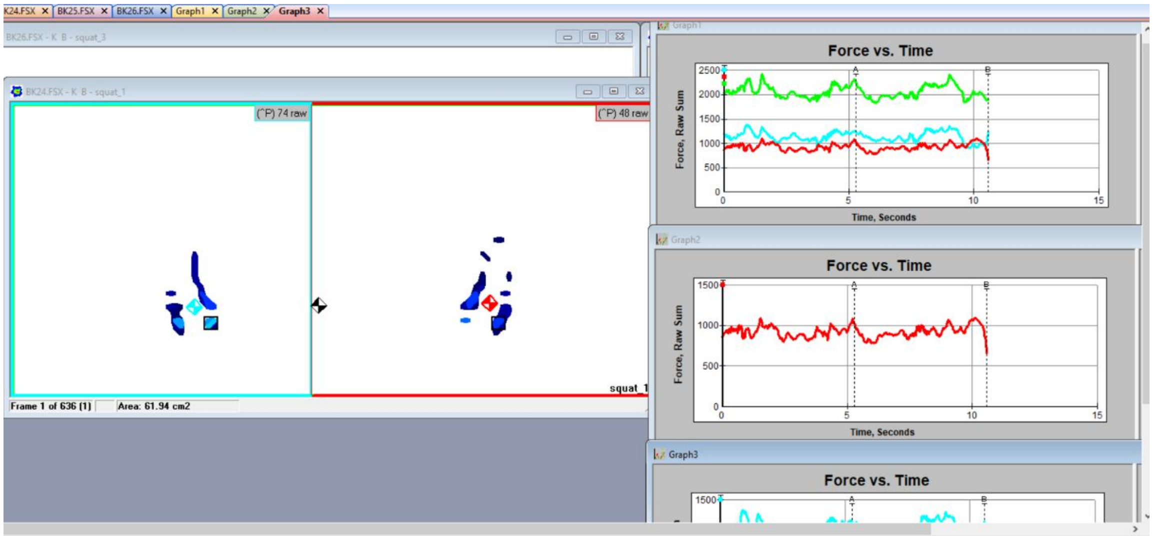


Table C9. Tekscan SB Mat Data Export

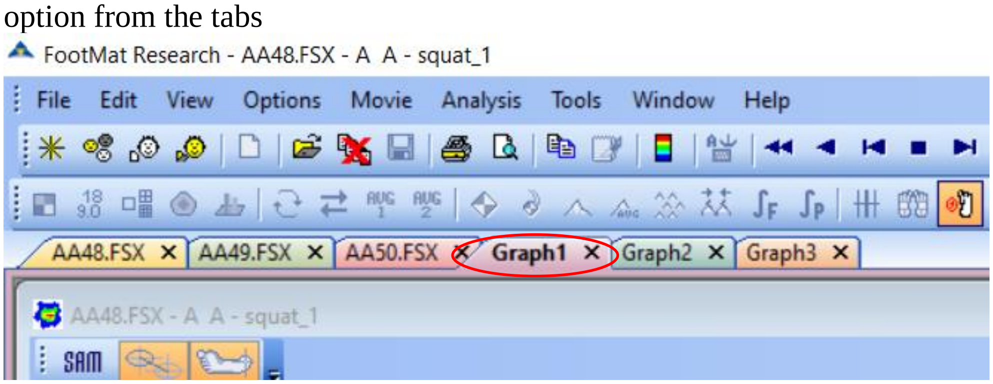
Data Export

Table C9.1. Graph 1 Data Export

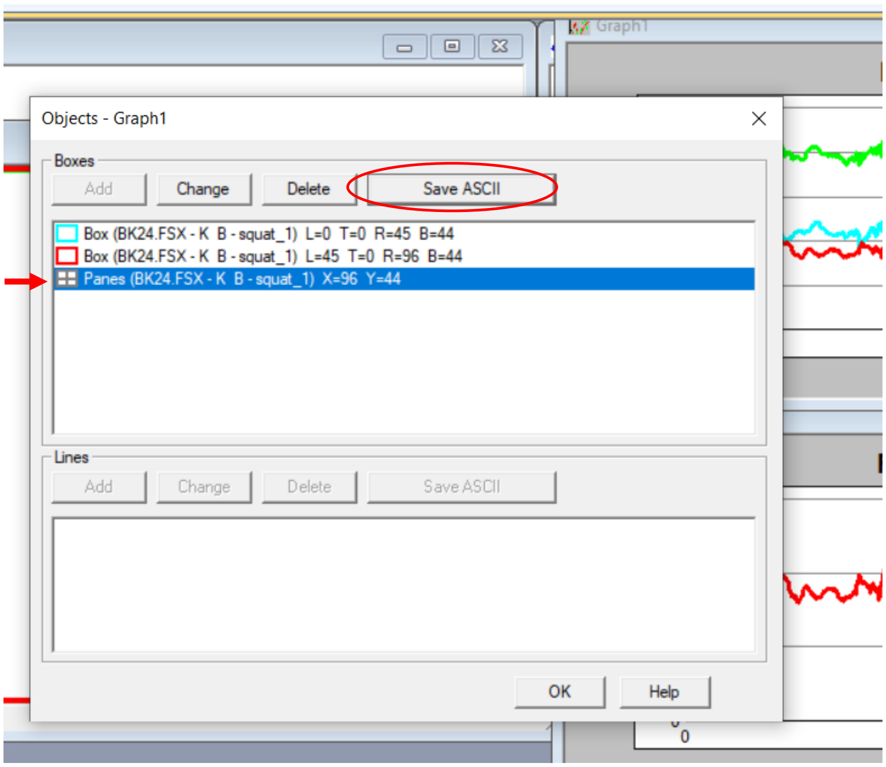
Graph 1

1. Click on “Graph1” tab at the top of the page

   Figure C9.1.1. Tekscan screen highlighting where to click the “Graph1” option from the tabs

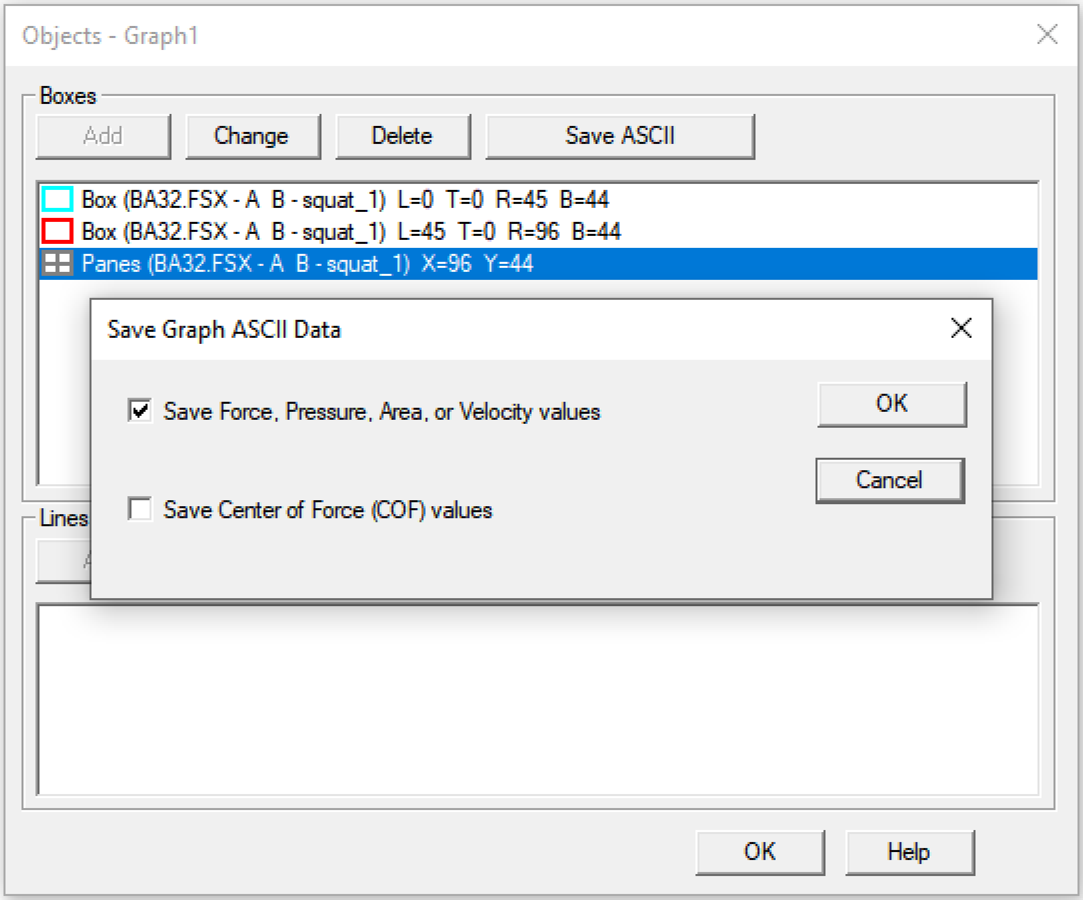


2. Once Graph1 is selected, click on “Analysis” then “Objects” from the tool bar at the top of the screen
3. Highlight “Panes” file and click “Save ASCII”
   Figure C9.1.3. Tekscan screen showing where to highlight the “Panes” file and where to click “Save ASCII”



4. Within the pop-up box, check the following box:
    1. Save Force, Pressure, Area, or Velocity values

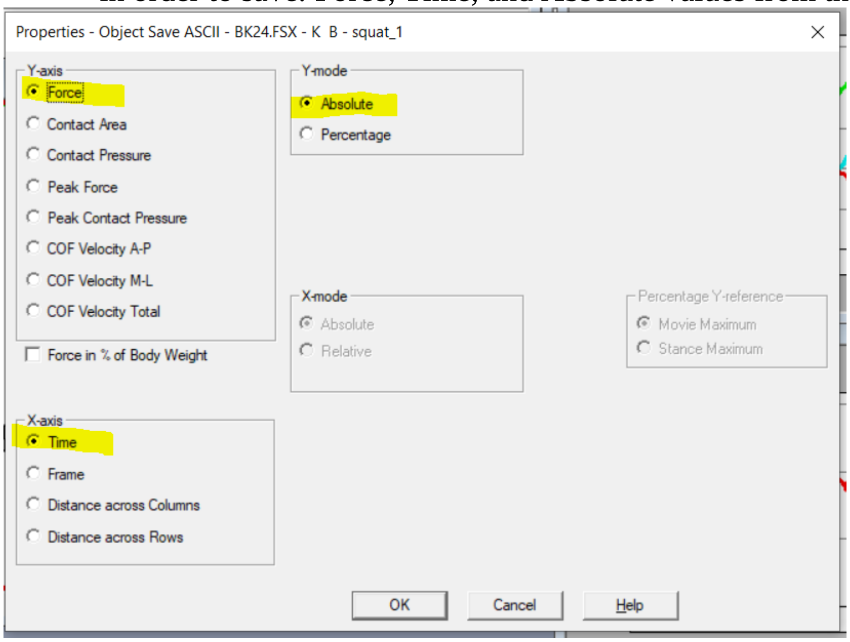
Figure C9.1.4. Tekscan screen showing the check box needed to save force, pressure, area, and velocity values from the squatting trial



5. Find the location of the patient file on ES3
    1. Hart -> 17399- LEAP -> Balance Tekscan -> Patient ANALYZED Files
    2. Save the file as "Squat1_total"

6. Within the pop-up box, check the following options:
    1. Y-axis: Force
    2. X-axis: Time
    3. Y mode: Absolute

Figure C9.1.6. Tekscan screen seen and the respective items needed to be checked in order to save: Force, Time, and Absolute values from the squatting trials



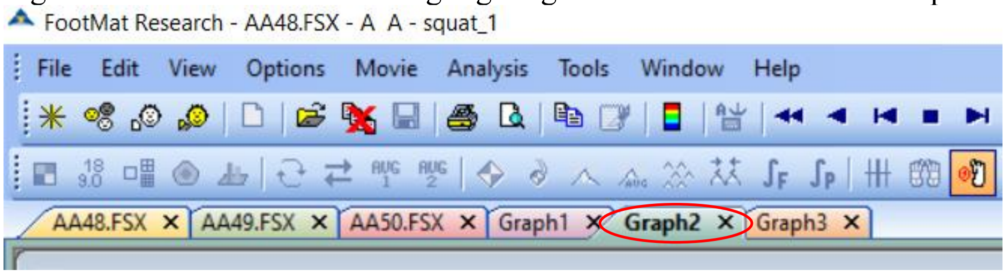
7. Click "OK"

Table C9.2. Graph 2 Data Export

Graph 2

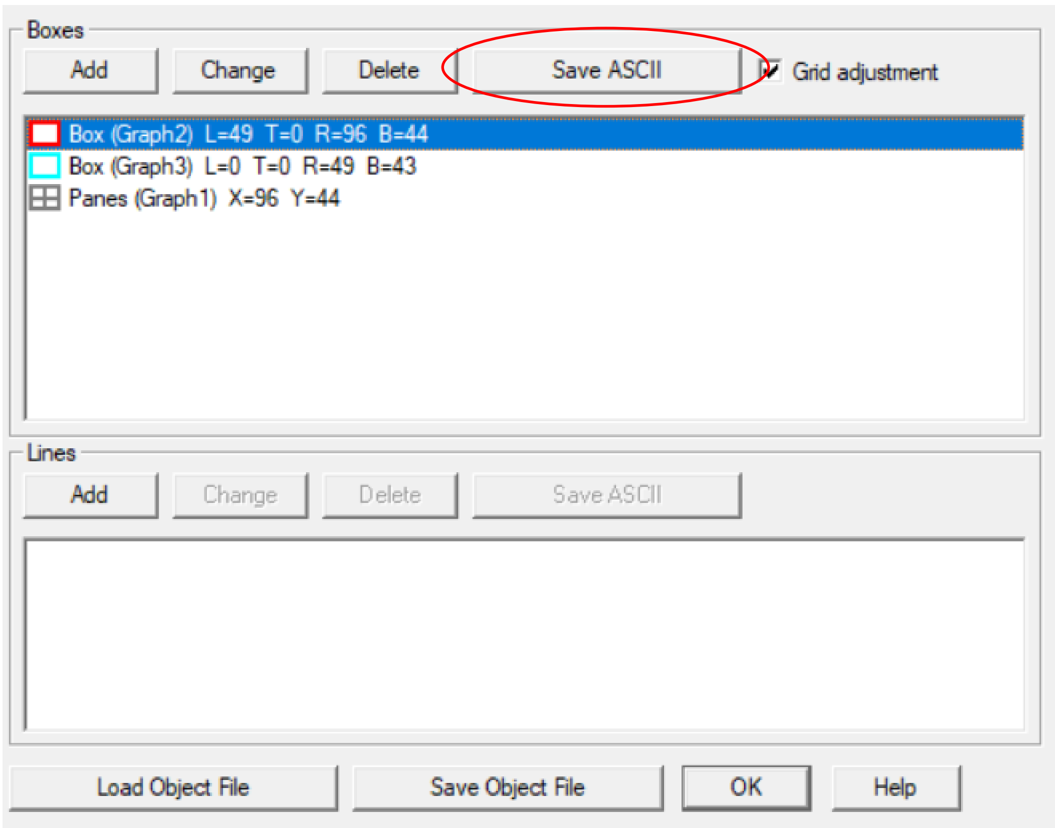
1. Click on the "Graph2" tab at the top of the page

   Figure C9.2.1. Tekscan screen highlighting where to click to select "Graph2"



2. Select "Analysis" then "Objects"
3. Highlight the red box file

Figure C9.2.3. Tekscan screen highlighting where to click to select the right limb data as well as where to click "Save ASCII"



4. Click "Save ASCII"
5. Repeat previous steps 4-5 in Table C9.1.1
   a. Find the location of the patient file on ES3
      i. Hart -> 17399- LEAP -> Balance Tekscan -> Patient ANALYZED Files

ii. Save the file as “Squat1_Right_F”

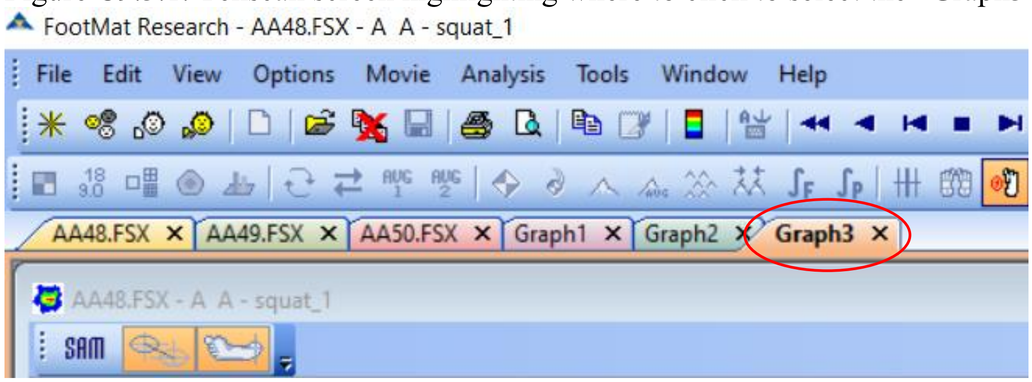
6. Repeat previous steps 6-7 in table C9.1.1
7. Click “OK”

Table C9.3. Graph 3 Data Export

Graph 3

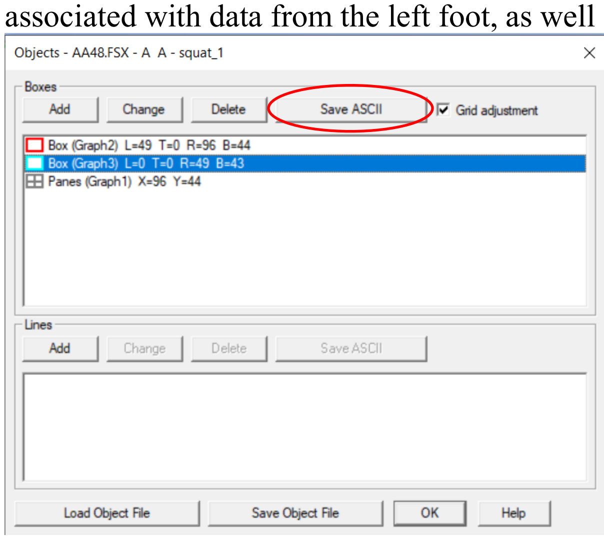
1. Click on the “Graph3” tab at the top of the page

Figure C9.3.1. Tekscan screen highlighting where to click to select the “Graph3”



2. Select “Analysis” then “Objects”
3. Highlight the cyan box file

Figure C9.3.3. Tekscan screen highlighting where to select the cyan color associated with data from the left foot, as well as where to click “Save ASCII”



4. Click “Save ASCII”
5. Repeat previous steps 4-5 in Table C91.1
   a. Find the location of the patient file on ES3
      i. Hart -> 17399- LEAP -> Balance Tekscan -> Patient ANALYZED Files

ii. Save the file as “Squat1_Left_F”

6. Repeat previous steps 6-7 in Table C9.1.1
7. Click “OK”

Table C9.4. Overall Graph Data Export

After completing all the previous steps for table C9.1.1 through C9.1.3. for saving graphs 1-3:

1. Repeat previous steps in table C9.1.1. through table C9.1.3. for squat sets 2 & 3
2. Following the completion of those steps:
    a. 9 total files should be in each patient file for each visit

Figure C9.4.2.a. Folder display when all squat data has been exported and saved in the correct location

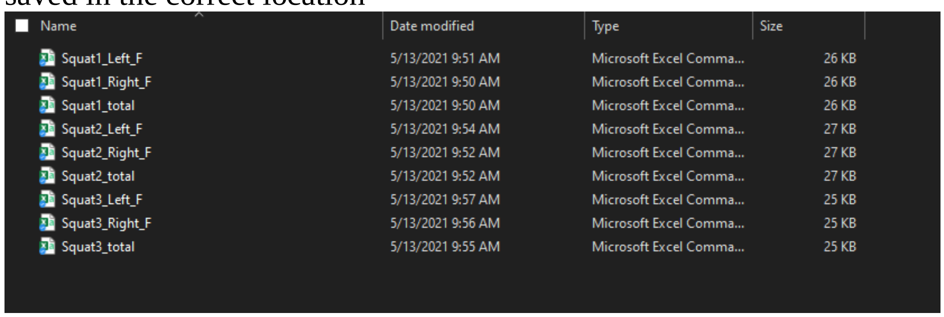


Table C9.5. Tekscan SB Mat Data Processing Instructions

Squat Metric Data processing:

1. Open MATLAB software (R2022a, ver 9.12.0)
2. Open TEKSCAN_PROCESS_V2.m MATLAB code for calibrated data
3. Adjust the path files as needed in the following locations:
    a) Line 27
    b) Line 67
    c) Line 737
    d) Line 1276
    e) Line 1735
    f) Line 2193
    g) Line 2210

Table C9.6 MATLAB Code Analyzing Squatting Data

```
% Tekscan Data Processing without Calibration
% Written by Alex Gioia (agioia@vt.edu) and Hannah Orens
(hannaho02@vt.edu) at
% Virginia Tech
%%
% Instructions
% -Save script to folder containing all patient folders
% -Change directories in lines 24, 46, 388, 648, 908, 1167, 1182 to
your own file path of
% the folder containing all subject folders
% -Ensure the Excel sheet for Body Mass is named correctly in lines 26,
28,
% 30-32
% -Navigate to the "Editor" tab at the top of screen and press "Run",
% progress and timestamps will be displayed in the command window
% -Processing takes approximately 2 minutes per visit folder



clear;clc;close all

datetime.setDefaultFormats('defaultdate','MM/dd/yyyy')

beginprogress = ['Processing started (',datestr(now, 'HH:MM:SS'),')'];
disp(beginprogress)

AllFiles = ['C:\Users\hannaho02\Virginia Tech\Granata Lab Files -
Amelia - Tekscan\Mock Data']; % set as file path of folder containing
all subject folders
Data = dir(AllFiles);
ACLR_Limb =
readtable('LEAP_Full_Data_14July2022.xlsx','Range','N:N','VariableNamin
gRule','preserve'); % reads the ACLR Limb of the patient
ACLR_Limb = table2cell(ACLR_Limb);
SubjectInfo(:,1) =
readtable('LEAP_Full_Data_14July2022.xlsx','Range','A:A','VariableNamin
gRule','preserve'); % reads the Subject ID
SubjectInfo(:,2) = eraseBetween(SubjectInfo{:,1},1,5);
SubjectInfo(:,3) =
readtable('LEAP_Full_Data_14July2022.xlsx','Range','L:L','VariableNamin
gRule','preserve'); % reads the Body Mass [Kg]
SubjectInfo(:,4) =
readtable('LEAP_Full_Data_14July2022.xlsx','Range','D:D','VariableNamin
gRule','preserve'); % reads the DOB
SubjectInfo(:,5) =
readtable('LEAP_Full_Data_14July2022.xlsx','Range','F:F','VariableNamin
gRule','preserve'); % reads the Visit Date
SubjectInfo =
renamevars(SubjectInfo,["Var2","Var3","Var4","Var5"],["ID","Body_Mass_K
g","Date_Birth","Date_LEAP"]);
Body_Mass_Kg = table2array(SubjectInfo(:,3));
```

```
Body_Mass_N = Body_Mass_Kg*9.81; % converts body mass of patient from Kilograms to Netwons
for n97 = 1:length(SubjectInfo.ID)
    if contains(SubjectInfo.ID{n97},'_V2') || contains(SubjectInfo.ID{n97},'_V3')
        SubjectInfo.ID{n97} = eraseBetween(SubjectInfo.ID{n97},length(SubjectInfo.ID{n97})-2,length(SubjectInfo.ID{n97}));
    end
end
SubjectInfo = sortrows(SubjectInfo,'Date_LEAP');
names{1} = SubjectInfo.ID(:);


%% Initializing Full Data Excel
cd('C:\Users\hannaho02\Virginia Tech\Granata Lab Files - Amelia - Tekscan\Mock Data')
fulldata(1,1:23) = {'Subject ID','Error','Date_Birth','Visit Date (Excel)','Visit Date (RAW)','ACLR Limb','Peak Force ACLR [N]','Peak Force Contralateral [N]','Avg Force Dist ACLR (%)','Avg Force Dist Contralateral (%)','Squat LSI ACLR','LSI Grouped AVG_<60%','LSI Grouped AVG_60-69%','LSI Grouped AVG_70-79%','LSI Grouped AVG_80-89%','LSI Grouped AVG_90-110%','LSI Grouped AVG_>110%','Peak Force ACLR SD [N]','Peak Force Contralateral SD [N]','Avg Force Dist ACLR SD','Avg Force Dist Contralateral SD','LSI ACLR SD','LSI Contralateral SD'};


%% Import Data
for n1 = 3:length(Data) % runs all patient folders (open 'Data' in the workspace and look at the field numbers to determine start and end points)
    progress = ['Processing ',num2str(n1-2), ' of ',num2str(length(Data)-2),' (',datestr(now, 'HH:MM:SS'),') [Subject ID: ', Data(n1).name,']']; % Progress and timestamps
    disp(progress)
    patient_folder = dir(fullfile(Data(n1).folder,Data(n1).name)); % establishes patient folder directory
    tempname = eraseBetween(Data(n1).name,1,5);
    if contains(Data(n1).name,'_V2') || contains(Data(n1).name,'_V3')
        Data(n1).name = eraseBetween(Data(n1).name,length(Data(n1.name)-2,length(Data(n1).name)));
    end
    testname = contains(names{1,1},tempname);
    subjectindex = find(testname);
        for n2 = 3:length(patient_folder) % runs through all visit folders in each patient folder
            visitnames = extractfield(patient_folder,'name');
            if length(subjectindex) == 1
                fulldata(subjectindex(1)+1,1) = {Data(n1).name};
                fulldata(subjectindex(1)+1,3) = {SubjectInfo.Date_Birth(subjectindex(1))};
                fulldata(subjectindex(1)+1,4) = {SubjectInfo.Date_LEAP(subjectindex(1))};
```

```
%                 if sum(contains(visitnames,["Visit_1","Visit1"])) ==
0
%                     fulldata(subjectindex(1)+1,2) = {'No Data'};
%                 end
            elseif length(subjectindex) == 2
                fulldata(subjectindex(1)+1,1) = {Data(n1).name};
                fulldata(subjectindex(1)+1,3) =
{SubjectInfo.Date_Birth(subjectindex(1))};
                fulldata(subjectindex(1)+1,4) =
{SubjectInfo.Date_LEAP(subjectindex(1))};
                fulldata(subjectindex(2)+1,1) = {Data(n1).name};
                fulldata(subjectindex(2)+1,3) =
{SubjectInfo.Date_Birth(subjectindex(2))};
                fulldata(subjectindex(2)+1,4) =
{SubjectInfo.Date_LEAP(subjectindex(2))};
%                 if sum(contains(visitnames,["Visit_2","Visit2"])) ==
0
%                     fulldata(subjectindex(2)+1,2) = {'No Data'};
%                 end
%                 if sum(contains(visitnames,["Visit_1","Visit1"])) ==
0
%                     fulldata(subjectindex(1)+1,2) = {'No Data'};
%                 end
                if
~isequal(SubjectInfo.Date_Birth(subjectindex(1)),SubjectInfo.Date_Birth
(subjectindex(2)))
                    fulldata(subjectindex(1)+1,2) = {'DOB error'};
                    fulldata(subjectindex(2)+1,2) = {'DOB error'};
                end
            elseif length(subjectindex) == 3
                fulldata(subjectindex(1)+1,1) = {Data(n1).name};
                fulldata(subjectindex(1)+1,3) =
{SubjectInfo.Date_Birth(subjectindex(1))};
                fulldata(subjectindex(1)+1,4) =
{SubjectInfo.Date_LEAP(subjectindex(1))};
                fulldata(subjectindex(2)+1,1) = {Data(n1).name};
                fulldata(subjectindex(2)+1,3) =
{SubjectInfo.Date_Birth(subjectindex(2))};
                fulldata(subjectindex(2)+1,4) =
{SubjectInfo.Date_LEAP(subjectindex(2))};
                fulldata(subjectindex(3)+1,1) = {Data(n1).name};
                fulldata(subjectindex(3)+1,3) =
{SubjectInfo.Date_Birth(subjectindex(3))};
                fulldata(subjectindex(3)+1,4) =
{SubjectInfo.Date_LEAP(subjectindex(3))};
%                 if sum(contains(visitnames,["Visit_3","Visit3"])) ==
0
%                     fulldata(subjectindex(3)+1,2) = {'No Data'};
%                 end
%                 if sum(contains(visitnames,["Visit_2","Visit2"])) ==
0
%                     fulldata(subjectindex(2)+1,1) = {Data(n1).name};
%                     fulldata(subjectindex(2)+1,2) = {'No Data'};
%                 end
```

```
%                   if sum(contains(visitnames,["Visit_1","Visit1"])) ==
0
%                       fulldata(subjectindex(1)+1,1) = {Data(n1).name};
%                       fulldata(subjectindex(1)+1,2) = {'No Data'};
%                   end
                  if
~isequal(SubjectInfo.Date_Birth(subjectindex(1)),SubjectInfo.Date_Birth
(subjectindex(2)),SubjectInfo.Date_Birth(subjectindex(3)))
                      if isempty(fulldata{subjectindex(1)+1,2})
                          fulldata(subjectindex(1)+1,2) = {'DOB error'};
                      else
                          fulldata(subjectindex(1)+1,2) =
append(fulldata(subjectindex(1)+1,2),', DOB error');
                      end
                      if isempty(fulldata{subjectindex(2)+1,2})
                          fulldata(subjectindex(2)+1,2) = {'DOB error'};
                      else
                          fulldata(subjectindex(2)+1,2) =
append(fulldata(subjectindex(2)+1,2),', DOB error');
                      end
                      if isempty(fulldata{subjectindex(3)+1,2})
                          fulldata(subjectindex(3)+1,2) = {'DOB error'};
                      else
                          fulldata(subjectindex(3)+1,2) =
append(fulldata(subjectindex(3)+1,2),', DOB error');
                      end
                  end
              end



              %% All Visits Exporting to FullData
              if contains(patient_folder(n2).name, 'Visit')
                  visit1_folder =
dir(fullfile(patient_folder(n2).folder,patient_folder(n2).name)); %
establishes visit folder directory
                  if isempty(subjectindex) == 0
                      for n3 = 3:length(visit1_folder) % reads folder
fields 3 through 8 for Squat 1 files
                          if isequal(visit1_folder(n3).name,
'Squat1_COF.csv') % reads for Squat 1 COF
                              opts =
detectImportOptions(fullfile(visit1_folder(n3).folder,visit1_folder(n3)
.name));
                              varopts = getvaropts(opts,{'Var3'});
                              opts =
setvaropts(opts,"Var3",'InputFormat','MM/dd/uuuu');
                              visitdate =
readtable(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),opt
s);
                              visitdate1 = visitdate(1,3);
                              COF1_1 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
); % Imports Squat 1 COF file (NAMING CONV: First number is the visit
number, second number is the squat number
```

```
                        elseif
isequal(visit1_folder(n3).name,'Squat1_Left_COF.csv') % reads for Squat
1 Left COF
                            LCOF1_1 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
);
                        elseif
isequal(visit1_folder(n3).name,'Squat1_Right_COF.csv') % reads for
Squat 1 Right COF
                            RCOF1_1 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
);
                        elseif
isequal(visit1_folder(n3).name,'Squat1_total.csv') % reads for Squat 1
Total
                            TOTALF1_1 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
); % imports all total force values
%                             CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30'); % imports first 5 frames of raw sum values
%                             CALIBREAD_AVG = mean(CALIBREAD); %
averages first 5 raw sum values
%                             CALIB_FACTOR =
Body_Mass_N(subjectindex(1),1)/CALIBREAD_AVG; % establishes calibration
factor based on body weight in newtons
%                             TOTALF1_1 = TOTALF1_1*CALIB_FACTOR; %
applies calbibration factor to all frames of total force values
                        elseif
isequal(visit1_folder(n3).name,'Squat1_Left_F.csv') % reads for Squat 1
Left F
                            LEFTF1_1 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
); % imports all left force values
%                             CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30'); % imports first 5 frames of raw sum values
%                             CALIBREAD_AVG = mean(CALIBREAD); %
averages first 5 raw sum values
%                             CALIB_FACTOR =
Body_Mass_N(subjectindex(1),1)/CALIBREAD_AVG; % establishes calibration
factor based on body weight in newtons
%                             LEFTF1_1 = LEFTF1_1*CALIB_FACTOR; %
applies calibration factor to all frames of left force values
                        elseif
isequal(visit1_folder(n3).name,'Squat1_Right_F.csv') % reads for Squat
1 Right F
                            RIGHTF1_1 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
); % imports all right force values
%                             CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30'); % imports first 5 frames of raw sum values
%                             CALIBREAD_AVG = mean(CALIBREAD); %
averages first 5 raw sum values
```

```
%                              CALIB_FACTOR =
Body_Mass_N(subjectindex(1),1)/CALIBREAD_AVG; % establishes calibration
factor based on body weight in newtons
%                              RIGHTF1_1 = RIGHTF1_1*CALIB_FACTOR; %
applies calibration factor to all frames of right force values
                        elseif isequal(visit1_folder(n3).name,
'Squat2_COF.csv')
                            COF1_2 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
); % First number is the visit number, second number is the squat
number
                        elseif
isequal(visit1_folder(n3).name,'Squat2_Left_COF.csv')
                            LCOF1_2 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
);
                        elseif
isequal(visit1_folder(n3).name,'Squat2_Right_COF.csv')
                            RCOF1_2 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
);
                        elseif
isequal(visit1_folder(n3).name,'Squat2_total.csv')
                            TOTALF1_2 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
);
%                              CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30');
%                              CALIBREAD_AVG = mean(CALIBREAD);
%                              CALIB_FACTOR =
Body_Mass_N(subjectindex(1),1)/CALIBREAD_AVG;
%                              TOTALF1_2 = TOTALF1_2*CALIB_FACTOR;
                        elseif
isequal(visit1_folder(n3).name,'Squat2_Left_F.csv')
                            LEFTF1_2 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
);
%                              CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30');
%                              CALIBREAD_AVG = mean(CALIBREAD);
%                              CALIB_FACTOR =
Body_Mass_N(subjectindex(1),1)/CALIBREAD_AVG;
%                              LEFTF1_2 = LEFTF1_2*CALIB_FACTOR;
                        elseif
isequal(visit1_folder(n3).name,'Squat2_Right_F.csv')
                            RIGHTF1_2 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
);
%                              CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30');
%                              CALIBREAD_AVG = mean(CALIBREAD);
```

```
%                               CALIB_FACTOR =
Body_Mass_N(subjectindex(1),1)/CALIBREAD_AVG;
%                               RIGHTF1_2 = RIGHTF1_2*CALIB_FACTOR;
                          elseif isequal(visit1_folder(n3).name,
'Squat3_COF.csv')
                              COF1_3 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
); % First number is the visit number, second number is the squat
number
                          elseif
isequal(visit1_folder(n3).name,'Squat3_Left_COF.csv')
                              LCOF1_3 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
);
                          elseif
isequal(visit1_folder(n3).name,'Squat3_Right_COF.csv')
                              RCOF1_3 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
);
                          elseif
isequal(visit1_folder(n3).name,'Squat3_total.csv')
                              TOTALF1_3 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
);
%                               CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30');
%                               CALIBREAD_AVG = mean(CALIBREAD);
%                               CALIB_FACTOR =
Body_Mass_N(subjectindex(1),1)/CALIBREAD_AVG;
%                               TOTALF1_3 = TOTALF1_3*CALIB_FACTOR;
                          elseif
isequal(visit1_folder(n3).name,'Squat3_Left_F.csv')
                              LEFTF1_3 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
);
%                               CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30');
%                               CALIBREAD_AVG = mean(CALIBREAD);
%                               CALIB_FACTOR =
Body_Mass_N(subjectindex(1),1)/CALIBREAD_AVG;
%                               LEFTF1_3 = LEFTF1_3*CALIB_FACTOR;
                          elseif
isequal(visit1_folder(n3).name,'Squat3_Right_F.csv')
                              RIGHTF1_3 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
);
%                               CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30');
%                               CALIBREAD_AVG = mean(CALIBREAD);
%                               CALIB_FACTOR =
Body_Mass_N(subjectindex(1),1)/CALIBREAD_AVG;
%                               RIGHTF1_3 = RIGHTF1_3*CALIB_FACTOR;
```

```
                            end
                        end

                        %% Organizing VISIT_1 Excel Export
                        vectorarray = {LEFTF1_1 LEFTF1_2 LEFTF1_3}; %
creates array of Left Force Squat 1, Squat 2, Squat 3
                        maxlength = max(cellfun(@numel, vectorarray)); %
determines length of longest vector (Squat 1 or Squat 2 or Squat 3)
                        alldata = NaN(maxlength,27); % creates empty data
matrix set to row length of longest trial
                        rawsquat1_1 = [LEFTF1_1 RIGHTF1_1 TOTALF1_1 LCOF1_1
RCOF1_1 COF1_1]; % creates matrix with all Squat 1 data
                        NaN1_1 = NaN(maxlength-length(LEFTF1_1),9); %
creates NaN matrix with row legnth of difference between longest trial
and Squat 1
                        squat1_1 = [rawsquat1_1;NaN1_1]; % creates full
length squat 1 matrix
                        rawsquat1_2 = [LEFTF1_2 RIGHTF1_2 TOTALF1_2 LCOF1_2
RCOF1_2 COF1_2]; % creates matrix with all Squat 2 data
                        NaN1_2 = NaN(maxlength-length(LEFTF1_2),9); %
creates NaN matrix with row length of difference between longest trial
and Squat 2
                        squat1_2 = [rawsquat1_2;NaN1_2]; % creates full
length squat 2 matrix
                        rawsquat1_3 = [LEFTF1_3 RIGHTF1_3 TOTALF1_3 LCOF1_3
RCOF1_3 COF1_3]; % creates matrix with all Squat 3 data
                        NaN1_3 = NaN(maxlength-length(LEFTF1_3),9); %
creates NaN matrix with row length of difference between longest trial
and Squat 3
                        squat1_3 = [rawsquat1_3;NaN1_3]; % creates full
length squat 3 matrix
                        alldata = [squat1_1 squat1_2 squat1_3]; % updates
data matrix to be a full matrix containing all data for Squat 1, Squat
2, and Squat 3
                        alldatacell = cell(maxlength+2,27); % creates empty
cell type matrix of correct dimensions to allow for headers in the
exported excel file
                        alldataheader = {'Squat
1','','','','','','','','','Squat 2','','','','','','','','','Squat
3'}; % creates header for Squat 1, Squat 2, Squat 3
                        alldatasubheader = {'Force Left [N]','Force Right
[N]','Force Total [N]','COF Left Y [cm]','COF Left X [cm]','COF Right Y
[cm]','COF Right X [cm]','COF Total Y [cm]','COF Total X [cm]',...
                            'Force Left [N]','Force Right [N]','Force Total
[N]','COF Left Y [cm]','COF Left X [cm]','COF Right Y [cm]','COF Right
X [cm]','COF Total Y [cm]','COF Total X [cm]',...
                            'Force Left [N]','Force Right [N]','Force Total
[N]','COF Left Y [cm]','COF Left X [cm]','COF Right Y [cm]','COF Right
X [cm]','COF Total Y [cm]','COF Total X [cm]'}; % creates subheader for
each column
                        alldatacell(1,1:19) = alldataheader; % adds header
to top of the alldatacell matrix
                        alldatacell(2,:) = alldatasubheader; % adds
subheaders to alldatacell matrix
```

```
                    alldatacell(3:maxlength+2,:) = num2cell(alldata); %
converts alldata matrix from number type to cell type and adds it to
alldatacell matrix
                    savetofolder = visit1_folder.folder; % sets the
folder to save to as the current visit folder
                    cd(savetofolder); % sets current directory to the
visit folder
                    %writecell(alldatacell,
'VISIT_1.xlsx','Sheet','Data'); % exports alldatacell matrix to excel
sheet named "VISIT_1"

                    %% Squat Metrics Calculations
                    % Peak Force Left
                    peakLEFTF1_1 = max(LEFTF1_1); % calculates peak
force in left limb for squat 1
                    peakLEFTF1_2 = max(LEFTF1_2); % calculates peak
force in left limb for squat 2
                    peakLEFTF1_3 = max(LEFTF1_3); % calculates peak
force in left limb for squat 3
                    peakLEFTF1 = [peakLEFTF1_1 peakLEFTF1_2
peakLEFTF1_3]; % creates matrix with each squat trial of the left limb
                    peakLEFTF1_AVG = mean(peakLEFTF1); % calculates
average peak force in left limb across all squat trials
                    peakLEFTF1_SD = std(peakLEFTF1); % calcualtes
standard deviation for the 3 peak squat values of the left limb
                    % Peak Force Right
                    peakRIGHTF1_1 = max(RIGHTF1_1); % peak force in
right limb for squat 1
                    peakRIGHTF1_2 = max(RIGHTF1_2); % peak force in
right limb for squat 2
                    peakRIGHTF1_3 = max(RIGHTF1_3); % peak force in
right limb for squat 3
                    peakRIGHTF1 = [peakRIGHTF1_1 peakRIGHTF1_2
peakRIGHTF1_3]; % creates matrix with each squat trial of the right
limb
                    peakRIGHTF1_AVG = mean(peakRIGHTF1); % calculates
average peak force in the right limb across all squat trials
                    peakRIGHTF1_SD = std(peakRIGHTF1); % calculates
standard deviation for the 3 peak squat values of the right limb
                    % Average Force Distribution Left
                    LEFTF_DIST1_1 = LEFTF1_1./TOTALF1_1; % divides the
left force by the total force for every frame of Squat 1
                    LEFTF_DIST1_1_AVG = mean(LEFTF_DIST1_1); %
calculates the average of the left distribution for every frame of
Squat 1
                    LEFTF_DIST1_2 = LEFTF1_2./TOTALF1_2; % divides the
left force by the total force for every frame of Squat 2
                    LEFTF_DIST1_2_AVG = mean(LEFTF_DIST1_2); %
calculates the average of the left distribution for every frame of
Squat 2
                    LEFTF_DIST1_3 = LEFTF1_3./TOTALF1_3; % divides the
left force by the total force for every frame of Squat 3
                    LEFTF_DIST1_3_AVG = mean(LEFTF_DIST1_3); %
calculates the average of the left distribution for every frame of
Squat 3
```

```
                    LEFTF_DIST1 = [LEFTF_DIST1_1_AVG LEFTF_DIST1_2_AVG LEFTF_DIST1_3_AVG]; % matrix containing the Left Distribution Average for all squat trials
                    LEFTF_DIST1_AVG = mean(LEFTF_DIST1); % calculates the overall left distribution average
                    LEFTF_DIST1_SD = std(LEFTF_DIST1); % calculates the overall left distribution standard deviation
                    % Average Force Distribution Right
                    RIGHTF_DIST1_1 = RIGHTF1_1./TOTALF1_1;
                    RIGHTF_DIST1_1_AVG = mean(RIGHTF_DIST1_1);
                    RIGHTF_DIST1_2 = RIGHTF1_2./TOTALF1_2;
                    RIGHTF_DIST1_2_AVG = mean(RIGHTF_DIST1_2);
                    RIGHTF_DIST1_3 = RIGHTF1_3./TOTALF1_3;
                    RIGHTF_DIST1_3_AVG = mean(RIGHTF_DIST1_3);
                    RIGHTF_DIST1 = [RIGHTF_DIST1_1_AVG RIGHTF_DIST1_2_AVG RIGHTF_DIST1_3_AVG];
                    RIGHTF_DIST1_AVG = mean(RIGHTF_DIST1);
                    RIGHTF_DIST1_SD = std(RIGHTF_DIST1);
                    % LSI LEFT ACLR
                    LSI_LEFTF1_1 = LEFTF1_1./RIGHTF1_1; % divides the left force by the right force for every frame of Squat 1
                    LSI_LEFTF1_1_AVG = mean(LSI_LEFTF1_1); % calculates the mean LSI of Squat 1
                    LSI_LEFTF1_2 = LEFTF1_2./RIGHTF1_2; % divides the left force by the right force for every frame of Squat 2
                    LSI_LEFTF1_2_AVG = mean(LSI_LEFTF1_2); % calculates the mean LSI of Squat 2
                    LSI_LEFTF1_3 = LEFTF1_3./RIGHTF1_3; % divides the left force by the right force for every frame of Squat 3
                    LSI_LEFTF1_3_AVG = mean(LSI_LEFTF1_3); % calculates the mean LSI of Squat 3
                    LSI_LEFTF1 = [LSI_LEFTF1_1_AVG LSI_LEFTF1_2_AVG LSI_LEFTF1_3_AVG]; % matrix containing the LSI Average for all squat trials
                    LSI_LEFTF1_AVG = mean(LSI_LEFTF1); % calculates the overall average LSI
                    LSI_LEFTF1_SD = std(LSI_LEFTF1); % calculates the overall LSI standard deviation
                    % LSI RIGHT ACLR
                    LSI_RIGHTF1_1 = RIGHTF1_1./LEFTF1_1;
                    LSI_RIGHTF1_1_AVG = mean(LSI_RIGHTF1_1);
                    LSI_RIGHTF1_2 = RIGHTF1_2./LEFTF1_2;
                    LSI_RIGHTF1_2_AVG = mean(LSI_RIGHTF1_2);
                    LSI_RIGHTF1_3 = RIGHTF1_3./LEFTF1_3;
                    LSI_RIGHTF1_3_AVG = mean(LSI_RIGHTF1_3);
                    LSI_RIGHTF1 = [LSI_RIGHTF1_1_AVG LSI_RIGHTF1_2_AVG LSI_RIGHTF1_3_AVG];
                    LSI_RIGHTF1_AVG = mean(LSI_RIGHTF1);
                    LSI_RIGHTF1_SD = std(LSI_RIGHTF1);
                    % Limb Symmetry Grouped Left
                    for n6 = 1:length(LSI_LEFTF1_1) % Squat 1
                        LS1_countless60 = sum(LSI_LEFTF1_1<.6)/length(LSI_LEFTF1_1); % counts number of frames with LSI  <0.6 and divides by total number of frames in the trial
```

```
                        LS1_count60_69 = sum(LSI_LEFTF1_1>=0.6 &
LSI_LEFTF1_1<0.7)/length(LSI_LEFTF1_1); % counts number of frames with
LSI 0.6-0.7 and divides by total number of frames in the trial
                        LS1_count70_79 = sum(LSI_LEFTF1_1>=0.7 &
LSI_LEFTF1_1<0.8)/length(LSI_LEFTF1_1); % counts number of frames with
LSI 0.7-0.8 and divides by total number of frames in the trial
                        LS1_count80_89 = sum(LSI_LEFTF1_1>=0.8 &
LSI_LEFTF1_1<0.9)/length(LSI_LEFTF1_1); % counts number of frames with
LSI 0.8-0.9 and divides by total number of frames in the trial
                        LS1_count90_110 = sum(LSI_LEFTF1_1>=0.9 &
LSI_LEFTF1_1<1.1)/length(LSI_LEFTF1_1); % counts number of frames with
LSI 0.9-1.1 and divides by total number of frames in the trial
                        LS1_countmore110 =
sum(LSI_LEFTF1_1>=1.1)/length(LSI_LEFTF1_1); % counts number of frames
with LSI  >1.1 and divides by total number of frames in the trial
                    end
                    for n6 = 1:length(LSI_LEFTF1_2) % Squat 2
                        LS2_countless60 =
sum(LSI_LEFTF1_2<.6)/length(LSI_LEFTF1_2);
                        LS2_count60_69 = sum(LSI_LEFTF1_2>=0.6 &
LSI_LEFTF1_2<0.7)/length(LSI_LEFTF1_2);
                        LS2_count70_79 = sum(LSI_LEFTF1_2>=0.7 &
LSI_LEFTF1_2<0.8)/length(LSI_LEFTF1_2);
                        LS2_count80_89 = sum(LSI_LEFTF1_2>=0.8 &
LSI_LEFTF1_2<0.9)/length(LSI_LEFTF1_2);
                        LS2_count90_110 = sum(LSI_LEFTF1_2>=0.9 &
LSI_LEFTF1_2<1.1)/length(LSI_LEFTF1_2);
                        LS2_countmore110 =
sum(LSI_LEFTF1_2>=1.1)/length(LSI_LEFTF1_2);
                    end
                    for n6 = 1:length(LSI_LEFTF1_3) % Squat 3
                        LS3_countless60 =
sum(LSI_LEFTF1_3<.6)/length(LSI_LEFTF1_3);
                        LS3_count60_69 = sum(LSI_LEFTF1_3>=0.6 &
LSI_LEFTF1_3<0.7)/length(LSI_LEFTF1_3);
                        LS3_count70_79 = sum(LSI_LEFTF1_3>=0.7 &
LSI_LEFTF1_3<0.8)/length(LSI_LEFTF1_3);
                        LS3_count80_89 = sum(LSI_LEFTF1_3>=0.8 &
LSI_LEFTF1_3<0.9)/length(LSI_LEFTF1_3);
                        LS3_count90_110 = sum(LSI_LEFTF1_3>=0.9 &
LSI_LEFTF1_3<1.1)/length(LSI_LEFTF1_3);
                        LS3_countmore110 =
sum(LSI_LEFTF1_3>=1.1)/length(LSI_LEFTF1_3);
                    end
                    % Limb Symmetry Grouped Right
                    for n6 = 1:length(LSI_RIGHTF1_1) % Squat 1
                        RS1_countless60 =
sum(LSI_RIGHTF1_1<.6)/length(LSI_RIGHTF1_1);
                        RS1_count60_69 = sum(LSI_RIGHTF1_1>=0.6 &
LSI_RIGHTF1_1<0.7)/length(LSI_RIGHTF1_1);
                        RS1_count70_79 = sum(LSI_RIGHTF1_1>=0.7 &
LSI_RIGHTF1_1<0.8)/length(LSI_RIGHTF1_1);
                        RS1_count80_89 = sum(LSI_RIGHTF1_1>=0.8 &
LSI_RIGHTF1_1<0.9)/length(LSI_RIGHTF1_1);
```

```
                        RS1_count90_110 = sum(LSI_RIGHTF1_1>=0.9 &
LSI_RIGHTF1_1<1.1)/length(LSI_RIGHTF1_1);
                        RS1_countmore110 =
sum(LSI_RIGHTF1_1>=1.1)/length(LSI_RIGHTF1_1);
                    end
                    for n6 = 1:length(LSI_RIGHTF1_2) % Squat 2
                        RS2_countless60 =
sum(LSI_RIGHTF1_2<.6)/length(LSI_RIGHTF1_2);
                        RS2_count60_69 = sum(LSI_RIGHTF1_2>=0.6 &
LSI_RIGHTF1_2<0.7)/length(LSI_RIGHTF1_2);
                        RS2_count70_79 = sum(LSI_RIGHTF1_2>=0.7 &
LSI_RIGHTF1_2<0.8)/length(LSI_RIGHTF1_2);
                        RS2_count80_89 = sum(LSI_RIGHTF1_2>=0.8 &
LSI_RIGHTF1_2<0.9)/length(LSI_RIGHTF1_2);
                        RS2_count90_110 = sum(LSI_RIGHTF1_2>=0.9 &
LSI_RIGHTF1_2<1.1)/length(LSI_RIGHTF1_2);
                        RS2_countmore110 =
sum(LSI_RIGHTF1_2>=1.1)/length(LSI_RIGHTF1_2);
                    end
                    for n6 = 1:length(LSI_RIGHTF1_3) % Squat 3
                        RS3_countless60 =
sum(LSI_RIGHTF1_3<.6)/length(LSI_RIGHTF1_3);
                        RS3_count60_69 = sum(LSI_RIGHTF1_3>=0.6 &
LSI_RIGHTF1_3<0.7)/length(LSI_RIGHTF1_3);
                        RS3_count70_79 = sum(LSI_RIGHTF1_3>=0.7 &
LSI_RIGHTF1_3<0.8)/length(LSI_RIGHTF1_3);
                        RS3_count80_89 = sum(LSI_RIGHTF1_3>=0.8 &
LSI_RIGHTF1_3<0.9)/length(LSI_RIGHTF1_3);
                        RS3_count90_110 = sum(LSI_RIGHTF1_3>=0.9 &
LSI_RIGHTF1_3<1.1)/length(LSI_RIGHTF1_3);
                        RS3_countmore110 =
sum(LSI_RIGHTF1_3>=1.1)/length(LSI_RIGHTF1_3);
                    end
                    LEFT_LSI_GROUPED = [LS1_countless60 LS1_count60_69
LS1_count70_79 LS1_count80_89 LS1_count90_110 LS1_countmore110;...
                        LS2_countless60 LS2_count60_69 LS2_count70_79
LS2_count80_89 LS2_count90_110 LS2_countmore110;...
                        LS3_countless60 LS3_count60_69 LS3_count70_79
LS3_count80_89 LS3_count90_110 LS3_countmore110]; % matrix of Left ACLR
LSI grouped values for all squat trials
                    LEFT_LSI_GROUPED_AVG = mean(LEFT_LSI_GROUPED); %
calculates the average of each grouping across Squat 1, Squat 2, and
Squat 3 (does a column average)
                    RIGHT_LSI_GROUPED = [RS1_countless60 RS1_count60_69
RS1_count70_79 RS1_count80_89 RS1_count90_110 RS1_countmore110;...
                        RS2_countless60 RS2_count60_69 RS2_count70_79
RS2_count80_89 RS2_count90_110 RS2_countmore110;...
                        RS3_countless60 RS3_count60_69 RS3_count70_79
RS3_count80_89 RS3_count90_110 RS3_countmore110]; % matrix of Right
ACLR LSI grouped values for all squat trials
                    RIGHT_LSI_GROUPED_AVG = mean(RIGHT_LSI_GROUPED); %
calculates the average of each grouping across Squat 1, Squat 2, Squat
3 (does a column average)

                    for n01 = 1:length(subjectindex)
```

```
                        fulldata(subjectindex(n01)+1,1) =
{Data(n1).name};
                        fulldata(subjectindex(n01)+1,6) =
{ACLR_Limb{subjectindex(n01),1}};
                        if SubjectInfo.Date_LEAP(subjectindex(n01))-7 <
visitdate1{1,1} && visitdate1{1,1} <
SubjectInfo.Date_LEAP(subjectindex(n01))+7
                            fulldata(subjectindex(n01)+1,5) =
{visitdate1{1,1}};
                            if
isequal(ACLR_Limb{subjectindex(n01),1},'Right')
                                fulldata(subjectindex(n01)+1,7) =
{peakRIGHTF1_AVG};
                                fulldata(subjectindex(n01)+1,8) =
{peakLEFTF1_AVG};
                                fulldata(subjectindex(n01)+1,9) =
{RIGHTF_DIST1_AVG};
                                fulldata(subjectindex(n01)+1,10) =
{LEFTF_DIST1_AVG};
                                fulldata(subjectindex(n01)+1,11) =
{LSI_RIGHTF1_AVG};
                                fulldata(subjectindex(n01)+1,12) =
{RIGHT_LSI_GROUPED_AVG(1)};
                                fulldata(subjectindex(n01)+1,13) =
{RIGHT_LSI_GROUPED_AVG(2)};
                                fulldata(subjectindex(n01)+1,14) =
{RIGHT_LSI_GROUPED_AVG(3)};
                                fulldata(subjectindex(n01)+1,15) =
{RIGHT_LSI_GROUPED_AVG(4)};
                                fulldata(subjectindex(n01)+1,16) =
{RIGHT_LSI_GROUPED_AVG(5)};
                                fulldata(subjectindex(n01)+1,17) =
{RIGHT_LSI_GROUPED_AVG(6)};
                                fulldata(subjectindex(n01)+1,18) =
{peakRIGHTF1_SD};
                                fulldata(subjectindex(n01)+1,19) =
{peakLEFTF1_SD};
                                fulldata(subjectindex(n01)+1,20) =
{RIGHTF_DIST1_SD};
                                fulldata(subjectindex(n01)+1,21) =
{LEFTF_DIST1_SD};
                                fulldata(subjectindex(n01)+1,22) =
{LSI_RIGHTF1_SD};
                                fulldata(subjectindex(n01)+1,23) =
{LSI_LEFTF1_SD};
                            elseif
isequal(ACLR_Limb{subjectindex(n01),1},'Left')
                                fulldata(subjectindex(n01)+1,7) =
{peakLEFTF1_AVG};
                                fulldata(subjectindex(n01)+1,8) =
{peakRIGHTF1_AVG};
                                fulldata(subjectindex(n01)+1,9) =
{LEFTF_DIST1_AVG};
                                fulldata(subjectindex(n01)+1,10) =
{RIGHTF_DIST1_AVG};
```

```
                                fulldata(subjectindex(n01)+1,11) =
{LSI_LEFTF1_AVG};
                                fulldata(subjectindex(n01)+1,12) =
{LEFT_LSI_GROUPED_AVG(1)};
                                fulldata(subjectindex(n01)+1,13) =
{LEFT_LSI_GROUPED_AVG(2)};
                                fulldata(subjectindex(n01)+1,14) =
{LEFT_LSI_GROUPED_AVG(3)};
                                fulldata(subjectindex(n01)+1,15) =
{LEFT_LSI_GROUPED_AVG(4)};
                                fulldata(subjectindex(n01)+1,16) =
{LEFT_LSI_GROUPED_AVG(5)};
                                fulldata(subjectindex(n01)+1,17) =
{LEFT_LSI_GROUPED_AVG(6)};
                                fulldata(subjectindex(n01)+1,18) =
{peakLEFTF1_SD};
                                fulldata(subjectindex(n01)+1,19) =
{peakRIGHTF1_SD};
                                fulldata(subjectindex(n01)+1,20) =
{LEFTF_DIST1_SD};
                                fulldata(subjectindex(n01)+1,21) =
{RIGHTF_DIST1_SD};
                                fulldata(subjectindex(n01)+1,22) =
{LSI_LEFTF1_SD};
                                fulldata(subjectindex(n01)+1,23) =
{LSI_RIGHTF1_SD};
                            end
                        end
                    end
                end
            end
             cd('C:\Users\hannaho02\Virginia Tech\Granata Lab Files -
Amelia - Tekscan\Mock Data'); % sets directory back to original file
path

            %% Visit 1
            if isequal(patient_folder(n2).name, 'Visit_1') ||
isequal(patient_folder(n2).name, 'Visit1') % begins this if statement
if the folder name is Visit 1
                if isempty(subjectindex) == 0
                    visit1_folder =
dir(fullfile(patient_folder(n2).folder,patient_folder(n2).name)); %
establishes visit folder directory
                    for n3 = 3:length(visit1_folder) % reads folder
fields 3 through 8 for Squat 1 files
                        if isequal(visit1_folder(n3).name,
'Squat1_COF.csv') % reads for Squat 1 COF
                            opts =
detectImportOptions(fullfile(visit1_folder(n3).folder,visit1_folder(n3)
.name));
                            varopts = getvaropts(opts,{'Var3'});
                            opts =
setvaropts(opts,"Var3",'InputFormat','MM/dd/uuuu');
```

```
                                visitdate =
readtable(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),opt
s);
                                visitdate1 = visitdate(1,3);
                                COF1_1 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
); % Imports Squat 1 COF file (NAMING CONV: First number is the visit
number, second number is the squat number
                            elseif
isequal(visit1_folder(n3).name,'Squat1_Left_COF.csv') % reads for Squat
1 Left COF
                                LCOF1_1 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
);
                            elseif
isequal(visit1_folder(n3).name,'Squat1_Right_COF.csv') % reads for
Squat 1 Right COF
                                RCOF1_1 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
);
                            elseif
isequal(visit1_folder(n3).name,'Squat1_total.csv') % reads for Squat 1
Total
                                TOTALF1_1 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
); % imports all total force values
%                                 CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30'); % imports first 5 frames of raw sum values
%                                 CALIBREAD_AVG = mean(CALIBREAD); %
averages first 5 raw sum values
%                                 CALIB_FACTOR =
Body_Mass_N(subjectindex(1),1)/CALIBREAD_AVG; % establishes calibration
factor based on body weight in newtons
%                                 TOTALF1_1 = TOTALF1_1*CALIB_FACTOR; %
applies calbibration factor to all frames of total force values
                            elseif
isequal(visit1_folder(n3).name,'Squat1_Left_F.csv') % reads for Squat 1
Left F
                                LEFTF1_1 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
); % imports all left force values
%                                 CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30'); % imports first 5 frames of raw sum values
%                                 CALIBREAD_AVG = mean(CALIBREAD); %
averages first 5 raw sum values
%                                 CALIB_FACTOR =
Body_Mass_N(subjectindex(1),1)/CALIBREAD_AVG; % establishes calibration
factor based on body weight in newtons
%                                 LEFTF1_1 = LEFTF1_1*CALIB_FACTOR; %
applies calibration factor to all frames of left force values
                            elseif
isequal(visit1_folder(n3).name,'Squat1_Right_F.csv') % reads for Squat
1 Right F
```

```
                            RIGHTF1_1 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
); % imports all right force values
%                             CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30'); % imports first 5 frames of raw sum values
%                             CALIBREAD_AVG = mean(CALIBREAD); %
averages first 5 raw sum values
%                             CALIB_FACTOR =
Body_Mass_N(subjectindex(1),1)/CALIBREAD_AVG; % establishes calibration
factor based on body weight in newtons
%                             RIGHTF1_1 = RIGHTF1_1*CALIB_FACTOR; %
applies calibration factor to all frames of right force values
                        elseif isequal(visit1_folder(n3).name,
'Squat2_COF.csv')
                            COF1_2 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
); % First number is the visit number, second number is the squat
number
                        elseif
isequal(visit1_folder(n3).name,'Squat2_Left_COF.csv')
                            LCOF1_2 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
);
                        elseif
isequal(visit1_folder(n3).name,'Squat2_Right_COF.csv')
                            RCOF1_2 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
);
                        elseif
isequal(visit1_folder(n3).name,'Squat2_total.csv')
                            TOTALF1_2 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
);
%                             CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30');
%                             CALIBREAD_AVG = mean(CALIBREAD);
%                             CALIB_FACTOR =
Body_Mass_N(subjectindex(1),1)/CALIBREAD_AVG;
%                             TOTALF1_2 = TOTALF1_2*CALIB_FACTOR;
                        elseif
isequal(visit1_folder(n3).name,'Squat2_Left_F.csv')
                            LEFTF1_2 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
);
%                             CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30');
%                             CALIBREAD_AVG = mean(CALIBREAD);
%                             CALIB_FACTOR =
Body_Mass_N(subjectindex(1),1)/CALIBREAD_AVG;
%                             LEFTF1_2 = LEFTF1_2*CALIB_FACTOR;
                        elseif
isequal(visit1_folder(n3).name,'Squat2_Right_F.csv')
```

```
                                RIGHTF1_2 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
);
%                               CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30');
%                               CALIBREAD_AVG = mean(CALIBREAD);
%                               CALIB_FACTOR =
Body_Mass_N(subjectindex(1),1)/CALIBREAD_AVG;
%                               RIGHTF1_2 = RIGHTF1_2*CALIB_FACTOR;
                            elseif isequal(visit1_folder(n3).name,
'Squat3_COF.csv')
                                COF1_3 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
); % First number is the visit number, second number is the squat
number
                            elseif
isequal(visit1_folder(n3).name,'Squat3_Left_COF.csv')
                                LCOF1_3 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
);
                            elseif
isequal(visit1_folder(n3).name,'Squat3_Right_COF.csv')
                                RCOF1_3 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
);
                            elseif
isequal(visit1_folder(n3).name,'Squat3_total.csv')
                                TOTALF1_3 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
);
%                               CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30');
%                               CALIBREAD_AVG = mean(CALIBREAD);
%                               CALIB_FACTOR =
Body_Mass_N(subjectindex(1),1)/CALIBREAD_AVG;
%                               TOTALF1_3 = TOTALF1_3*CALIB_FACTOR;
                            elseif
isequal(visit1_folder(n3).name,'Squat3_Left_F.csv')
                                LEFTF1_3 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
);
%                               CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30');
%                               CALIBREAD_AVG = mean(CALIBREAD);
%                               CALIB_FACTOR =
Body_Mass_N(subjectindex(1),1)/CALIBREAD_AVG;
%                               LEFTF1_3 = LEFTF1_3*CALIB_FACTOR;
                            elseif
isequal(visit1_folder(n3).name,'Squat3_Right_F.csv')
                                RIGHTF1_3 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
);
```

```
%                              CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30');
%                              CALIBREAD_AVG = mean(CALIBREAD);
%                              CALIB_FACTOR =
Body_Mass_N(subjectindex(1),1)/CALIBREAD_AVG;
%                              RIGHTF1_3 = RIGHTF1_3*CALIB_FACTOR;
                        end
                    end
                end

                %% Organizing VISIT_1 Excel Export
                vectorarray = {LEFTF1_1 LEFTF1_2 LEFTF1_3}; % creates
array of Left Force Squat 1, Squat 2, Squat 3
                maxlength = max(cellfun(@numel, vectorarray)); %
determines length of longest vector (Squat 1 or Squat 2 or Squat 3)
                alldata = NaN(maxlength,27); % creates empty data
matrix set to row length of longest trial
                rawsquat1_1 = [LEFTF1_1 RIGHTF1_1 TOTALF1_1 LCOF1_1
RCOF1_1 COF1_1]; % creates matrix with all Squat 1 data
                NaN1_1 = NaN(maxlength-length(LEFTF1_1),9); % creates
NaN matrix with row legnth of difference between longest trial and
Squat 1
                squat1_1 = [rawsquat1_1;NaN1_1]; % creates full length
squat 1 matrix
                rawsquat1_2 = [LEFTF1_2 RIGHTF1_2 TOTALF1_2 LCOF1_2
RCOF1_2 COF1_2]; % creates matrix with all Squat 2 data
                NaN1_2 = NaN(maxlength-length(LEFTF1_2),9); % creates
NaN matrix with row length of difference between longest trial and
Squat 2
                squat1_2 = [rawsquat1_2;NaN1_2]; % creates full length
squat 2 matrix
                rawsquat1_3 = [LEFTF1_3 RIGHTF1_3 TOTALF1_3 LCOF1_3
RCOF1_3 COF1_3]; % creates matrix with all Squat 3 data
                NaN1_3 = NaN(maxlength-length(LEFTF1_3),9); % creates
NaN matrix with row length of difference between longest trial and
Squat 3
                squat1_3 = [rawsquat1_3;NaN1_3]; % creates full length
squat 3 matrix
                alldata = [squat1_1 squat1_2 squat1_3]; % updates data
matrix to be a full matrix containing all data for Squat 1, Squat 2,
and Squat 3
                alldatacell = cell(maxlength+2,27); % creates empty
cell type matrix of correct dimensions to allow for headers in the
exported excel file
                alldataheader = {'Squat
1','','','','','','','','','Squat 2','','','','','','','','','Squat
3'}; % creates header for Squat 1, Squat 2, Squat 3
                alldatasubheader = {'Force Left [N]','Force Right
[N]','Force Total [N]','COF Left Y [cm]','COF Left X [cm]','COF Right Y
[cm]','COF Right X [cm]','COF Total Y [cm]','COF Total X [cm]',...
                    'Force Left [N]','Force Right [N]','Force Total
[N]','COF Left Y [cm]','COF Left X [cm]','COF Right Y [cm]','COF Right
X [cm]','COF Total Y [cm]','COF Total X [cm]',...
```

```
                    'Force Left [N]','Force Right [N]','Force Total [N]','COF Left Y [cm]','COF Left X [cm]','COF Right Y [cm]','COF Right X [cm]','COF Total Y [cm]','COF Total X [cm]'}; % creates subheader for each column
                alldatacell(1,1:19) = alldataheader; % adds header to top of the alldatacell matrix
                alldatacell(2,:) = alldatasubheader; % adds subheaders to alldatacell matrix
                alldatacell(3:maxlength+2,:) = num2cell(alldata); % converts alldata matrix from number type to cell type and adds it to alldatacell matrix
                savetofolder = visit1_folder.folder; % sets the folder to save to as the current visit folder
                cd(savetofolder); % sets current directory to the visit folder
                writecell(alldatacell, 'VISIT_1.xlsx','Sheet','Data'); % exports alldatacell matrix to excel sheet named "VISIT_1"

                %% Squat Metrics Calculations
                % Peak Force Left
                peakLEFTF1_1 = max(LEFTF1_1); % calculates peak force in left limb for squat 1
                peakLEFTF1_2 = max(LEFTF1_2); % calculates peak force in left limb for squat 2
                peakLEFTF1_3 = max(LEFTF1_3); % calculates peak force in left limb for squat 3
                peakLEFTF1 = [peakLEFTF1_1 peakLEFTF1_2 peakLEFTF1_3]; % creates matrix with each squat trial of the left limb
                peakLEFTF1_AVG = mean(peakLEFTF1); % calculates average peak force in left limb across all squat trials
                peakLEFTF1_SD = std(peakLEFTF1); % calcualtes standard deviation for the 3 peak squat values of the left limb
                % Peak Force Right
                peakRIGHTF1_1 = max(RIGHTF1_1); % peak force in right limb for squat 1
                peakRIGHTF1_2 = max(RIGHTF1_2); % peak force in right limb for squat 2
                peakRIGHTF1_3 = max(RIGHTF1_3); % peak force in right limb for squat 3
                peakRIGHTF1 = [peakRIGHTF1_1 peakRIGHTF1_2 peakRIGHTF1_3]; % creates matrix with each squat trial of the right limb
                peakRIGHTF1_AVG = mean(peakRIGHTF1); % calculates average peak force in the right limb across all squat trials
                peakRIGHTF1_SD = std(peakRIGHTF1); % calculates standard deviation for the 3 peak squat values of the right limb
                % Average Force Distribution Left
                LEFTF_DIST1_1 = LEFTF1_1./TOTALF1_1; % divides the left force by the total force for every frame of Squat 1
                LEFTF_DIST1_1_AVG = mean(LEFTF_DIST1_1); % calculates the average of the left distribution for every frame of Squat 1
                LEFTF_DIST1_2 = LEFTF1_2./TOTALF1_2; % divides the left force by the total force for every frame of Squat 2
                LEFTF_DIST1_2_AVG = mean(LEFTF_DIST1_2); % calculates the average of the left distribution for every frame of Squat 2
```

```
            LEFTF_DIST1_3 = LEFTF1_3./TOTALF1_3; % divides the left force by the total force for every frame of Squat 3
            LEFTF_DIST1_3_AVG = mean(LEFTF_DIST1_3); % calculates the average of the left distribution for every frame of Squat 3
            LEFTF_DIST1 = [LEFTF_DIST1_1_AVG LEFTF_DIST1_2_AVG LEFTF_DIST1_3_AVG]; % matrix containing the Left Distribution Average for all squat trials
            LEFTF_DIST1_AVG = mean(LEFTF_DIST1); % calculates the overall left distribution average
            LEFTF_DIST1_SD = std(LEFTF_DIST1); % calculates the overall left distribution standard deviation
            % Average Force Distribution Right
            RIGHTF_DIST1_1 = RIGHTF1_1./TOTALF1_1;
            RIGHTF_DIST1_1_AVG = mean(RIGHTF_DIST1_1);
            RIGHTF_DIST1_2 = RIGHTF1_2./TOTALF1_2;
            RIGHTF_DIST1_2_AVG = mean(RIGHTF_DIST1_2);
            RIGHTF_DIST1_3 = RIGHTF1_3./TOTALF1_3;
            RIGHTF_DIST1_3_AVG = mean(RIGHTF_DIST1_3);
            RIGHTF_DIST1 = [RIGHTF_DIST1_1_AVG RIGHTF_DIST1_2_AVG RIGHTF_DIST1_3_AVG];
            RIGHTF_DIST1_AVG = mean(RIGHTF_DIST1);
            RIGHTF_DIST1_SD = std(RIGHTF_DIST1);
            % LSI LEFT ACLR
            LSI_LEFTF1_1 = LEFTF1_1./RIGHTF1_1; % divides the left force by the right force for every frame of Squat 1
            LSI_LEFTF1_1_AVG = mean(LSI_LEFTF1_1); % calculates the mean LSI of Squat 1
            LSI_LEFTF1_2 = LEFTF1_2./RIGHTF1_2; % divides the left force by the right force for every frame of Squat 2
            LSI_LEFTF1_2_AVG = mean(LSI_LEFTF1_2); % calculates the mean LSI of Squat 2
            LSI_LEFTF1_3 = LEFTF1_3./RIGHTF1_3; % divides the left force by the right force for every frame of Squat 3
            LSI_LEFTF1_3_AVG = mean(LSI_LEFTF1_3); % calculates the mean LSI of Squat 3
            LSI_LEFTF1 = [LSI_LEFTF1_1_AVG LSI_LEFTF1_2_AVG LSI_LEFTF1_3_AVG]; % matrix containing the LSI Average for all squat trials
            LSI_LEFTF1_AVG = mean(LSI_LEFTF1); % calculates the overall average LSI
            LSI_LEFTF1_SD = std(LSI_LEFTF1); % calculates the overall LSI standard deviation
            % LSI RIGHT ACLR
            LSI_RIGHTF1_1 = RIGHTF1_1./LEFTF1_1;
            LSI_RIGHTF1_1_AVG = mean(LSI_RIGHTF1_1);
            LSI_RIGHTF1_2 = RIGHTF1_2./LEFTF1_2;
            LSI_RIGHTF1_2_AVG = mean(LSI_RIGHTF1_2);
            LSI_RIGHTF1_3 = RIGHTF1_3./LEFTF1_3;
            LSI_RIGHTF1_3_AVG = mean(LSI_RIGHTF1_3);
            LSI_RIGHTF1 = [LSI_RIGHTF1_1_AVG LSI_RIGHTF1_2_AVG LSI_RIGHTF1_3_AVG];
            LSI_RIGHTF1_AVG = mean(LSI_RIGHTF1);
            LSI_RIGHTF1_SD = std(LSI_RIGHTF1);
            % Limb Symmetry Grouped Left
            for n6 = 1:length(LSI_LEFTF1_1) % Squat 1
```

```
                    LS1_countless60 =
sum(LSI_LEFTF1_1<.6)/length(LSI_LEFTF1_1); % counts number of frames
with LSI  <0.6 and divides by total number of frames in the trial
                    LS1_count60_69 = sum(LSI_LEFTF1_1>=0.6 &
LSI_LEFTF1_1<0.7)/length(LSI_LEFTF1_1); % counts number of frames with
LSI 0.6-0.7 and divides by total number of frames in the trial
                    LS1_count70_79 = sum(LSI_LEFTF1_1>=0.7 &
LSI_LEFTF1_1<0.8)/length(LSI_LEFTF1_1); % counts number of frames with
LSI 0.7-0.8 and divides by total number of frames in the trial
                    LS1_count80_89 = sum(LSI_LEFTF1_1>=0.8 &
LSI_LEFTF1_1<0.9)/length(LSI_LEFTF1_1); % counts number of frames with
LSI 0.8-0.9 and divides by total number of frames in the trial
                    LS1_count90_110 = sum(LSI_LEFTF1_1>=0.9 &
LSI_LEFTF1_1<1.1)/length(LSI_LEFTF1_1); % counts number of frames with
LSI 0.9-1.1 and divides by total number of frames in the trial
                    LS1_countmore110 =
sum(LSI_LEFTF1_1>=1.1)/length(LSI_LEFTF1_1); % counts number of frames
with LSI  >1.1 and divides by total number of frames in the trial
                end
                for n6 = 1:length(LSI_LEFTF1_2) % Squat 2
                    LS2_countless60 =
sum(LSI_LEFTF1_2<.6)/length(LSI_LEFTF1_2);
                    LS2_count60_69 = sum(LSI_LEFTF1_2>=0.6 &
LSI_LEFTF1_2<0.7)/length(LSI_LEFTF1_2);
                    LS2_count70_79 = sum(LSI_LEFTF1_2>=0.7 &
LSI_LEFTF1_2<0.8)/length(LSI_LEFTF1_2);
                    LS2_count80_89 = sum(LSI_LEFTF1_2>=0.8 &
LSI_LEFTF1_2<0.9)/length(LSI_LEFTF1_2);
                    LS2_count90_110 = sum(LSI_LEFTF1_2>=0.9 &
LSI_LEFTF1_2<1.1)/length(LSI_LEFTF1_2);
                    LS2_countmore110 =
sum(LSI_LEFTF1_2>=1.1)/length(LSI_LEFTF1_2);
                end
                for n6 = 1:length(LSI_LEFTF1_3) % Squat 3
                    LS3_countless60 =
sum(LSI_LEFTF1_3<.6)/length(LSI_LEFTF1_3);
                    LS3_count60_69 = sum(LSI_LEFTF1_3>=0.6 &
LSI_LEFTF1_3<0.7)/length(LSI_LEFTF1_3);
                    LS3_count70_79 = sum(LSI_LEFTF1_3>=0.7 &
LSI_LEFTF1_3<0.8)/length(LSI_LEFTF1_3);
                    LS3_count80_89 = sum(LSI_LEFTF1_3>=0.8 &
LSI_LEFTF1_3<0.9)/length(LSI_LEFTF1_3);
                    LS3_count90_110 = sum(LSI_LEFTF1_3>=0.9 &
LSI_LEFTF1_3<1.1)/length(LSI_LEFTF1_3);
                    LS3_countmore110 =
sum(LSI_LEFTF1_3>=1.1)/length(LSI_LEFTF1_3);
                end
                % Limb Symmetry Grouped Right
                for n6 = 1:length(LSI_RIGHTF1_1) % Squat 1
                    RS1_countless60 =
sum(LSI_RIGHTF1_1<.6)/length(LSI_RIGHTF1_1);
                    RS1_count60_69 = sum(LSI_RIGHTF1_1>=0.6 &
LSI_RIGHTF1_1<0.7)/length(LSI_RIGHTF1_1);
                    RS1_count70_79 = sum(LSI_RIGHTF1_1>=0.7 &
LSI_RIGHTF1_1<0.8)/length(LSI_RIGHTF1_1);
```

```
                RS1_count80_89 = sum(LSI_RIGHTF1_1>=0.8 & LSI_RIGHTF1_1<0.9)/length(LSI_RIGHTF1_1);
                RS1_count90_110 = sum(LSI_RIGHTF1_1>=0.9 & LSI_RIGHTF1_1<1.1)/length(LSI_RIGHTF1_1);
                RS1_countmore110 = sum(LSI_RIGHTF1_1>=1.1)/length(LSI_RIGHTF1_1);
            end
            for n6 = 1:length(LSI_RIGHTF1_2) % Squat 2
                RS2_countless60 = sum(LSI_RIGHTF1_2<.6)/length(LSI_RIGHTF1_2);
                RS2_count60_69 = sum(LSI_RIGHTF1_2>=0.6 & LSI_RIGHTF1_2<0.7)/length(LSI_RIGHTF1_2);
                RS2_count70_79 = sum(LSI_RIGHTF1_2>=0.7 & LSI_RIGHTF1_2<0.8)/length(LSI_RIGHTF1_2);
                RS2_count80_89 = sum(LSI_RIGHTF1_2>=0.8 & LSI_RIGHTF1_2<0.9)/length(LSI_RIGHTF1_2);
                RS2_count90_110 = sum(LSI_RIGHTF1_2>=0.9 & LSI_RIGHTF1_2<1.1)/length(LSI_RIGHTF1_2);
                RS2_countmore110 = sum(LSI_RIGHTF1_2>=1.1)/length(LSI_RIGHTF1_2);
            end
            for n6 = 1:length(LSI_RIGHTF1_3) % Squat 3
                RS3_countless60 = sum(LSI_RIGHTF1_3<.6)/length(LSI_RIGHTF1_3);
                RS3_count60_69 = sum(LSI_RIGHTF1_3>=0.6 & LSI_RIGHTF1_3<0.7)/length(LSI_RIGHTF1_3);
                RS3_count70_79 = sum(LSI_RIGHTF1_3>=0.7 & LSI_RIGHTF1_3<0.8)/length(LSI_RIGHTF1_3);
                RS3_count80_89 = sum(LSI_RIGHTF1_3>=0.8 & LSI_RIGHTF1_3<0.9)/length(LSI_RIGHTF1_3);
                RS3_count90_110 = sum(LSI_RIGHTF1_3>=0.9 & LSI_RIGHTF1_3<1.1)/length(LSI_RIGHTF1_3);
                RS3_countmore110 = sum(LSI_RIGHTF1_3>=1.1)/length(LSI_RIGHTF1_3);
            end

            % Squat Metrics Data
            squatmetrics_limb = ACLR_Limb(subjectindex(1),1); % determines the ACLR Limb of the patient
            squatmetrics = [peakLEFTF1_AVG peakRIGHTF1_AVG LEFTF_DIST1_AVG RIGHTF_DIST1_AVG LSI_LEFTF1_AVG LSI_RIGHTF1_AVG]; % matrix of all desired squat metrics
            squatmetricscell = cell(13,8); % creates empty cell matrix of desired size
            squatmetricsheader = {'Peak Force Left [N]','Peak Force Right[N]','Avg Force Dist Left','Avg Force Dist Right','LSI Left ACLR','LSI Right ACLR','','ACLR Limb'}; % header for squat metrics
            squatmetricscell(1,1:8) = squatmetricsheader; % places header in desired location of squatmetricscell
            squatmetricscell(2,1:6) = num2cell(squatmetrics); % converts squatmetrics number type matrix to cell type matrix and places it in the desired location of the squatmetricscell
            squatmetricscell(2,8) = squatmetrics_limb; % places the ACLR limb of patient into the the squatmatricscell

```

```
                LEFT_LSI_GROUPED = [LS1_countless60 LS1_count60_69
LS1_count70_79 LS1_count80_89 LS1_count90_110 LS1_countmore110;...
                    LS2_countless60 LS2_count60_69 LS2_count70_79
LS2_count80_89 LS2_count90_110 LS2_countmore110;...
                    LS3_countless60 LS3_count60_69 LS3_count70_79
LS3_count80_89 LS3_count90_110 LS3_countmore110]; % matrix of Left ACLR
LSI grouped values for all squat trials
                LEFT_LSI_GROUPED_AVG = mean(LEFT_LSI_GROUPED); %
calculates the average of each grouping across Squat 1, Squat 2, and
Squat 3 (does a column average)
                RIGHT_LSI_GROUPED = [RS1_countless60 RS1_count60_69
RS1_count70_79 RS1_count80_89 RS1_count90_110 RS1_countmore110;...
                    RS2_countless60 RS2_count60_69 RS2_count70_79
RS2_count80_89 RS2_count90_110 RS2_countmore110;...
                    RS3_countless60 RS3_count60_69 RS3_count70_79
RS3_count80_89 RS3_count90_110 RS3_countmore110]; % matrix of Right
ACLR LSI grouped values for all squat trials
                RIGHT_LSI_GROUPED_AVG = mean(RIGHT_LSI_GROUPED); %
calculates the average of each grouping across Squat 1, Squat 2, Squat
3 (does a column average)
                LSI_GROUPED_HEADER = {'<60%','60-69%','70-79%','80-
89%','90-110%','>110%'}; % column headers for LSI groups
                LSI_GROUPED_SUB1 = {'LSI Grouped','','Left
ACLR','','','','','Right ACLR'}; % row headers for LSI groups
                LSI_GROUPED_SUB2 = {'Squat 1','Squat 2','Squat
3','AVG','','Squat 1','Squat 2','Squat 3','AVG'}; % row subheaders for
LSI groups

                squatmetricscell(5,3:8) = LSI_GROUPED_HEADER; % places
column headers for LSI groups in desired location of squatmetricscell
                squatmetricscell(4:11,1) = LSI_GROUPED_SUB1; % places
row headers for LSI groups in desired location of squatmetricscell
                squatmetricscell(6:14,2) = LSI_GROUPED_SUB2; % place
row subheaders for LSI groups in desired location of squatmetricscell
                squatmetricscell(6:8,3:8) = num2cell(LEFT_LSI_GROUPED);
% converts Left ACLR LSI grouped values from number type matrix to cell
type matrix and places it in the desired location of the
squatmetricscell
                squatmetricscell(9,3:8) =
num2cell(LEFT_LSI_GROUPED_AVG); % converts Left ACLR LSI grouped
average values from number type matrix to cell type matrix and places
it in the desired location of the squatmetricscell
                squatmetricscell(11:13,3:8) =
num2cell(RIGHT_LSI_GROUPED); % converts Right ACLR LSI grouped values
from number type matrix to cell type matrix and places it in the
desired location of the squatmetricscell
                squatmetricscell(14,3:8) =
num2cell(RIGHT_LSI_GROUPED_AVG); % converts Left ACLR LSI grouped
average values from number type matrix to cell type matrix and places
it in the desired location of the squatmetricscell

                sdcell = cell(2,6); % creates empty cell matrix of the
desired size
```

```
                sd_header = {'Peak Force Left SD [N]','Peak Force Right
SD [N]', 'Avg Force Dist Left SD','Avg Force Dist Right SD','LSI Left
ACLR SD','LSI Right ACLR SD'}; % header for standard deviations
                sddata = [peakLEFTF1_SD peakRIGHTF1_SD LEFTF_DIST1_SD
RIGHTF_DIST1_SD LSI_LEFTF1_SD LSI_RIGHTF1_SD]; % matrix of desired
standard deviations
                sdcell(1,1:6) = sd_header; % places standard deviation
header in the desired location of the sdcell
                sdcell(2,1:6) = num2cell(sddata); % converts the
standard deviation values from number type matrix to cell type matrix
and places it in the desired location of the sdcell

                savetofolder = visit1_folder.folder;  % sets the folder
to save to as the current visit folder
                cd(savetofolder); % sets current directory to the visit
folder
                writecell(squatmetricscell,
'VISIT_1_SQUAT_METRICS.xlsx','Sheet','Metrics'); % exports squat
metrics matrix to excel on the "Metrics" sheet named
"VISIT_1_SQUAT_METRICS"
                writecell(sdcell,
'VISIT_1_SQUAT_METRICS.xlsx','Sheet','Metrics SD') % exports squat
metrics standard deviations to excel on the "Metrics SD" sheet named
"VISIT_1_SQUAT_METRICS"

                cd('C:\Users\hannaho02\Virginia Tech\Granata Lab Files
- Amelia - Tekscan\Mock Data'); % sets directory back to original file
path

                %% Visit 2
            elseif isequal(patient_folder(n2).name, 'Visit_2') ||
isequal(patient_folder(n2).name, 'Visit2')
                visit1_folder =
dir(fullfile(patient_folder(n2).folder,patient_folder(n2).name)); %
establishes visit folder directory
                if isempty(subjectindex) == 0
                    for n3 = 3:length(visit1_folder) % reads folder
fields 3 through 8 for Squat 1 files
                        if isequal(visit1_folder(n3).name,
'Squat1_COF.csv') % reads for Squat 1 COF
                            opts =
detectImportOptions(fullfile(visit1_folder(n3).folder,visit1_folder(n3)
.name));
                            varopts = getvaropts(opts,{'Var3'});
                            opts =
setvaropts(opts,"Var3",'InputFormat','MM/dd/uuuu');
                            visitdate =
readtable(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),opt
s);
                            visitdate1 = visitdate(1,3);
                            COF1_1 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
); % Imports Squat 1 COF file (NAMING CONV: First number is the visit
number, second number is the squat number
```

```
                            elseif
isequal(visit1_folder(n3).name,'Squat1_Left_COF.csv') % reads for Squat
1 Left COF
                                LCOF1_1 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
);
                            elseif
isequal(visit1_folder(n3).name,'Squat1_Right_COF.csv') % reads for
Squat 1 Right COF
                                RCOF1_1 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
);
                            elseif
isequal(visit1_folder(n3).name,'Squat1_total.csv') % reads for Squat 1
Total
                                TOTALF1_1 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
); % imports all total force values
%                                 CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30'); % imports first 5 frames of raw sum values
%                                 CALIBREAD_AVG = mean(CALIBREAD); %
averages first 5 raw sum values
%                                 CALIB_FACTOR =
Body_Mass_N(subjectindex(2),1)/CALIBREAD_AVG; % establishes calibration
factor based on body weight in newtons
%                                 TOTALF1_1 = TOTALF1_1*CALIB_FACTOR; %
applies calbibration factor to all frames of total force values
                            elseif
isequal(visit1_folder(n3).name,'Squat1_Left_F.csv') % reads for Squat 1
Left F
                                LEFTF1_1 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
); % imports all left force values
%                                 CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30'); % imports first 5 frames of raw sum values
%                                 CALIBREAD_AVG = mean(CALIBREAD); %
averages first 5 raw sum values
%                                 CALIB_FACTOR =
Body_Mass_N(subjectindex(2),1)/CALIBREAD_AVG; % establishes calibration
factor based on body weight in newtons
%                                 LEFTF1_1 = LEFTF1_1*CALIB_FACTOR; %
applies calibration factor to all frames of left force values
                            elseif
isequal(visit1_folder(n3).name,'Squat1_Right_F.csv') % reads for Squat
1 Right F
                                RIGHTF1_1 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
); % imports all right force values
%                                 CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30'); % imports first 5 frames of raw sum values
%                                 CALIBREAD_AVG = mean(CALIBREAD); %
averages first 5 raw sum values
```

```
%                              CALIB_FACTOR =
Body_Mass_N(subjectindex(2),1)/CALIBREAD_AVG; % establishes calibration
factor based on body weight in newtons
%                              RIGHTF1_1 = RIGHTF1_1*CALIB_FACTOR; %
applies calibration factor to all frames of right force values
                        elseif isequal(visit1_folder(n3).name,
'Squat2_COF.csv')
                            COF1_2 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
); % First number is the visit number, second number is the squat
number
                        elseif
isequal(visit1_folder(n3).name,'Squat2_Left_COF.csv')
                            LCOF1_2 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
);
                        elseif
isequal(visit1_folder(n3).name,'Squat2_Right_COF.csv')
                            RCOF1_2 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
);
                        elseif
isequal(visit1_folder(n3).name,'Squat2_total.csv')
                            TOTALF1_2 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
);
%                              CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30');
%                              CALIBREAD_AVG = mean(CALIBREAD);
%                              CALIB_FACTOR =
Body_Mass_N(subjectindex(2),1)/CALIBREAD_AVG;
%                              TOTALF1_2 = TOTALF1_2*CALIB_FACTOR;
                        elseif
isequal(visit1_folder(n3).name,'Squat2_Left_F.csv')
                            LEFTF1_2 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
);
%                              CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30');
%                              CALIBREAD_AVG = mean(CALIBREAD);
%                              CALIB_FACTOR =
Body_Mass_N(subjectindex(2),1)/CALIBREAD_AVG;
%                              LEFTF1_2 = LEFTF1_2*CALIB_FACTOR;
                        elseif
isequal(visit1_folder(n3).name,'Squat2_Right_F.csv')
                            RIGHTF1_2 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
);
%                              CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30');
%                              CALIBREAD_AVG = mean(CALIBREAD);
```

```
%                               CALIB_FACTOR =
Body_Mass_N(subjectindex(2),1)/CALIBREAD_AVG;
%                               RIGHTF1_2 = RIGHTF1_2*CALIB_FACTOR;
                         elseif isequal(visit1_folder(n3).name,
'Squat3_COF.csv')
                             COF1_3 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
); % First number is the visit number, second number is the squat
number
                         elseif
isequal(visit1_folder(n3).name,'Squat3_Left_COF.csv')
                             LCOF1_3 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
);
                         elseif
isequal(visit1_folder(n3).name,'Squat3_Right_COF.csv')
                             RCOF1_3 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
);
                         elseif
isequal(visit1_folder(n3).name,'Squat3_total.csv')
                             TOTALF1_3 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
);
%                               CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30');
%                               CALIBREAD_AVG = mean(CALIBREAD);
%                               CALIB_FACTOR =
Body_Mass_N(subjectindex(2),1)/CALIBREAD_AVG;
%                               TOTALF1_3 = TOTALF1_3*CALIB_FACTOR;
                         elseif
isequal(visit1_folder(n3).name,'Squat3_Left_F.csv')
                             LEFTF1_3 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
);
%                               CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30');
%                               CALIBREAD_AVG = mean(CALIBREAD);
%                               CALIB_FACTOR =
Body_Mass_N(subjectindex(2),1)/CALIBREAD_AVG;
%                               LEFTF1_3 = LEFTF1_3*CALIB_FACTOR;
                         elseif
isequal(visit1_folder(n3).name,'Squat3_Right_F.csv')
                             RIGHTF1_3 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
);
%                               CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30');
%                               CALIBREAD_AVG = mean(CALIBREAD);
%                               CALIB_FACTOR =
Body_Mass_N(subjectindex(2),1)/CALIBREAD_AVG;
%                               RIGHTF1_3 = RIGHTF1_3*CALIB_FACTOR;
```

```
                    end
                end
            end
            %% Organizing VISIT_2 Excel Export
            vectorarray = {LEFTF1_1 LEFTF1_2 LEFTF1_3}; % creates
array to determine longest trial
            maxlength = max(cellfun(@numel, vectorarray)); %
determines length of longest trial
            alldata = NaN(maxlength,27); % creates data matrix set
to length of longest trial
            rawsquat1_1 = [LEFTF1_1 RIGHTF1_1 TOTALF1_1 LCOF1_1
RCOF1_1 COF1_1]; % creates squat 1 matrix
            NaN1_1 = NaN(maxlength-length(LEFTF1_1),9); % creates
NaN matrix with legnth of difference between longest trial and current
trial
            squat1_1 = [rawsquat1_1;NaN1_1];
            rawsquat1_2 = [LEFTF1_2 RIGHTF1_2 TOTALF1_2 LCOF1_2
RCOF1_2 COF1_2];
            NaN1_2 = NaN(maxlength-length(LEFTF1_2),9);
            squat1_2 = [rawsquat1_2;NaN1_2];
            rawsquat1_3 = [LEFTF1_3 RIGHTF1_3 TOTALF1_3 LCOF1_3
RCOF1_3 COF1_3];
            NaN1_3 = NaN(maxlength-length(LEFTF1_3),9);
            squat1_3 = [rawsquat1_3;NaN1_3];
            alldata = [squat1_1 squat1_2 squat1_3];
            alldatacell = cell(maxlength+2,27);
            alldataheader = {'Squat
1','','','','','','','','','Squat 2','','','','','','','','','Squat
3'};
            alldatasubheader = {'Force Left [N]','Force Right
[N]','Force Total [N]','COF Left Y [cm]','COF Left X [cm]','COF Right Y
[cm]','COF Right X [cm]','COF Total Y [cm]','COF Total X [cm]',...
                'Force Left [N]','Force Right [N]','Force Total
[N]','COF Left Y [cm]','COF Left X [cm]','COF Right Y [cm]','COF Right
X [cm]','COF Total Y [cm]','COF Total X [cm]',...
                'Force Left [N]','Force Right [N]','Force Total
[N]','COF Left Y [cm]','COF Left X [cm]','COF Right Y [cm]','COF Right
X [cm]','COF Total Y [cm]','COF Total X [cm]'};
            alldatacell(1,1:19) = alldataheader;
            alldatacell(2,:) = alldatasubheader;
            alldatacell(3:maxlength+2,:) = num2cell(alldata);
            savetofolder = visit1_folder.folder;
            cd(savetofolder);
            writecell(alldatacell, 'VISIT_2.xlsx','Sheet','Data');

            %% Squat Metrics Calculations
            % Peak Force Left
            peakLEFTF1_1 = max(LEFTF1_1); % peak force in left limb
for squat 1
            peakLEFTF1_2 = max(LEFTF1_2); % peak force in left limb
for squat 2
            peakLEFTF1_3 = max(LEFTF1_3); % peak force in left limb
for squat 3
            peakLEFTF1 = [peakLEFTF1_1 peakLEFTF1_2 peakLEFTF1_3];
            peakLEFTF1_AVG = mean(peakLEFTF1);
```

```
peakLEFTF1_SD = std(peakLEFTF1);
% Peak Force Right
peakRIGHTF1_1 = max(RIGHTF1_1); % peak force in right limb for squat 1
peakRIGHTF1_2 = max(RIGHTF1_2); % peak force in right limb for squat 2
peakRIGHTF1_3 = max(RIGHTF1_3); % peak force in right limb for squat 3
peakRIGHTF1 = [peakRIGHTF1_1 peakRIGHTF1_2 peakRIGHTF1_3];
peakRIGHTF1_AVG = mean(peakRIGHTF1);
peakRIGHTF1_SD = std(peakRIGHTF1);
% Average Force Distribution Left
LEFTF_DIST1_1 = LEFTF1_1./TOTALF1_1;
LEFTF_DIST1_1_AVG = mean(LEFTF_DIST1_1);
LEFTF_DIST1_2 = LEFTF1_2./TOTALF1_2;
LEFTF_DIST1_2_AVG = mean(LEFTF_DIST1_2);
LEFTF_DIST1_3 = LEFTF1_3./TOTALF1_3;
LEFTF_DIST1_3_AVG = mean(LEFTF_DIST1_3);
LEFTF_DIST1 = [LEFTF_DIST1_1_AVG LEFTF_DIST1_2_AVG LEFTF_DIST1_3_AVG];
LEFTF_DIST1_AVG = mean(LEFTF_DIST1);
LEFTF_DIST1_SD = std(LEFTF_DIST1);
% Average Force Distribution Right
RIGHTF_DIST1_1 = RIGHTF1_1./TOTALF1_1;
RIGHTF_DIST1_1_AVG = mean(RIGHTF_DIST1_1);
RIGHTF_DIST1_2 = RIGHTF1_2./TOTALF1_2;
RIGHTF_DIST1_2_AVG = mean(RIGHTF_DIST1_2);
RIGHTF_DIST1_3 = RIGHTF1_3./TOTALF1_3;
RIGHTF_DIST1_3_AVG = mean(RIGHTF_DIST1_3);
RIGHTF_DIST1 = [RIGHTF_DIST1_1_AVG RIGHTF_DIST1_2_AVG RIGHTF_DIST1_3_AVG];
RIGHTF_DIST1_AVG = mean(RIGHTF_DIST1);
RIGHTF_DIST1_SD = std(RIGHTF_DIST1);
% LSI LEFT ACLR
LSI_LEFTF1_1 = LEFTF1_1./RIGHTF1_1;
LSI_LEFTF1_1_AVG = mean(LSI_LEFTF1_1);
LSI_LEFTF1_2 = LEFTF1_2./RIGHTF1_2;
LSI_LEFTF1_2_AVG = mean(LSI_LEFTF1_2);
LSI_LEFTF1_3 = LEFTF1_3./RIGHTF1_3;
LSI_LEFTF1_3_AVG = mean(LSI_LEFTF1_3);
LSI_LEFTF1 = [LSI_LEFTF1_1_AVG LSI_LEFTF1_2_AVG LSI_LEFTF1_3_AVG];
LSI_LEFTF1_AVG = mean(LSI_LEFTF1);
LSI_LEFTF1_SD = std(LSI_LEFTF1);
% LSI RIGHT ACLR
LSI_RIGHTF1_1 = RIGHTF1_1./LEFTF1_1;
LSI_RIGHTF1_1_AVG = mean(LSI_RIGHTF1_1);
LSI_RIGHTF1_2 = RIGHTF1_2./LEFTF1_2;
LSI_RIGHTF1_2_AVG = mean(LSI_RIGHTF1_2);
LSI_RIGHTF1_3 = RIGHTF1_3./LEFTF1_3;
LSI_RIGHTF1_3_AVG = mean(LSI_RIGHTF1_3);
LSI_RIGHTF1 = [LSI_RIGHTF1_1_AVG LSI_RIGHTF1_2_AVG LSI_RIGHTF1_3_AVG];
LSI_RIGHTF1_AVG = mean(LSI_RIGHTF1);
```

```
                LSI_RIGHTF1_SD = std(LSI_RIGHTF1);
                % Limb Symmetry Grouped Left
                for n6 = 1:length(LSI_LEFTF1_1)
                    LS1_countless60 =
sum(LSI_LEFTF1_1<.6)/length(LSI_LEFTF1_1); % counts number of frames
with LSI  <0.6
                    LS1_count60_69 = sum(LSI_LEFTF1_1>=0.6 &
LSI_LEFTF1_1<0.7)/length(LSI_LEFTF1_1); % counts number of frames with
LSI 0.6-0.7
                    LS1_count70_79 = sum(LSI_LEFTF1_1>=0.7 &
LSI_LEFTF1_1<0.8)/length(LSI_LEFTF1_1); % counts number of frames with
LSI 0.7-0.8
                    LS1_count80_89 = sum(LSI_LEFTF1_1>=0.8 &
LSI_LEFTF1_1<0.9)/length(LSI_LEFTF1_1); % counts number of frames with
LSI 0.8-0.9
                    LS1_count90_110 = sum(LSI_LEFTF1_1>=0.9 &
LSI_LEFTF1_1<1.1)/length(LSI_LEFTF1_1); % counts number of frames with
LSI 0.9-1.1
                    LS1_countmore110 =
sum(LSI_LEFTF1_1>=1.1)/length(LSI_LEFTF1_1); % counts number of frames
with LSI  >1.1
                end
                for n6 = 1:length(LSI_LEFTF1_2)
                    LS2_countless60 =
sum(LSI_LEFTF1_2<.6)/length(LSI_LEFTF1_2);
                    LS2_count60_69 = sum(LSI_LEFTF1_2>=0.6 &
LSI_LEFTF1_2<0.7)/length(LSI_LEFTF1_2);
                    LS2_count70_79 = sum(LSI_LEFTF1_2>=0.7 &
LSI_LEFTF1_2<0.8)/length(LSI_LEFTF1_2);
                    LS2_count80_89 = sum(LSI_LEFTF1_2>=0.8 &
LSI_LEFTF1_2<0.9)/length(LSI_LEFTF1_2);
                    LS2_count90_110 = sum(LSI_LEFTF1_2>=0.9 &
LSI_LEFTF1_2<1.1)/length(LSI_LEFTF1_2);
                    LS2_countmore110 =
sum(LSI_LEFTF1_2>=1.1)/length(LSI_LEFTF1_2);
                end
                for n6 = 1:length(LSI_LEFTF1_3)
                    LS3_countless60 =
sum(LSI_LEFTF1_3<.6)/length(LSI_LEFTF1_3);
                    LS3_count60_69 = sum(LSI_LEFTF1_3>=0.6 &
LSI_LEFTF1_3<0.7)/length(LSI_LEFTF1_3);
                    LS3_count70_79 = sum(LSI_LEFTF1_3>=0.7 &
LSI_LEFTF1_3<0.8)/length(LSI_LEFTF1_3);
                    LS3_count80_89 = sum(LSI_LEFTF1_3>=0.8 &
LSI_LEFTF1_3<0.9)/length(LSI_LEFTF1_3);
                    LS3_count90_110 = sum(LSI_LEFTF1_3>=0.9 &
LSI_LEFTF1_3<1.1)/length(LSI_LEFTF1_3);
                    LS3_countmore110 =
sum(LSI_LEFTF1_3>=1.1)/length(LSI_LEFTF1_3);
                end
                % Limb Symmetry Grouped Right
                for n6 = 1:length(LSI_RIGHTF1_1)
                    RS1_countless60 =
sum(LSI_RIGHTF1_1<.6)/length(LSI_RIGHTF1_1);
```

```
            RS1_count60_69 = sum(LSI_RIGHTF1_1>=0.6 &
LSI_RIGHTF1_1<0.7)/length(LSI_RIGHTF1_1);
            RS1_count70_79 = sum(LSI_RIGHTF1_1>=0.7 &
LSI_RIGHTF1_1<0.8)/length(LSI_RIGHTF1_1);
            RS1_count80_89 = sum(LSI_RIGHTF1_1>=0.8 &
LSI_RIGHTF1_1<0.9)/length(LSI_RIGHTF1_1);
            RS1_count90_110 = sum(LSI_RIGHTF1_1>=0.9 &
LSI_RIGHTF1_1<1.1)/length(LSI_RIGHTF1_1);
            RS1_countmore110 =
sum(LSI_RIGHTF1_1>=1.1)/length(LSI_RIGHTF1_1);
        end
        for n6 = 1:length(LSI_RIGHTF1_2)
            RS2_countless60 =
sum(LSI_RIGHTF1_2<.6)/length(LSI_RIGHTF1_2);
            RS2_count60_69 = sum(LSI_RIGHTF1_2>=0.6 &
LSI_RIGHTF1_2<0.7)/length(LSI_RIGHTF1_2);
            RS2_count70_79 = sum(LSI_RIGHTF1_2>=0.7 &
LSI_RIGHTF1_2<0.8)/length(LSI_RIGHTF1_2);
            RS2_count80_89 = sum(LSI_RIGHTF1_2>=0.8 &
LSI_RIGHTF1_2<0.9)/length(LSI_RIGHTF1_2);
            RS2_count90_110 = sum(LSI_RIGHTF1_2>=0.9 &
LSI_RIGHTF1_2<1.1)/length(LSI_RIGHTF1_2);
            RS2_countmore110 =
sum(LSI_RIGHTF1_2>=1.1)/length(LSI_RIGHTF1_2);
        end
        for n6 = 1:length(LSI_RIGHTF1_3)
            RS3_countless60 =
sum(LSI_RIGHTF1_3<.6)/length(LSI_RIGHTF1_3);
            RS3_count60_69 = sum(LSI_RIGHTF1_3>=0.6 &
LSI_RIGHTF1_3<0.7)/length(LSI_RIGHTF1_3);
            RS3_count70_79 = sum(LSI_RIGHTF1_3>=0.7 &
LSI_RIGHTF1_3<0.8)/length(LSI_RIGHTF1_3);
            RS3_count80_89 = sum(LSI_RIGHTF1_3>=0.8 &
LSI_RIGHTF1_3<0.9)/length(LSI_RIGHTF1_3);
            RS3_count90_110 = sum(LSI_RIGHTF1_3>=0.9 &
LSI_RIGHTF1_3<1.1)/length(LSI_RIGHTF1_3);
            RS3_countmore110 =
sum(LSI_RIGHTF1_3>=1.1)/length(LSI_RIGHTF1_3);
        end

        % Squat Metrics Data
        squatmetrics_limb = ACLR_Limb(subjectindex(2),1); %
determines the ACLR Limb
        %          of the patient
        squatmetrics = [peakLEFTF1_AVG peakRIGHTF1_AVG
LEFTF_DIST1_AVG RIGHTF_DIST1_AVG LSI_LEFTF1_AVG LSI_RIGHTF1_AVG];
        squatmetricscell = cell(13,8);
        squatmetricsheader = {'Peak Force Left [N]','Peak Force
Right[N]','Avg Force Dist Left','Avg Force Dist Right','LSI Left
ACLR','LSI Right ACLR','','ACLR Limb'};
        squatmetricscell(1,1:8) = squatmetricsheader;
        squatmetricscell(2,1:6) = num2cell(squatmetrics);
        squatmetricscell(2,8) = squatmetrics_limb;

```

```
                LEFT_LSI_GROUPED = [LS1_countless60 LS1_count60_69
LS1_count70_79 LS1_count80_89 LS1_count90_110 LS1_countmore110;...
                    LS2_countless60 LS2_count60_69 LS2_count70_79
LS2_count80_89 LS2_count90_110 LS2_countmore110;...
                    LS3_countless60 LS3_count60_69 LS3_count70_79
LS3_count80_89 LS3_count90_110 LS3_countmore110];
                LEFT_LSI_GROUPED_AVG = mean(LEFT_LSI_GROUPED);
                RIGHT_LSI_GROUPED = [RS1_countless60 RS1_count60_69
RS1_count70_79 RS1_count80_89 RS1_count90_110 RS1_countmore110;...
                    RS2_countless60 RS2_count60_69 RS2_count70_79
RS2_count80_89 RS2_count90_110 RS2_countmore110;...
                    RS3_countless60 RS3_count60_69 RS3_count70_79
RS3_count80_89 RS3_count90_110 RS3_countmore110];
                RIGHT_LSI_GROUPED_AVG = mean(RIGHT_LSI_GROUPED);
                LSI_GROUPED_HEADER = {'<60%','60-69%','70-79%','80-
89%','90-110%','>110%'};
                LSI_GROUPED_SUB1 = {'LSI Grouped','','Left
ACLR','','','','','Right ACLR'};
                LSI_GROUPED_SUB2 = {'Squat 1','Squat 2','Squat
3','AVG','','Squat 1','Squat 2','Squat 3','AVG'};

                squatmetricscell(5,3:8) = LSI_GROUPED_HEADER;
                squatmetricscell(4:11,1) = LSI_GROUPED_SUB1;
                squatmetricscell(6:14,2) = LSI_GROUPED_SUB2;
                squatmetricscell(6:8,3:8) = num2cell(LEFT_LSI_GROUPED);
                squatmetricscell(9,3:8) =
num2cell(LEFT_LSI_GROUPED_AVG);
                squatmetricscell(11:13,3:8) =
num2cell(RIGHT_LSI_GROUPED);
                squatmetricscell(14,3:8) =
num2cell(RIGHT_LSI_GROUPED_AVG);

                sdcell = cell(2,6);
                sd_header = {'Peak Force Left SD [N]','Peak Force Right
SD [N]', 'Avg Force Dist Left SD','Avg Force Dist Right SD','LSI Left
ACLR SD','LSI Right ACLR SD'};
                sddata = [peakLEFTF1_SD peakRIGHTF1_SD LEFTF_DIST1_SD
RIGHTF_DIST1_SD LSI_LEFTF1_SD LSI_RIGHTF1_SD];
                sdcell(1,1:6) = sd_header;
                sdcell(2,1:6) = num2cell(sddata);

                savetofolder = visit1_folder.folder;
                cd(savetofolder);
                writecell(squatmetricscell,
'VISIT_2_SQUAT_METRICS.xlsx','Sheet','Metrics');
                writecell(sdcell,
'VISIT_2_SQUAT_METRICS.xlsx','Sheet','Metrics SD')

                cd('C:\Users\hannaho02\Virginia Tech\Granata Lab Files
- Amelia - Tekscan\Mock Data'); % sets directory back to original file
path

                %% Visit 3
            elseif isequal(patient_folder(n2).name, 'Visit_3') ||
isequal(patient_folder(n2).name, 'Visit3')
```

```
                visit1_folder =
dir(fullfile(patient_folder(n2).folder,patient_folder(n2).name)); %
establishes visit folder directory
                if isempty(subjectindex) == 0
                    for n3 = 3:length(visit1_folder) % reads folder
fields 3 through 8 for Squat 1 files
                        if isequal(visit1_folder(n3).name,
'Squat1_COF.csv') % reads for Squat 1 COF
                            opts =
detectImportOptions(fullfile(visit1_folder(n3).folder,visit1_folder(n3)
.name));
                            varopts = getvaropts(opts,{'Var3'});
                            opts =
setvaropts(opts,"Var3",'InputFormat','MM/dd/uuuu');
                            visitdate =
readtable(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),opt
s);
                            visitdate1 = visitdate(1,3);
                            COF1_1 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
); % Imports Squat 1 COF file (NAMING CONV: First number is the visit
number, second number is the squat number
                        elseif
isequal(visit1_folder(n3).name,'Squat1_Left_COF.csv') % reads for Squat
1 Left COF
                            LCOF1_1 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
);
                        elseif
isequal(visit1_folder(n3).name,'Squat1_Right_COF.csv') % reads for
Squat 1 Right COF
                            RCOF1_1 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
);
                        elseif
isequal(visit1_folder(n3).name,'Squat1_total.csv') % reads for Squat 1
Total
                            TOTALF1_1 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
); % imports all total force values
%                             CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30'); % imports first 5 frames of raw sum values
%                             CALIBREAD_AVG = mean(CALIBREAD); %
averages first 5 raw sum values
%                             CALIB_FACTOR =
Body_Mass_N(subjectindex(3),1)/CALIBREAD_AVG; % establishes calibration
factor based on body weight in newtons
%                             TOTALF1_1 = TOTALF1_1*CALIB_FACTOR; %
applies calbibration factor to all frames of total force values
                        elseif
isequal(visit1_folder(n3).name,'Squat1_Left_F.csv') % reads for Squat 1
Left F
```

```
                            LEFTF1_1 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
); % imports all left force values
%                             CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30'); % imports first 5 frames of raw sum values
%                             CALIBREAD_AVG = mean(CALIBREAD); %
averages first 5 raw sum values
%                             CALIB_FACTOR =
Body_Mass_N(subjectindex(3),1)/CALIBREAD_AVG; % establishes calibration
factor based on body weight in newtons
%                             LEFTF1_1 = LEFTF1_1*CALIB_FACTOR; %
applies calibration factor to all frames of left force values
                        elseif
isequal(visit1_folder(n3).name,'Squat1_Right_F.csv') % reads for Squat
1 Right F
                            RIGHTF1_1 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
); % imports all right force values
%                             CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30'); % imports first 5 frames of raw sum values
%                             CALIBREAD_AVG = mean(CALIBREAD); %
averages first 5 raw sum values
%                             CALIB_FACTOR =
Body_Mass_N(subjectindex(3),1)/CALIBREAD_AVG; % establishes calibration
factor based on body weight in newtons
%                             RIGHTF1_1 = RIGHTF1_1*CALIB_FACTOR; %
applies calibration factor to all frames of right force values
                        elseif isequal(visit1_folder(n3).name,
'Squat2_COF.csv')
                            COF1_2 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
); % First number is the visit number, second number is the squat
number
                        elseif
isequal(visit1_folder(n3).name,'Squat2_Left_COF.csv')
                            LCOF1_2 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
);
                        elseif
isequal(visit1_folder(n3).name,'Squat2_Right_COF.csv')
                            RCOF1_2 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
);
                        elseif
isequal(visit1_folder(n3).name,'Squat2_total.csv')
                            TOTALF1_2 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
);
%                             CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30');
%                             CALIBREAD_AVG = mean(CALIBREAD);
```

```
%                              CALIB_FACTOR =
Body_Mass_N(subjectindex(3),1)/CALIBREAD_AVG;
%                              TOTALF1_2 = TOTALF1_2*CALIB_FACTOR;
                        elseif
isequal(visit1_folder(n3).name,'Squat2_Left_F.csv')
                            LEFTF1_2 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
);
%                              CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30');
%                              CALIBREAD_AVG = mean(CALIBREAD);
%                              CALIB_FACTOR =
Body_Mass_N(subjectindex(3),1)/CALIBREAD_AVG;
%                              LEFTF1_2 = LEFTF1_2*CALIB_FACTOR;
                        elseif
isequal(visit1_folder(n3).name,'Squat2_Right_F.csv')
                            RIGHTF1_2 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
);
%                              CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30');
%                              CALIBREAD_AVG = mean(CALIBREAD);
%                              CALIB_FACTOR =
Body_Mass_N(subjectindex(3),1)/CALIBREAD_AVG;
%                              RIGHTF1_2 = RIGHTF1_2*CALIB_FACTOR;
                        elseif isequal(visit1_folder(n3).name,
'Squat3_COF.csv')
                            COF1_3 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
); % First number is the visit number, second number is the squat
number
                        elseif
isequal(visit1_folder(n3).name,'Squat3_Left_COF.csv')
                            LCOF1_3 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
);
                        elseif
isequal(visit1_folder(n3).name,'Squat3_Right_COF.csv')
                            RCOF1_3 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'G:H'
);
                        elseif
isequal(visit1_folder(n3).name,'Squat3_total.csv')
                            TOTALF1_3 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
);
%                              CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30');
%                              CALIBREAD_AVG = mean(CALIBREAD);
%                              CALIB_FACTOR =
Body_Mass_N(subjectindex(3),1)/CALIBREAD_AVG;
%                              TOTALF1_3 = TOTALF1_3*CALIB_FACTOR;
```

```
                        elseif
isequal(visit1_folder(n3).name,'Squat3_Left_F.csv')
                            LEFTF1_3 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
);
%                             CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30');
%                             CALIBREAD_AVG = mean(CALIBREAD);
%                             CALIB_FACTOR =
Body_Mass_N(subjectindex(3),1)/CALIBREAD_AVG;
%                             LEFTF1_3 = LEFTF1_3*CALIB_FACTOR;
                        elseif
isequal(visit1_folder(n3).name,'Squat3_Right_F.csv')
                            RIGHTF1_3 =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'E:E'
);
%                             CALIBREAD =
xlsread(fullfile(visit1_folder(n3).folder,visit1_folder(n3).name),'D26:
D30');
%                             CALIBREAD_AVG = mean(CALIBREAD);
%                             CALIB_FACTOR =
Body_Mass_N(subjectindex(3),1)/CALIBREAD_AVG;
%                             RIGHTF1_3 = RIGHTF1_3*CALIB_FACTOR;
                        end
                    end
                end
                %% Organizing VISIT_3 Excel Export
                vectorarray = {LEFTF1_1 LEFTF1_2 LEFTF1_3}; % creates
array to determine longest trial
                maxlength = max(cellfun(@numel, vectorarray)); %
determines length of longest trial
                alldata = NaN(maxlength,27); % creates data matrix set
to length of longest trial
                rawsquat1_1 = [LEFTF1_1 RIGHTF1_1 TOTALF1_1 LCOF1_1
RCOF1_1 COF1_1]; % creates squat 1 matrix
                NaN1_1 = NaN(maxlength-length(LEFTF1_1),9); % creates
NaN matrix with legnth of difference between longest trial and current
trial
                squat1_1 = [rawsquat1_1;NaN1_1];
                rawsquat1_2 = [LEFTF1_2 RIGHTF1_2 TOTALF1_2 LCOF1_2
RCOF1_2 COF1_2];
                NaN1_2 = NaN(maxlength-length(LEFTF1_2),9);
                squat1_2 = [rawsquat1_2;NaN1_2];
                rawsquat1_3 = [LEFTF1_3 RIGHTF1_3 TOTALF1_3 LCOF1_3
RCOF1_3 COF1_3];
                NaN1_3 = NaN(maxlength-length(LEFTF1_3),9);
                squat1_3 = [rawsquat1_3;NaN1_3];
                alldata = [squat1_1 squat1_2 squat1_3];
                alldatacell = cell(maxlength+2,27);
                alldataheader = {'Squat
1','','','','','','','','','Squat 2','','','','','','','','','Squat
3'};
```

```
                    alldatasubheader = {'Force Left [N]','Force Right
[N]','Force Total [N]','COF Left Y [cm]','COF Left X [cm]','COF Right Y
[cm]','COF Right X [cm]','COF Total Y [cm]','COF Total X [cm]',...
                    'Force Left [N]','Force Right [N]','Force Total
[N]','COF Left Y [cm]','COF Left X [cm]','COF Right Y [cm]','COF Right
X [cm]','COF Total Y [cm]','COF Total X [cm]',...
                    'Force Left [N]','Force Right [N]','Force Total
[N]','COF Left Y [cm]','COF Left X [cm]','COF Right Y [cm]','COF Right
X [cm]','COF Total Y [cm]','COF Total X [cm]'};
                alldatacell(1,1:19) = alldataheader;
                alldatacell(2,:) = alldatasubheader;
                alldatacell(3:maxlength+2,:) = num2cell(alldata);
                savetofolder = visit1_folder.folder;
                cd(savetofolder);
                writecell(alldatacell, 'VISIT_3.xlsx','Sheet','Data');

                %% Squat Metrics Calculations
                % Peak Force Left
                peakLEFTF1_1 = max(LEFTF1_1); % peak force in left limb
for squat 1
                peakLEFTF1_2 = max(LEFTF1_2); % peak force in left limb
for squat 2
                peakLEFTF1_3 = max(LEFTF1_3); % peak force in left limb
for squat 3
                peakLEFTF1 = [peakLEFTF1_1 peakLEFTF1_2 peakLEFTF1_3];
                peakLEFTF1_AVG = mean(peakLEFTF1);
                peakLEFTF1_SD = std(peakLEFTF1);
                % Peak Force Right
                peakRIGHTF1_1 = max(RIGHTF1_1); % peak force in right
limb for squat 1
                peakRIGHTF1_2 = max(RIGHTF1_2); % peak force in right
limb for squat 2
                peakRIGHTF1_3 = max(RIGHTF1_3); % peak force in right
limb for squat 3
                peakRIGHTF1 = [peakRIGHTF1_1 peakRIGHTF1_2
peakRIGHTF1_3];
                peakRIGHTF1_AVG = mean(peakRIGHTF1);
                peakRIGHTF1_SD = std(peakRIGHTF1);
                % Average Force Distribution Left
                LEFTF_DIST1_1 = LEFTF1_1./TOTALF1_1;
                LEFTF_DIST1_1_AVG = mean(LEFTF_DIST1_1);
                LEFTF_DIST1_2 = LEFTF1_2./TOTALF1_2;
                LEFTF_DIST1_2_AVG = mean(LEFTF_DIST1_2);
                LEFTF_DIST1_3 = LEFTF1_3./TOTALF1_3;
                LEFTF_DIST1_3_AVG = mean(LEFTF_DIST1_3);
                LEFTF_DIST1 = [LEFTF_DIST1_1_AVG LEFTF_DIST1_2_AVG
LEFTF_DIST1_3_AVG];
                LEFTF_DIST1_AVG = mean(LEFTF_DIST1);
                LEFTF_DIST1_SD = std(LEFTF_DIST1);
                % Average Force Distribution Right
                RIGHTF_DIST1_1 = RIGHTF1_1./TOTALF1_1;
                RIGHTF_DIST1_1_AVG = mean(RIGHTF_DIST1_1);
                RIGHTF_DIST1_2 = RIGHTF1_2./TOTALF1_2;
                RIGHTF_DIST1_2_AVG = mean(RIGHTF_DIST1_2);
                RIGHTF_DIST1_3 = RIGHTF1_3./TOTALF1_3;
```

```
        RIGHTF_DIST1_3_AVG = mean(RIGHTF_DIST1_3);
        RIGHTF_DIST1 = [RIGHTF_DIST1_1_AVG RIGHTF_DIST1_2_AVG RIGHTF_DIST1_3_AVG];
        RIGHTF_DIST1_AVG = mean(RIGHTF_DIST1);
        RIGHTF_DIST1_SD = std(RIGHTF_DIST1);
        % LSI LEFT ACLR
        LSI_LEFTF1_1 = LEFTF1_1./RIGHTF1_1;
        LSI_LEFTF1_1_AVG = mean(LSI_LEFTF1_1);
        LSI_LEFTF1_2 = LEFTF1_2./RIGHTF1_2;
        LSI_LEFTF1_2_AVG = mean(LSI_LEFTF1_2);
        LSI_LEFTF1_3 = LEFTF1_3./RIGHTF1_3;
        LSI_LEFTF1_3_AVG = mean(LSI_LEFTF1_3);
        LSI_LEFTF1 = [LSI_LEFTF1_1_AVG LSI_LEFTF1_2_AVG LSI_LEFTF1_3_AVG];
        LSI_LEFTF1_AVG = mean(LSI_LEFTF1);
        LSI_LEFTF1_SD = std(LSI_LEFTF1);
        % LSI RIGHT ACLR
        LSI_RIGHTF1_1 = RIGHTF1_1./LEFTF1_1;
        LSI_RIGHTF1_1_AVG = mean(LSI_RIGHTF1_1);
        LSI_RIGHTF1_2 = RIGHTF1_2./LEFTF1_2;
        LSI_RIGHTF1_2_AVG = mean(LSI_RIGHTF1_2);
        LSI_RIGHTF1_3 = RIGHTF1_3./LEFTF1_3;
        LSI_RIGHTF1_3_AVG = mean(LSI_RIGHTF1_3);
        LSI_RIGHTF1 = [LSI_RIGHTF1_1_AVG LSI_RIGHTF1_2_AVG LSI_RIGHTF1_3_AVG];
        LSI_RIGHTF1_AVG = mean(LSI_RIGHTF1);
        LSI_RIGHTF1_SD = std(LSI_RIGHTF1);
        % Limb Symmetry Grouped Left
        for n6 = 1:length(LSI_LEFTF1_1)
            LS1_countless60 = sum(LSI_LEFTF1_1<.6)/length(LSI_LEFTF1_1); % counts number of frames with LSI  <0.6
            LS1_count60_69 = sum(LSI_LEFTF1_1>=0.6 & LSI_LEFTF1_1<0.7)/length(LSI_LEFTF1_1); % counts number of frames with LSI 0.6-0.7
            LS1_count70_79 = sum(LSI_LEFTF1_1>=0.7 & LSI_LEFTF1_1<0.8)/length(LSI_LEFTF1_1); % counts number of frames with LSI 0.7-0.8
            LS1_count80_89 = sum(LSI_LEFTF1_1>=0.8 & LSI_LEFTF1_1<0.9)/length(LSI_LEFTF1_1); % counts number of frames with LSI 0.8-0.9
            LS1_count90_110 = sum(LSI_LEFTF1_1>=0.9 & LSI_LEFTF1_1<1.1)/length(LSI_LEFTF1_1); % counts number of frames with LSI 0.9-1.1
            LS1_countmore110 = sum(LSI_LEFTF1_1>=1.1)/length(LSI_LEFTF1_1); % counts number of frames with LSI  >1.1
        end
        for n6 = 1:length(LSI_LEFTF1_2)
            LS2_countless60 = sum(LSI_LEFTF1_2<.6)/length(LSI_LEFTF1_2);
            LS2_count60_69 = sum(LSI_LEFTF1_2>=0.6 & LSI_LEFTF1_2<0.7)/length(LSI_LEFTF1_2);
            LS2_count70_79 = sum(LSI_LEFTF1_2>=0.7 & LSI_LEFTF1_2<0.8)/length(LSI_LEFTF1_2);
```

```
                    LS2_count80_89 = sum(LSI_LEFTF1_2>=0.8 &
LSI_LEFTF1_2<0.9)/length(LSI_LEFTF1_2);
                    LS2_count90_110 = sum(LSI_LEFTF1_2>=0.9 &
LSI_LEFTF1_2<1.1)/length(LSI_LEFTF1_2);
                    LS2_countmore110 =
sum(LSI_LEFTF1_2>=1.1)/length(LSI_LEFTF1_2);
                end
                for n6 = 1:length(LSI_LEFTF1_3)
                    LS3_countless60 =
sum(LSI_LEFTF1_3<.6)/length(LSI_LEFTF1_3);
                    LS3_count60_69 = sum(LSI_LEFTF1_3>=0.6 &
LSI_LEFTF1_3<0.7)/length(LSI_LEFTF1_3);
                    LS3_count70_79 = sum(LSI_LEFTF1_3>=0.7 &
LSI_LEFTF1_3<0.8)/length(LSI_LEFTF1_3);
                    LS3_count80_89 = sum(LSI_LEFTF1_3>=0.8 &
LSI_LEFTF1_3<0.9)/length(LSI_LEFTF1_3);
                    LS3_count90_110 = sum(LSI_LEFTF1_3>=0.9 &
LSI_LEFTF1_3<1.1)/length(LSI_LEFTF1_3);
                    LS3_countmore110 =
sum(LSI_LEFTF1_3>=1.1)/length(LSI_LEFTF1_3);
                end
                % Limb Symmetry Grouped Right
                for n6 = 1:length(LSI_RIGHTF1_1)
                    RS1_countless60 =
sum(LSI_RIGHTF1_1<.6)/length(LSI_RIGHTF1_1);
                    RS1_count60_69 = sum(LSI_RIGHTF1_1>=0.6 &
LSI_RIGHTF1_1<0.7)/length(LSI_RIGHTF1_1);
                    RS1_count70_79 = sum(LSI_RIGHTF1_1>=0.7 &
LSI_RIGHTF1_1<0.8)/length(LSI_RIGHTF1_1);
                    RS1_count80_89 = sum(LSI_RIGHTF1_1>=0.8 &
LSI_RIGHTF1_1<0.9)/length(LSI_RIGHTF1_1);
                    RS1_count90_110 = sum(LSI_RIGHTF1_1>=0.9 &
LSI_RIGHTF1_1<1.1)/length(LSI_RIGHTF1_1);
                    RS1_countmore110 =
sum(LSI_RIGHTF1_1>=1.1)/length(LSI_RIGHTF1_1);
                end
                for n6 = 1:length(LSI_RIGHTF1_2)
                    RS2_countless60 =
sum(LSI_RIGHTF1_2<.6)/length(LSI_RIGHTF1_2);
                    RS2_count60_69 = sum(LSI_RIGHTF1_2>=0.6 &
LSI_RIGHTF1_2<0.7)/length(LSI_RIGHTF1_2);
                    RS2_count70_79 = sum(LSI_RIGHTF1_2>=0.7 &
LSI_RIGHTF1_2<0.8)/length(LSI_RIGHTF1_2);
                    RS2_count80_89 = sum(LSI_RIGHTF1_2>=0.8 &
LSI_RIGHTF1_2<0.9)/length(LSI_RIGHTF1_2);
                    RS2_count90_110 = sum(LSI_RIGHTF1_2>=0.9 &
LSI_RIGHTF1_2<1.1)/length(LSI_RIGHTF1_2);
                    RS2_countmore110 =
sum(LSI_RIGHTF1_2>=1.1)/length(LSI_RIGHTF1_2);
                end
                for n6 = 1:length(LSI_RIGHTF1_3)
                    RS3_countless60 =
sum(LSI_RIGHTF1_3<.6)/length(LSI_RIGHTF1_3);
                    RS3_count60_69 = sum(LSI_RIGHTF1_3>=0.6 &
LSI_RIGHTF1_3<0.7)/length(LSI_RIGHTF1_3);
```

```
                    RS3_count70_79 = sum(LSI_RIGHTF1_3>=0.7 &
LSI_RIGHTF1_3<0.8)/length(LSI_RIGHTF1_3);
                    RS3_count80_89 = sum(LSI_RIGHTF1_3>=0.8 &
LSI_RIGHTF1_3<0.9)/length(LSI_RIGHTF1_3);
                    RS3_count90_110 = sum(LSI_RIGHTF1_3>=0.9 &
LSI_RIGHTF1_3<1.1)/length(LSI_RIGHTF1_3);
                    RS3_countmore110 =
sum(LSI_RIGHTF1_3>=1.1)/length(LSI_RIGHTF1_3);
                end

                % Squat Metrics Data
                squatmetrics_limb = ACLR_Limb(subjectindex(3),1); %
determines the ACLR Limb of the patient
                squatmetrics = [peakLEFTF1_AVG peakRIGHTF1_AVG
LEFTF_DIST1_AVG RIGHTF_DIST1_AVG LSI_LEFTF1_AVG LSI_RIGHTF1_AVG];
                squatmetricscell = cell(13,8);
                squatmetricsheader = {'Peak Force Left [N]','Peak Force
Right[N]','Avg Force Dist Left','Avg Force Dist Right','LSI Left
ACLR','LSI Right ACLR','','ACLR Limb'};
                squatmetricscell(1,1:8) = squatmetricsheader;
                squatmetricscell(2,1:6) = num2cell(squatmetrics);
                squatmetricscell(2,8) = squatmetrics_limb;

                LEFT_LSI_GROUPED = [LS1_countless60 LS1_count60_69
LS1_count70_79 LS1_count80_89 LS1_count90_110 LS1_countmore110;...
                    LS2_countless60 LS2_count60_69 LS2_count70_79
LS2_count80_89 LS2_count90_110 LS2_countmore110;...
                    LS3_countless60 LS3_count60_69 LS3_count70_79
LS3_count80_89 LS3_count90_110 LS3_countmore110];
                LEFT_LSI_GROUPED_AVG = mean(LEFT_LSI_GROUPED);
                RIGHT_LSI_GROUPED = [RS1_countless60 RS1_count60_69
RS1_count70_79 RS1_count80_89 RS1_count90_110 RS1_countmore110;...
                    RS2_countless60 RS2_count60_69 RS2_count70_79
RS2_count80_89 RS2_count90_110 RS2_countmore110;...
                    RS3_countless60 RS3_count60_69 RS3_count70_79
RS3_count80_89 RS3_count90_110 RS3_countmore110];
                RIGHT_LSI_GROUPED_AVG = mean(RIGHT_LSI_GROUPED);
                LSI_GROUPED_HEADER = {'<60%','60-69%','70-79%','80-
89%','90-110%','>110%'};
                LSI_GROUPED_SUB1 = {'LSI Grouped','','Left
ACLR','','','','','Right ACLR'};
                LSI_GROUPED_SUB2 = {'Squat 1','Squat 2','Squat
3','AVG','','Squat 1','Squat 2','Squat 3','AVG'};

                squatmetricscell(5,3:8) = LSI_GROUPED_HEADER;
                squatmetricscell(4:11,1) = LSI_GROUPED_SUB1;
                squatmetricscell(6:14,2) = LSI_GROUPED_SUB2;
                squatmetricscell(6:8,3:8) = num2cell(LEFT_LSI_GROUPED);
                squatmetricscell(9,3:8) =
num2cell(LEFT_LSI_GROUPED_AVG);
                squatmetricscell(11:13,3:8) =
num2cell(RIGHT_LSI_GROUPED);
                squatmetricscell(14,3:8) =
num2cell(RIGHT_LSI_GROUPED_AVG);
```

```
                sdcell = cell(2,6);
                sd_header = {'Peak Force Left SD [N]','Peak Force Right
SD [N]', 'Avg Force Dist Left SD','Avg Force Dist Right SD','LSI Left
ACLR SD','LSI Right ACLR SD'};
                sddata = [peakLEFTF1_SD peakRIGHTF1_SD LEFTF_DIST1_SD
RIGHTF_DIST1_SD LSI_LEFTF1_SD LSI_RIGHTF1_SD];
                sdcell(1,1:6) = sd_header;
                sdcell(2,1:6) = num2cell(sddata);

                savetofolder = visit1_folder.folder;
                cd(savetofolder);
                writecell(squatmetricscell,
'VISIT_3_SQUAT_METRICS.xlsx','Sheet','Metrics');
                writecell(sdcell,
'VISIT_3_SQUAT_METRICS.xlsx','Sheet','Metrics SD')

                cd('C:\Users\hannaho02\Virginia Tech\Granata Lab Files
- Amelia - Tekscan\Mock Data'); % sets directory back to original file
path

            else
                continue

            end
        end
end

writecell(fulldata, 'LEAP_FullData1.xlsx','Sheet','Data_Entry')

endprogress = ['Processing completed (',datestr(now, 'HH:MM:SS'),')'];
disp(endprogress)


cd('C:\Users\hannaho02\Virginia Tech\Granata Lab Files - Amelia -
Tekscan\Mock Data'); % sets directory back to original file path
```

Table C9.7. Squat Metric Formulas

Squat Metric Formulas Calculated within the TEKSCAN_PROCESS_V2.m MATLAB:

a) Peak Force of the ACLR Limb (N) (Peak.Force.ACLR..N)
   1. Maximum force value (N) recorded of the ACLR limb averaged across the three squat trials

Equation 1: $ACLR\ (i) = \frac{\sum_{i=1}^{3} Peak_{ACLR\ limb}(i)}{3}$

b) Peak Force of the Contralateral Limb (N) (Peak.Force.Contralateral..N)
   2. Maximum force value (N) recorded of the Contralateral limb averaged across the three squat trials

Equation 2: $Contralateral\ (i) = \frac{\sum_{i=1}^{3} Peak_{Contralateral\ \ limb}(i)}{3}$

c) Unilateral cumulative load of the ACLR Limb (%) (Avg.Force.Dist.ACLR)
   3. Force (N) of the ACLR limb divided by total force (N) of both limbs averaged across the three squat trials.

Equation 3: $ACLR(i) = \frac{\sum_{j=1}^{n} \frac{Force_{ACLR}^{i}(j)}{Force_{ACLR}^{i}(j) + Force_{Contralateral}^{i}(j)}}{n}$; $\frac{\sum_{i=1}^{3} ACLR(i)}{3}$

d) Unilateral cumulative load of the Contralateral Limb (%) (Avg.Force.Dist.Contralateral)
   4. Force (N) of the contralateral limb divided by total force (N) of both limbs averaged across the three squat trials.

Equation 4: $ACLR(i) = \frac{\sum_{j=1}^{n} \frac{Force_{Contralateral}^{i}(j)}{Force_{ACLR}^{i}(j) + Force_{Contralateral}^{i}(j)}}{n}$; $\frac{\sum_{i=1}^{3} Contralateral(i)}{3}$

e) Average Limb Symmetry Index (%) (Mean_Avg_LSI)

5. Force (N) of the ACLR limb divided by force (N) of the Contralateral limb, averaged across the three squat trails.

Equation 5: $Limb\ Symmetry\ Index\ (LSI) = \frac{\sum_{j=1}^{n} \frac{Force^{i}_{ACLR}(j)}{Force^{i}_{Contralateral}(j)}}{n}$

; $\frac{\sum_{i=1}^{3} LSI(i)}{3}$

Table C10. Landing Error Scoring System (LESS) Set-up and Procedures (Only Performed at Visit 2)

Table C10.1. LESS Set-up

Camera Set-up and patient instruction

1. Place camera 3 m from the jump landing area in the frontal and sagittal plane
   Figure C10.1.1 LESS protocol positioning

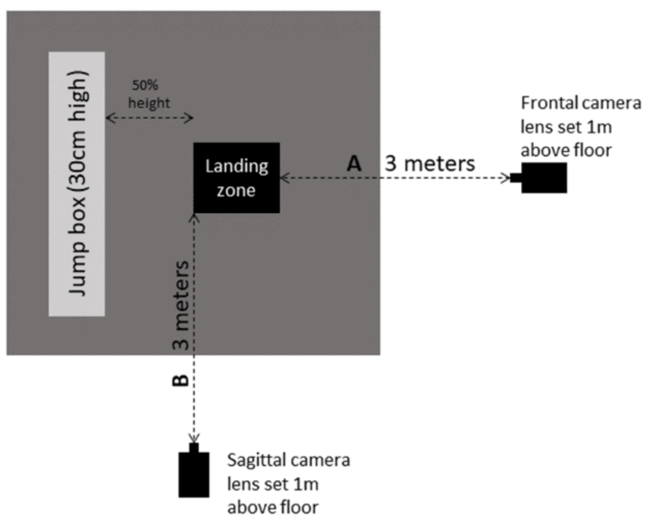
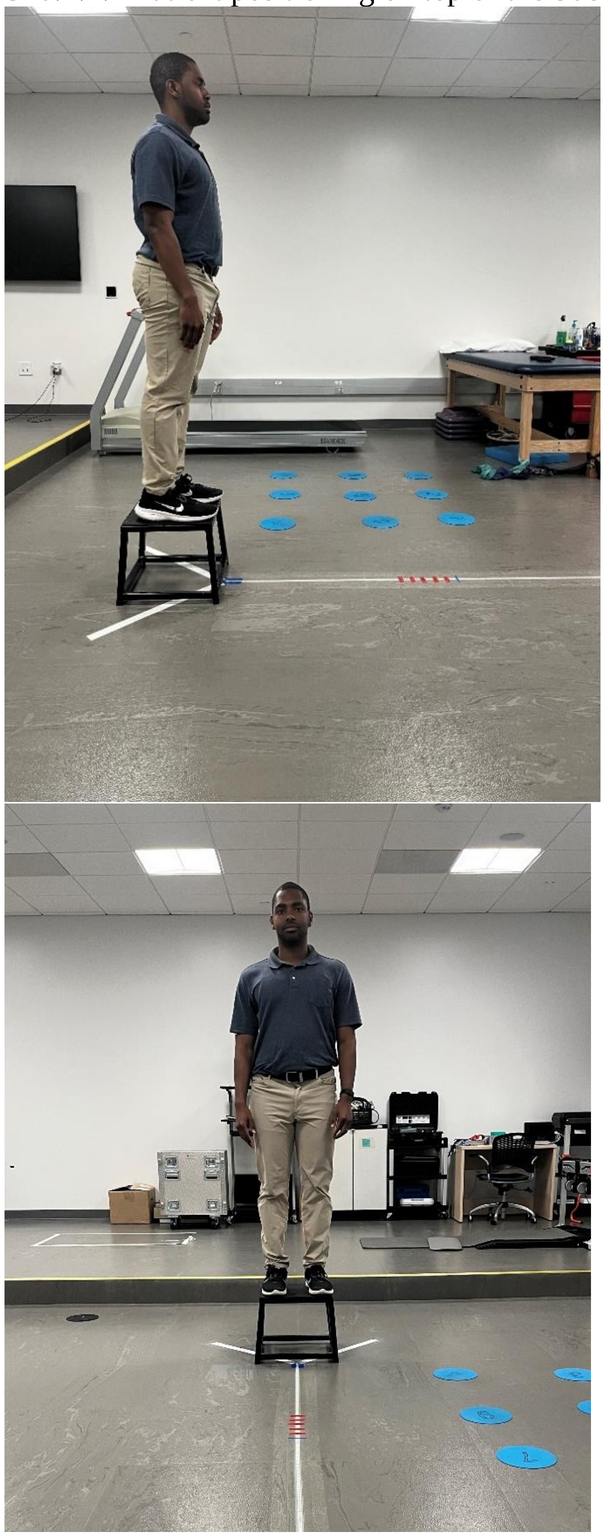


Figure C10.1.1.2 Patient positioning on top of the 30cm box



2. Educate the patient on the task
    a) Obtain the patient's height from demographics and health history form
    b) Tell the patient to jump out with both feet at the same time and aim to land with the "ball of your feet" at a specific red line on the ground (Distance = approximately 50% of their height)
    c) After landing, patients should jump up as high as they can while landing back in the same spot
    d) Allow patient to perform practice trails until they feel comfortable with the task

Table C10.2 Data Collection

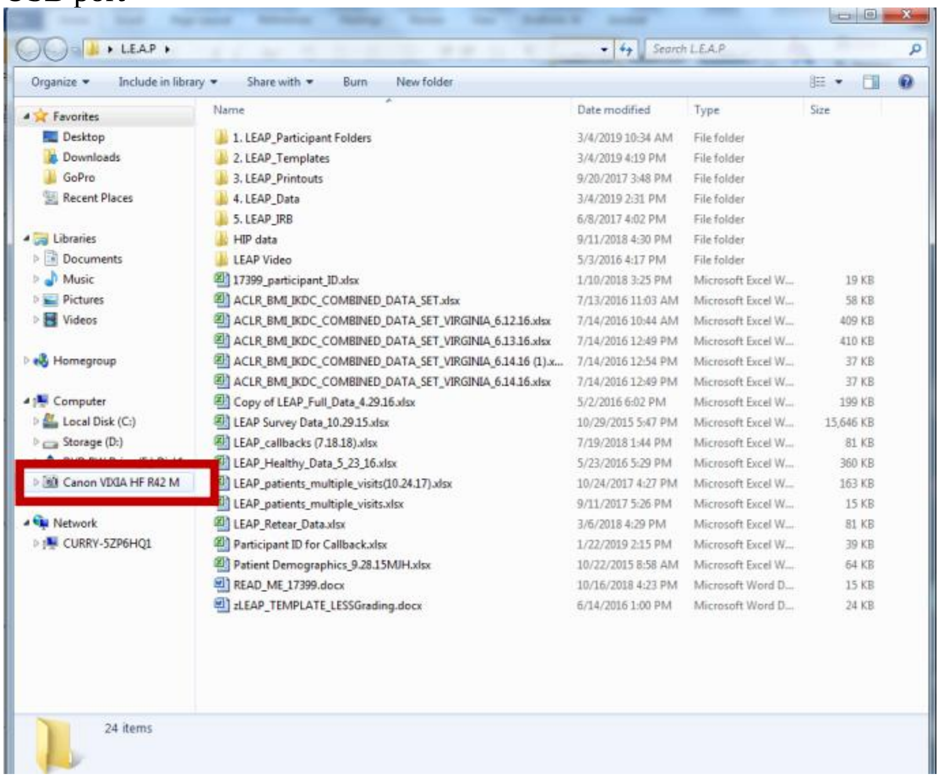
1. Start recording on the video camera in the frontal and sagittal plane view
2. Patient successfully completes all three LESS trials
3. Stop recording on the video camera in the frontal and sagittal plane view

Table C10.3 Data Export

Data Export

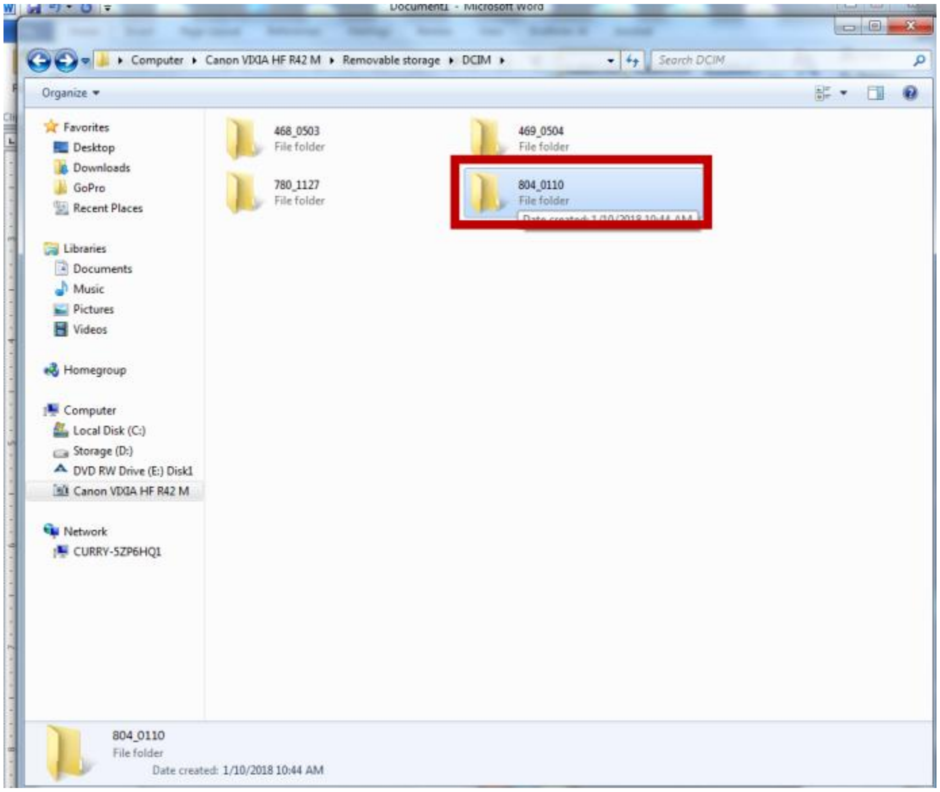
1. Plug the video camera into the standing computer through the micro-USB port
2. Press the “play” button on the camera
3. Open the camera’s files through any desktop folder

   Figure C10.3.3. Computer folder display once cameras are connect via micro-USB port

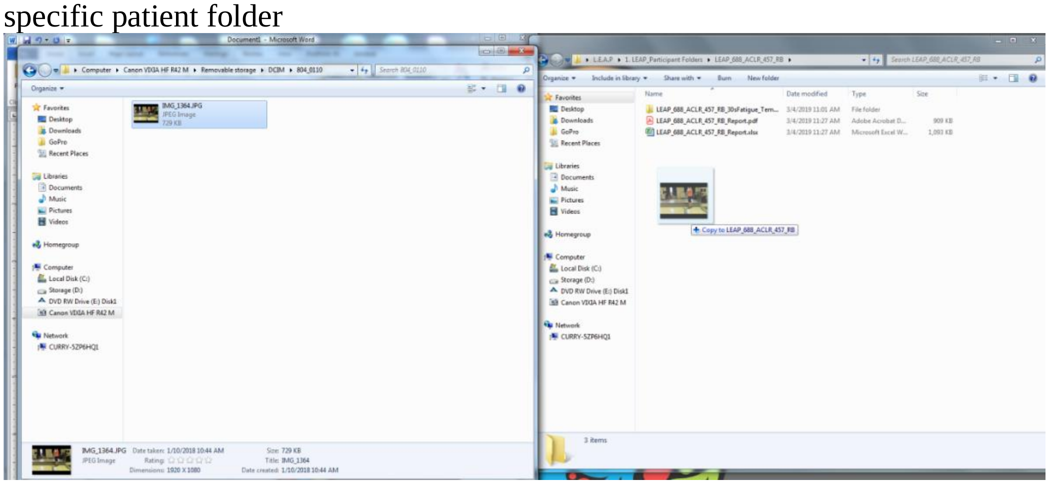


4. Select “Removable Storage”
5. Select “DCIM”

6. Select the last folder on the screen
   Figure C10.3.6 Computer screen showing where to find the video files on each camera



7. Drag the file to the patient's respective folder
   Figure C10.3.7. Computer screen showing where to copy the video file to each specific patient folder



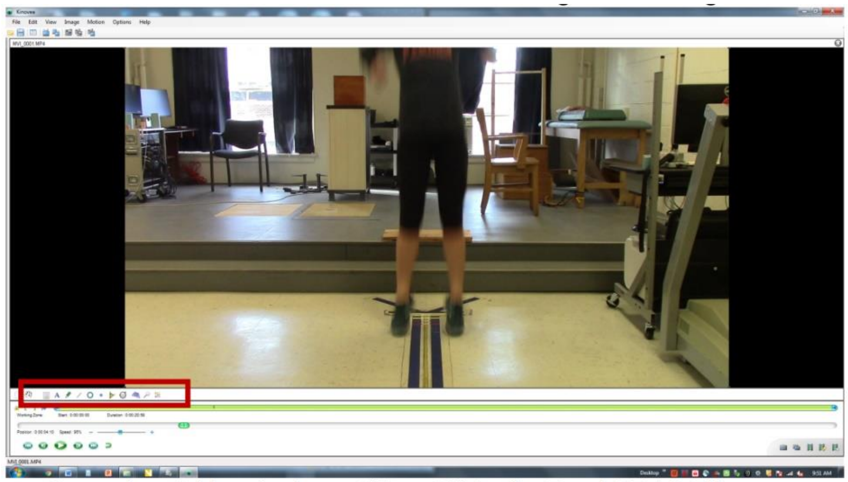
8. Perform steps 1-7 from Table C10.3. with the secondary camera

Table C10.4. Data Processing

Data Processing

1. Load the data from the patient’s LEAP folder into Kinovea (Version 0.8.15)
2. Find the correct time of the video for scoring (i.e., initial contact, max knee flexion, etc.) based on the scoring template for the LESS
   a) Use the space bar to start and stop the video
   b) Use the right arrow to continue through the video by a single frame at a time
   c) Use the tools on the tool bar to reference a straight line or angle measurement

Figure C10.4.2. Kinovea screen showing where all the tools needed to assess the LESS test



3. Score the trial by placing a "1" or "0" in the Excel LEAP file for the sagittal and frontal plane views

Figure C10.4.4. Sagittal plane view LESS error scoring template

Jump Landing - LESS		
Sagittal View		
1. At time point of initial contact... (0) - Knee of the test leg is flexed more than 30 degrees. (1) - Knee is not flexed more than 30 degrees.	1 2 3	0
2. At time point of initial contact... (0) - Thigh of test leg is in line with the trunk then hips not flexed. (1) - Thigh of test leg is flexed on the trunk.	1 2 3	0
3. At time point of initial contact... (0) - Trunk is flexed on the hips. (1) - Trunk is vertical or extended on hips.	1 2 3	0
4. When landing.. (0) - Foot of test limb lands toe-to-heel. (1) - Foot of test leg lands heel-to-toe or flat foot.	1 2 3	0
5. From initial contact to max knee flexion: (0) - Knee of test leg flexes more than 45 degrees. (1) - Knee of test leg flexes less than 45 degrees.	1 2 3	0
6. From initial contact to max knee flexion: (0) - Hip of test leg flexes more on trunk. (1) - Hip of test leg does not flex more or extends.	1 2 3	0
7. From initial contact to max knee flexion: (0) - Trunk flexes more. (1) - Trunk does not flex more or extends.	1 2 3	0
8. Joint Displacement: (0) - Large displacement of trunk, hips, and knees. (1) - Some displacement of trunk, hips, and knees. (2) - Very little displacement of trunk, hips, and knees.	1 2 3	0

Figure C10.4.5. Frontal plane view LESS error scoring template

Frontal View		
9. At the point of initial contact... (0) - Center of patella is vertically aligned with mid-foot. (1) - Center of patella is vertically aligned medial to mid-foot.	1 2 3	0
10. At the time point of initial contact... (0) - Midline of trunk is not flexed to the left or right of the body. (1) - Midline of trunk is flexed to the left or right of the body.	1 2 3	0
11. At the time point of initial contact... (0) Feet land symmetrically. (1) 1 foot lands first or 1 foot lands heel-toe & other toe-to-heel.	1 2 3	0
12. Once the entire foot is in contact with the ground... (0) - Medial heel of test leg is *inline with shoulder width* (1) - Medial heel of test leg is *wider than shoulder width*. (1) - Medial heel of test leg is *narrower than shoulder width*.	1 2 3	0
13. From initial contact to max flexion... (0) - Test leg foot is *between 30° external & 30° internal rotation* (1) - Test leg foot is *internally rotated > 30°* (1) - Test leg foot is *externally rotated > 30°*	1 2 3	0
14. At the time point of max knee valgus of test leg... (0) Center of patella is lateral to great toe. (1) Center of patella inline or medial to great toe.	1 2 3	0
15. Overall Impression: (0) - Displays soft landing and no frontal plane motion at knee. (1) - Displays easy landing and some frontal plane motion at knee. (2) - Displays stiff landing and large frontal plane motion at knee.	1 2 3	0
	Total Score:	0

4. Repeat steps 1-3 for each of the three jump landing trials

APPENDIX D

Additional Results

MANUSCRIPT I: Comparison of limb loading characteristics and subjective functional outcomes between sexes following ACLR

Table 1: Patient demographics in all participants.

All Patients	
Patients, n	143
Age, years	24.53±11.12
Sex (Female:Male)	71:71
Mass, kg	78.32±17.48
Height, cm	172.87±9.99
Time Since Surgery, Months	5.16±1.41
Surgical Limb = Dominant limb (n(%))**	58 (40.8%)
Surgical Limb = Nondominant limb (n(%))**	84 (59.2%)
Graft Type (n(%))**	
Patella Tendon	113 (79.6%)
Hamstring Tendon	17 (12%)
Quadriceps Tendon	11 (7.7%)
Allograft	1 (0.7%)

Table 2: Patient breakdown by sex and surgical limb dominance.

Sex and Surgical Limb Dominance			
Sex	**Surgical Limb = Dominant Limb**	**Frequency (n)**	**Percent (%)**
Female	No	46	64.8
	Yes	25	35.2
	Total	71	100
Male	No	38	53.5
	Yes	33	46.5
	Total	71	100

Table 3: Descriptive Statistics

Descriptive Statistics				
		Sex	Mean	Std. Deviation
ACLR Limb	Normalized Peak Force	Female	6.25	1.38
		Male	6.98	1.65
		Total	6.62	1.56
	Unilateral Cumulative Load	Female	0.48	0.09
		Male	0.49	0.10
		Total	0.49	0.09
Contralateral Limb	Normalized Peak Force	Female	7.24	1.62
		Male	7.42	1.60
		Total	7.33	1.61
	Unilateral Cumulative Load	Female	0.52	0.09
		Male	0.51	0.10
		Total	0.51	0.09
	Limb Symmetry Index	Male	0.99	0.33
		Female	0.91	0.28

Table 4: Independent Samples Test for Normalized Peak Force

Independent Samples Test							
	Levene's Test for Equality of Variances	T-Test for Equality of Means					
						95% Confidence Interval of the Difference	
	F	*t*	*p*-value	Mean Difference	Std. Error Difference	Lower	Upper
Normalized Peak Force ACLR Limb	1.21	2.88	0.002	0.737	0.255	0.232	1.242
Normalized Peak Force Contralateral Limb	0.22	0.67	0.251	0.182	0.270	-0.352	0.716

Table 5: Independent Samples Cohen's D Effect Sizes for Normalized Peak Force Across Limbs

Independent Samples Effect Sizes					
				95% Confidence Interval	
		Standardizer[a]	Point Estimate	Lower	Upper
Normalized Peak Force ACLR Limb	Cohen's d	1.52	0.484	0.15	0.82
Normalized Peak Force Contralateral Limb	Cohen's d	1.61	0.113	-0.22	0.44

a. The denominator used in estimating the effect sizes.
Cohen's d uses the pooled standard deviation.

Table 6: Independent Samples Test for Limb Symmetry Index

Independent Samples Test

	Levene's Test for Equality of Variances	T-Test for Equality of Means					
						95% Confidence Interval of the Difference	
	F	*t*	*p*-value	Mean Difference	Std. Error Difference	Lower	Upper
Limb Symmetry Index	0.47	1.54	0.063	0.08	0.05	-0.022	0.180

Table 7: Independent Samples Cohen's D Effect Sizes for Limb Symmetry Index

Independent Samples Effect Sizes

		Standardizer[a]	Point Estimate	95% Confidence Interval	
				Lower	Upper
Limb Symmetry Index	Cohen's d	0.31	0.26	-0.07	0.59

a. The denominator used in estimating the effect sizes.
Cohen's d uses the pooled standard deviation.

Table 8: Correlation matrix between PROs (KOOS, IKDC, and ACL-RSI) and limb loading metrics

Spearman rho correlation coefficient values for limb loading metrics and PROs across ACLR and Contralateral Limbs						
		ACLR Limb		Contralateral Limb		Abs. Value
		Normalized Peak Force	Unilateral Cumulative Load	Normalized Peak Force	Unilateral Cumulative Load	Peak Force LSI
IKDC	Spearman Rho Correlation	0.01	0.11	-0.16	-0.11	-0.003
	p-value	0.25	0.19	0.05	0.19	0.97
KOOS Symptom	Spearman Rho Correlation	0.03	0.17*	-0.23**	-0.17*	0.06
	p-value	0.69	0.046	0.01	0.046	0.51
KOOS Pain	Spearman Rho Correlation	-0.02	0.03	-0.07	-0.03	0.08
	p-value	0.78	0.74	0.44	0.74	0.38
KOOS ADL	Spearman Rho Correlation	0.11	0.19*	-0.17*	-0.19*	-0.04
	p-value	0.20	0.03	0.04	0.03	0.65
KOOS Sport	Spearman Rho Correlation	0.03	0.10	-0.13	-0.10	0.005
	p-value	0.72	0.23	0.12	0.23	0.96
KOOS QOL	Spearman Rho Correlation	0.02	0.07	-0.13	-0.07	0.01
	p-value	0.79	0.44	0.14	0.44	0.89
ACL RSI	Spearman Rho Correlation	0.03	0.08	-0.18*	-0.08	-0.01
	p-value	0.70	0.38	0.04	0.38	0.95

*Indicates significant relationships between PRO and limb loading metric variable (p<0.05), **Indicates significant relationships between PRO and limb loading metric variable (p<0.01)

Table 9: Correlation matrix between PROs (Tegner, Godin, Tampa, and VR12) and limb loading metrics

Spearman rho correlation coefficient values for limb loading metrics and PROs across ACLR and Contralateral Limbs

		ACLR Limb		Contralateral Limb		Abs. Value
		Normalized Peak Force	Unilateral Cumulative Load	Normalized Peak Force	Unilateral Cumulative Load	Peak Force LSI
Tegner Pre	Spearman Rho Correlation	0.11	0.15	-0.07	-0.15	-0.04
	p-value	0.18	0.09	0.38	0.09	0.65
Tegner Current	Spearman Rho Correlation	0.18*	0.09	0.02	-0.09	-0.04
	p-value	0.03	0.27	0.84	0.27	0.62
Godin	Spearman Rho Correlation	-0.06	-0.01	-0.02	0.01	-0.04
	p-value	0.48	0.94	0.82	0.94	0.64
Tampa	Spearman Rho Correlation	0.09	-0.01	0.16	0.01	0.08
	p-value	0.32	0.90	0.07	0.90	0.35
VR12	Spearman Rho Correlation	-0.03	0.22	-0.11	-0.22	-0.08
	p-value	0.78	0.80	0.21	0.80	0.33

*Indicates significant relationships between PRO and limb loading metric variable (p<0.05)

MANUSCRIPT II: Analysis of lower extremity strength and limb loading recovery across time following ACLR.

Table 1: Participant Demographics (Mean±SD)

Patient Demographics	
	Total Participants (n=60)
Sex (Male/Female)	28M/32F
Age (yrs)	22.55±9.35
Mass (kg)	76.95±15.42
Height (cm)	172.05±9.51
Time post-surgery (months)	Visit 1: 4.85±1.44 Visit 2: 7.96±1.90
Surgical limb = Dominant limb (n(%))*	23 (38.3%)
Surgical limb = Nondominant limb (n(%))*	37 (61.7%)
Graft Type (n(%))*	
Patella Tendon	49 (81.7%)
Hamstring Tendon	8 (13%)
Quadriceps Tendon	3 (5%)

*****Limb dominance and graft type is listed as the number of participants followed by the cumulative percentage.

Table 2: Limb loading and strength metrics across limbs at Visit 1 and Visit 2 (n=60).

Descriptive Statistics			
	ACLR Limb	Contralateral Limb	Effect Size (95% CI)
Visit 1: Peak Force (N)	502.79±142.64	560.32±149.58*	0.31 (0.05,0.57)
Visit 2: Peak Force (N)	527.02±159.41	547.30±152.56	0.13 (-0.13, 0.38)
Visit 1: Unilateral Cumulative Load (%)	49.1±10.0	50.9±9.6	0.10 (-0.16, 0.35)
Visit 2: Unilateral Cumulative Load (%)	50.0±8.43	50.0±8.4	0.004 (-0.25, 0.26)
Visit 1: Peak Quadriceps Torque (Nm)	99.24±37.80	169.38±47.29*	1.90 (1.47, 2.32)
Visit 2: Peak Quadriceps Torque (Nm)	123.36±43.46	173.29±48.84*	1.45 (1.08, 1.81)
Visit 1: Peak Hamstring Torque (Nm)	68.61±21.75	72.87±18.37	0.30 (0.04, 0.56)
Visit 2: Peak Hamstring Torque (Nm)	78.21±20.33	80.15±18.99	0.18 (-0.08, 0.44)

Indicates significant differences between the ACLR limb and the contralateral limb ($p<0.05$)

Table 3: Paired Samples t-test comparing limb loading metric across Visit 1 and Visit 2

Paired Samples T-Test									
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	*p*-value
ACLR Limb	Peak Force	-24.24	102.73	13.26	-50.77	2.30	-2	59	0.036*
	UCL	-0.009	0.052	0.007	-0.022	0.005	-1	59	0.095
Contra Limb	Peak Force	13.02	124.97	16.13	-19.26	45.31	1	59	0.211
	UCL	0.009	0.052	0.007	-0.005	0.022	1	59	0.095

Indicates significant differences between the ACLR limb and the contralateral limb. Contralateral (Contra), Unilateral Cumulative Load (UCL)($p<0.05$)

Table 4: Paired samples t-test effect sizes for limb loading metrics across Visit 1 and Visit 2

Paired Samples Effect Sizes						
					95% Confidence Interval	
			Standardizer[a]	Point Estimate	Lower	Upper
ACLR Limb	Peak Force	Cohen's d	102.73	-0.2	-0.49	0.02
	Unilateral Cumulative Load	Cohen's d	0.052	-0.2	-0.43	0.08
Contralateral Limb	Peak Force	Cohen's d	124.97	0.1	-0.15	0.36
	Unilateral Cumulative Load	Cohen's d	0.052	0.2	-0.08	0.43

a. The denominator used in estimating the effect sizes.
Cohen's d uses the sample standard deviation of the mean difference.

Table 5: Paired samples t-test comparing limb loading metrics across the ACLR and Contralateral limbs

Paired Samples Test									
		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	*p*-value
Visit 1	Peak Force	-57.53	184.47	23.81	-105.19	-9.88	-2.4	59	0.009*
	UCL	-0.019	0.192	0.025	-0.068	0.031	-0.7	59	0.228
Visit 2	Peak Force	-20.28	158.30	20.44	-61.17	20.62	-1.0	59	0.163
	UCL	-0.001	0.169	0.022	-0.044	0.043	0.0	59	0.486

Indicates significant differences between the ACLR limb and the contralateral limb. Unilateral Cumulative Load (UCL) ($p<0.05$)

Table 6: Paired samples t-test effect sizes for limb loading metrics across ACLR and Contralateral limbs

Paired Samples Effect Sizes						
					95% Confidence Interval	
			Standardizer[a]	Point Estimate	Lower	Upper
Visit 1	Peak Force	Cohen's d	184.47	-0.31	-0.570	-0.051
	Unilateral Cumulative Load	Cohen's d	0.19	-0.10	-0.350	0.157
Visit 2	Peak Force	Cohen's d	158.30	-0.13	-0.382	0.127
	Unilateral Cumulative Load	Cohen's d	0.17	0.00	-0.257	0.249

a. The denominator used in estimating the effect sizes.
Cohen's d uses the sample standard deviation of the mean difference.

Table 7: Paired samples t-test comparing lower extremity strength metrics across Visit 1 and Visit 2

Paired Samples Test									
		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	*p*-value
ACLR Limb	Quad	-24.12	19.27	2.49	-29.09	-19.14	-9.7	59	<0.01*
	Ham	-9.60	13.74	1.77	-13.15	-6.05	-5.4	59	<0.01*
Contra Limb	Quad	-3.90	20.75	2.68	-9.26	1.46	-1.5	59	0.075
	Ham	-7.28	10.88	1.40	-10.09	-4.46	-5.2	59	<0.01*

Indicates significant differences between the ACLR limb and the contralateral limb, Contralateral (Cont.), Quadriceps (Quad), Hamstrings (Ham). ($p<0.05$)

Table 8: Paired samples t-test effect sizes for lower extremity strength metrics across Visit 1 and Visit 2

Paired Samples Effect Sizes						
					95% Confidence Interval	
			Standardizer[a]	Point Estimate	Lower	Upper
ACLR Limb	Quad	Cohen's d	19.27	-1.25	-1.59	-0.91
	Ham	Cohen's d	13.74	-0.70	-0.98	-0.41
Contralateral Limb	Quad	Cohen's d	20.75	-0.19	-0.44	0.07
	Ham	Cohen's d	10.88	-0.67	-0.95	-0.39

Quadriceps (Quad), Hamstrings (Ham)
a. The denominator used in estimating the effect sizes.
Cohen's d uses the sample standard deviation of the mean difference.

Table 9: Paired samples t-test comparing lower extremity strength metrics across the ACLR and Contralateral limb.

Paired Samples Test									
		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	*p*-value
Visit 1	Quad	-70.15	36.99	4.78	-79.70	-60.59	-14.7	59	<0.01**
	Ham	-4.26	14.27	1.84	-7.95	-0.58	-2.3	59	0.012*
Visit 2	Quad	-49.93	34.43	4.45	-58.83	-41.04	-11.2	59	<0.01**
	Ham	-1.94	10.70	1.38	-4.70	0.83	-1.4	59	0.083

Indicates significant differences between the ACLR limb and the contralateral limb. Quadriceps (Quad), Hamstrings (Ham). (p<0.05, **p<0.001)

Table 10: Paired samples t-test effect sizes for lower extremity strength metrics across the ACLR and Contralateral limbs

Paired Samples Effect Sizes						
					95% Confidence Interval	
			Standardizer[a]	Point Estimate	Lower	Upper
Visit 1	Quad	Cohen's d	36.991	-1.90	-2.32	-1.47
	Ham	Cohen's d	14.270	-0.30	-0.56	-0.04
Visit 2	Quad	Cohen's d	34.433	-1.45	-1.81	-1.08
	Ham	Cohen's d	10.695	-0.18	-0.44	0.07

Quadriceps (Quad), Hamstrings (Ham)
a. The denominator used in estimating the effect sizes.
Cohen's d uses the sample standard deviation of the mean difference.

Table 11. Correlation coefficient values for limb loading metrics and lower extremity strength changes scores

	Pearson Correlation				
	Peak Force LSI	Peak Force ACLR Limb	Peak Force Contralateral Limb	Unilateral Cumulative Load ACLR Limb	Unilateral Cumulative Load Contralateral Limb
Quadriceps Peak Torque LSI	-0.17	0.03	-0.21	0.23	-0.23
Hamstring Peak Torque LSI	-0.20	0.03	-0.12	0.14	-0.14
Quadriceps Peak Torque ACLR Limb	-0.20	0.13	-0.14	0.25	-0.25
Hamstring Peak Torque ACLR Limb	-0.07	0.06	0.06	0.02	-0.02
Quadriceps Peak Torque Contralateral Limb	0.08	0.02	0.18	-0.09	0.09
Hamstring Peak Torque Contralateral Limb	0.23	-0.03	0.21	-0.19	0.19

Table 12: Correlation coefficient values for limb loading metrics and patient reported outcomes

		ACLR Limb		Contralateral Limb		Limb Symmetry Index
		Peak Force Change Score	Unilateral Cumulative Load Change Score	Peak Force Change Score	Unilateral Cumulative Load Change Score	Peak Force Change Score
ACL-RSI Change Score	Pearson Correlation	-0.030	-0.049	-0.040	0.049	0.082
	p-value	0.788	0.664	0.723	0.664	0.460
IKDC Change Score	Pearson Correlation	0.022	0.123	-.250*	-0.123	.219*
	p-value	0.839	0.266	0.021	0.265	0.044
TSK-17 Change Score	Pearson Correlation	-0.010	-0.055	0.090	0.055	-0.108
	p-value	0.934	0.632	0.431	0.632	0.345

*. Correlation is significant at the 0.05 level (2-tailed).

Table 13: Correlation coefficient values for lower extremity strength metrics and patient reported outcomes

Correlations							
		ACLR Limb		**Contralateral Limb**		**Limb Symmetry Index**	
		Quad: Change Score	Ham: Change Score	Quad: Change Score	Ham: Change Score	Quad: Change Score	Ham: Change Score
ACL-RSI Change Score	Pearson Correlation	-0.036	0.074	-0.023	-0.057	-0.040	0.138
	p-value	0.746	0.509	0.838	0.609	0.716	0.214
IKDC Change Score	Pearson Correlation	0.143	.257*	-0.076	-0.092	0.137	.287**
	p-value	0.192	0.018	0.488	0.405	0.211	0.008
TSK-17 Change Score	Pearson Correlation	-0.118	-0.149	0.050	-0.040	-0.086	-0.094
	p-value	0.302	0.192	0.664	0.726	0.452	0.413

Anterior Cruciate Ligament - Return to Sport after Injury (ACL-RSI), International Knee Documentation Committee Subjective Knee Form (IKDC), Tampa Scale of Kinesiophobia (TSK-17), Quadriceps (Quad), Hamstrings (Ham).

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

MANUSCRIPT III: An exploratory analysis of the predictive ability of limb loading on functional performance outcomes after ACLR

Table 1: Participant Demographics (Mean±SD)

Patient Demographics		
	Exploratory Analysis Sample Participants (n=203)	Main Analysis Sample Participants (n=45)
Sex (Male/Female)	107M/96F	22M/23F
Age (yrs)	21.81±7.77	20.43±7.11
Mass (kg)	77.55±16.12	76.93±14.22
Height (cm)	172.60±15.97	172.95±9.59
Time post-surgery (months)	8.82±6.71	Visit 1: 5.09±1.42 Visit 2: 8.27±1.81
Surgical limb = Dominant limb (n(%))*	99 (48.8%)	18 (40%)
Surgical limb = Nondominant limb (n(%))*	104 (51.2%)	27 (60%)

***Limb dominance and graft type is listed as the number of participants followed by the cumulative percentage.

Table 2: The LESS scoring template with an example of how errors during each trail are calculated for each LESS error item from the sagittal camera view.

Sagittal View		**Error Committed**	
LESS Error Item	**Segment of jump landing task:**	**No**	**Yes**
1.	At the time of initial contact	Knee of the test leg is flexed more than 30 degrees	Knee is not flexed more than 30 degrees
2.	At the time of initial contact	Thigh of test leg is in line with the trunk then hips not flexed	Thigh of test leg is flexed on the trunk
3.	At the time of initial contact	Trunk is flexed on the hips	Trunk is vertical or extended on the hips
4.	When landing	Foot of test limb lands toe-to-heal	Foot of test limb lands heel-to-toe or flat foot
5.	From initial contact to max knee flexion	Knee of test leg flexes more than 45 degrees	Knee of test leg flexes less than 45 degrees
6.	From initial contact to max knee flexion	Hip of test leg flexes more on trunk	Hip of test leg does not flex more or extends
7.	From initial contact to max knee flexion	Trunk flexes more	Trunk does not flex more or extends
8.	Joint Displacement	Large displacement of trunk, hips, and knees	Some or very little displacement of the trunk, hips, and knees

Table 3. The LESS scoring template with an example of how errors during each trial are calculated for each LESS error item from the frontal camera view

Frontal View		**Error Committed**	
LESS Error Item	**Segment of jump landing task:**	**No**	**Yes**
9.	At the time of initial contact	Center of patella is vertically aligned with the mid-foot	Center of patella is vertically aligned medial to mid-foot
10.	At the time of initial contact	Midline of the trunk is not flexed to the left or right of the body	Midline of the trunk is flexed to the left or right of the body
11.	At the time of initial contact	Feet land symmetrically	One foot lands first or one foot lands heel-to-toe & other toe-to-heel
12.	Once the entire foot is in contact with the ground	Medial heel of test leg is in line with shoulder width	Medial heel of test leg is wider or narrower than shoulder width
13.	From initial contact to max knee flexion	Test leg foot is between 30º external & 30º internal rotation	Test leg foot is internally rotated > 30º or externally rotated > 30º
14.	At the time of max knee flexion	Center of patella is lateral to great toe	Center of patella is inline or medial to toe
15.	Overall impression	Displays soft landing and no frontal plane motion at the knee	Displays easy to stiff landing and large frontal plane motion at the knee

Table 4: Exploratory factor analysis loading values for Biplanar and Frontal factors

	Factors	
Error Items	Biplanar	Frontal
Sagittal Plane View		
1		
2		
3		
4		
5		
6	0.701	
7	0.638	
8	0.584	
Frontal Plane View		
9		
10		
11		
12	0.392	
13		
14		0.719
15		0.807
Eigenvalue	1.6012	1.0098

Table 5: Exploratory factor analysis model fit statistics

	RMSEA 90% CI				Model Test		
RMSEA	Lower	Upper	TLI	BIC	X^2	df	*p*
0.095	0.081	0.111	0.497	-187	216	76	<0.001

Root mean square error of approximation (RMSEA), Tucker-Lewis Index (TLI), Bayesian information criterion (BIC), degrees of freedom (df)

Table 6: Results from multiple linear regression from the summation factor scores

	Predictor	Unstandardized β coefficient	*t* statistic	*p*-value
	Symmetry Predictors			
Biplanar Factor: Sum of Errors	Limb Loading Symmetry	-0.84	-1.027	0.21
	Quadriceps Strength LSI	-2.01	-1.75	0.09
	ACL-RSI	-0.01	-1.14	0.26
	Unilateral Predictors			
Biplanar Factor: Sum of Errors	ACLR Limb Peak Force	-0.002	-1.02	0.32
	ACLR Limb Quadriceps Peak Torque	-0.007	-1.04	0.31
	ACL-RSI	-0.01	-1.13	0.27
	Symmetry Predictors			
Frontal Factor: Sum of Errors	Limb Loading Symmetry	-0.19	-0.41	0.69
	Quadriceps Strength LSI	-0.24	-0.30	0.77
	ACL-RSI	0.01	2.13	0.04
	Unilateral Predictors			
Frontal Factor: Sum of Errors	ACLR Limb Loading Peak Force	-0.001	-0.56	0.58
	ACLR Limb Quadriceps Peak Torque	-0.006	-1.32	0.20
	ACL-RSI	0.01	2.27	0.03

Table 7: Results from multiple linear regression from the weighted Thurston factor scores

	Predictor	Unstandardized β coefficient	*t* statistic	*p*-value
	Symmetry Predictors			
Biplanar Factor: Weighted Thurstone	Limb Loading Symmetry	-0.51	-1.20	0.24
	Quadriceps Strength LSI	-1.31	-1.80	0.08
	ACL-RSI	-0.006	-1.03	0.31
	Unilateral Predictors			
Biplanar Factor: Weighted Thurstone	ACLR Limb Loading Peak Force	-0.001	-1.01	0.32
	ACLR Limb Quadriceps Peak Torque	-0.004	-1.02	0.32
	ACL-RSI	-0.006	-1.02	0.32
	Symmetry Predictors			
Frontal Factor: Weighted Thurstone	Limb Loading Symmetry	-0.27	-0.66	0.51
	Quadriceps Strength LSI	-0.50	-0.71	0.48
	ACL-RSI	0.01	2.52	0.02
	Unilateral Predictors			
Frontal Factor: Weighted Thurstone	ACLR Limb Loading Peak Force	-0.001	-0.56	0.58
	ACLR Limb Quadriceps Peak Torque	-0.01	-1.33	0.19
	ACL-RSI	0.02	2.63	0.01

Table 8: Results of binary logistic regression from the binary factor scores

	Predictor	β coefficient	Wald Statistic	*p*-value	Odds Ratio	95% CI Lower	95% CI Upper
	Symmetry Predictors						
Biplanar Factor: Binary (Yes/No) Any error committed	Limb Loading Symmetry	-2.25	3.75	0.05	0.11	0.01	1.03
	Quadriceps Strength LSI	-0.91	0.26	0.61	0.40	0.01	13.40
	ACL-RSI	-0.01	0.54	0.46	0.99	0.96	1.02
	Unilateral Predictors						
Biplanar Factor: Binary (Yes/No) Any error committed	ACLR Limb Loading Peak Force	-0.001	0.21	0.647	1.00	0.99	1.004
	ACLR Limb Quadriceps Peak Torque	-0.005	0.28	0.60	1.00	0.98	1.01
	ACL-RSI	-0.01	0.46	0.50	1.00	0.96	1.02
	Symmetry Predictors						
Frontal Factor: Binary (Yes/No) Any error committed	Limb Loading Symmetry	-1.13	0.94	0.33	0.32	0.03	3.18
	Quadriceps Strength LSI	0.95	0.16	0.69	2.59	0.02	298.01
	ACL-RSI	0.03	3.76	0.05	1.03	1.00	1.07
	Limb Loading Predictors						
Frontal Factor: Binary (Yes/No) Any error committed	ACLR Limb Loading Peak Force	-0.01	4.10	0.04	0.99	0.985	1.00
	ACLR Limb Quadriceps Peak Torque	-0.01	0.72	0.40	0.99	0.97	1.01
	ACL-RSI	0.04	3.81	0.05	1.04	1.00	1.09

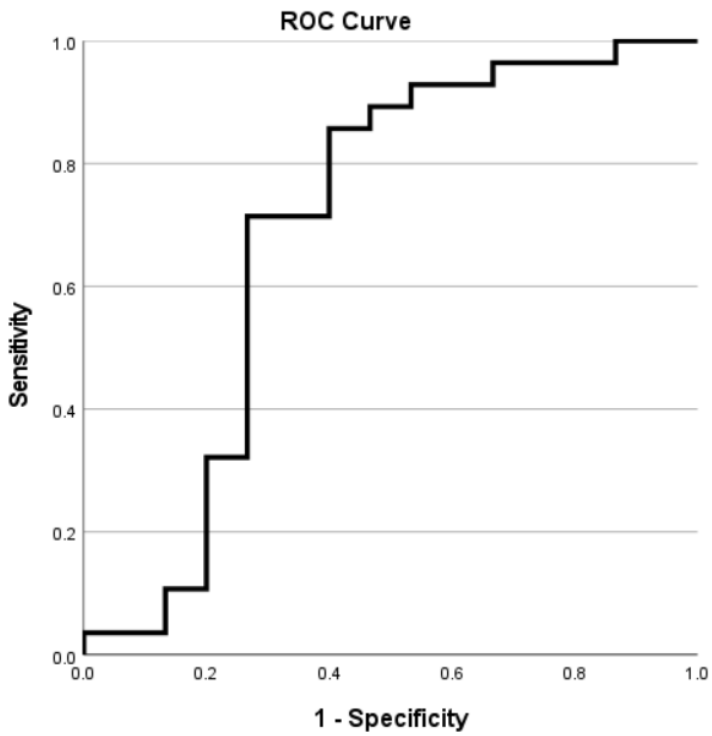


Figure 1: Receiver operator characteristic (ROC) curve used to calculate area under the curve (AUC) for the biplanar factor and symmetry predictors model.

Table 9: The area under the curve metric from the biplanar factor and symmetry predictors

Area Under the Curve				
			Asymptotic 95% Confidence Interval	
Area	Std. Error[a]	Asymptotic Sig.[b]	Lower Bound	Upper Bound
0.695	0.099	0.037	0.502	0.889

a. Under the nonparametric assumption
b. Null hypothesis: true area =0.5

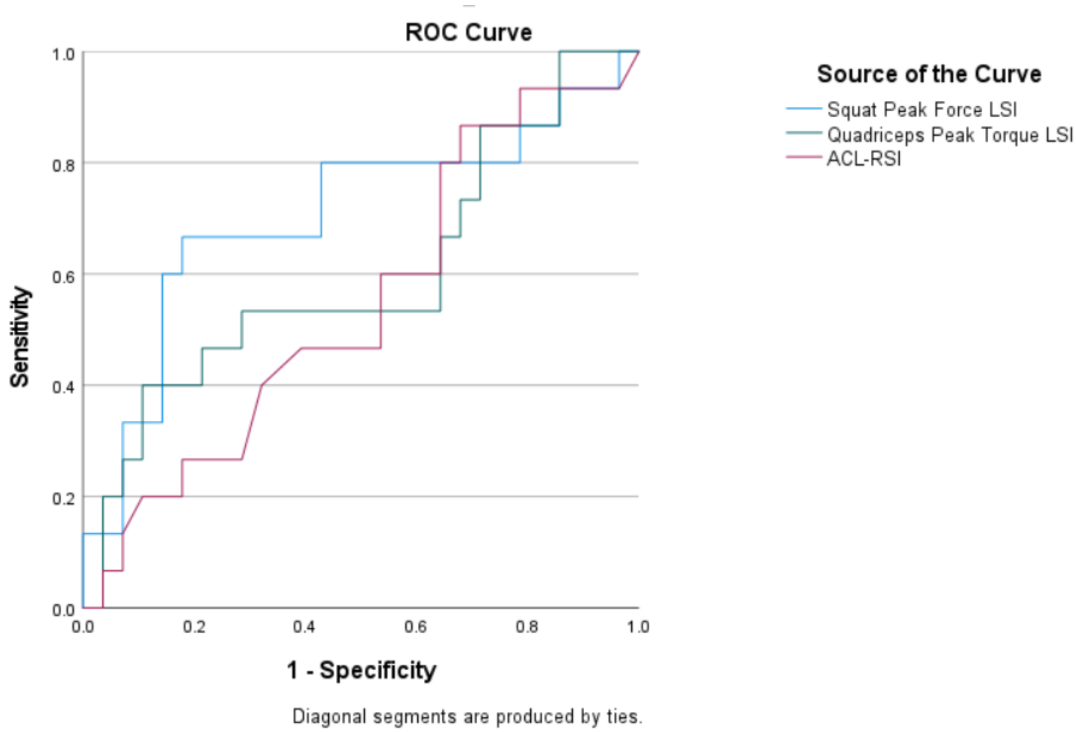


Figure 2: Receiver operator characteristic (ROC) curve used to calculate area under the curve (AUC) for the biplanar factor and limb loading symmetry, quadriceps peak torque symmetry, and ACL-RSI score predictors.

Table 10: The area under the curve metric from the biplanar factor and itemized symmetry predictors

Area Under the Curve					
				Asymptotic 95% Confidence Interval	
Test Result Variable(s)	Area	Std. Error[a]	Asymptotic Sig.[b]	Lower Bound	Upper Bound
Squat Peak Force LSI	0.705	0.092	0.028	0.525	0.884
Quadriceps Peak Torque LSI	0.600	0.096	0.285	0.411	0.789
ACL-RSI	0.548	0.092	0.610	0.367	0.729

a. Under the nonparametric assumption
b. Null hypothesis: true area =0.5

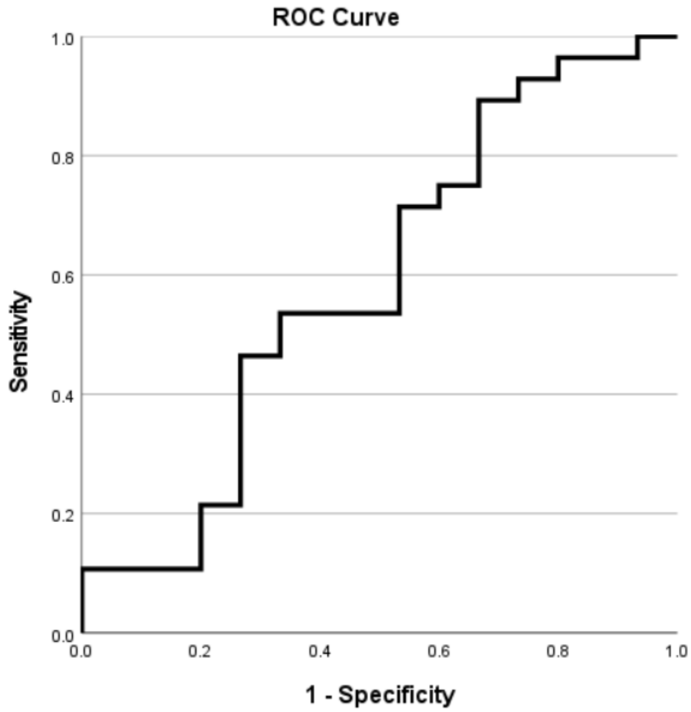


Figure 3: Receiver operator characteristic (ROC) curve used to calculate area under the curve (AUC) for the biplanar factor and unilateral predictors model.

Table 11: The area under the curve metric from the biplanar factor and unilateral predictors

Area Under the Curve				
			Asymptotic 95% Confidence Interval	
Area	Std. Error[a]	Asymptotic Sig.[b]	Lower Bound	Upper Bound
0.588	0.096	0.346	0.399	0.777

a. Under the nonparametric assumption
b. Null hypothesis: true area =0.5

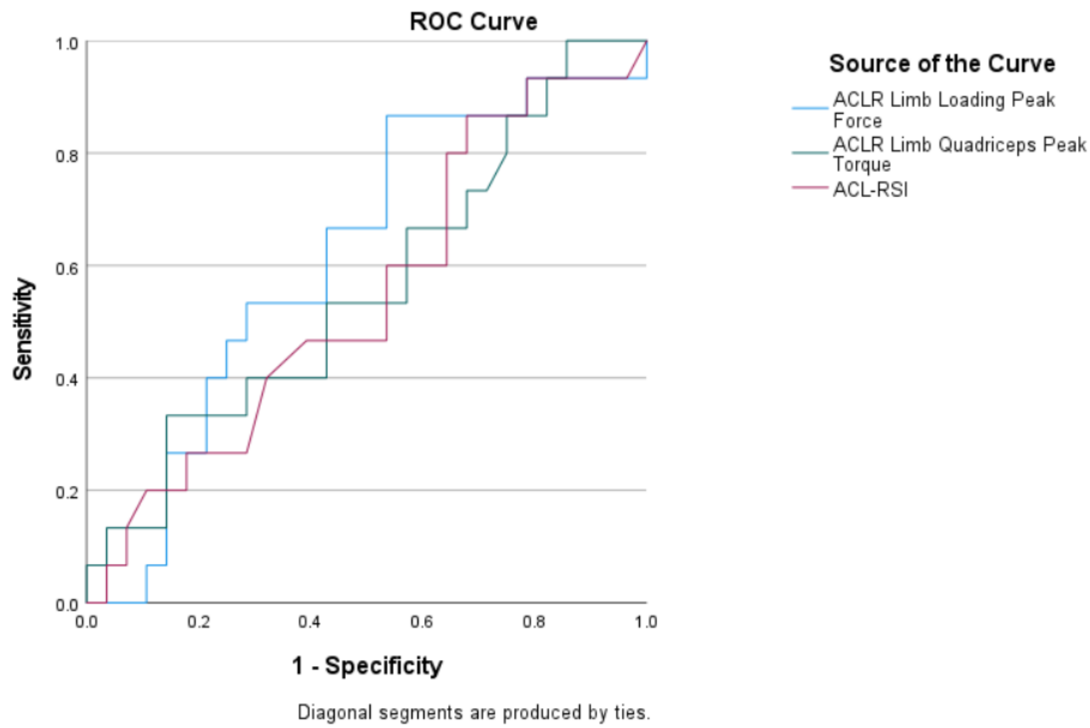


Figure 4: Receiver operator characteristic (ROC) curve used to calculate area under the curve (AUC) for the biplanar factor and ACLR limb loading peak force, ACLR limb quadriceps peak torque, and ACL-RSI score predictors.

Table 12: The area under the curve metric from the biplanar factor and itemized unilateral predictors

Area Under the Curve					
				Asymptotic 95% Confidence Interval	
Test Result Variable(s)	Area	Std. Error[a]	Asymptotic Sig.[b]	Lower Bound	Upper Bound
ACLR Limb Loading Peak Force	0.617	0.089	0.212	0.441	0.792
ACLR Limb Quadriceps Peak Torque	0.561	0.093	0.516	0.378	0.743
ACL-RSI	0.548	0.092	0.610	0.367	0.729

a. Under the nonparametric assumption
b. Null hypothesis: true area =0.5

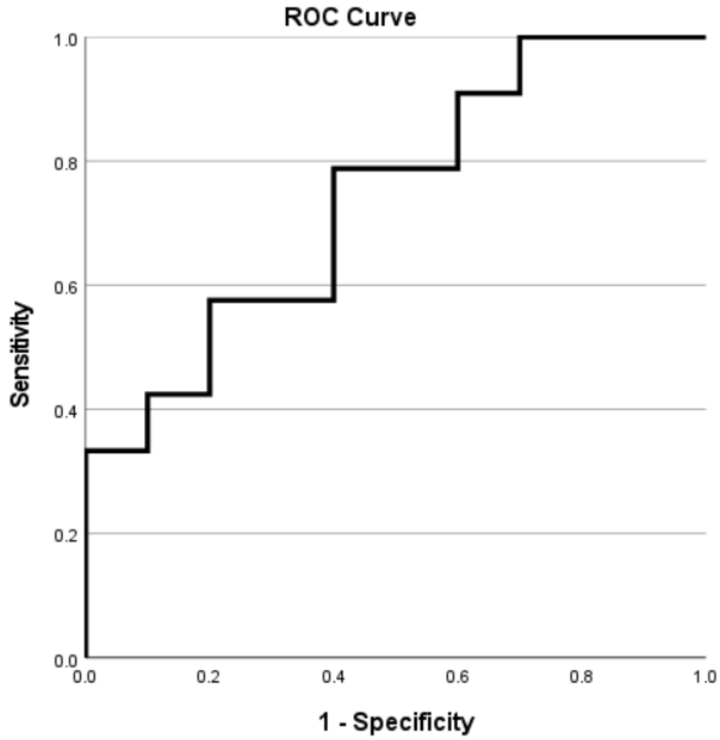


Figure 5: Receiver operator characteristic (ROC) curve used to calculate area under the curve (AUC) for the frontal factor symmetry predictors model.

Table 13: The area under the curve metric from the frontal factor and symmetry predictors

Area Under the Curve				
			Asymptotic 95% Confidence Interval	
Area	Std. Error[a]	Asymptotic Sig.[b]	Lower Bound	Upper Bound
0.739	0.087	0.023	0.568	0.911

a. Under the nonparametric assumption
b. Null hypothesis: true area =0.5

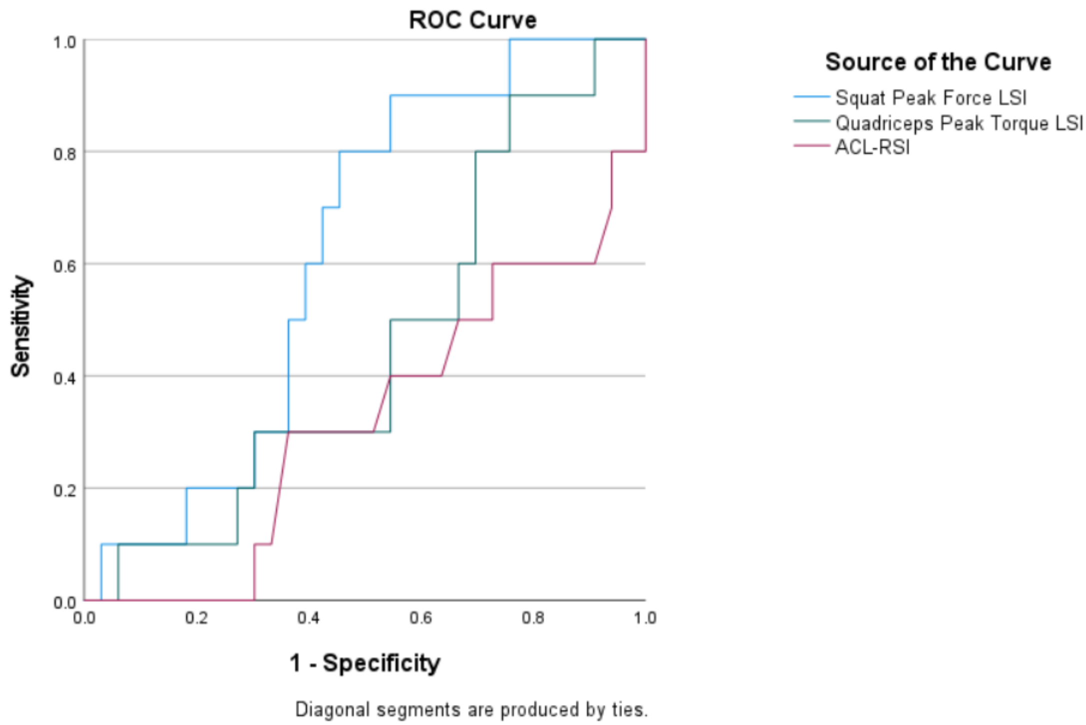


Figure 6: Receiver operator characteristic (ROC) curve used to calculate area under the curve (AUC) for the frontal factor and limb loading symmetry, quadriceps peak torque symmetry, and ACL-RSI score predictors.

Table 14: The area under the curve metric from the frontal factor and itemized symmetry predictors

Area Under the Curve					
				Asymptotic 95% Confidence Interval	
Test Result Variable(s)	Area	Std. Error[a]	Asymptotic Sig.[b]	Lower Bound	Upper Bound
Squat Peak Force LSI	0.618	0.088	0.262	0.446	0.791
Quadriceps Peak Torque LSI	0.455	0.098	0.666	0.262	0.647
ACL-RSI	0.323	0.097	0.093	0.132	0.514

a. Under the nonparametric assumption
b. Null hypothesis: true area =0.5

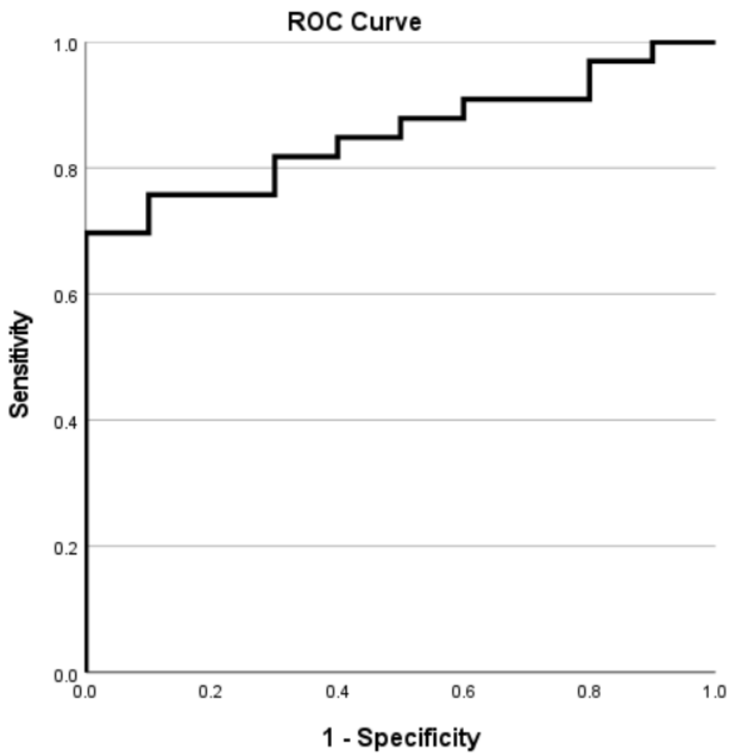


Figure 7: Receiver operator characteristic (ROC) curve used to calculate area under the curve (AUC) for the biplanar factor and unilateral predictors model.

Table 15: The area under the curve metric from the frontal factor and unilateral predictors

Area Under the Curve				
			Asymptotic 95% Confidence Interval	
Area	Std. Error[a]	Asymptotic Sig.[b]	Lower Bound	Upper Bound
0.855	0.056	0.001	0.744	0.965

a. Under the nonparametric assumption
b. Null hypothesis: true area =0.5

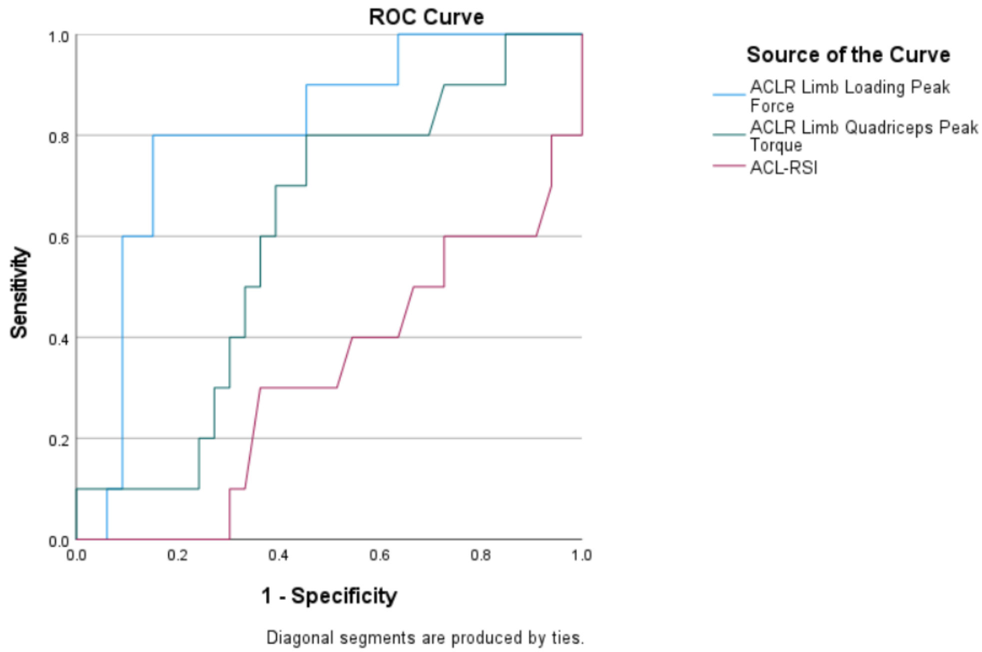


Figure 8: Receiver operator characteristic (ROC) curve used to calculate area under the curve (AUC) for the frontal factor and ACLR limb loading peak force, ACLR limb quadriceps peak torque, and ACL-RSI score predictors.

Table 16: The area under the curve metric from the frontal factor and itemized unilateral predictors

Area Under the Curve					
				Asymptotic 95% Confidence Interval	
Test Result Variable(s)	Area	Std. Error[a]	Asymptotic Sig.[b]	Lower Bound	Upper Bound
ACLR Limb Loading Peak Force	0.809	0.076	0.003	0.661	0.957
ACLR Limb Quadriceps Peak Torque	0.608	0.094	0.307	0.422	0.793
ACL-RSI	0.323	0.097	0.093	0.132	0.514

a. Under the nonparametric assumption
b. Null hypothesis: true area =0.5

APPENDIX E

Recommendations for future research:

1. In patients following ACLR, how does limb loading during a bilateral body weight squat predict long term outcomes such as re-injury, engagement in physical activity and joint degeneration after return to unrestricted activity?

2. How does previous sport participation and limb dominance influence limb loading recovery during a bilateral body weight squat in individuals who have undergone an ACLR?

3. How do more demanding tasks, such as loaded squats alter the relationship between lower extremity strength and limb loading over the course of recovery following ACLR?

4. In patients following ACLR, what is the minimum time between performance testing sessions to successfully identify changes in limb loading performance during a bilateral body weight squat?

5. What is the best clinically accessible approach/methodology to treat and modify limb loading motor behaviors at an interim return-to-activity assessment following ACLR?

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