INVESTIGATION OF TIME OF DAY EFFECTS ON KNEE JOINT LOADING IN PEOPLE WITH KNEE OSTEOARTHRITIS

by

Daniel Morgan

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by

Daniel Morgan

Greenville, NC

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Approved by:

Ryan D. Wedge PT, PhD

Department of Physical Therapy, College of Allied Health Sciences

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Chapter 1: Introduction

Osteoarthritis (OA) is the most common joint disease in adults, affecting over 40 million individuals in the United States (Taruc-Uy & Lynch, 2013). OA is not a curable disease at present; therefore, pain management is key for people with OA. People with knee OA can have a combination of clinical symptoms which are pain and loss of function (Andriacchi & Favre, 2014), and changes to articular cartilage seen on a radiograph (Baliunas et al., 2002). Many OA patients will have severe limitations with walking and mobility such as knee stiffness (Baliunas et al., 2002). Knee OA is the most prevalent cause of "mobility dependency" (Messier et al., 2013). High joint loads often correlate with knee OA, since elevated contact forces cause the degradation of knee cartilage (Messier et al., 2013). However, it is unclear from the literature if time of day influences everyone with knee osteoarthritis and how they may take that into consideration for daily movement patterns.

How the time of day affects performance and movement has been examined to determine the best time of day to train, perform, and collect data. The topic of diurnal rhythms is very prevalent in sports and exercise medicine research; however, there have been no studies to find joint contact force data regarding OA symptoms and performance outcomes over the course of a day. The purpose of this study is to determine the effect of time of day on knee joint contact forces in people with knee joint OA. We hypothesize that knee joint loads will be higher during the evening compared to the morning.

Chapter 2: Review of Literature

Osteoarthritis (OA) is the most common joint disease in adults, affecting over 40 million individuals in the United States (Taruc-Uy & Lynch, 2013). OA costs the United States economy more than $100 billion annually in medical care (Mobasheri & Batt, 2016). OA effects people by limiting walking and overall quality of life (Michael et al., 2010), and without proper treatment, OA can be a debilitating disease for individuals.

Osteoarthritis is not a curable disease at present; therefore, pain management is key for people with OA. Symptoms include a deep, painful sensation that can become continuous as the disease progresses (Taruc-Uy & Lynch, 2013). However, the severity of symptoms does vary from person to person. People with knee OA can have a combination of clinical symptoms which are pain and loss of function (Andriacchi & Favre, 2014), and changes to articular cartilage seen on a radiograph (Baliunas et al., 2002). The severity of clinical symptoms and radiographic changes are not always similar (Baliunas et al., 2002). Some patients may have an unnoticeable case of knee OA, but there will be evidence of disease on a radiograph. Others will have severe limitations with walking and mobility such as knee stiffness (Baliunas et al., 2002). Clinical OA is patient driven due to their need for treatment of their cartilage degradation (Andriacchi & Favre, 2014). OA is treated with a combination of pain medication, physical therapy, and sometimes surgery (Taruc-Uy & Lynch, 2013). However, the current treatments do not stop all symptoms or prevent further progression of the disease, as pharmacological prescriptions only reduce pain symptoms by 30% at best (Messier et al., 2013). Physicians treat OA on an individual basis to assist each patient to regain function (Taruc-Uy & Lynch, 2013). Physicians prescribe cardiovascular and resistance exercise as well as intense dieting to patients with OA, since weight loss and consistent exercise have been shown to produce positive effects for

osteoarthritic joints (Guilak, 2011). Enhancing patient health in this way can result in less pain and inflammation, faster walking speeds, and better function (Messier et al., 2013).

Researchers do not fully understand the causes of this disease, but there are biomechanical factors that initiate and progress the disease (Guilak, 2011). Malignment and joint instability are factors in the onset of OA (Guilak, 2011), along with modifiable factors like obesity (Guilak, 2011) and non-modifiable factors like age (Michael et al., 2010). As the disease progresses, people can walk with an asymmetric, seen by limping, gait and have increased mechanical joint stress (Michael et al., 2010). People with knee OA or those that have knee issues which can progress to OA can have improved function and quality of life if they modify lifestyle factors such as diet and frequently do physical activity.

Knee OA can be a debilitating disease when not addressed leading to a diminished quality of life and mobility deficits. Knee OA is the most prevalent cause of "mobility dependency" (Messier et al., 2013). High joint loads often correlate with knee OA, since elevated contact forces cause the degradation of knee cartilage (Messier et al., 2013). Peak loading and tibiofemoral compressive impulse are two biomechanical factors that can predict the severity of the joint disease, given there is an accumulation of joint loads at the knee (Messier et al., 2020). The compressive load per step is critical for determining knee joint health (Messier et al., 2020). Furthermore, the knee adduction moment (KAM) is a method of measure which has been identified as an integral factor in knee OA (Telfer et al., 2017). KAM measures "medial-to-lateral knee joint load distribution during gait" (Hall et al., 2017). KAM relates to OA because the force data including peak and impulse correlate to the thinning of cartilage resulting from knee OA (Hall et al., 2017). We expect that higher KAM values will be associated with higher knee joint loads, and therefore an increased risk or degree of OA (Baliunas et al., 2002). Even

with the acknowledgement of KAM data, it is unclear from the literature if time of day has an effect on everyone with knee osteoarthritis and how they may take that into consideration for daily movement patterns.

How the time of day affects performance and movement has been examined to determine the best time of day to train, perform, and collect data. Isokinetic mechanical data, electromyography (EMG), and rectal temperature have been used to record differences in physiological output due to time of day effects (Deschenes et al., n.d.). Results from a study found that maximal athletic performance occurs between 0800-2000h, which was largely based on speed of movement, peak torque, as well as power (Deschenes et al., n.d.). Other results have indicated that neuromuscular performance is generally improved in the afternoon/early evening when peak body temperature values are also attained (Jaafar & Lajili, 2018). Related, EMG shows a significant increase in muscle electrical activity in the evening compared to the morning (Martin et al., 1999). People with knee OA have decreased peak knee joint torque output with testing and have different muscle activity patterns compared to people without knee OA (Baliunas et al., 2002). People with osteoarthritis often lack the motivation to exercise due to the pain resulting from joint disease. Time of day is a consideration that individuals may account for when designing their exercise regimen and be related to commonly seen deficits. The topic of diurnal rhythms is very prevalent in sports and exercise medicine research; however, there have been no studies to find joint contact force data regarding OA symptoms and performance outcomes over the course of a day.

Chapter 3: Methods

Participants

This study included a convenience sample of eight adults, seven females and one male, between 36-59 years old, and BMI from 22.6 – 45.0 kg/m^2 (**Table 1)**. Participants were recruited via flyers, in-person recruitment, and word of mouth. Potential participants were informed about the details of the study and were told that they can end their participation in the study at any point. Participants were excluded if they did not have one-sided knee OA. Participation was voluntary with no financial incentives, and they provided written consent as approved by the University Internal Review Board (Appendix B) before taking part in the study. During data collection, one participant dropped out after only completing the evening portion of the study. Another participant completed both the morning and evening sessions but could only walk at their preferred speed because the set speed was too fast.

Table 1: Participant Demographics, Mean (SD)

	Females (n = 7)	Males (n = 1)	Total (n = 8)
Age (Years)	45.7 (11.5)	58.0	47.3 (11.5)
Height (m)	1.69 (0.1)	1.99	1.72 (0.1)
Mass (kg)	98.3 (27.6)	101.7	98.8 (25.6)
BMI (kg·m^{-2})	35.0 (11.6)	25.6	33.8 (11.2)
Preferred Speed (m·s^{-1})	1.16 (0.2)	1.41	1.19 (0.2)

m: meters. kg: kilograms. s: seconds.

Instruments

The Physical Activity and Readiness Questionnaire (PAR-Q) determined if the participant was able to perform the activity without consulting a physician. Height and weight was measured

with a height and weight mechanical beam physician scale. Leg length from greater trochanter to lateral malleolus was measured via tape measure. Leg dominance was self-reported. Reflective markers were applied by the principle investigator to sixty-six bony landmarks. Gait data was obtained via three-dimensional motion capture, which consisted of a 17-camera motion capture system (Qualisys, Göteburg, Sweden) collected at 200 hz. The gait and lower extremity force data, sampled at 2000 hz, was collected on an instrumented dual belt treadmill with two embedded force plates (Bertec, Columbus, Ohio). Raw gait data was cleaned and organized in Qualisys Track Manager software (QTM). A custom program in LabVIEW (National Instruments, Austin, Texas) called a custom pipeline in Visual 3-D (C-Motion, Germantown, Maryland) to build the static model and to calculate joint angles and moments from the motion files, which were then used as inputs to an axial musculoskeletal model by DeVita & Hortobágyi (2001) including the later additions described in Messier et al. (2011) to compute tibiofemoral joint contact forces. Output variables were organized in Excel via LabVIEW. Statistics were conducted in SPSS v.29 (IBM, Chicago, Illinois), and figures were constructed in MATLAB.

Design and Procedures

The design of this study was experimental in nature.

Over the phone, the researcher marked participant responses to the Health Survey and Physical Activity and Readiness questionnaire to determine if they met the criteria for the study. Participants were then scheduled to visit the Human Movement Analysis Lab (HMAL) in the Department of Physical therapy which is located in the Health Science Building at East Carolina University in Greenville, North Carolina. There were two data collection days for each participant which were each completed within a three-day period. The participants were asked to wear tight

fitting spandex; if a participant did not have adequate clothing for motion capture, then the lab provided clothing. Upon arrival, participants read and signed the informed consent and were given a chance to ask any questions about the study. Anthropometric measures including height, mass, and leg length from greater trochanter to lateral malleolus were obtained along with self-reported leg dominance. To determine leg dominance, participants were asked which leg they would kick a ball with. Hypoallergenic tape and elastic wraps were used to attach sixty-six retroreflective markers to bony landmarks on the participants' upper and lower extremities, trunk, and pelvis for the collection of 3-D motion capture data.

Participants then stood on an instrumented split-belt treadmill and with their arms out for static motion capture. The participant was given a one-to-two-minute familiarization period with the treadmill as well as a one-to-two-minute warm up on the treadmill at the 70% of their preferred walking speed determined from the average of the three trials earlier. The participant was asked to rate their pain, perceived exertion, and knee stiffness after the warm-up. Data collection began with the first trials being performed at preferred speed for 2 minutes. During this time, motion and force data were recorded three times via Qualisys Track Manager (QTM). After the first trial, the participant was again asked to rate their pain, perceived exertion, and knee stiffness. The participant then had a seated rest period for 5 minutes. After rest, the participant was asked to rate their pain, perceived exertion, and knee stiffness. The same procedure was repeated for the set speed of 1.3 $m \cdot s^{-1}$. After the last condition, markers were removed from the participant and they were dismissed from the study.

Chapter 4: Results

The purpose of this study was to determine the effect of time of day on knee joint contact forces in people with knee joint OA. We hypothesized that knee joint loads would be higher during the evening compared to the morning.

The difference between affected and unaffected limbs on total ($p = 0.044$; $\eta_p^2 = 0.015$), medial ($p = 0.005$; $\eta_p^2 = 0.28$), and lateral ($p = 0.034$; $\eta_p^2 = 0.016$) peak joint contact forces was significant with small effect sizes. The difference between time of day was significant for total ($p = 0.004$, $\eta_p^2 = 0.03$) and lateral ($p < 0.001$, $\eta_p^2 = 0.047$) peak contact forces and had small effect sizes. However, the difference between time of day was not significant for medial ($p = 0.127$; $\eta_p^2 = 0.009$) peak contact forces. The interaction of limb by time of day was not significant for any peak forces: total ($p = 0.264$; $\eta_p^2 = 0.005$), medial ($p = 0.986$; $\eta_p^2 = 0$), nor lateral ($p = 0.389$; $\eta_p^2 = 0.003$).

Table 2: Tibiofemoral Joint Contact Forces, Mean (SD)

Variable	AM	PM	Main Effects
Affected/Unaffected			*p*
Total	2.61 (.55)	2.42 (.40)	**< .001**
Medial	1.73 (.39)	1.64 (.36)	**< .001**
Lateral	1.01 (.30)	0.91 (.26)	**< .001**
Total	2.73 (.62)	2.64 (.57)	**0.037**
Medial	1.90 (.55)	1.85 (.51)	**< .001**
Lateral	1.09 (.34)	0.10 (.29)	**< .001**

Averages (SD) for peak forces of the tibiofemoral joint.

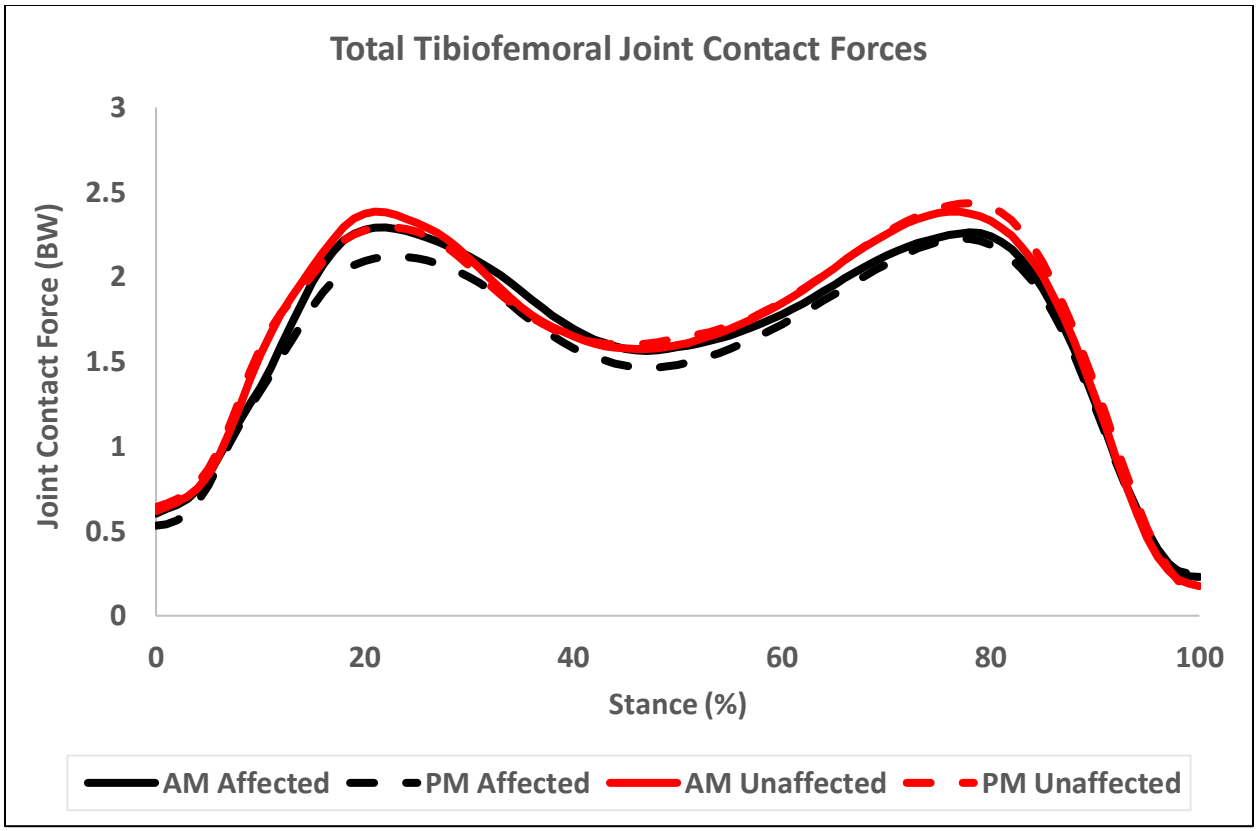

Figure 1: Total Tibiofemoral Joint Contact Forces During Walking Trials
Total tibiofemoral contact forces over percent stance during walking trials. The lines represent the mean across all participants. During the morning, the unaffected limb had higher peaks than the affected limb. During the evening, the unaffected limb produced similar first peaks to the affected limb, but higher second peaks.

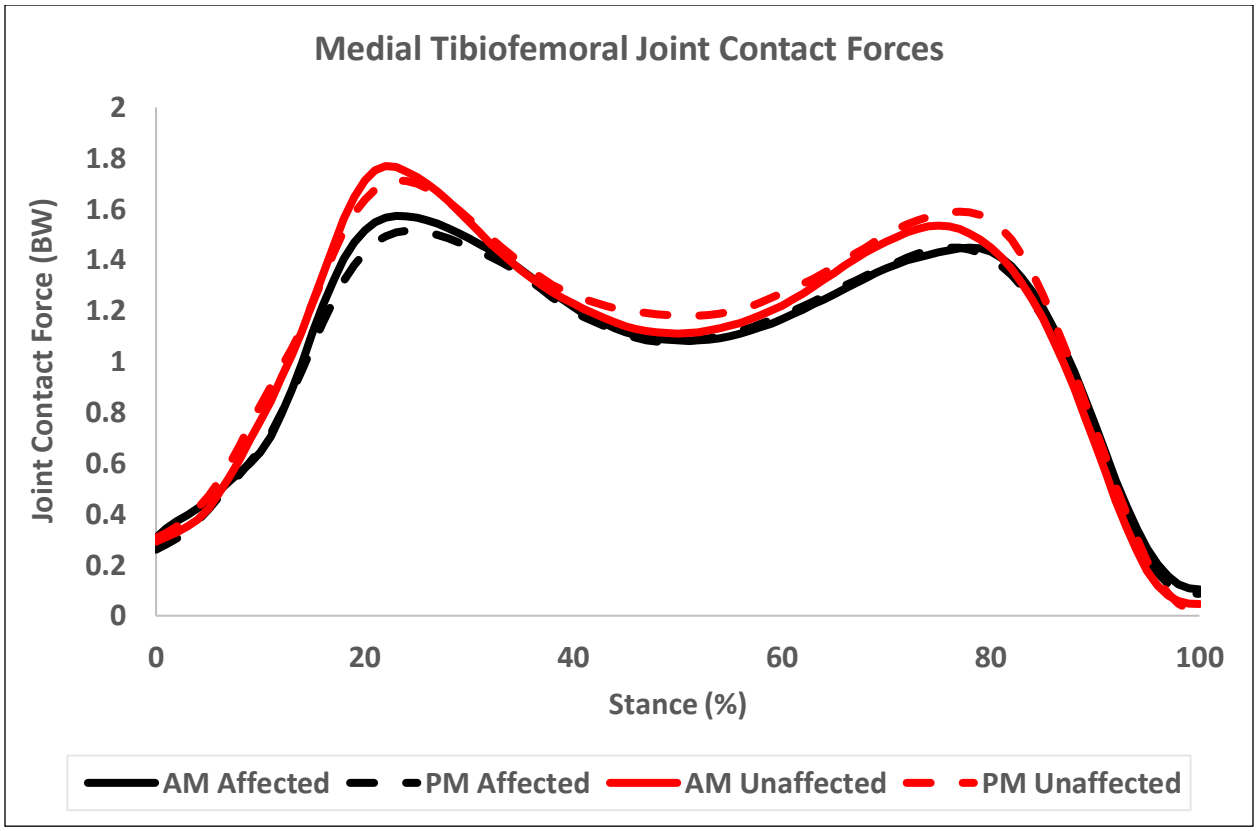

Figure 2: Medial Tibiofemoral Joint Contact Forces During Walking Trials
Medial tibiofemoral contact forces over percent stance during walking trials. The lines represent the mean across all participants. During the morning and the evening, the unaffected limb had higher first and second peaks than the affected limb.

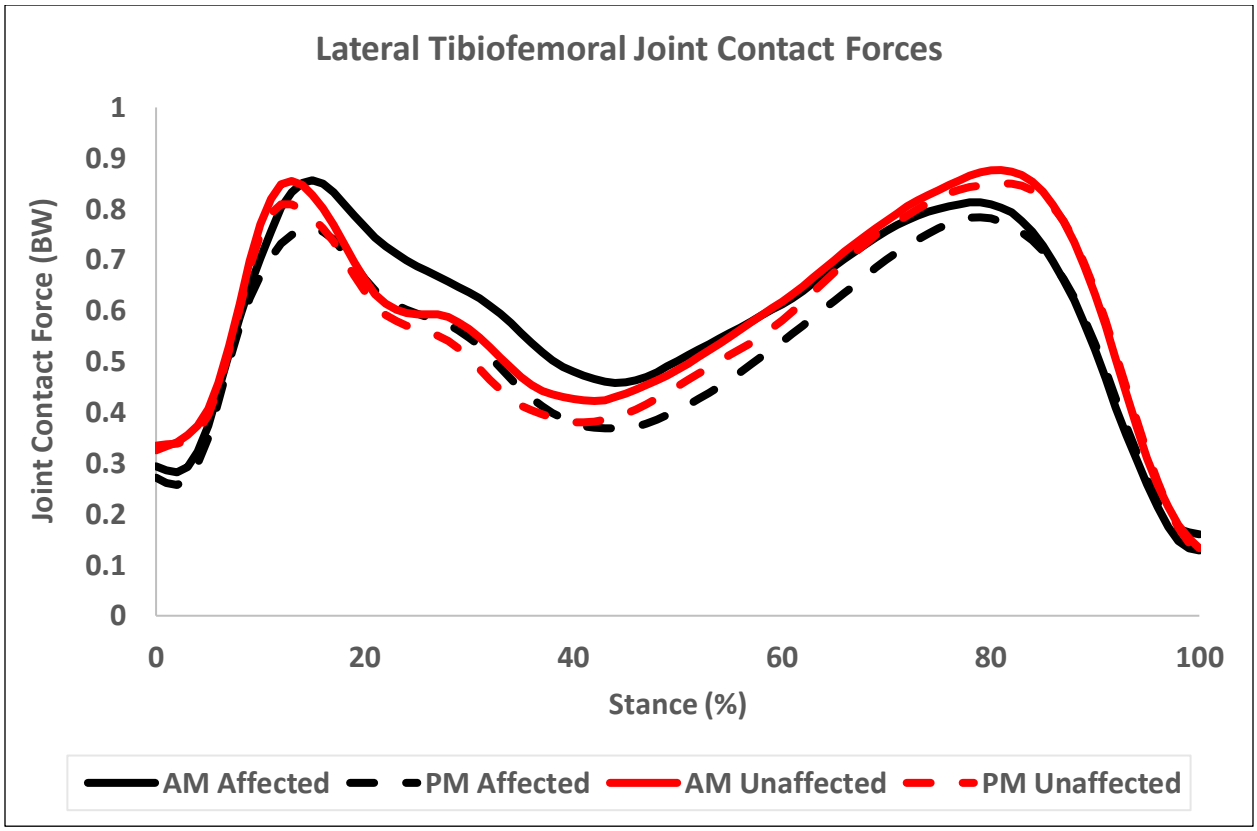

Figure 3: Lateral Tibiofemoral Joint Contact Forces During Walking Trials
Lateral tibiofemoral contact forces over percent stance during walking trials. The lines represent the mean across all participants. The unaffected limb during the morning condition produced similar results as the affected limb in the morning. The unaffected limb in the evening had higher peaks than the affected limb in the evening. During the morning and the evening, the unaffected limb produced higher second peaks than the affected limb.

Chapter 5: Discussion

The purpose of this study was to determine the effect of time of day on knee joint contact forces in people with unilateral knee joint OA. We hypothesized that knee joint loads would be higher during the evening compared to the morning.

We found that the difference between affected and unaffected limbs on total, medial, and lateral peak joint contact forces was significant with small effect sizes. The difference between time of day was significant for total and lateral peak contact forces and had small effect sizes. Results from previous studies found a general trend that neuromuscular performance and peak body temperatures increase in the evening (Deschenes et al., n.d.). One study showed a gradual increase in rectal temperature of ~0.5ºC observed from morning to evening regardless of biorhythmic changes due to exercise (Deschenes et al., n.d.). Meanwhile, they did not observe significant biorhythmicity due to time of day in heart rate or blood pressure responses (Deschenes et al., n.d.). In addition to the temperature changes, muscle performance metrics, such as peak torque, were significantly affected by time of day effects, but only at the highest speeds of movement tested (Deschenes et al., n.d.). Another study's results showed that oral temperature was significantly higher in the evening compared to in the morning (Jaafar & Lajili, 2018). Our results are different than these studies' findings, in that we found higher forces in the morning than the evening. Joint contact forces may not be linked to temperature and isolated muscle testing because it requires coordination of other limbs and walking is not a maximal activity.

One potential cause of this finding is different sequencing between the morning and evening sessions. Six out of the eight participants' morning session occurred prior to their evening session. Due to the morning session being their initial session in the lab, there could

have been variation in participant comfort and acclimation to the treadmill and the lab setting, even though we provided a warmup on both days. We did not compare the participants who started with a morning session versus those who started with an evening session because of a small sample size. According to one study, treadmill experience mitigates the degree to which a person adapts their walking pattern (Meyer et al., 2019). It is a reasonable assumption that additional familiarization time on the split-belt treadmill would allow for more gait adaptations. The six participants who walked on the treadmill during the morning could have experienced increased knee stiffness and discomfort due to a lack of prior treadmill experience. Also, we did not control for the amount of activity prior to each session, which could have affected mechanics, but we decided on this because people will exercise after varying levels of morning and evening activity.

Knee stiffness in the morning and evening was also considered as a cause of the higher forces seen in the morning sessions. When examining the KOOS and WOMAC scores for each participant, we found that knee stiffness outcome scores were similar for the morning and the evening. Knee stiffness takes effect in those with knee OA for 30 minutes or less during the morning (Duong et al., 2023). However, knee stiffness should not have induced any changes to the contact forces because each participant had been awake and ambulatory for at least 30 minutes prior to walking on the treadmill.

Limitations

The sample size was limited due to a short period of time to use funds, but there are trends for the interaction of time of day and limb which should be further explored with more participants. In addition, seven out of eight participants who took part in the present study were

female. To better represent the population of people with knee OA, more male participants should be recruited.

Summary

Trends in the data of the present study point to a possible time of day effect for knee joint contact forces. If we can determine how time of day affects knee joint contact forces in people with and without OA, we could better prescribe when to exercise. Further studies should be conducted with a larger and more balanced sample size to identify significant results.

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The funding for this study was provided by the Undergraduate Research and Creative Activity (URCA) fund. Thank you, Dr. Ryan Wedge, for supporting my endeavors and my growth as an individual. Thank you, Dr. John Willson, for your instruction in the laboratory all throughout the study. Thank you to the East Carolina University Honors College for encouraging research opportunities. Thank you to each of the participants who took the time to partake in the research study.

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Appendices

Appendix A: Informed Consent

Informed Consent to Participate in Research
Information to consider before taking part in research that has no more than minimal risk.

Title of Research Study: Investigation of Time of Day Effects on Knee Joint Loading in People with Knee Osteoarthritis

Principal Investigator: Dr. Ryan Wedge, PT, PhD
Institution, Department or Division: Department of Physical Therapy, East Carolina
University Address: 2410 Health Sciences Building
Telephone #: 252.744.6237

Researchers at East Carolina University (ECU) study problems in society, health problems, environmental problems, behavior problems and the human condition. Our goal is to try to find ways to improve the lives of you and others. To do this, we need the help of volunteers who are willing to take part in research.

Why am I being invited to take part in this research?
The purpose of this study is to determine the effect of time of day on knee joint contact forces in people with knee joint osteoarthritis (OA). Findings from this study might be used to help clinicians design exercise plans that prioritize performance and minimize pain based on time of day. You are being invited to take part in this research because you are between the ages of 18 and 70 with a diagnosis of OA affecting one of your knee joints. The decision to take part in this research is yours to make. A potential benefit includes estimating the most optimal time of day to exercise. This information can be used to promote efficiency of physical activity in populations that have mobility limitations. If you volunteer to take part in this research, you will be one of about 32 people to do so.

Are there reasons I should not take part in this research?
I understand I should not participate in this research if I have any health problems that get worse when I walk other than OA or if I have had any surgeries or major injuries to my legs in the past twelve months. I should not volunteer for this study if I am under 18 years of age or older than 70 years of age, or unable to walk.

What other choices do I have if I do not take part in this research?
You can choose not to participate. You may stop participating at any point during the study.

Where is the research going to take place and how long will it last?
The research will take place in the Human Movement Analysis Laboratory in the Health Sciences Building of East Carolina University. You will need to come to the laboratory 2 times during the study over the course of 3 days. The first session will occur before 9 AM and the second session will occur after 5 PM, on separate days within 3 days of each other. The total amount of time you will be asked to volunteer for this study is approximately 2 hours and 30 minutes.

What will I be asked to do?
You will take the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) and Knee Injury and Osteoarthritis Outcome Score (KOOS) questionnaires before each collection. You will be asked to rate your pain, perceived exertion, and knee stiffness after those questionnaires. After those questions, you will be fitted with tight-fitting clothing. You will have height, weight, and leg length measured. You will have retroreflective

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markers placed on bony landmarks and limb segments with two-side tape and wraps. Your preferred walking speed will be determined by walking a 10-meter distance three times while timing the middle 6 meters with photogates. You will then walk on an instrumented split belt treadmill. You will have a one to two minute familiarization period with the treadmill as well as a one to two minute warm up on the treadmill at the preferred walking speed determined from the average of the three trials earlier. You will be asked to rate your pain, perceived exertion, and knee stiffness after the warm-up. During data collection, one trial will be performed at preferred speed for 3 minutes. After the first trial, you will be asked to rate their pain, perceived exertion, and knee stiffness. You will then have a seated rest period for 5 minutes. After rest, you will be asked to rate your pain, perceived exertion, and knee stiffness. The second trial will be performed at a set speed of 1.3 m/s for 3 minutes. After the second trial, you will be asked to rate their pain, perceived exertion, and knee stiffness once more. After you finish the second bout of walking, you can ask any final questions before changing back into loose clothing.

What might I experience if I take part in the research?
The risks involved in this study are minimal, as you will only be walking on a treadmill. To minimize risk of injury, a treadmill stop button will be available if you are walking improperly or you feel unsafe. There may not be any personal benefit to you, however, the potential for health care professionals to better understand the changes in force data of an individual with knee OA, over the span of a day, could be helpful for others with knee OA. Individuals trained in CPR, AED, and First Aid will be present in the lab during the duration of the tests. If you experience any pain or any complications occur, the test will be terminated immediately.

Will I be paid for taking part in this research?
You will be paid $25 per completed session via a Greenphire Clin Card, totaling $50 for the two sessions.

Will it cost me to take part in this research?
There are no costs associated with this study. In the unlikely event that an injury occurs as a result of this research, payment for treatment must be provided by you or your third party-payer. If any injury occurs during the collection, please notify the investigator in charge.

Who will know that I took part in this research and learn personal information about me?
The people and organizations listed below may know that you took part in this research and may see information about you that is normally kept private. With your permission, these people may use your private information to do this research:

- The University & Medical Center Institutional Review Board (UMCIRB) and its staff, who have responsibility for overseeing your welfare during this research, and other ECU staff who oversee this research.
- Any agency of the federal, state, or local government that regulates human research. This includes the Department of Health and Human Services (DHHS), the North Carolina Department of health, and the Office for Human Research Protections.
- Research assistants under direct supervision of the primary investigator.

How will you keep the information you collect about me secure? How long will you keep it?
No visual record or otherwise identifiable record of your performance is kept other than force and motion data. All electronic and other information pertaining to your participation will be kept confidential through the use of number codes. All questionaries and any form with your name will be stored in a locked file cabinet in the Human Movement Laboratory, which remains locked except when in use. The only people with access to the passwords or your personal information will be the researchers identified above. Motion analysis data collected during the study will not be linked with any personally identifiable information. Electronic information from this study is also password protected. The results of this study may be published in scientific literature or presented at professional meetings. If used for these reasons, no information that could be used to identify you will be included. We may ask to take a photograph of you during the data collection. If you consent to a photograph, it will not include your face

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or any other identifiable marks. The information from this study will be maintained for four years. At the end of this time, hard copies of your information will be destroyed and electronic information will be archived in Human Motional Analysis Laboratory piratedrive (piratedrive is an individual folder created on an ECU server for each faculty, staff and student for data file storage).

What if I decide I don't want to continue in this research?
You can stop at any time after if it has already started. There will be no consequences if you stop, and you will not be criticized. You will not lose any benefits that you normally receive.

Who should I contact if I have questions?
The people conducting this study will be available to answer any questions concerning this research, now or in the future. You may contact the Principal Investigator Dr. Ryan Wedge via email at wedger19@ecu.edu.

If you have questions about your rights as someone taking part in research, you may call the University & Medical Center Institutional Review Board (UMCIRB) at phone number 252-744-2914 (days, 8:00 am-5:00 pm). If you would like to report a complaint or concern about this research study, you may call the Director for Human Research Protections, at 252-744-2914.

Is there anything else I should know?
Identifiers might be removed from the identifiable private information or identifiable biospecimens and, after such removal, the information or biospecimens could be used for future research studies or distributed to another investigator for future research studies without additional informed consent from you or your Legally Authorized Representative (LAR). However, there still may be a chance that someone could figure out the information is about you.

I have decided I want to take part in this research. What should I do now?
The person obtaining informed consent will ask you to read the following and if you agree, you should sign this form:

- I have read (or had read to me) all of the above information.
- I have had an opportunity to ask questions about things in this research I did not understand and have received satisfactory answers.
- I know that I can stop taking part in this study at any time.
- By signing this informed consent form, I am not giving up any of my rights.
- I have been given a copy of this consent document, and it is mine to keep.

Do you consent to a photograph of your trunk and legs to be potentially used for publication purposes? The photograph will not include any identifiable information, identifiable features, and will not include your face.
Yes ( ) No ( )

Participant's Name (PRINT)	Signature	Date

Person Obtaining Informed Consent: I have conducted the initial informed consent process. I have orally reviewed the contents of the consent document with the person who has signed above, and answered all of the person's questions about the research.

Person Obtaining Consent (PRINT)	Signature	Date

Appendix B: KOOS

KOOS KNEE SURVEY

Today's date: _____/_____/_____ Date of birth: _____/_____/_____

Name _____

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**.

S1. Do you have swelling in your knee?
Never ☐ Rarely ☐ Sometimes ☐ Often ☐ Always ☐

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

S3. Does your knee catch or hang up when moving?
Never ☐ Rarely ☐ Sometimes ☐ Often ☐ Always ☐

S4. Can you straighten your knee fully?
Always ☐ Often ☐ Sometimes ☐ Rarely ☐ Never ☐

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.

S6. How severe is your knee joint stiffness after first waking in the morning?
None ☐ Mild ☐ Moderate ☐ Severe ☐ Extreme ☐

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

Pain
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?

P2. Twisting/pivoting on your knee
None ☐ Mild ☐ Moderate ☐ Severe ☐ Extreme ☐

P3. Straightening knee fully
None ☐ Mild ☐ Moderate ☐ Severe ☐ Extreme ☐

P4. Bending knee fully
None ☐ Mild ☐ Moderate ☐ Severe ☐ Extreme ☐

P5. Walking on flat surface
None ☐ Mild ☐ Moderate ☐ Severe ☐ Extreme ☐

P6. Going up or down stairs
None ☐ Mild ☐ Moderate ☐ Severe ☐ Extreme ☐

P7. At night while in bed
None ☐ Mild ☐ Moderate ☐ Severe ☐ Extreme ☐

P8. Sitting or lying
None ☐ Mild ☐ Moderate ☐ Severe ☐ Extreme ☐

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.

A1. Descending stairs
None ☐ Mild ☐ Moderate ☐ Severe ☐ Extreme ☐

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

A3. Rising from sitting
None ☐ Mild ☐ Moderate ☐ Severe ☐ Extreme ☐

A4. Standing
None ☐ Mild ☐ Moderate ☐ Severe ☐ Extreme ☐

A5. Bending to floor/pick up an object
None ☐ Mild ☐ Moderate ☐ Severe ☐ Extreme ☐

A6. Walking on flat surface
None ☐ Mild ☐ Moderate ☐ Severe ☐ Extreme ☐

A7. Getting in/out of car
None ☐ Mild ☐ Moderate ☐ Severe ☐ Extreme ☐

A8. Going shopping
None ☐ Mild ☐ Moderate ☐ Severe ☐ Extreme ☐

A9. Putting on socks/stockings
None ☐ Mild ☐ Moderate ☐ Severe ☐ Extreme ☐

A10. Rising from bed
None ☐ Mild ☐ Moderate ☐ Severe ☐ Extreme ☐

A11. Taking off socks/stockings
None ☐ Mild ☐ Moderate ☐ Severe ☐ Extreme ☐

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

A13. Getting in/out of bath
None ☐ Mild ☐ Moderate ☐ Severe ☐ Extreme ☐

A14. Sitting
None ☐ Mild ☐ Moderate ☐ Severe ☐ Extreme ☐

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

A16. Heavy domestic duties (moving heavy boxes, scrubbing floors, etc)
None ☐ Mild ☐ Moderate ☐ Severe ☐ Extreme ☐

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.

SP1. Squatting
None ☐ Mild ☐ Moderate ☐ Severe ☐ Extreme ☐

SP2. Running
None ☐ Mild ☐ Moderate ☐ Severe ☐ Extreme ☐

SP3. Jumping
None ☐ Mild ☐ Moderate ☐ Severe ☐ Extreme ☐

SP4. Twisting/pivoting on your injured knee
None ☐ Mild ☐ Moderate ☐ Severe ☐ Extreme ☐

SP5. Kneeling
None ☐ Mild ☐ Moderate ☐ Severe ☐ Extreme ☐

Quality of Life

Q1. How often are you aware of your knee problem?
Never ☐ Monthly ☐ Weekly ☐ Daily ☐ Constantly ☐

Q2. Have you modified your life style to avoid potentially damaging activities to your knee?
Not at all ☐ A little ☐ Moderately ☐ Severely ☐ Totally ☐

Q3. How much are you troubled with lack of confidence in your knee?
Not at all ☐ A little ☐ Moderately ☐ Severely ☐ Extremely ☐

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

Thank you very much for completing all the questions in this questionnaire.

Appendix C: WOMAC

The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)

Name:_____ Date:_____

Instructions: Please rate the activities in each category according to the following scale of difficulty: 0 = None, 1 = Slight, 2 = Moderate, 3 = Very, 4 = Extremely

Circle **one number** for each activity

Pain	1. Walking	0 1 2 3 4
	2. Stair Climbing	0 1 2 3 4
	3. Nocturnal	0 1 2 3 4
	4. Rest	0 1 2 3 4
	5. Weight bearing	0 1 2 3 4
Stiffness	1. Morning stiffness	0 1 2 3 4
	2. Stiffness occurring later in the day	0 1 2 3 4
Physical Function	1. Descending stairs	0 1 2 3 4
	2. Ascending stairs	0 1 2 3 4
	3. Rising from sitting	0 1 2 3 4
	4. Standing	0 1 2 3 4
	5. Bending to floor	0 1 2 3 4
	6. Walking on flat surface	0 1 2 3 4
	7. Getting in / out of car	0 1 2 3 4
	8. Going shopping	0 1 2 3 4
	9. Putting on socks	0 1 2 3 4
	10. Lying in bed	0 1 2 3 4
	11. Taking off socks	0 1 2 3 4
	12. Rising from bed	0 1 2 3 4
	13. Getting in/out of bath	0 1 2 3 4
	14. Sitting	0 1 2 3 4
	15. Getting on/off toilet	0 1 2 3 4
	16. Heavy domestic duties	0 1 2 3 4
	17. Light domestic duties	0 1 2 3 4

Total Score: _____ / 96 = _____%

Comments / Interpretation (to be completed by therapist only):

Appendix D: Motion Capture Marker Locations

Trunk markers
T1
T2
T3
T4

Pelvis
RASI (Right Anterior Superior Iliac Spine)
LASI (Left Anterior Superior Iliac Spine)
RPSI (Right Posterior Superior Iliac Spine)
L5S1 (Lumbar 5/Sacrum 1)
LPSI (Left Posterior Superior Iliac Spine)

Right Thigh
TMTH (Top Medial Thigh)
TLTH (Top Lateral Thigh)
BMTH (Bottom Medial Thigh)
BLTH (Bottom Lateral Thigh)
MEKN (Medial Femoral Epicondyle)
LAKN (Lateral Femoral Epicondyle)

Left thigh
LTMT (Top Medial Thigh)
LTLT (Top Lateral Thigh)
LBMT (Bottom Medial Thigh)
LBLT (Bottom Lateral Thigh)
LMEK (Medial Femoral Epicondyle)
LLAK (Lateral Femoral Epicondyle)

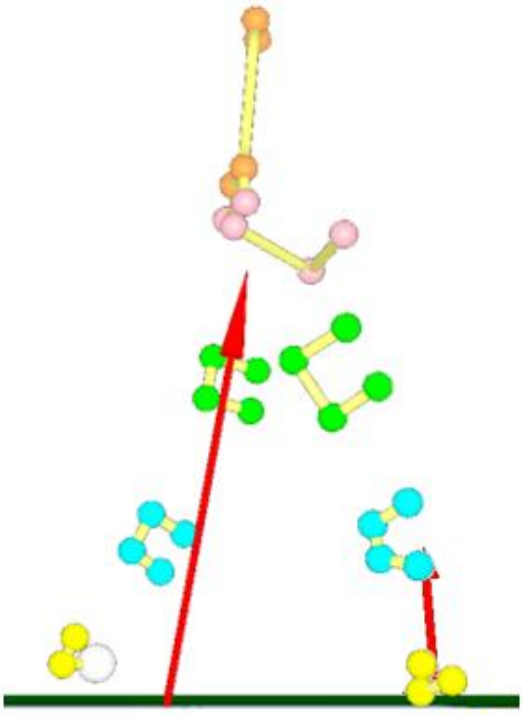
Right shank
MTIB (Medial Tibial Epicondyle)
LTIB (Tibial Plateau)
TMSH (Top Medial Shank)
TLSH (Top Lateral Shank)
BMSH (Bottom Medial Shank)
BLSH (Bottom Lateral Shank)
MEMA (Medial Malleolus)
LAMA (Lateral Malleolus)

Left shank
LMTIB (Medial Tibial Epicondyle)
LLTIB (Tibial Plateau)
LTMS (Top Medial Shank)
LTLS (Top Lateral Shank)
LBMS (Bottom Medial Shank)
LBLS (Bottom Lateral Shank)

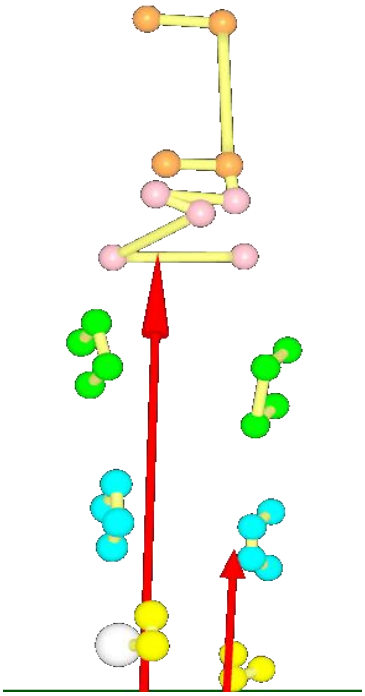
Right foot
PRHE (Proximal Heel)
DIHE (Distal Heel)
LAHE (Lateral Heel)
MTH1 (Metatarsal Head 1)
MTH5 (Metatarsal Head 5)
DIFT (Distal Great Toe)

Left foot
LPRH (Proximal Heel)
LDIH (Distal Heel)
LLAH Lateral Heel)
LMT1 (Metatarsal Head 1)
LMT5 (Metatarsal Head 5)
LDIFT (Distal Great Toe)

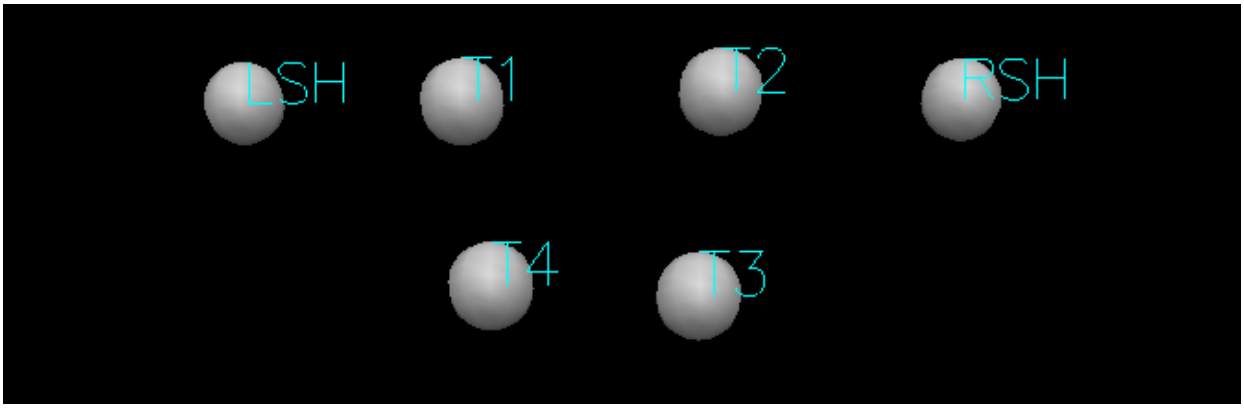
Right side view



Rear view

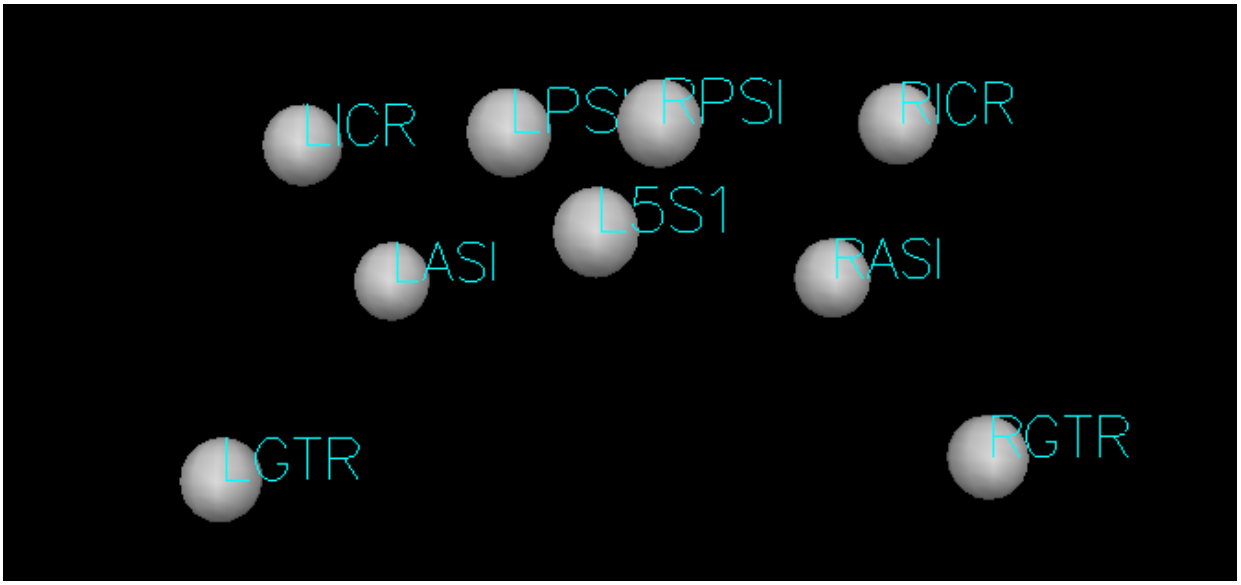


Trunk



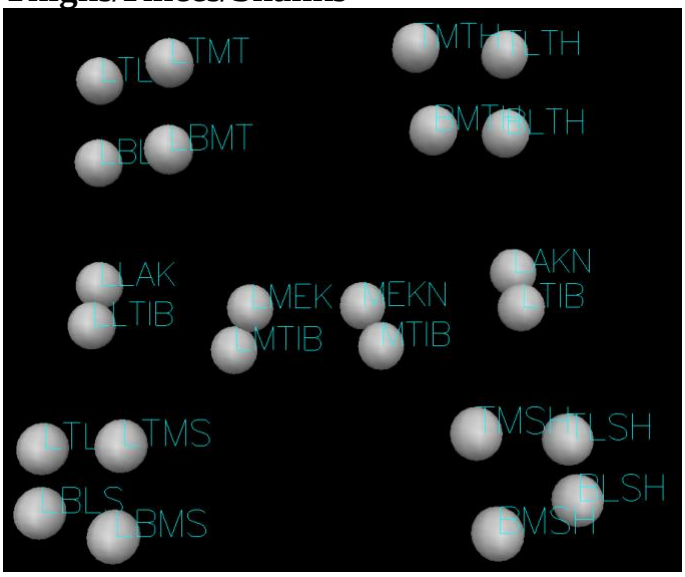
RSH
LSH
T1
T2
T3
T4

Pelvis



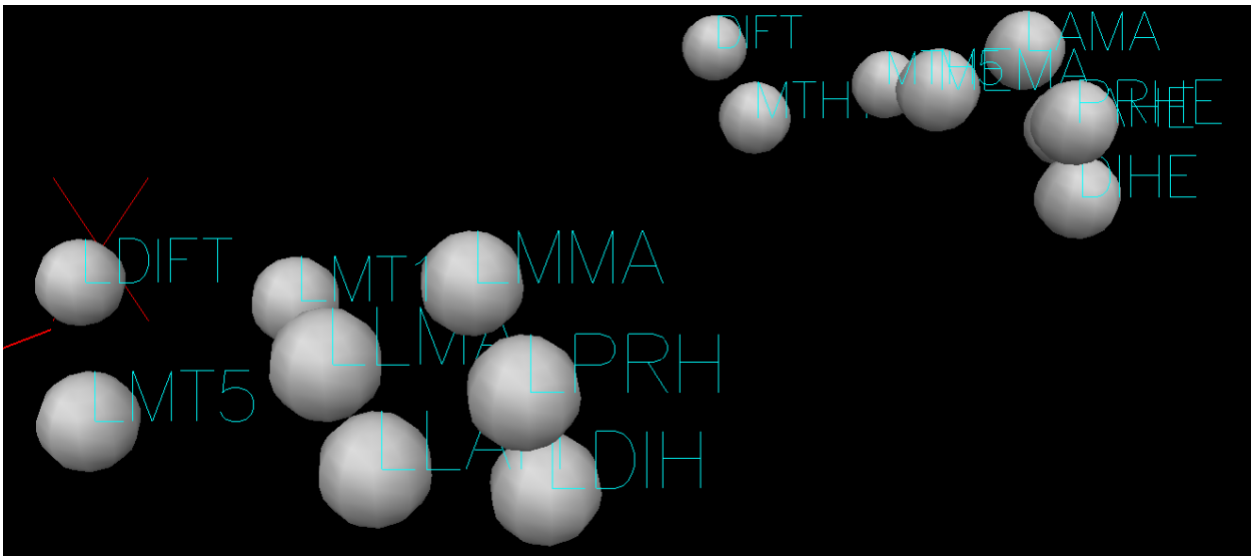
RICR
LICR
RPSI
LPSI
L5S1
RASI
LASI
RGTR
LGTR

Thighs/Knees/Shanks



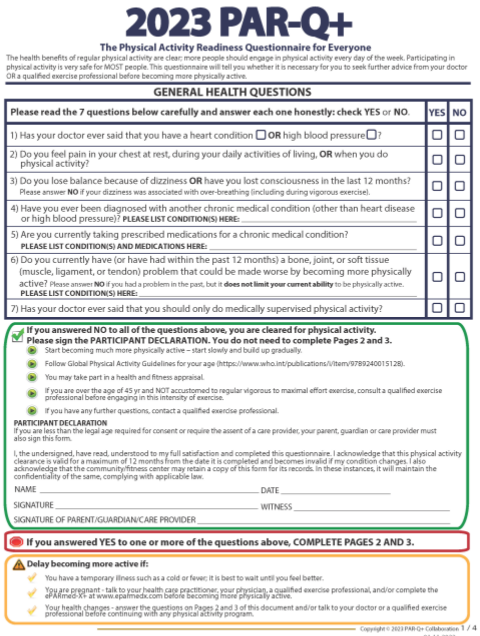
Right	Left
TMTH	LTMT
TLTH	LTLT
BMTH	LBMT
BLTH	LBLT
MEKN	**LMEK**
LAKN	**LLAK**
MTIB	**LMTIB**
LTIB	**LLTIB**
TMSH	LTLS
TLSH	LTMS
BMSH	LBMS
BLSH	LBLS

Ankles/Feet



Right	Left
PRHE	LPRH
DIHE	LDIH
LAHE	LLAH
MEMA	**LMMA**
LAMA	**LLMA**
MTH1	**LMT1**
MTH5	**LMT5**
DIFT	**LDIFT**

Appendix E: Par-Q



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The Physical Activity Readiness Questionnaire for Everyone

The health benefits of regular physical activity are clear; more people should engage in physical activity every day of the week. Participating in physical activity is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

GENERAL HEALTH QUESTIONS

Please read the 7 questions below carefully and answer each one honestly: check YES or NO.	YES	NO
1) Has your doctor ever said that you have a heart condition ☐ **OR** high blood pressure ☐?	☐	☐
2) Do you feel pain in your chest at rest, during your daily activities of living, **OR** when you do physical activity?	☐	☐
3) Do you lose balance because of dizziness **OR** have you lost consciousness in the last 12 months? Please answer **NO** if your dizziness was associated with over-breathing (including during vigorous exercise).	☐	☐
4) Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)? **PLEASE LIST CONDITION(S) HERE:** ______	☐	☐
5) Are you currently taking prescribed medications for a chronic medical condition? **PLEASE LIST CONDITION(S) AND MEDICATIONS HERE:** ______	☐	☐
6) Do you currently have (or have had within the past 12 months) a bone, joint, or soft tissue (muscle, ligament, or tendon) problem that could be made worse by becoming more physically active? Please answer **NO** if you had a problem in the past, but it **does not limit your current ability** to be physically active. **PLEASE LIST CONDITION(S) HERE:** ______	☐	☐
7) Has your doctor ever said that you should only do medically supervised physical activity?	☐	☐

If you answered NO to all of the questions above, you are cleared for physical activity. Please sign the PARTICIPANT DECLARATION. You do not need to complete Pages 2 and 3.

- Start becoming much more physically active – start slowly and build up gradually.
- Follow Global Physical Activity Guidelines for your age (https://www.who.int/publications/i/item/9789240015128).
- You may take part in a health and fitness appraisal.
- If you are over the age of 45 yr and NOT accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.
- If you have any further questions, contact a qualified exercise professional.

PARTICIPANT DECLARATION

If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for its records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME ______ DATE ______

SIGNATURE ______ WITNESS ______

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER ______

If you answered YES to one or more of the questions above, COMPLETE PAGES 2 AND 3.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ at www.eparmedx.com before becoming more physically active.
- Your health changes - answer the questions on Pages 2 and 3 of this document and/or talk to your doctor or a qualified exercise professional before continuing with any physical activity program.

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FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

1. Do you have Arthritis, Osteoporosis, or Back Problems?
If the above condition(s) is/are present, answer questions 1a-1c — If **NO** ☐ go to question 2

1a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) YES ☐ NO ☐

1b. Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)? YES ☐ NO ☐

1c. Have you had steroid injections or taken steroid tablets regularly for more than 3 months? YES ☐ NO ☐

2. Do you currently have Cancer of any kind?
If the above condition(s) is/are present, answer questions 2a-2b — If **NO** ☐ go to question 3

2a. Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and/or neck? YES ☐ NO ☐

2b. Are you currently receiving cancer therapy (such as chemotheraphy or radiotherapy)? YES ☐ NO ☐

3. Do you have a Heart or Cardiovascular Condition? This includes Coronary Artery Disease, Heart Failure, Diagnosed Abnormality of Heart Rhythm
If the above condition(s) is/are present, answer questions 3a-3d — If **NO** ☐ go to question 4

3a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) YES ☐ NO ☐

3b. Do you have an irregular heart beat that requires medical management? (e.g., atrial fibrillation, premature ventricular contraction) YES ☐ NO ☐

3c. Do you have chronic heart failure? YES ☐ NO ☐

3d. Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months? YES ☐ NO ☐

4. Do you currently have High Blood Pressure?
If the above condition(s) is/are present, answer questions 4a-4b — If **NO** ☐ go to question 5

4a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) YES ☐ NO ☐

4b. Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer **YES** if you do not know your resting blood pressure) YES ☐ NO ☐

5. Do you have any Metabolic Conditions? This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes
If the above condition(s) is/are present, answer questions 5a-5e — If **NO** ☐ go to question 6

5a. Do you often have difficulty controlling your blood sugar levels with foods, medications, or other physician-prescribed therapies? YES ☐ NO ☐

5b. Do you often suffer from signs and symptoms of low blood sugar (hypoglycemia) following exercise and/or during activities of daily living? Signs of hypoglycemia may include shakiness, nervousness, unusual irritability, abnormal sweating, dizziness or light-headedness, mental confusion, difficulty speaking, weakness, or sleepiness. YES ☐ NO ☐

5c. Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, **OR** the sensation in your toes and feet? YES ☐ NO ☐

5d. Do you have other metabolic conditions (such as current pregnancy-related diabetes, chronic kidney disease, or liver problems)? YES ☐ NO ☐

5e. Are you planning to engage in what for you is unusually high (or vigorous) intensity exercise in the near future? YES ☐ NO ☐

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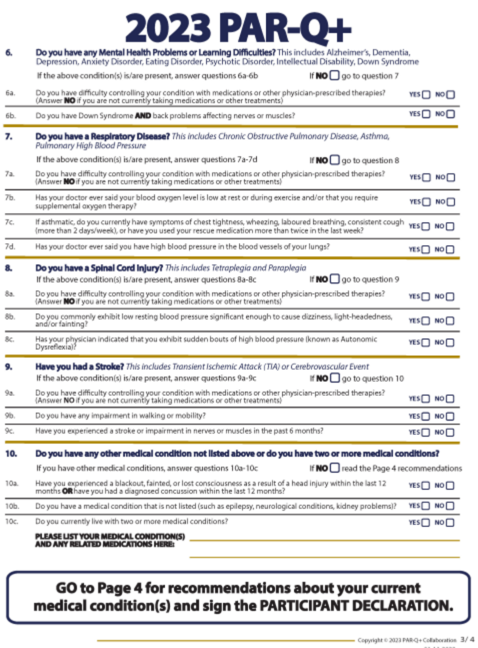

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6. Do you have any Mental Health Problems or Learning Difficulties? This includes Alzheimer's, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome
If the above condition(s) is/are present, answer questions 6a-6b — If **NO** ☐ go to question 7

6a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) YES ☐ NO ☐

6b. Do you have Down Syndrome **AND** back problems affecting nerves or muscles? YES ☐ NO ☐

7. Do you have a Respiratory Disease? *This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure*
If the above condition(s) is/are present, answer questions 7a-7d — If **NO** ☐ go to question 8

7a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) YES ☐ NO ☐

7b. Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy? YES ☐ NO ☐

7c. If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week? YES ☐ NO ☐

7d. Has your doctor ever said you have high blood pressure in the blood vessels of your lungs? YES ☐ NO ☐

8. Do you have a Spinal Cord Injury? *This includes Tetraplegia and Paraplegia*
If the above condition(s) is/are present, answer questions 8a-8c — If **NO** ☐ go to question 9

8a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) YES ☐ NO ☐

8b. Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting? YES ☐ NO ☐

8c. Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)? YES ☐ NO ☐

9. Have you had a Stroke? *This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event*
If the above condition(s) is/are present, answer questions 9a-9c — If **NO** ☐ go to question 10

9a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) YES ☐ NO ☐

9b. Do you have any impairment in walking or mobility? YES ☐ NO ☐

9c. Have you experienced a stroke or impairment in nerves or muscles in the past 6 months? YES ☐ NO ☐

10. Do you have any other medical condition not listed above or do you have two or more medical conditions?
If you have other medical conditions, answer questions 10a-10c — If **NO** ☐ read the Page 4 recommendations

10a. Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months **OR** have you had a diagnosed concussion within the last 12 months? YES ☐ NO ☐

10b. Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)? YES ☐ NO ☐

10c. Do you currently live with two or more medical conditions? YES ☐ NO ☐

PLEASE LIST YOUR MEDICAL CONDITION(S) AND ANY RELATED MEDICATIONS HERE: ______

GO to Page 4 for recommendations about your current medical condition(s) and sign the PARTICIPANT DECLARATION.

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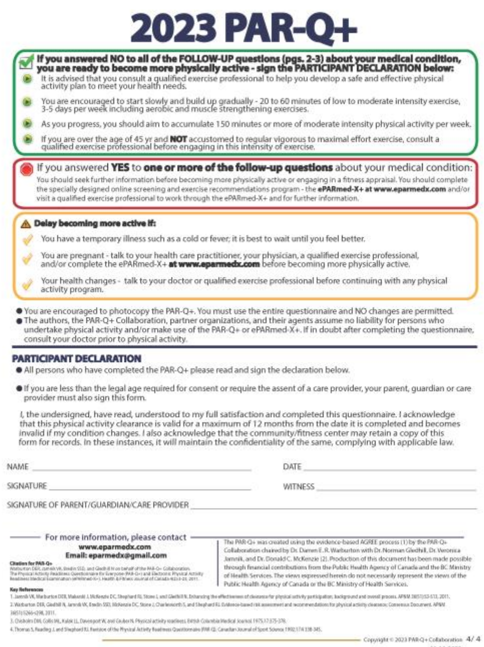

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If you answered NO to all of the FOLLOW-UP questions (pgs. 2-3) about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:

- It is advised that you consult a qualified exercise professional to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually - 20 to 60 minutes of low to moderate intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate intensity physical activity per week.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.

If you answered **YES** to **one or more of the follow-up questions** about your medical condition: You should seek further information before becoming more physically active or engaging in a fitness appraisal. You should complete the specially designed online screening and exercise recommendations program - the **ePARmed-X+ at www.eparmedx.com** and/or visit a qualified exercise professional to work through the ePARmed-X+ and for further information.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ **at www.eparmedx.com** before becoming more physically active.
- Your health changes - talk to your doctor or qualified exercise professional before continuing with any physical activity program.

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The authors, the PAR-Q+ Collaboration, partner organizations, and their agents assume no liability for persons who undertake physical activity and/or make use of the PAR-Q+ or ePARmed-X+. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.

PARTICIPANT DECLARATION

- All persons who have completed the PAR-Q+ please read and sign the declaration below.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME ______ DATE ______

SIGNATURE ______ WITNESS ______

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER ______

For more information, please contact
www.eparmedx.com
Email: eparmedx@gmail.com

The PAR-Q+ was created using the evidence-based AGREE process (1) by the PAR-Q+ Collaboration chaired by Dr. Darren E. R. Warburton with Dr. Norman Gledhill, Dr. Veronica Jamnik, and Dr. Donald C. McKenzie (2). Production of this document has been made possible through financial contributions from the Public Health Agency of Canada and the BC Ministry of Health Services. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or the BC Ministry of Health Services.

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