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Proximal Strength and Functional Testing Applicable to Patellofemoral Instability: A Preliminary Study

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Background: Much of the current literature around risk factors for patellar instability directs attention to anatomical/structural features such as femoral antero-version, patellar alignment, Q-angle, and MPFL disruption. There is limited research indicating clinically relevant tests to identify functional and strength-associated risk factors for patients with patellar instability.

Purpose: To determine reliability and validity of lower extremity functional tests applicable to patients with patellofemoral instability in a healthy control group.

Methods: Twenty-four healthy subjects underwent hip strength, endurance, and lower extremity functional tests on their dominant and non-dominant lower extremities. Hip abduction, extension, and external rotation strength were assessed with hand-held dynamometry utilizing reinforcing straps. Functional endurance tests were assessed bilaterally. Functional assessments were videotaped and assessed at a later date. Each subject completed the International Physical Activity Questionnaire (IPAQ) to determine his or her weekly activity levels. Independent t-tests were used to assess differences between subjects who tested positive versus negative on the functional tests. Inter-rater reliability for functional tests was assessed using kappa and Pearson correlations were used to assess relationships among the strength, endurance, and functional tests.

Results: Inter-rater reliability for the single leg squat and step down test was determined to have fair-moderate agreement among 5 raters. The side plank endurance test was significantly lower for subjects who were positive for knee medial to toe on the single leg squat test. Low correlations were found between hip strength and functional endurance testing. Scores on the IPAQ had moderate correlation with the side plank.

Conclusions: Single leg squat showed adequate reliability and demonstrated good construct validity with the lateral plank endurance test. The low correlation between hip strength and functional endurance suggests that these measurements identify different aspects of muscle function in healthy controls. Given these findings, it is recommended that clinicians utilize both strength measurements and endurance tests along with lower extremity functional testing in the assessment of individuals with lower extremity dysfunction. Further testing is needed in a patient population with patellofemoral instability.

The undersigned certify that they have read, and recommended approval of the research project entitled

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Submitted by

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Table of Contents:

Chapter 1: Introduction

Patellofemoral instability (PFI) can be defined as a sudden lateral misalignment of the patella in the patellofemoral groove.[1] Severity can range from a small subluxation to a complete dislocation with varying degrees of trauma to the surrounding structures. This damage to surrounding structures increases the risk for recurrent episodes of instability in the patellofemoral joint. In 2012, the incidence of PFI was documented to be approximately 2.29 per 100,000 person-years in the US.[2] There is roughly a 50/50 split between episodes related to anatomical characteristics versus traumatic events.[2] Those that experience PFI may be more prone to future instability due to the disruption of joint stabilizing structures such as the medial patellofemoral ligament (MFPL). Those that experience PFI may be more prone to future instability due to the disruption of joint stabilizing structures such as the medial patellofemoral ligament (MFPL). The risk of instability is greater with poor positioning of the knee such as with inward collapse, or valgus positioning (knee medial to the second toe), during squat or step down movement patterns that influence patellar tracking in the patellofemoral groove. Therefore, reducing the incidence of faulty knee mechanics is important in order to maintain the integrity of the knee.[3]

Risk factors that lead to instability can be characterized as non-modifiable and modifiable. Both types of characteristics influence patellar stability and tracking within the patellofemoral groove by maintaining appropriate joint alignment statically and with dynamic movement. These characteristics are measured by both manual analysis using dynamometers to measure strength, observation by skilled researchers for endurance performance, and video analysis to evaluate the degree of mechanical dysfunction like with a dynamic Q-angle.

Non-modifiable risks factors are well studied in PFI, and are typically addressed surgically as they refer to structural characteristics such as femoral antero-torsion and general joint laxity. Non-modifiable risks factors have been thoroughly examined in the literature related to both patellar instability and patellofemoral pain syndrome as discussed later in this literature review. Also, many patients with non-modifiable risk factors, including MPFL disruption do not have surgery. For these patients, mechanics are essential to preventing further instability events.

Modifiable risk factors refer to dynamic or functional characteristics such as strength or dynamic valgus. These factors, under the influence of physical therapists, including muscular and functional movement patterns have been studied in PFPS populations, but PFI patients are routinely excluded from these studies

Upon this review of the literature, no studies currently exist investigating the relationship between hip strength, core endurance, and functional tests with incidence of patellofemoral instability. The purpose of this study aims to document the reliability of lower extremity functional tests and their relationship to clinical measurements of proximal strength and core endurance in a healthy control group. This study serves as a preliminary report to ultimately identify reliable and valid functional tests applicable to patients with patellar instability.

We hypothesized that subjects who were positive for inward collapse of the knee on the functional tests would have lower hip strength and core endurance compared to those who did not demonstrate faulty mechanics on the functional tests.

Chapter 2: Literature Review

Non-modifiable Risk Factors:

Non-modifiable risks factors associated with PFI can include femoral antero-torsion, femoral internal rotation, trochlear dysplasia, and joint laxity amongst others. These risk factors have been thoroughly examined in the literature in patellofemoral instability populations.

Femoral antero-torsion occurs when the femoral head is positioned anteriorly compared to the femoral neck. This has been found to be more prevalent in patients with a history of patellar dislocation and is associated with patellar instability when compared to healthy controls.[4] Femoral internal rotation was found to lead to greater lateral patellar tilt and maltracking of the patella in the patellofemoral groove, and therefore increases the incidence of patellar instability.[5] Higher incidence of patellar mechanical axis deviations was found in the patient groups with history of patellar dislocation and those who demonstrate genu valgum.[4]

Trochlear dysplasia is described as a flattening of the femoral sulcus angle, decreasing the depth of the patellofemoral groove and its ability to provide stable tracking for the patella. It has been widely recognized as a factor leading to patellar instability.[3] Trochlear dysplasia is consistently found in patients with patellar instability and heightens the risk of recurrence.[4,6] However, researchers found conflicting evidence in adolescents, observing no differences between affected knees and control knees.[7]

General joint laxity is determined using manual assessment of the patellofemoral joint, or a 9-point hypermobility screen indicating possible decreased ligamentous stability around the patellofemoral joint. General joint laxity has been indicated as a risk factor for patellar instability and recurrence [4,8] but conflicting research suggests a lack of association between joint laxity and patellar events. [4,9]

Patella alta is commonly indicated as a risk factor for patellar instability due to its high prevalence in patients that have experienced dislocation or subluxation for the first time.[4,10,11] Lateral patellar tilt during eccentric quadriceps loading has a higher incidence in patellar instability populations compared to controls. [5,6]

There is conflicting evidence in the literature as to the contribution of the Q-angle to patellar instability and incidence of subluxation. [4]

MPFL disruption is thought to be a risk factor for patellar dislocation due to its medial attachment to the patella, and its common injury with dislocation. When comparing lateral patellar displacement in those that dislocate their patellas, it was found that dislocated patellas had greater displacement values, or laxity, compared to subjects' unaffected knee.[4] In a prospective cohort study, 72 military males who were first time dislocators were found to have ruptured the MPFL 100% of the time, and that the MPFL contributed to 50% of patellar restraint during forceful lateral displacement resulting in dislocation.[12] In another prospective cohort study, 189 patients were followed to assess resulting instability 2-5 years post-damage to MPFL during patellar dislocation. This study found that individuals who had damage to MPFL had a lower risk of instability, though these findings were not significant. This finding may be due to the varied degree of damage to the MFPL in particular individuals but the severity of damage was not reported.[1]

Modifiable Risk Factors

Modifiable risks factors, including muscular endurance, strength, and flexibility, as well as aspects of dynamic and static movement, can be affected with targeted training. There is a large volume of evidence investigating these factors as they relate to the patellofemoral pain population. These authors theorize that modifiable factors including hip strength, core endurance, and lower extremity movement patterns may indicate risks for impaired function at the knee joint. It is well accepted that lack of proximal strength and dynamic control is a primary driver of inward collapse at the knee causing the patella to track laterally and thus increase the risk of patellofemoral pain. [5, 13-17] This same mechanism could increase the risk for patellar subluxation and dislocation and has not been previously been studied in the PFI population.

Static Modifiable Risks Factor Measurements

VMO Strength

A systematic literature review by Lankhorst, Bierma-Zeinstra & Middelkoop investigated quadriceps strength as a risk factor for patellofemoral pain.[13] Quadriceps strength was included in two of the studies in this review. In one reviewed study, researchers found greater isometric quadriceps strength to be a risk factor, but only when it was looked at independently. When they compared strength to the participants' body weight, the findings were not significant. The second reviewed study concluded quadriceps weakness was a risk factor for future occurrence of patellofemoral pain syndrome (PFPS). The reviewed studies demonstrate conflicting findings on the influence of the quadriceps, and thus VMO on patellofemoral joint function. VMO weakness is suggested to lead to reduced patellofemoral joint function by decreasing medial patellar stability leading to excessive lateral tracking, and thus increase risk for PFP. With decreased quad strength and VMO activation, the patella is thought to have greater movement laterally and create dysfunction and patellofemoral instability.

Hip Strength

Hip strength has been investigated as a risk factor for patellofemoral pain syndrome as hip weakness increases risk of inward collapse at the knee due to decreased control during dynamic movement, but two different systematic reviews have provided conflicting results. Lankhorst et al.'s systematic review found one cohort study that included four different hip strength variables.[13] The findings of the study showed no significant difference between hip strength and future occurrence of patellofemoral pain syndrome. Conversely, a systematic review by Prins and van der Wurff [18] looked at the hip strength findings from five case control studies with female subjects. The authors concluded there was strong evidence for weak hip abduction, extension and external rotation in the

PFPS subjects compared to the control subjects. With conflicting evidence, and a well-documented relationship between hip and knee function, it may be important to further investigate the relationship between hip strength and patellofemoral instability as this has not been previously documented.

Core Proprioception

It has been previously noted by several studies that deficits in core proprioception may cause poor neuromuscular function of the lower extremities, and ultimately result in increased strain of the knee ligaments. In a cohort study by Zazulak et al.[19], 277 college athletes were prospectively tested for active and passive proprioceptive repositioning using a previously validated apparatus. The athletes were followed for three years while being monitored for injury. The results of this study concluded that decreased active core proprioception predicted knee injury in female athletes, but not male participants. The analysis of the results focused mainly on the ACL/MCL injuries, but 12 of the 25 athletes that sustained an injury within the time period of the study were non-specific patellofemoral injuries.[19]

Dynamic Modifiable Risks Factor Measurements

Functional and Endurance Testing

Poor strength measures of the core, hip and quadriceps are thought to correlate with faulty mechanics as these muscles stabilize the pelvis during dynamic activities such as walking, squatting, stair climbing. Not all studies have shown this relationship clearly, however. Dynamic alignment of the lower extremity is considered to be a key risk factor for lower extremity injury including patellofemoral dysfunction.[5] With functional testing, dynamic muscular control and movement pattern quality can be assessed to help discern whether muscular strength, poor mechanics, or poor motor control is at fault. Two previously studied lower extremity functional tests that visually assess knee and pelvic control during movement are the step down test and the single leg squat, also referred to in the literature as the single leg small knee bend. Due to the required hip and core muscle stabilization of the pelvis, assessment of plank and single leg bridge testing may also identify correlations in dynamic movement dysfunction and endurance performance. It should be noted that patients with patellar instability were excluded from prior studies.

Step Down Test

The step down test involves weight-bearing stress and requires dynamic muscular control at the pelvis in order to control descent. Improper muscular control or poor mechanics can create a valgus stress at the knee specifically at the tibiofemoral and patellofemoral joints. A study by Kyung et al [20] looked at inter-rater reliability of the step down test in addition to comparing it to hip muscle strength, lower extremity range of motion (LE ROM), and flexibility in asymptomatic women. Inter-rater reliability was good with a kappa coefficient of 0.80 and 85% agreement. Women who demonstrated only moderate movement quality showed significant differences with decreased hip abduction strength, decreased knee flexion range of motion in prone positioning, decreased adduction range of motion of the hip in sidelying and decreased quadriceps and tensor fascia latae/iliotibial band flexibility when compared to women with good movement quality.[20]

A study by Crossley et al (2011) [21] looked at the intra-rater reliability of the single leg squat test and compared the test to hip muscle strength and the onset of timing of the anterior and posterior gluteus medius muscles through use of EMG activity. Intra-rater agreement was found to be excellent to substantial with a kappa coefficient ranging from 0.613 to 0.800 and agreement from 73% to 87%. Subjects in the study were rated as good or poor performers of the single leg squat test. Subjects who were rated as good performers were found to have greater hip abduction torque than those subjects who were rated as poor performers and no difference was found between the 2 groups in hip external rotation torque. Subjects who were good performers were also found to have a significantly earlier onset of anterior and posterior gluteus medius activation.[21]

Single Leg Squat

The single leg squat is a functional test similar to the double legged squat but it requires standing on one leg at a time while the contralateral hip is held in neutral and the knee bent to about 80 degrees or as low as the individual is able. The primary observations during this movement are focused at holding the pelvis in neutral and keeping the knee in-line or just lateral of the great toe of the stance foot. A cross sectional study by Ageberg et al [16] had 25 non-injured individuals performing a single leg small knee bend with 2 physiotherapists observing and compared it to a 3D analysis in which inter-rater reliability between the two therapists was excellent with a kappa coefficient of 0.92. Ageberg also found that the knee could be correctly identified as being in-line or falling medially to the foot. When compared to 3D analysis it was found that if the knee falls medially to the foot the hip was more internally rotated.[16] Whatman et al also looked at the single leg small knee bend and the ability among 66 physiotherapists to correctly observe knee and pelvis alignment. Intra-rater and inter-rater reliability in identifying the knee alignment was good at 0.71 and moderate at 0.52 respectively, and was 0.73 and 0.53 when rating the pelvis as dropped on one side from the front plane view.[17]

Endurance Tests

The single leg glute bridge and the side plank are two tests that assess the endurance capacity of the hip and core musculature. The single leg glute bridge assesses the lumbo-pelvic stability during a high demand movement.[22] Poor mechanics throughout the test can be due to muscle imbalances which will require compensation strategies to maintain the position. Research by Andrade et al in 2012, [22] determined substantial inter-rater reliability and fair to moderate intra-rater reliability for the transverse plane measurement. The side plank assesses the endurance of the core musculature of the trunk and the lateral musculature of the hip. It has been noted in clinical practice and theorized in research that the core musculature contributes to knee positioning in functional testing.[23, 24] Reliability has been reported to be excellent with an ICC of 0.95 to 0.99 and an SEM of 3.40 to 9.93 seconds.[25]

Chapter 3: Methods

Study Design and Setting

This study utilized a cross-sectional design. Participants that were recruited attended one testing session at the St. Catherine University, Minneapolis campus.

Participants

Twenty-three healthy participants (21 females and 2 males) were recruited through the local university. Exclusion criteria included current lower extremity pain, history of knee surgery, history of fracture in the lower extremity within the last three years, current pregnancy, cancer, or other active systemic disease. Given these criteria, twenty-three healthy college-age subjects volunteered and gave informed consent. Due to only 2 males in the subject population, those subjects were dropped and 21 female subjects were assessed.

Measures

Each subject underwent testing that assessed hip strength, core and hip endurance, and lower extremity functional tests on both their dominant and non-dominant lower extremities. Height and weight were recorded and all completed an International Physical Activity Questionnaire (IPAQ) to determine their weekly activity levels.

Strength Testing

Hip isometric strength was assessed with hand-held dynamometry and utilized reinforcing straps. Krause et al found that hand-held dynamometry had excellent inter- and intra-rater reliability for hip strength testing.[26] Each strength measure was collected over two maximal effort trials after one practice trial at fifty percent effort. Moment arm length was recorded for each test and used to determine torque. Three hip strength measures were collected using standardized positions shown in Figures 1-3: external rotation (ER) , extension, and abduction.

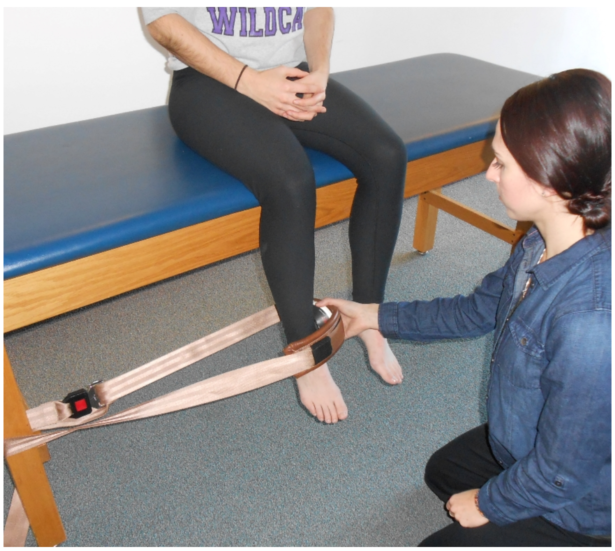

Figure 1. Hip External Rotation test position for maximum strength assessment with hand-held dynamometry.

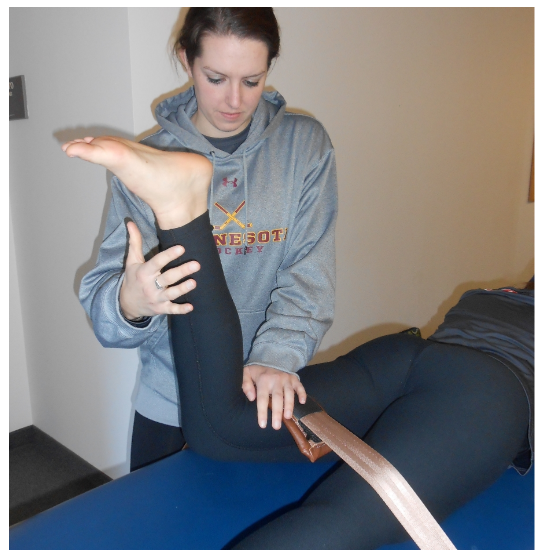

Figure 2. Hip extension test position for maximum strength assessment with hand-held dynamometry.

Figure 3. Hip abduction test position for maximum strength assessment with hand-held dynamometry.

For external rotation strength, the subject was positioned seated on the edge of a table with a reinforcing strap and dynamometer placed just above the medial malleolus. The knees were bent at ninety degrees and the feet were off the ground. The arms were rested on the lap to avoid upper extremity stabilization. Tibia moment arm length was recorded on each subject to determine torque.

For hip abduction, the subjects were positioned lying on their side with the strap and dynamometer placed superior to the lateral femoral condyle. The leg being tested was held in neutral flexion-extension and placed in ten degrees of abduction. Femur moment arm length was recorded to determine torque.

Hip extension strength emphasizing the gluteus maximus was assessed with the subject positioned prone with the legs underneath the reinforcing strap. The strap and dynamometer were placed just superior to the popliteal fossa, the knee bent to ninety degrees, and the leg lifted ten degrees into extension off the table. Femur moment arm length was used to determine torque.

Endurance Testing

Endurance tests were assessed bilaterally with a minimum five-minute rest break between each test. Once instructed, the subject was asked to demonstrate the position for five seconds to ensure understanding and correct any errors in form. When ready, participants were asked to attain the position and instructed to hold as long as they could. Throughout all endurance tests the subject would receive one form correction, if needed. A test was ended once the subject reached fatigue noted by subject collapse, or a loss of form.

The first measure was the side plank, which is described in multiple studies by McGill et al and has demonstrated excellent reliability.[25] As shown in Figure 4, the subjects would lie on their side on top of a table. The top foot was placed in front of the bottom foot on the table for support. The bottom elbow was placed under the shoulder to support the upper body. Subjects were instructed to lift the hips up off the table to maintain neutral trunk and hips and support themselves through their elbow and feet. The uninvolved arm was placed at the subject's side. Loss of form was noted by a break in neutral trunk alignment by either a drop in hip height or trunk rotation at the hips or shoulder.

The second endurance test was a single leg bridge shown in Figure 5. A study by Andrade et al describes the basic positioning for this test with a few adaptations being made by the researchers.[22] The subjects were positioned supine on a table with both knees bent to a self-selected range of motion, feet flat on the table, and arms across the chest. The subject was instructed to raise the pelvis from the mat and extend one knee while maintaining a level trunk and pelvis. An elastic string was positioned above the subject's anterior superior iliac spine, or ASIS, for the rater's ability to visualize a pelvic drop. Loss of form was determined by either a drop in the height of the pelvis, or a drop in one side of the pelvis noting an inability to maintain a level trunk and pelvis.

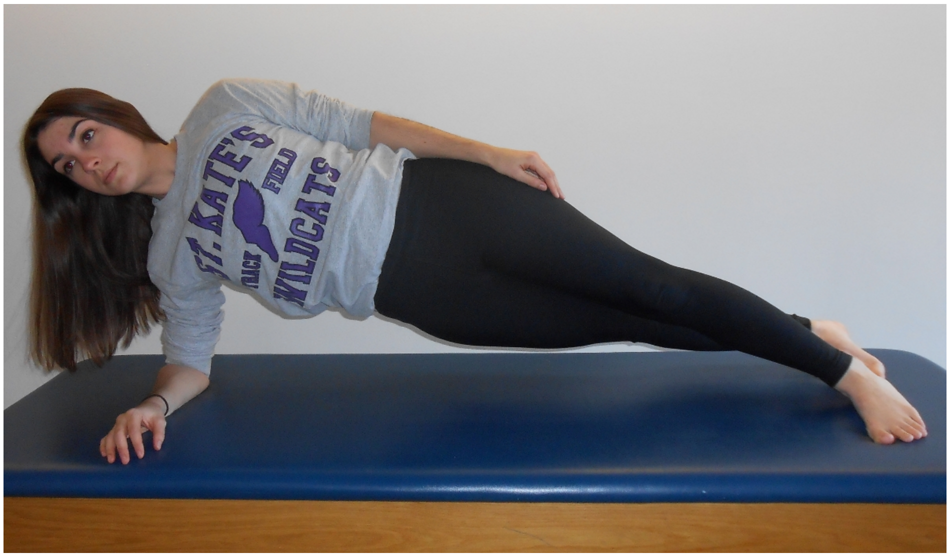

Figure 4. Side plank test position for maximum hold time.

Figure 5. Single leg bridge test position for maximum hold time.

Functional Testing

Two lower extremity functional tests were used to assess neuromuscular control. Each test was performed five times on the dominant and non-dominant lower extremities. All tests were recorded using a video camera positioned fifteen feet directly in front of the subject for a frontal view. Videos were reviewed on a later date and assessed by five novice researchers, and one experienced researcher. All items assessed during functional testing were considered positive if they occurred on three or more repetitions.

The first of these measures was the step down test shown in Figure 6. In this study, subjects were positioned on a step with a height that allowed the knee to bend to approximately sixty degrees, with hands placed on the hips. The subject was instructed to step down in a slow and controlled motion until the heel tapped the floor, and then return back to the starting position. Videos were assessed using two different scales: 1) observation for increase in the dynamic Q angle noted by a decreased angle between the pelvis and femur determined as none, mild, or moderate-major, and 2) a 5-point scale with each item rated as yes/no: knee medial to the second toe, a unilateral drop of the pelvis, maintained balance, demonstration of a trunk lean, or if the subject utilized an arm strategy to maintain balance.[14]

The final test was a single leg squat shown in Figure 7. The subject was instructed to stand on one leg with upper extremity assist for balance provided by a dowel placed horizontally at the height of the subject's ASIS. A metronome was set at a rate of 40 beats per minute for timing of the squat. Subjects were then instructed to bend their knee until they could no longer visualize a marker placed in front of the great toe and then return to the starting position. The marker was placed so that the subject's knee flexion angle was approximately sixty degrees.

Video assessment focused on 1) if the knee fell medial to the second toe and 2) whether a dynamic Q was present, rated as none, mild, or moderate-major rated as 0, 1 or 2 respectively.

Figure 6. Step down test to assess knee medial to second toe.

Figure 7. Single leg squat test to assess knee medial to second toe.

International Physical Activity Questionnaire

The IPAQ was developed in 1996 as a tool to assess physical activity level in adults ages 18-65. Scores indicate level of activity in MET-minutes per week. It has since been used nationally and internationally as a reliable measure and when compared with seven other self report measures it has shown 7 day repeatability demonstrated by an average Spearman coefficient of 0.80 and criterion validity of 0.30 .[27] Subjects completed this questionnaire during their testing session.

Statistical Analysis:

Descriptive statistics were run to determine the mean age, weight and hold times for the endurance tests for the participants. Kappa coefficients were utilized to determine the inter-rater reliability of the single leg squat and step down tests for each pair of raters using different scoring criteria and cut-off values. Average kappa coefficients were calculated for all lower extremity functional testing and used for categorization of the value. The kappa coefficient categories can be found in Table 1. For the most reliable scoring systems, we used consensus ratings to define groups of subjects that were positive or negative on the functional tests.

Independent t-tests were run to determine between group differences on the strength, endurance, and physical activity measures. Strength was expressed as a percentage of body weight. Mann-Whitney U tests were used if data were not normally distributed. We hypothesized that subjects who were positive for inward collapse on the functional tests would have lower hip strength, core endurance, and activity levels compared to those who were negative on the test. Lastly, Pearson product-moment correlations were used to assess the relationship among the three strength measurements, the two endurance tests, and the total IPAQ scores. Due to only two male participants in the study, they were excluded from the main analyses.

Chapter IV: Results

Descriptive Statistics

Means for age, height and weight, isometric strength and endurance test hold times were calculated for both male and female participants. These values are found in tables 2 and 3.

Reliability

A summary of the inter-rater reliability can be found in Tables 4 and 5. For dynamic Q angle, 0-1 was classified as normal with the patient demonstrating none to mild dynamic Q, while 2 was classified as abnormal with the patient demonstrating moderate to severe dynamic Q. For the step down total score, 0-1 was classified as normal, while a score of 2 or more was classified abnormal or a positive finding. Moderate reliability was found between the raters for knee medial to toe during single leg stance on both dominant and non-dominant lower extremities with a mean kappa value of 0.41. Though these mean kappa values show moderate reliability, it should be noted that a large range was present among the raters. Additionally, a substantial level of reliability was calculated for a dynamic Q angle with a mean kappa value of 0.66 on the dominant and 0.80 on the non-dominant lower extremities. Moderate reliability was found for the total score of the step down on the non-dominant side with a kappa value of 0.41. A total score was classified as abnormal if the individuals had a score greater than 1. All other step down findings were not clinically adequate due to the kappa values ranging from slight to fair reliability.

Between Group Differences

Significant between group differences were found between those who tested positive versus negative for knee medial to toe on the single leg squat test for the side plank endurance test on the dominant side. Those who tested positive for knee medial toe on the single leg squat test had significantly lower side plank hold times. (Figure 8) Positive and negative ratings were determined by consensus among the 6 raters. Differences between positive versus negative SLS tests on the non-dominant side were near significance with p=0.079. No between group differences were noted for the SL Bridge tests between subjects who tested positive vs. negative on the SLS and step down test.

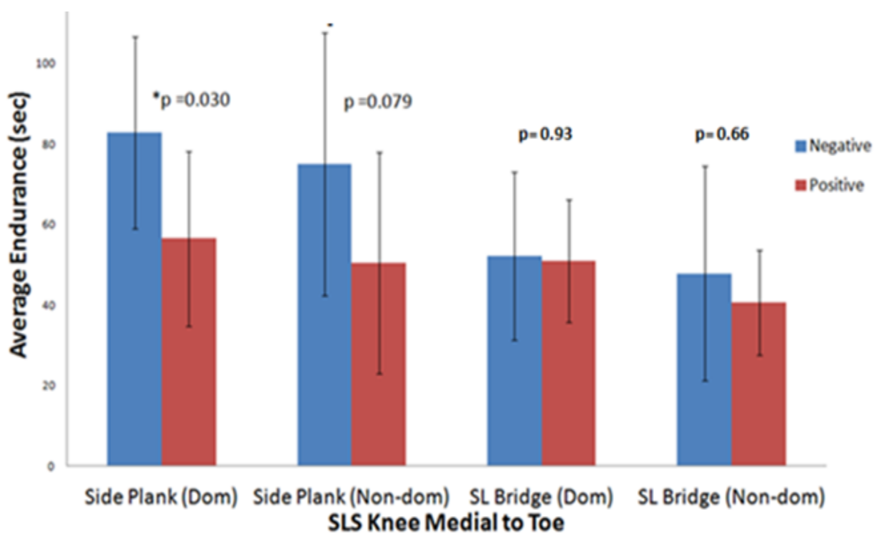

Figure 8: Between group differences of the endurance tests and those who tested positive or negative on the SLS for knee medial to toe.

A significant difference was found in average weekly sitting time based on the IPAQ subscale between those who tested positive and those who tested negative on the SLS test on the dominant lower extremity (Figure 9). No significant differences were found based on SLS test results for the non-dominant lower extremity. Additionally, no differences were found between torque values for the isometric strength tests on the dominant or non-dominant lower extremities.

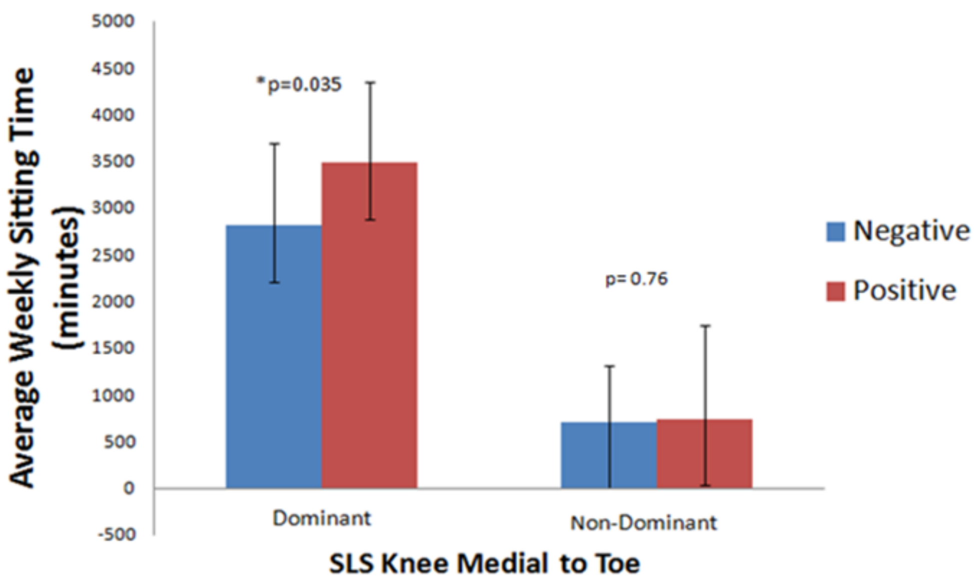

Figure 9: Between group differences of the average sitting time per week of those who tested positive and negative on the SLS knee medial to toe.

<u>Associations Between Measures</u>

Fair to moderate correlation was found between the side plank and total physical activity level on the IPAQ with r = 0.52 on the dominant side and r = 0.50 on the non-dominant side in the female subgroup.**(Table 6 and 7)** Total physical activity scores did not show a strong correlation with the single leg bridge or isometric strength tests. Additionally, no significant correlations were found between the isometric strength tests and the endurance tests in the female subject population. Moderate correlation was found between hip extension and ER isometric strength on the non-dominant lower extremity, but this was not seen on the dominant side.

Chapter V: Discussion

The goal of our study was to identify reliable and valid lower extremity functional tests and to determine if there is a relationship to proximal strength, core endurance, and physical activity levels in a healthy control group. It is our hope that the information gained from this preliminary study may be used in a future study on patients with patellofemoral instability.

This study is one of the first to look at the relationship among core endurance, isometric hip strength, and LE functional movement testing. The t-test results indicated that those subjects with higher endurance values on the side plank had better scores on their functional tests. Due to the limited research our finding has implications for future research testing in a patient population as well as current testing in the clinic. The results from our study may imply what testing is most beneficial when assessing lower extremity conditions. From these results, we conclude that endurance had a greater effect on functional ability compared to isometric maximal hip strength.

Our finding that endurance has a greater effect on functional ability has implications for future testing in a patient population. Core endurance can be assessed easily in a clinic, requires few materials, and is not time consuming. Therefore, based on our results, if a clinician is limited by time during an evaluation then it may be more beneficial to assess core endurance in addition to isometric hip strength when assessing lower extremity overuse conditions.

Previous literature has found that there was moderate to substantial inter-rater reliability when rating knee medial to toe on the single leg squat test. [17] Our statistical analyses revealed moderate inter-rater reliability for ratings of knee medial to toe scored as positive or negative on the single leg squat, which we determined was adequate for clinical use. The reliability results from our study are also in agreement with previous reliability studies with researchers who have less than 5 years of experience.[17]

Higher inter-rater reliability was found for dynamic Q angle scored as moderate or greater during the same single leg squat test. In our study, healthy control subjects were used and the cutoff criteria for rating the dynamic Q angles was having a score greater than or equal to 2. Even though only 8% or 2 of our 21 subjects had a positive finding, there will most likely be a higher prevalence of positive tests within a patient population. Therefore, it may be more reliable to use moderate to severe as a cutoff score when determining a positive dynamic Q angle when having a patient population perform the functional test, as they will likely have more obvious impairments while performing the test.

The rest of our reliability scores were much lower than previous research has shown. These findings may be explained by several limiting factors. The primary limitation may involve the technology that was used to analyze the videos of the functional tests. Our video analysis used a 2-dimensional representation of the functional tests, which lead to a lack of depth perception when viewing the videos and made analysis of the recordings more challenging.

Even though the 2-dimensional representation has its limitations, it was chosen for our study because it was more practical for a clinical measure compared to a 3-dimensional motion analysis. We chose video analysis because it was the only measure feasible for reliability testing with multiple testers. Based on our findings, we would recommend that video analysis not be used in a clinic setting. Additionally, we only allowed one viewing of the functional tests in order to simulate clinical practice. Performing the functional tests in the clinic would eliminate this limitation by increasing the overall visual quality of the movement as compared to a 2-D video.

Due to time constraints, there was also limited training for researchers to learn how to rate the functional testing videos. Researchers assessed a limited number of videos of each other performing the functional tests when learning to rate the functional testing videos. In future studies, it would be beneficial for researchers to practice assessing a greater number of functional tests and come to a clear consensus on ratings in order to become more efficient and accurate raters.

A moderate correlation between the side plank endurance test and the total physical activity of each subject was found, which was determined based on the IPAQ results. These results indicate that greater amounts of total physical activity are associated with better core endurance values. These results can be applied to a patient population in a clinic because they suggest that improving total physical activity levels can impact a patient’s core endurance. This information is exciting because it may follow that improving core endurance through physical activity may also improve ability to perform good quality LE functional movements.

Another limitation from our study was only having one researcher assess the side plank endurance test for each subject. In order to determine if a subject had a loss of form, the researcher had to be aware of either a drop in hip height or trunk rotation at the hips or shoulder. There were different optimal viewing positions for the researcher to be in order to note these losses of forms and it was difficult for a single researcher to view the side plank endurance test from multiple angles. The difficulties with view proper side plank form may have allowed a subject to correct a loss of form before the researcher was aware of it and may make this measurement more difficult to perform in the clinic.

Additionally, some subjects found it confusing and difficult to fill out the IPAQ. The IPAQ required subjects to specify the number of minutes each week spent performing certain activities and recall of these activities may have been limited. However, this measure was chosen for our study because it had good reliability and requires less time than many alternative measures. Even though we chose to use the IPAQ for our study, we would recommend that another measure be used in the clinic that is easier to complete and quicker to score.

There were no significant correlations found between isometric strength tests and the functional endurance tests in our study. Due to the low correlation values between hip strength and functional endurance, we infer that strength and endurance assess different aspects of muscular function in healthy control subjects. Therefore, it is important to measure both in a clinical exam in order to assess all aspects of a patient's muscular function.

Recommendations for further research would be to include more training for researchers who are rating functional tests. This could potentially improve the reliability of the functional measures making them more appropriate for use in the clinical setting. Additionally, our study only included healthy control subjects and it would be beneficial to include a greater number of subjects, both healthy controls and those with patellofemoral instability. Comparing results of functional movements, endurance and strength tests between a healthy population and a patient population could help identify risk factors and baseline impairments for patients with patellofemoral instability.

In conclusion, there does appear to be a relationship between core endurance and functional ability as evidenced by the significant association between side plank endurance and quality of movement on functional tests. This study also found a lack of correlation between maximal isometric hip strength and functional movement quality. These two findings together suggest that core endurance may be more important than maximal isometric hip strength when evaluating individuals with lower extremity dysfunction.

Chapter VI: Conclusion

From our results, we conclude that strength, endurance, and LE functional tests assess different aspects of muscle function. Additionally, core endurance may be more important than hip strength when evaluating individuals with lower extremity dysfunction. Clinicians should utilize these tests in combination when assessing individuals with lower extremity dysfunction in order to gain a greater understanding of a patient’s functional limitations. Further investigation of these factors in a patient population with patellofemoral instability will be needed.

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Table 1. Kappa coefficient categories

Kappa coefficient	***Interpretation (Landis and Koch. Biometrics. 33(1)159-174.)***[28]
0.00- 0.20	Slight
0.21- 0.40	Fair
0.41- 0.60	Moderate
0.61- 0.80	Substantial
0.81 -1.0	Almost perfect

Table 2. Descriptive Statistics

	Female (n=21)	Male (n=2)
Age	23.9 ± 2.0	22.5 ± 0.7
Height (in)	66.9 ± 2.5	70.0 ± 4.2
Weight (lbs)	141.3 ± 14.1	180.0 ± 22.6

Table 3. Descriptive statistics

Isometric Strength Non- Dominant Side (Percent of body weight)	**Female (n=21)**	**Male (n=2)**
Abduction	0.39 ± 0.06	0.49 ± 0.07
External Rotation	0.17 ± 0.04	0.22 ± 0.02
Extension	0.29 ± 0.07	0.30 ± 0.01
Isometric Strength Dominant Side (Percent of bodyweight)		
Abduction	0.39 ± 0.06	0.43 ± 0.06
External Rotation	0.17 ± 0.05	0.22 ± 0.08
Extension	0.31 ± 0.06	0.36 ± 0.12
Endurance Hold times Non- Dominant Side (sec)		
Side Plank	68.3 ± 20.0	65.5 ± 14.8
Single Leg Bridge	43.2 ± 23.3	60.0 ± 36.8
Endurance Hold times Dominant Side (sec)		
Side Plank	67.6 ± 24.2	79.6 ± 11.9
Single Leg Bridge	49.2 ± 28.6	48.5 ± 30.4

Table 4. Inter-Rater Reliability on Dominant Lower Extremity

	Kappa (κ) Value Range	Mean κ Value	Classification
SLS Knee Medial to Toe	0.08-0.64	0.41	Moderate
SLS Dynamic Q Angle (0-1 vs. 2)	0.47-1.0	0.66	Substantial
SD Dynamic Q Angle (0-1 vs. 2)	0.08-0.65	0.30	Fair
SD Total Score (0-1 vs. 2 or more)	0.08-0.65	0.29	Fair

SLS: Single leg squat, SD: Step down

Table. 5 Inter-Rater Reliability on Non-Dominant Lower Extremity

	Kappa (κ) Value Range	Mean κ Value	Classification
SLS Knee Medial to Toe	0.24-0.70	0.41	Moderate
SLS Dynamic Q Angle (0-1 vs. 2)	0.51-1.0	0.80	Substantial
SD Dynamic Q Angle (0-1 vs. 2)	-.08- 0.62	0.19	Slight
SD Total Score (0-1 vs. 2 or more)	0.11-0.66	0.41	Moderate

SLS: Single leg squat, SD: Step down

Table: 6 Dominant Lower Extremity Correlation Results

	Hip ABD	**Hip ER**	**Hip EXT**	**Side Plank**	**SL Bridge**	**Total Physical Activity**
Hip ABD		0.43*	0.48*	0.23	-0.17	0.18
Hip ER			0.65**	-0.004	-0.23	-0.097
Hip EXT				0.09	-0.17	-0.12
Side Plank					-0.19	0.52**
SL Bridge						-0.35

* Fair correlation   **Moderate correlation

Table: 7 Non-Dominant Lower Extremity Correlation Results

	Hip ABD	Hip ER	Hip EXT	Side Plank	SL Bridge	Total Physical Activity
Hip ABD		0.28*	0.49*	0.20	-0.06	-0.07
Hip ER			0.67**	0.59**	-0.23	0.02
Hip EXT				0.52**	-0.29	0.15
Side Plank					-0.18	0.53**
SL Bridge						-0.13

* Fair correlation **Moderate correlation

Appendix A: Informed Consent Form

Reliability and Validity of Lower Extremity Functional Measures
INFORMATION AND CONSENT FORM

Introduction:
You are invited to participate in a research study investigating measurements of lower extremity functional ability. This study is being conducted by Samantha Alschlager, Danielle Honnette, Katelyn Ley, Brianna Ludtke, and Kristen Reed graduate students at St. Catherine University under the supervision of John Schmitt, PT, PhD, and Kristen Gerlach, PT, PhD, faculty members in the Doctor of Physical Therapy Program. You were selected as a possible participant in this research because you are a healthy individual with no current leg pain between ages 14 and 40. Please read this form and ask questions before you decide whether or not to agree to be in the study.

Background Information:
The purpose of this study is to assess the reliability of clinical measures of functional ability, and to test how they relate to measures of core and lower extremity strength and endurance. The data from subjects in this study may also be useful for comparison to patients with lower extremity overuse syndromes or other lower extremity conditions in future studies. Approximately 50 people are expected to participate in this research.

Procedures:
If you decide to participate, you will be asked to provide information on age, sex, education, and race, and will complete a questionnaire on activity level. You will then be tested on isometric hip strength for 3 muscle groups, the single leg squat and step down tests which will be video-recorded, and 2 tests of core muscle endurance. This study will take approximately 50-60 minutes in one session.

Risks and Benefits of being in the study:
The study has a small risk of next day muscle soreness which should dissipate within a few days. There are no direct benefits to you for participating in this research. For future practitioners, knowledge of the reliability of clinically relevant measures and a clearer understanding of how hip strength and core endurance relate to lower extremity biomechanics may help focus treatment strategies, and could impact the long term success of rehabilitation.

Compensation:
If you participate, you will receive a $10 gift card from Target.

In the event that this research activity results in muscle soreness or an injury, we will assist you with advice on how to care for it. Any medical care for research-related injuries should be paid by you or your insurance company. If you think you have suffered a research-related injury, please let us know right away.

Confidentiality:

Any information obtained in connection with this research study that can be identified with you will be disclosed only with your permission; your results will be kept confidential. In any written reports or publications, no one will be identified or identifiable and only group data will be presented.

We will keep the research results in a locked file cabinet in Dr. Schmitt's office and only the researchers named in this form and our advisors will have access to the records while we work on this project. We will finish analyzing the data by December 30, 2015. We will then destroy all original reports and identifying information that can be linked back to you.

Video recordings will be framed from the shoulders down so as reduce the potential to identify you. Digital videos will be transferred from the camera to Dr. Schmitt's password protected University laptop computer, then they will be erased from the camera. For purposes of this study, only the above named researchers will have access to the videos. However, if you give permission at the end of this form, video recordings will be kept indefinitely for future research and teaching purposes, as these would provide useful for researchers and student physical therapists to examine their reliability and to learn about how to score these functional tests. If you do not wish to allow permanent storage, the digital recordings will be erased by December 30, 2016.

Voluntary nature of the study:
Participation in this research study is voluntary. Your decision whether or not to participate will not affect your future relations with St. Catherine University in any way. If you decide to participate, you are free to stop at any time without affecting these relationships. You may decline to answer questions on the survey or ask to skip a particular test, but you will need to stay for the entire research protocol to receive the $10 gift card.

Contacts and questions:
If you have any questions, please feel free to ask questions now, or contact Danielle Honnette at 507.841.1380. If you have any additional questions later, the faculty advisor, John Schmitt (651.690.7739; jsschmitt@stkate.edu) will be happy to answer them. If you have other questions or concerns regarding the study and would like to talk to someone other than the researcher(s), you may also contact Debbie Yang of the St. Catherine University Institutional Review Board, at (651) 690-6204 or debbieyang@stkate.edu.

You may keep a copy of this form for your records.

Statement of Consent:
You are making a decision whether or not to participate. Your signature indicates that you have read this information and your questions have been answered. Even after signing this form, please know that you may withdraw from the study.

I consent to participate in the study, and I agree to be video-recorded.

☐ (Optional): By checking this box, I give my permission for my video-recordings to be kept indefinitely for future research and teaching purposes.

Signature of Participant Date

Signature of Parent, Legal Guardian, or Witness Date
(if subject is between ages 14-17)

Signature of Researcher Date

Appendix B: IPAQ Form

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE (October 2002)

LONG LAST 7 DAYS SELF-ADMINISTERED FORMAT

FOR USE WITH YOUNG AND MIDDLE-AGED ADULTS (15-69 years)

The International Physical Activity Questionnaires (IPAQ) comprises a set of 4 questionnaires. Long (5 activity domains asked independently) and short (4 generic items) versions for use by either telephone or self-administered methods are available. The purpose of the questionnaires is to provide common instruments that can be used to obtain internationally comparable data on health–related physical activity.

Background on IPAQ
The development of an international measure for physical activity commenced in Geneva in 1998 and was followed by extensive reliability and validity testing undertaken across 12 countries (14 sites) during 2000. The final results suggest that these measures have acceptable measurement properties for use in many settings and in different languages, and are suitable for national population-based prevalence studies of participation in physical activity.

Using IPAQ
Use of the IPAQ instruments for monitoring and research purposes is encouraged. It is recommended that no changes be made to the order or wording of the questions as this will affect the psychometric properties of the instruments.

Translation from English and Cultural Adaptation
Translation from English is encouraged to facilitate worldwide use of IPAQ. Information on the availability of IPAQ in different languages can be obtained at www.ipaq.ki.se. If a new translation is undertaken we highly recommend using the prescribed back translation methods available on the IPAQ website. If possible please consider making your translated version of IPAQ available to others by contributing it to the IPAQ website. Further details on translation and cultural adaptation can be downloaded from the website.

Further Developments of IPAQ
International collaboration on IPAQ is on-going and an ***International Physical Activity Prevalence Study*** is in progress. For further information see the IPAQ website.

More Information
More detailed information on the IPAQ process and the research methods used in the development of IPAQ instruments is available at www.ipaq.ki.se and Booth, M.L. (2000). *Assessment of Physical Activity: An International Perspective.* Research Quarterly for Exercise and Sport, 71 (2): s114-20. Other scientific publications and presentations on the use of IPAQ are summarized on the website.

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** and **moderate** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal.

PART 1: JOB-RELATED PHYSICAL ACTIVITY

The first section is about your work. This includes paid jobs, farming, volunteer work, course work, and any other unpaid work that you did outside your home. Do not include unpaid work you might do around your home, like housework, yard work, general maintenance, and caring for your family. These are asked in Part 3.

1. Do you currently have a job or do any unpaid work outside your home?

☐ Yes

☐ No → ***Skip to PART 2: TRANSPORTATION***

The next questions are about all the physical activity you did in the **last 7 days** as part of your paid or unpaid work. This does not include traveling to and from work.

2. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, heavy construction, or climbing up stairs **as part of your work**? Think about only those physical activities that you did for at least 10 minutes at a time.

_____ **days per week**

☐ No vigorous job-related physical activity → ***Skip to question 4***

3. How much time did you usually spend on one of those days doing **vigorous** physical activities as part of your work?

_____ **hours per day**
_____ **minutes per day**

4. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads **as part of your work**? Please do not include walking.

_____ **days per week**

☐ No moderate job-related physical activity → ***Skip to question 6***

5. How much time did you usually spend on one of those days doing **moderate** physical activities as part of your work?

_____ **hours per day**
_____ **minutes per day**

6. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time **as part of your work**? Please do not count any walking you did to travel to or from work.

_____ **days per week**

☐ No job-related walking → ***Skip to PART 2: TRANSPORTATION***

7. How much time did you usually spend on one of those days **walking** as part of your work?

_____ **hours per day**
_____ **minutes per day**

PART 2: TRANSPORTATION PHYSICAL ACTIVITY

These questions are about how you traveled from place to place, including to places like work, stores, movies, and so on.

8. During the **last 7 days**, on how many days did you **travel in a motor vehicle** like a train, bus, car, or tram?

_____ **days per week**

☐ No traveling in a motor vehicle → ***Skip to question 10***

9. How much time did you usually spend on one of those days **traveling** in a train, bus, car, tram, or other kind of motor vehicle?

_____ **hours per day**
_____ **minutes per day**

Now think only about the **bicycling** and **walking** you might have done to travel to and from work, to do errands, or to go from place to place.

10. During the **last 7 days**, on how many days did you **bicycle** for at least 10 minutes at a time to go **from place to place**?

_____ **days per week**

☐ No bicycling from place to place → ***Skip to question 12***

11. How much time did you usually spend on one of those days to **bicycle** from place to place?

_____ **hours per day**
_____ **minutes per day**

12. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time to go **from place to place**?

_____ **days per week**

☐ No walking from place to place → ***Skip to PART 3: HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY***

13. How much time did you usually spend on one of those days **walking** from place to place?

_____ **hours per day**
_____ **minutes per day**

PART 3: HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY

This section is about some of the physical activities you might have done in the **last 7 days** in and around your home, like housework, gardening, yard work, general maintenance work, and caring for your family.

14. Think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, chopping wood, shoveling snow, or digging **in the garden or yard**?

_____ **days per week**

☐ No vigorous activity in garden or yard → ***Skip to question 16***

15. How much time did you usually spend on one of those days doing **vigorous** physical activities in the garden or yard?

_____ **hours per day**
_____ **minutes per day**

16. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** activities like carrying light loads, sweeping, washing windows, and raking **in the garden or yard**?

_____ **days per week**

☐ No moderate activity in garden or yard → ***Skip to question 18***

17. How much time did you usually spend on one of those days doing **moderate** physical activities in the garden or yard?

_____ **hours per day**
_____ **minutes per day**

18. Once again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** activities like carrying light loads, washing windows, scrubbing floors and sweeping **inside your home**?

_____ **days per week**

☐ No moderate activity inside home → ***Skip to PART 4: RECREATION, SPORT AND LEISURE-TIME PHYSICAL ACTIVITY***

19. How much time did you usually spend on one of those days doing **moderate** physical activities inside your home?

_____ **hours per day**
_____ **minutes per day**

PART 4: RECREATION, SPORT, AND LEISURE-TIME PHYSICAL ACTIVITY

This section is about all the physical activities that you did in the **last 7 days** solely for recreation, sport, exercise or leisure. Please do not include any activities you have already mentioned.

20. Not counting any walking you have already mentioned, during the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time **in your leisure time**?

_____ **days per week**

☐ No walking in leisure time → ***Skip to question 22***

21. How much time did you usually spend on one of those days **walking** in your leisure time?

_____ **hours per day**
_____ **minutes per day**

22. Think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **vigorous** physical activities like aerobics, running, fast bicycling, or fast swimming **in your leisure time**?

_____ **days per week**

☐ No vigorous activity in leisure time → ***Skip to question 24***

23. How much time did you usually spend on one of those days doing **vigorous** physical activities in your leisure time?

_____ hours per day
_____ minutes per day

24. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** physical activities like bicycling at a regular pace, swimming at a regular pace, and doubles tennis **in your leisure time**?

_____ days per week

☐ No moderate activity in leisure time → ***Skip to PART 5: TIME SPENT SITTING***

25. How much time did you usually spend on one of those days doing **moderate** physical activities in your leisure time?
_____ hours per day
_____ minutes per day

PART 5: TIME SPENT SITTING

The last questions are about the time you spend sitting while at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading or sitting or lying down to watch television. Do not include any time spent sitting in a motor vehicle that you have already told me about.

26. During the **last 7 days**, how much time did you usually spend **sitting** on a **weekday**?

_____ hours per day
_____ minutes per day

27. During the **last 7 days**, how much time did you usually spend **sitting** on a **weekend day**?

_____ hours per day
_____ minutes per day

This is the end of the questionnaire, thank you for participating.