

A. COVER PAGE

Project Title: In Vivo Changes in the Lower Extremity Joints and Muscles during Prolonged Standing	
Grant Number: 5K01OH010759-03	Project/Grant Period: 09/01/2015 - 08/31/2018
Reporting Period: 09/01/2017 - 08/31/2018	Requested Budget Period: 09/01/2017 - 08/31/2018
Report Term Frequency: Annual	Date Submitted: 12/02/2019
Program Director/Principal Investigator Information: APRIL J CHAMBERS , BS MS PHD Phone number: 4126249898 Email: ajcst49@pitt.edu	Recipient Organization: UNIVERSITY OF PITTSBURGH AT PITTSBURGH UNIVERSITY OF PITTSBURGH OFFICE OF SPONSORED PROGRAMS PITTSBURGH, PA 152132303 DUNS: 004514360 EIN: 1250965591A6 RECIPIENT ID:
Change of Contact PD/PI: N/A	
Administrative Official: BRITTANY L CROKER 123 University Place Pittsburgh, PA 15213 Phone number: 412-624-7412 Email: blk33@pitt.edu	Signing Official: BRITTANY L CROKER 123 University Place Pittsburgh, PA 15213 Phone number: 412-624-7412 Email: blk33@pitt.edu
Human Subjects:	Vertebrate Animals:
hESC: No	Inventions/Patents: No

B. ACCOMPLISHMENTS

B.1 WHAT ARE THE MAJOR GOALS OF THE PROJECT?

The goal of the research project within this career development proposal is to enhance the understanding of environmental and physiological factors involved in occupational prolonged standing. Prolonged standing in the workplace is a significant ergonomic problem, directly linked to numerous health problems and high economic costs. Worker complaints of musculoskeletal discomfort in the lower extremities are frequently associated with occupational prolonged standing and identified as a risk factor in the development of injuries. Unfortunately, the underlying mechanisms of joint and muscle discomfort and injury during standing are unclear. The hypothesis of the proposed project is that prolonged standing has a significant impact on the musculoskeletal system that occurs over time and can be measured. The objective is to investigate the impact of standing on: (Specific Aim 1) articular cartilage deformation within the knee joint and (Specific Aim 2) lower extremity muscle characteristics. A second objective is to investigate the impact of human factors (obesity) and environmental factors (flooring) on these effects. Two experiments will address the specific aims using novel and innovative methodologies including dynamic stereo x-ray, near-infrared spectroscopy, electromyography, and biomechanical analysis. Obesity is a growing concern in the United States with more than one-third of Americans being obese. Obese workers tend to have higher injury rates and associated cost. Obesity-related differences in musculoskeletal physiology likely impact injury risk during standing, the extent to which is unknown. Although preliminary data included in this proposal demonstrates that obesity does impact measures proposed. As such, we anticipate that the weight of the subject will have an impact on the results. Finally, we will examine whether a standard intervention, incorporating a floor mat in the environment, alters the changes in the muscles seen over time. Examining human factors (obesity) and environmental factors (flooring) will lead to both the design and evaluation of new, more effective interventions aimed at reducing discomfort and injuries associated with occupational standing.

Specific Aim 1: To investigate the impact of prolonged standing on in vivo articular cartilage deformation within the knee joint; the effects of obesity also will be examined.

H1.1: Articular cartilage deformation at the knee will increase with time during prolonged standing.

H1.2: Effects of prolonged standing on articular cartilage deformation at the knee joint (H1.1) will be greater in obese individuals.

H1.3: Psychophysical measures of joint pain and discomfort will be correlated with changes in articular cartilage deformation.

Specific Aim 2: To investigate the impact of prolonged standing on lower extremity muscles; the effects of obesity and flooring will also be examined.

H2.1: Muscle oxygenation, blood volume, and hemoglobin levels of lower extremity muscles, as measured with near-infrared spectroscopy, will decrease with time during prolonged standing. This finding will be correlated with muscle fatigue, as measured by electromyography.

H2.2: Physiological variables of the lower extremity muscles stated in H2.1 will be negatively affected by obesity.

H2.3: Standing on a floor mat will reduce the negative impact of standing on the physiological variables of the lower extremity muscles.

H2.4: Psychophysical measures of muscular pain and discomfort will be correlated with changes in the physiological muscle variables.

B.1.a Have the major goals changed since the initial competing award or previous report?

No

B.2 WHAT WAS ACCOMPLISHED UNDER THESE GOALS?

File uploaded: Accomplishments.pdf

B.3 COMPETITIVE REVISIONS/ADMINISTRATIVE SUPPLEMENTS

For this reporting period, is there one or more Revision/Supplement associated with this award for which reporting is required?

No

B.4 WHAT OPPORTUNITIES FOR TRAINING AND PROFESSIONAL DEVELOPMENT HAS THE PROJECT PROVIDED?

File uploaded: Training and Development.pdf

B.5 HOW HAVE THE RESULTS BEEN DISSEMINATED TO COMMUNITIES OF INTEREST?

Time spent standing: Our finding that time is the most prominent predictor of all outcomes is currently being translated into determination of appropriate dosage for sit stand desks. The methods utilized in this study are being incorporated into determining best practice of sit stand desks. Additional work is planned in this area to further explore how appropriate timing or movement interventions can be incorporated into occupations that require prolonged standing.

Novel testing methods: The use of dynamic stereo x-rays and near infra-red spectroscopy in the field of ergonomics is novel and was proven effective in this study. These techniques have been used to evaluate flooring in collaboration with industry partners. They will be used to evaluate and develop ergonomic interventions in future work. This will improve interventions aimed at preventing injury and discomfort during prolonged standing.

Environmental and human factors: Flooring and BMI impact musculoskeletal physiology and injury mechanisms during prolonged standing. These factors are also inter-related and should be considered in future interventions. Internal funding has been received to

further the examination of obese adults and their performance. A better understanding is needed to assist with translation of these preliminary findings. Once that is achieved, we will work with industry partners to redesign environmental interventions while considering obesity and other human factors. This will ensure that interventions are tailored to the individual and more successful in preventing injury and discomfort during prolonged standing.

B.6 WHAT DO YOU PLAN TO DO DURING THE NEXT REPORTING PERIOD TO ACCOMPLISH THE GOALS?

Not Applicable

Accomplishments

Prolonged standing in the workplace is a significant ergonomic problem that is directly linked to musculoskeletal injuries, health problems and high economic costs. The general hypothesis of the proposed project is that prolonged standing impacts tissues within the joints and muscles, which in-turn results in increased pain and risk of injury. However, the specific changes that occur during standing are not, as of yet, understood. The project objective was to investigate the impact of prolonged standing on in vivo changes in articular cartilage deformation within the knee joint and lower extremity muscle characteristics. A second objective was to investigate the impact of human and environmental factors on these effects. A total of 31 young adults aged 21-35 years old in two BMI groups, healthy weight and obese, participated in this study. Novel and innovative methodologies including dynamic stereo x-ray, near-infrared spectroscopy, electromyography, and biomechanical analysis were employed to assess the effect of prolonged standing on measures of joint and muscle injury risk. Additionally, the impact of obesity and flooring on these novel objective measures was examined.

Key findings were made for each of the proposed specific aims. Human studies were performed to evaluate possible underlying mechanisms of musculoskeletal injury during prolonged standing. The human and environmental factors of obesity and flooring were also explored during prolonged standing.

Key Finding 1: Time is the most prominent predictor of all outcomes, including discomfort, gap distance, EMG, and NIRS. Converging models for DSX indicated overall decreases in gap distance as a function of time spent standing (Aim 1). Soleus muscle HbO, HbR, HbT, and blood flow increased with time (Aim 2).

Key Finding 2: Flooring tended to display a beneficial physiological effect on prolonged standing. The mat condition tended to lead to decreased leg tiredness and foot discomfort than the hard floor condition. The terminal gap within the knee joint reached when standing on a mat may be slightly increased compared to hard floor, suggesting less cartilage compression over time (Aim 1). EMG measures indicated that the mat may lead to less fatigue than the hard floor. Overall, HbO was higher on the hard floor than on the mat (Aim 2). This may be a result of increased movement on a hard floor, a possible mechanism associated to discomfort.

Key Finding 3: The response to different flooring varied depending on BMI group. The time that it took to reach full cartilage compression was nearly 30 minutes later when using a mat in obese adults only. Leg muscle fatigue indicated that obese adults may use a different muscle strategy during prolonged standing on different flooring surfaces compared to healthy weight adults. Muscle oxygenation results indicated that it is possible that blood is moving more effectively through the legs on the mat condition, especially in healthy weight adults. Additional research is needed to further explore these findings. This implies that human factors should be taking into account in future work including evaluation and design of discomfort, injury and fatigue reducing products. This will ensure that interventions are tailored to the individual and more successful in preventing injury and discomfort during prolonged standing.

The results collected during this study will inform future endeavors to make standing more comfortable in the workplace and prevent the associated injuries. Understanding the underlying mechanisms behind musculoskeletal injuries during prolonged standing, through direct, objective measurements, will reduce injury and inform future occupational regulations. This project provided critical knowledge regarding musculoskeletal changes in the lower extremities due to prolonged standing that could result in injury. This research, in addition to a series of

studies that are naturally following in its path, has led to new methods of evaluating injury risk and more effective interventions to reduce musculoskeletal injuries in the workplace. Since prolonged standing is common in the workplace, the results of this research can impact multiple industry sectors including Healthcare and Social Assistance, Manufacturing, Mining, Public Safety, Transportation, Warehousing and Utilities, Wholesale and Retail Trade. The NIOSH cross-sector programs being addressed are Engineering Controls, Musculoskeletal Disorders, Prevention through Design, and Training Grants.

Career development and training activities during award period

My career development consisted of research, coursework, and mentored training. These provided me with the skills and knowledge necessary to become an independent investigator. Coursework and research training was used to increase my knowledge of ergonomics and injury prevention. I enrolled and took courses in the University of Pittsburgh's Graduate Program in Safety Engineering. In addition to this, I acquired a certificate in Occupational Ergonomics from Colorado State University. These programs broaden my ability to recognize, evaluate, and control ergonomic risk factors in a wide range of workplace settings. I was mentored by and collaborated with experts in occupational biomechanics, orthopedics, radiology and obesity research. I also received training in state of the art techniques and methodologies that are not typically used in the field of ergonomics. I successfully lead this study that investigated the impact of prolonged standing on in vivo changes in articular cartilage deformation with the knee joint and lower extremity muscles. The career development and training offered by this award have resulted in investigator independence. Since the start of this award, I have submitted or served as a principal investigator or co-investigator on over 10 external grants, 7 internal grants, and 4 corporate research agreements, with a funding rate of better than 60%. Additionally, I have published (or currently under review) 17 journal articles and 13 proceedings while mentoring numerous undergraduate and graduate students. Articles directly supported by this award are provided below:

Journal Articles

Chambers AJ, Robertson M, Baker N: [2019] The effect of sit-stand desks on office worker behavioral and health outcomes: A scoping review. *Applied Ergonomics* 78:37-53.

Rekant J, Wiltman S, Chambers AJ: [2019]. A Novel Method of Analysis for Prolonged-Standing Data: Accounting for Joint and Muscle Discomfort. *IISE Transactions on Occupational Ergonomics and Human Factors* 7(2):142-152.

Chambers AJ, Haney J, Huppert T, Redfern M: [2019]. The Effect of Prolonged Walking on Erector Spinae and Soleus Muscle Oxygenation and Discomfort. *Journal of Sports Science and Medicine* 18:337-343.

Proceedings

Wiltman S, Pechtl K, Huppert T, Chambers AJ: [2019] Influence of Flooring on Lower Extremity Blood Oxygenation and Volume during Prolonged Standing. *Proceedings of the 2019 Human Factors and Ergonomics Society, Seattle, WA, October 28-November 1.*

Wiltman S, Chambers AJ [2019] Measuring Medial Compartment Tibiofemoral Gap Distance Due to Prolonged Standing. *Proceedings of the 2019 Regional Meeting of the American Society of Biomechanics, State College, PA, April 12-13.*

Wiltman S, Chambers AJ: [2018] Effect of Standing on Tibiofemoral Gap Distance over Varying Flexion Angles. *Proceedings of the 2018 National Occupational Injury Research Symposium (NOIRS), Morgantown, WV, October 17.*

Wiltman S, Rekant J, Chambers AJ: [2018] A Novel Method for Identifying Weight Distribution Changes during Prolonged Standing. Proceedings of the 2018 Annual Regional Meeting of the American Society of Biomechanics, State College, PA, April 20-21.

Wiltman S, Chambers AJ [2017] Weight Shifting Strategies and Discomfort during Prolonged Standing. Proceedings of the 2017 the Annual Meeting of the Human Factors and Ergonomics Society, Austin, TX, October 9-13.

Bottorff E, Wiltman S, Chambers AJ: [2017] Effect of knee rotations on articular cartilage compression during knee flexion exercise. Proceedings of the 2017 the Annual Meeting of the American Society of Biomechanics, Boulder, Co, August 8-11.

Driggers J, McMurtry S, Wiltman S, Chambers AJ: [2017] Validating a novel 3D scanner for measuring leg swelling during prolonged standing. Proceedings of the 2017 the Annual Meeting of the American Society of Biomechanics, Boulder, Co, August 8-11.

Chambers AJ, Wiltman S: [2017] Time dependency of bilateral weight distribution during prolonged standing. Proceedings of the 2017 Annual Meeting of the International Society of Posture and Gait Research, Fort Lauderdale, FL, June 25-29.

Dissertation/Thesis

Wiltman SA: [2019] Using Objective Methods to Measure the Underlying Mechanisms of Discomfort during Prolonged Standing, Ph.D. Thesis, University of Pittsburgh.

C. PRODUCTS**C.1 PUBLICATIONS**

Are there publications or manuscripts accepted for publication in a journal or other publication (e.g., book, one-time publication, monograph) during the reporting period resulting directly from this award?

No

C.2 WEBSITE(S) OR OTHER INTERNET SITE(S)

Not Applicable

C.3 TECHNOLOGIES OR TECHNIQUES

Not Applicable

C.4 INVENTIONS, PATENT APPLICATIONS, AND/OR LICENSES

Have inventions, patent applications and/or licenses resulted from the award during the reporting period? No

If yes, has this information been previously provided to the PHS or to the official responsible for patent matters at the grantee organization?

C.5 OTHER PRODUCTS AND RESOURCE SHARING

Nothing to report

D. PARTICIPANTS

D.1 WHAT INDIVIDUALS HAVE WORKED ON THE PROJECT?

Commons ID	S/K	Name	Degree(s)	Role	Cal	Aca	Sum	Foreign Org	Country	SS
AJCHAMBERS	Y	Chambers, April J	BS,MS,PHD	PD/PI	9.0	0.0	0.0			NA
THUPPERT	Y	Huppert, Theodore James	PHD	Co-Investigator	1.0	0.0	0.0			NA
STASHMA1	Y	Tashman, Scott	MS,PHD	Co-Investigator	0.5	0.0	0.0			NA
	Y	Wiltman, Stephanie	BS	Graduate Student (research assistant)	12.0	0.0	0.0			NA
REDFERN	Y	REDFERN, MARK S	BS,PHD,MS	Co-Investigator	1.0	0.0	0.0			NA

<p>Glossary of acronyms: S/K - Senior/Key DOB - Date of Birth Cal - Person Months (Calendar) Aca - Person Months (Academic) Sum - Person Months (Summer)</p>	<p>Foreign Org - Foreign Organization Affiliation SS - Supplement Support RE - Reentry Supplement DI - Diversity Supplement OT - Other NA - Not Applicable</p>
--	---

D.2 PERSONNEL UPDATES

D.2.a Level of Effort

Not Applicable

D.2.b New Senior/Key Personnel

Not Applicable

D.2.c Changes in Other Support

Not Applicable

D.2.d New Other Significant Contributors

Not Applicable

D.2.e Multi-PI (MPI) Leadership Plan

Not Applicable

E. IMPACT

E.1 WHAT IS THE IMPACT ON THE DEVELOPMENT OF HUMAN RESOURCES?

Not Applicable

E.2 WHAT IS THE IMPACT ON PHYSICAL, INSTITUTIONAL, OR INFORMATION RESOURCES THAT FORM INFRASTRUCTURE?

Not Applicable

E.3 WHAT IS THE IMPACT ON TECHNOLOGY TRANSFER?

Not Applicable

E.4 WHAT DOLLAR AMOUNT OF THE AWARD'S BUDGET IS BEING SPENT IN FOREIGN COUNTRY(IES)?

NOTHING TO REPORT

G. SPECIAL REPORTING REQUIREMENTS

<p>G.1 SPECIAL NOTICE OF AWARD TERMS AND FUNDING OPPORTUNITIES ANNOUNCEMENT REPORTING REQUIREMENTS</p> <p>File(s) uploaded: Final Report.pdf</p>
<p>G.2 RESPONSIBLE CONDUCT OF RESEARCH</p> <p>NOTHING TO REPORT</p>
<p>G.3 MENTOR'S REPORT[CDA]</p> <p>File uploaded: Chambers Mentor Statement.pdf</p>
<p>G.4 HUMAN SUBJECTS</p> <p>G.4.a Does the project involve human subjects?</p>
<p>G.4.b Inclusion Enrollment Data</p> <p>File(s) uploaded: PHS Inclusion Enrollment Chart.pdf</p> <p>G.4.c ClinicalTrials.gov</p> <p>Does this project include one or more applicable clinical trials that must be registered in ClinicalTrials.gov under FDAAA?</p>
<p>G.5 HUMAN SUBJECTS EDUCATION REQUIREMENT</p> <p>Are there personnel on this project who are newly involved in the design or conduct of human subjects research?</p>
<p>G.6 HUMAN EMBRYONIC STEM CELLS (HESCS)</p> <p>Does this project involve human embryonic stem cells (only hESC lines listed as approved in the NIH Registry may be used in NIH funded research)?</p> <p>No</p>
<p>G.7 VERTEBRATE ANIMALS</p> <p>Does this project involve vertebrate animals?</p>
<p>G.8 PROJECT/PERFORMANCE SITES</p> <p>Not Applicable</p>
<p>G.9 FOREIGN COMPONENT</p> <p>No foreign component</p>
<p>G.10 ESTIMATED UNOBLIGATED BALANCE</p> <p>G.10.a Is it anticipated that an estimated unobligated balance (including prior year carryover) will be greater than 25% of the current year's total approved budget?</p>
<p>G.11 PROGRAM INCOME</p> <p>Not Applicable</p>

G.12 F&A COSTS

Not Applicable

Final Progress Report

Principal Investigator Information:

April Chambers, Ph.D.
University of Pittsburgh
302 Benedum Hall
3700 O'Hara Street
Pittsburgh, PA, 15261
412.624.9898
ajchambers@pitt.edu

Institution to which award was made:

University of Pittsburgh
Office of Sponsored Programs
123 University Place
B21 University Club
Pittsburgh, PA 15213

Project Information:

Title: In vivo changes in the lower extremity joints and muscles during prolonged standing
Project Director: April Chambers, PhD
Mentors: Mark Redfern, PhD; Scott Tashman, PhD; Theodore Huppert, PhD
Sponsor: National Institute of Occupational Safety and Health
Grant number: K01OH010759
Start date: 9/1/2015; End date: 8/31/2019

Final Progress Report Submitted in November, 2019.

A. Table of contents

A. Table of contents.....	2
B. List of terms and abbreviations.....	3
C. Abstract.....	4
D. Significant or Key Findings.....	5
E. Background.....	7
F. Specific Aims.....	10
G. Methodology.....	11
H. Results and discussion.....	22
I. Conclusions.....	38
J. References.....	39
K. Publications.....	42
L. Career development and training activities during award period.....	43
M. Cumulative Inclusion Enrollment Table.....	44
N. Inclusion of gender and minority study subjects.....	45
O. Inclusion of Children.....	45
P. Materials available for other investigators.....	46

B. List of Terms and Abbreviations

B: BMI

BMI: body mass index

CT: computer tomography

DPF: Differential path length factor

DSX: dynamic stereo x-ray

EMG: electromyography

F: flooring

GAS: Medial Gastrocnemius

GT: terminal gap

HAM: Medial Hamstrings

HbO: concentration of oxygenated hemoglobin

HbT: total hemoglobin

HF: hard floor

HHb: concentration of deoxygenated hemoglobin

HW: healthy weight

MPF: median power frequency

MT: anti-fatigue mat

MTFG: medial tibiofemoral gap

NIRS: near infrared spectroscopy

NOB: non-obese

OB: obese

PCA: principal component analysis

RF: Rectus Femoris

RMS: root mean square

ROC: receiver operating characteristic

SOL: Lateral Soleus

T: time

TA: Tibialis Anterior

TT: terminal gap time

C. Abstract

Title: In vivo changes in the lower extremity joints and muscles during prolonged standing

PI: April Chambers, Ph.D.

University of Pittsburgh

302 Benedum Hall, 3700 O'Hara Street, Pittsburgh, PA, 15261

412.624.9898; ajchambers@pitt.edu

Prolonged standing in the workplace is a significant ergonomic problem that is directly linked to musculoskeletal injuries, health problems and high economic costs. The general hypothesis of the proposed project is that prolonged standing impacts tissues within the joints and muscles, which in-turn results in increased pain and risk of injury. However, the specific changes that occur during standing are not, as of yet, understood. The project objective was to investigate the impact of prolonged standing on in vivo changes in articular cartilage deformation within the knee joint and lower extremity muscle characteristics. A second objective was to investigate the impact of human and environmental factors on these effects. A total of 31 young adults aged 21-35 years old in two BMI groups, healthy weight and obese, participated in this study. Novel and innovative methodologies including dynamic stereo x-ray, near-infrared spectroscopy, electromyography, and biomechanical analysis were employed to assess the effect of prolonged standing on measures of joint and muscle injury risk. Additionally, the impact of obesity and flooring on these novel objective measures was examined. Time was found to be the most prominent predictor of all outcomes, including discomfort, gap distance, EMG, and NIRS. Flooring tended to display a beneficial physiological effect on prolonged standing. The response to different flooring varied depending on BMI group. This implies that human factors should be taking into account in future work including evaluation and design of discomfort, injury and fatigue reducing products. This will ensure that interventions are tailored to the individual and more successful in preventing injury and discomfort during prolonged standing. The results collected during this study will inform future endeavors to make standing more comfortable in the workplace and prevent the associated injuries. Understanding the underlying mechanisms behind musculoskeletal injuries during prolonged standing, through direct, objective measurements, will reduce injury and inform future occupational regulations. The career development and training offered by this award have provided me with training in state of the art techniques and methodologies that are not typically used in the field of ergonomics and resulted in investigator independence.

This project provided critical knowledge regarding musculoskeletal changes in the lower extremities due to prolonged standing that could result in injury. This research, in addition to a series of studies that are naturally following in its path, has led to new methods of evaluating injury risk and more effective interventions to reduce musculoskeletal injuries in the workplace. Since prolonged standing is common in the workplace, the results of this research can impact multiple industry sectors including Healthcare and Social Assistance, Manufacturing, Mining, Public Safety, Transportation, Warehousing and Utilities, Wholesale and Retail Trade. The NIOSH cross-sector programs being addressed are Engineering Controls, Musculoskeletal Disorders, Prevention through Design, and Training Grants.

Section 1 of the Final Progress Report

D. Significant or Key Findings

Key findings were made for each of the proposed specific aims. Human studies were performed to evaluate possible underlying mechanisms of musculoskeletal injury during prolonged standing. The human and environmental factors of obesity and flooring were also explored during prolonged standing.

Key Finding 1: Time is the most prominent predictor of all outcomes, including discomfort, gap distance, EMG, and NIRS. Converging models for DSX indicated overall decreases in gap distance as a function of time spent standing (Aim 1). Soleus muscle HbO, HbR, HbT, and blood flow increased with time (Aim 2).

Key Finding 2: Flooring tended to display a beneficial physiological effect on prolonged standing. The mat condition tended to lead to decreased leg tiredness and foot discomfort than the hard floor condition. The terminal gap within the knee joint reached when standing on a mat may be slightly increased compared to hard floor, suggesting less cartilage compression over time (Aim 1). EMG measures indicated that the mat may lead to less fatigue than the hard floor. Overall, HbO was higher on the hard floor than on the mat (Aim 2). This may be a result of increased movement on a hard floor, a possible mechanism associated to discomfort.

Key Finding 3: The response to different flooring varied depending on BMI group. The time that it took to reach full cartilage compression was nearly 30 minutes later when using a mat in obese adults only. Leg muscle fatigue indicated that obese adults may use a different muscle strategy during prolonged standing on different flooring surfaces compared to healthy weight adults. Muscle oxygenation results indicated that it is possible that blood is moving more effectively through the legs on the mat condition, especially in healthy weight adults. Additional research is needed to further explore these findings.

Translation of findings

Time spent standing: Our finding that time is the most prominent predictor of all outcomes is currently being translated into determination of appropriate dosage for sit stand desks. The methods utilized in this study are being incorporated into determining best practice of sit stand desks. Additional work is planned in this area to further explore how appropriate timing or movement interventions can be incorporated into occupations that require prolonged standing.

Novel testing methods: The use of dynamic stereo x-rays and near infra-red spectroscopy in the field of ergonomics is novel and was proven effective in this study. These techniques have been used to evaluate flooring in collaboration with industry partners. They will be used to evaluate and develop ergonomic interventions in future work. This will improve interventions aimed at preventing injury and discomfort during prolonged standing.

Environmental and human factors: Flooring and BMI impact musculoskeletal physiology and injury mechanisms during prolonged standing. These factors are also inter-related and should be considered in future interventions. Internal funding has been received to further the examination of obese adults and their performance. A better understanding is needed to assist with translation of these preliminary findings. Once that is achieved, we will work with industry partners to redesign environmental interventions while considering obesity and other human factors. This will ensure that interventions are tailored to the individual and more successful in preventing injury and discomfort during prolonged standing.

Outcomes/Impact

Potential Outcomes

- The findings about time having the most consistent impact on have the potential to lead to improved workplace practices. Specifically, the finding that time is the most determining factor related to injury risk can be used by employers and employees to better limit long periods of standing or provide controls to alternate position more frequently.
- It was shown that using an anti-fatigue mat displayed musculoskeletal physiological benefits during prolonged standing. The methods used here, novel to ergonomics, can be used in future work to evaluate mats and floors for effectiveness and improve design.
- Lastly, the impact of flooring varied with obesity group. It was shown that traditional interventions may have different physiological impacts depending on the BMI of the individual using them. This implies that human factors should be even more prominent in future work in this area. This is an important finding that should be taking into account in future work including evaluation and design of discomfort, injury and fatigue reducing products.

Intermediate Outcomes

- Novel evaluation techniques of musculoskeletal discomfort and potential injury mechanism applied in this study have been used, in collaboration with flooring companies, by to evaluate floors for comfort under foot. In addition, these novel methods are being used to develop best dosage practice for sit stand desks in collaboration with sit stand desk companies and the office for ergonomics research committee.

End Outcomes

- No end outcomes are noted at this time. Future research is required to determine the effectiveness of the intermediate outcomes on end outcomes.

Section 2 of the Final Progress Report: Scientific Report

E. Background

Scope of the Problem

Many occupations, including retail, manufacturing and healthcare, require standing for long periods of time. Workers in the United States spend on average 61%—approximately 5 hours—of their workday standing (Statistics, 2016). Many common occupations, such as waiters and waitresses, hairdressers, retail salespersons, and nurses are on their feet throughout the workday (Engels et al., 1995; Halim, Omar, Saman, & Othman, 2011; Waters & Dick, 2015). In the United States, seven of the top ten largest occupations in 2012, with a total employment level of 19.5 million, required prolonged standing (Statistics, 2013). Worker complaints of musculoskeletal discomfort in the lower extremities are frequently associated with occupational prolonged standing. This discomfort is commonly identified as a risk factor associated with the development of occupational injuries (I Halim & Omar, 2011; I. Halim, Omar, Saman, & Othman, 2012). Prolonged standing is linked to increased occupational injuries and medical costs, decreased productivity and psychological fatigue resulting in demoralized workers and lost revenue (I Halim & Omar, 2011; I. Halim et al., 2012; King, 2002; Redfern & Cham, 2000; Zander, King, & Ezenwa, 2004). In particular, lower extremity discomfort and swelling have been found (Cham & Redfern, 2001; I Halim & Omar, 2011; I. Halim et al., 2012; Kim, Stuart-Battle, & Marras, 1994; King, 2002; Macfarlane et al., 1997; Marr & Quine, 1993). Repeated, long term exposure to standing also has been implicated in the development of serious health problems, particularly degenerative joint damage, muscle injury, and circulatory diseases, such as venous disorders, increased stroke risk, and carotid atherosclerosis, (I Halim & Omar, 2011; Macfarlane et al., 1997; Meijssen & Knibbe, 2007; Tomei, Baccolo, Tomao, Palmi, & Rosati, 1999).

The impact of prolonged standing on the body is difficult to measure due to a lack of understanding of the underlying mechanisms of discomfort and injury risk. Assessments using psychophysical, physiological and biomechanical methods have been reported. Psychophysical measures are the most reliable and often reported, using subjective discomfort surveys (Redfern & Cham, 2000). Physiological and biomechanical methods evaluating musculoskeletal changes such as leg movements, external swelling, temperature, and muscle activity, have produced inconsistent and often conflicting results (Cham & Redfern, 2001; King, 2002; Lin, Chen, & Cho, 2012; Redfern & Cham, 2000). As of yet, there are no reliable objective measures to evaluate musculoskeletal discomfort during standing. No study has examined the impact of occupational prolonged standing on articular cartilage and muscle characteristics to provide a better understanding of the underlying physiological injury risk. In order to gain a better understanding of the injury mechanisms associated with prolonged standing, consistent, repeatable, objective measures are needed to aid in evaluating and minimizing occupational discomfort and injury risk. Analysis of articular cartilage deformation over time using high-resolution biplane radiographic images during standing is a non-invasive technique that can evaluate cartilage deformation at the knee joint during prolonged standing. Given previous study results, our biplane dynamic stereo x-ray (DSX) system will accurately measure in vivo cartilage deformation during prolonged standing.

Mechanisms of musculoskeletal disorders such as degenerative joint damage caused by prolonged standing have been hypothesized to be tissue damage due to insufficient blood supply in the muscles and continuous concentrated compression of the cartilage of the joints

(Meijssen & Knibbe, 2007). Osteoarthritis is the most common joint disorder in the world and the development of knee osteoarthritis has been linked to occupational factors including prolonged standing (Helmick et al., 2008; Schouten, van den Ouweland, & Valkenburg, 1992). Additionally, workers who stand commonly report discomfort and swelling in the lower extremities as well as chronic venous insufficiencies (Krijnen, de Boer, Ader, Osinga, & Bruynzeel, 1997; Lin et al., 2012; Redfern & Cham, 2000). Standing is a risk factor for limb swelling due to increased hydrostatic pressure and diminished activity of the calf muscle during standing (L, SE, & DN, 2013). Dr. Redfern, mentor on the proposed study, collected leg volume measurements before and after standing for 4 hours using a volumetric approach finding that leg volume increased as much as 181 cm³ during standing (Cham & Redfern, 2001). Interventions, such as stockings, are at times effective in reducing swelling and injury risk (Krijnen et al., 1997). Previous research has only focused on external measurements of swelling such as circumference and volume and not internal muscle tissue changes (Krijnen et al., 1997; Lin et al., 2012; Redfern & Cham, 2000). Near Infrared Spectroscopy (NIRS) is a non-invasive technique used to measure changes in oxygenation, blood volume, and hemoglobin levels over time. NIRS has been used to provide a reliable estimate of changes in muscle oxygenation and blood flow in the lower back erector spinae muscle and leg muscles during incremental levels of prolonged contractions, during which oxygenation was found to decrease throughout a contraction (Kell & Bhambhani, 2008; McGill, Hughson, & Parks, 2000; Quaresima, Ferrari, Franceschini, Hoimes, & Fantini, 2004). Preliminary results suggest that NIRS could be as a measure of prolonged muscle oxygenation and fluid flow changes, and those measures are associated with subjective measures of discomfort.

To-date, direct measures of knee joint cartilage and lower extremity muscle characteristics during prolonged standing are missing and would increase our understanding of the etiology of occupational joint and muscle pain while informing new methods of reducing occupational injuries. This project addresses this need through novel use of cutting edge technology to examine articular cartilage deformation and muscle characteristics over time. Monitoring in vivo changes in the joints and muscles including cartilage deformation, oxygenation, blood flow, hemoglobin, swelling, electromyography, and biomechanics will aid in describing the physiological changes occurring during prolonged standing and provide useful information regarding the etiology of lower leg joint and muscle discomfort and injury.

Human Factors

Musculoskeletal injury mechanisms during prolonged standing are likely impacted by demographics, such as body weight. Obesity is a growing concern in the United States as more than one-third of Americans were obese in 2009-2010 (Ogden, Carroll, Kit, & Flegal, 2012). Obese workers file more compensation claims, have greater than six times higher associated costs and miss nearly thirteen times more days away from work due to occupational injuries than non-obese workers (Janssen, Bacon, & Pickett, 2011; Shuford & Restrepo, 2010). Investigating the relationship between obesity, musculoskeletal disorders, disability and health costs are a priority in the workplace to aid in injury prevention and ergonomic interventions (Capodaglio et al., 2010; Janssen et al., 2011). Obese individuals tend to report pain in multiple joints (Hitt, McMillen, Thornton-Neaves, Koch, & Cosby, 2007; Leboeuf-Yde, 2000; Sabharwal & Root, 2012). However, causality between obesity and musculoskeletal pain has yet to be determined due to the complex interaction of multiple factors that may impact pain (Chou & Shekelle, 2010). The effect of increased body weight on the lower extremity joints during prolonged standing has yet to be examined. Previous research has commonly found that obese individuals are at a higher risk of developing osteoarthritis in their lower extremity joints (Blagojevic, Jinks, Jeffery, & Jordan, 2010; Grazio & Balen, 2009; Schouten et al., 1992).

Excess weight imposes abnormal mechanics and stresses on the body including reduced muscle strength and capacity to hold prolonged fixed postures, which could account for the high incidence of musculoskeletal disorders in obese workers (Capodaglio et al., 2010). Obesity-related differences in circulation, muscle tissue, and cartilage likely impact injury risk during prolonged standing, the extent to which is unknown but preliminary data included in this proposal demonstrate that obesity does impact cartilage deformation during short term standing. This proposal will determine the impact of obesity on musculoskeletal injury risk during standing. These obesity-related differences can be described using novel objective measures such as in vivo cartilage deformation, muscle oxygenation, and blood fluid flow and when found, can be used to develop effective interventions incorporating human factors.

Environmental Factors

Modifying flooring and footwear is a common ergonomic intervention to reduce perceived discomfort. Mats appear to reduce subjective discomfort compared to hard floors (Cham & Redfern, 2001; King, 2002; Lin et al., 2012). Unfortunately, studies of flooring have had mixed results and there is no consensus about the influence of flooring on any physiological or biomechanical objective parameters (Lin et al., 2012; Redfern & Cham, 2000). This proposed study will identify the impact of flooring on lower extremity muscle oxygenation, swelling, blood volume, and hemoglobin levels during standing in relation to muscle fatigue. Having a greater understanding of the underlying physiological responses in the muscles to long term standing will lead to both the design of new interventions and the evaluation of interventions.

Impact of Research

Understanding the underlying physiological responses to prolonged standing will provide new objective data to evaluate injury risk and to inform interventions. Information gained from Specific Aims 1 and 2 can be used to improve the understanding of prolonged standing on joint and muscle mechanics, possibly developing new biomarkers to aid in injury risk assessments. Examining human factors (obesity) and environmental factors (flooring) on these effects will lead to both the design and evaluation of new, more effective interventions aimed at reducing discomfort and injuries associated with occupational prolonged standing.

This research, in addition to a series of studies that would naturally follow in its path, will lead to new methods of evaluating injury risk, developing guidelines, models and more effective interventions to reduce musculoskeletal injuries in the workplace. Since prolonged standing is common in the workplace, this research can impact multiple industry sectors including Healthcare and Social Assistance, Manufacturing, Mining, Public Safety, Transportation, Warehousing and Utilities, Wholesale and Retail Trade. The NIOSH cross-sector programs being addressed are Engineering Controls, Musculoskeletal Disorders, Prevention through Design, and Training Grants. This research directly contributes to the NIOSH Research to Practice initiative as it is aimed at reducing worker injury, specifically injuries associated with prolonged standing which is very common in the workplace.

Innovation

This research is innovative as it includes novel methods and approaches to study injury risk during standing not employed previously. The impact of occupational prolonged standing on articular cartilage deformation and muscle characteristics had yet to be examined. Current assessments for injury risk on articular cartilage depend on assumptions from static and cadaveric studies. Using high-resolution biplane radiographic images acquired from our

innovative biplane DSX system is a non-invasive technique that can accurately measure articular cartilage deformation in vivo over time during prolonged standing. This will not only provide new data directly relevant to joint disorders and injury risk, but also create a unique objective measure for evaluating existing or new interventions for occupational prolonged standing. Monitoring in vivo changes in venous blood flow and muscle oxygenation, swelling, and fatigue using electromyography and NIRS are also a novel application to understanding physiological changes occurring during prolonged standing. Utilizing NIRS to measure changes in muscle oxygenation during prolonged standing is also an innovative technique to evaluate these physiological changes. Additionally, the population of interest, including obese workers is a novel aspect of this research. There is no previous research examining weight-related contributions to musculoskeletal injury mechanisms during prolonged standing. The effect of flooring on changes in lower extremity muscles had not been examined using NIRS. Finally, this research is unique in the collaboration between experienced occupational biomechanists and a team with the unique expertise in acquisition and analysis of in vivo joint deformation and muscle characteristics.

F. Specific Aims

The goal of the research project within this career development proposal is to enhance the understanding of environmental and physiological factors involved in occupational prolonged standing. Prolonged standing in the workplace is a significant ergonomic problem, directly linked to numerous health problems and high economic costs. Worker complaints of musculoskeletal discomfort in the lower extremities are frequently associated with occupational prolonged standing and identified as a risk factor in the development of injuries. Unfortunately, the underlying mechanisms of joint and muscle discomfort and injury during standing are unclear. The hypothesis of the proposed project is that prolonged standing has a significant impact on the musculoskeletal system that occurs over time and can be measured. The objective is to investigate the impact of standing on: (Specific Aim 1) articular cartilage deformation within the knee joint and (Specific Aim 2) lower extremity muscle characteristics. A second objective is to investigate the impact of human factors (obesity) and environmental factors (flooring) on these effects. Two experiments will address the specific aims using novel and innovative methodologies including dynamic stereo x-ray, near-infrared spectroscopy, electromyography, and biomechanical analysis. Obesity is a growing concern in the United States with more than one-third of Americans being obese. Obese workers tend to have higher injury rates and associated cost. Obesity-related differences in musculoskeletal physiology likely impact injury risk during standing, the extent to which is unknown. Although preliminary data included in this proposal demonstrates that obesity does impact measures proposed. As such, we anticipate that the weight of the subject will have an impact on the results. Finally, we will examine whether a standard intervention, incorporating a floor mat in the environment, alters the changes in the muscles seen over time. Examining human factors (obesity) and environmental factors (flooring) will lead to both the design and evaluation of new, more effective interventions aimed at reducing discomfort and injuries associated with occupational standing.

Specific Aim 1: To investigate the impact of prolonged standing on in vivo articular cartilage deformation within the knee joint; the effects of obesity also will be examined.

H1.1: Articular cartilage deformation at the knee will increase with time during prolonged standing.

H1.2: Effects of prolonged standing on articular cartilage deformation at the knee joint (H1.1) will be greater in obese individuals.

H1.3: Psychophysical measures of joint pain and discomfort will be correlated with changes in articular cartilage deformation.

Specific Aim 2: To investigate the impact of prolonged standing on lower extremity muscles; the effects of obesity and flooring will also be examined.

H2.1: Muscle oxygenation, blood volume, and hemoglobin levels of lower extremity muscles, as measured with near-infrared spectroscopy, will decrease with time during prolonged standing. This finding will be correlated with muscle fatigue, as measured by electromyography.

H2.2: Physiological variables of the lower extremity muscles stated in H2.1 will be negatively affected by obesity.

H2.3: Standing on a floor mat will reduce the negative impact of standing on the physiological variables of the lower extremity muscles.

H2.4: Psychophysical measures of muscular pain and discomfort will be correlated with changes in the physiological muscle variables.

G. Methodology

Subject Population

Thirty-one healthy adults ages 21-35 in the greater Pittsburgh area were recruited for this study. Subjects were split into two body-mass index (BMI) subgroups, healthy weight (HW, 18 subjects, BMI < 29.9 kg/m²) and obese (OB, 13 subjects, BMI > 29.9 kg/m²). Subject demographics are listed in Table 1. Subjects were recruited through the use of advertising in media, flyers, and research registries including the University of Pittsburgh Clinical and Translational Science Institute Research Participant Registry and Pitt+Me. All subjects were screened for the following exclusionary criteria: (1) any orthopedic or muscular disorders that would impede safe standing for prolonged periods, (2) lower extremity joint replacements, (3) pregnancy, (4) 5 or more X-rays in the past year, and (5) medical scans performed in the past 10 days, such as a CT or bone scan. Written informed consent approved by the University of Pittsburgh Institutional Review Board was obtained prior to participation. If the subject met basic eligibility criteria assessed on the phone, the subject came in for an in-person screening and testing.

Table 1: Mean \pm STD and range of subject demographics. An unpaired t-test was performed on age, height, weight, and BMI to confirm differences between groups. $p < 0.0001$, ****		
	Healthy Weight	Obese
Gender	6 M, 12 F	5 M, 8 F
Age, years	26.3 \pm 4 (21.0 – 35.0)	28.5 \pm 4.6 (21.0 – 35.0)
Height, cm	172.5 \pm 7.3 (159.5 – 192.0)	175.3 \pm 7.1 (162.0 – 186.0)
Weight, kg ****	70.5 \pm 10.5 (53.6 – 88.5)	113.3 \pm 14.8 (91.1 – 135.0)
BMI, kg/m ² ****	23.6 \pm 2.7 (19.3 – 28.3)	36.9 \pm 4.9 (30.2 – 46.4)

Experimental Environment

Data collection was performed at two different locations: the Orthopaedic Biodynamics Laboratory (BDL, 3820 South Water Street, Pittsburgh, PA 15203) and the University of Pittsburgh Medical Center Mercy Hospital (Mercy Hospital, 1400 Locust St, Pittsburgh, PA 15219). All experimental testing was performed at the BDL. Equipment available at the BDL included a dual-stereo x-ray (DSX) system and a Bertec Instrumented Treadmill platform (TM-07, 2500 Citygate Dr, Columbus, OH 43219). A continuous wave near-infrared spectroscopy acquisition device (NIRS-2, ISS, Inc., IL) was provided by Dr. Theodore Huppert (Associate Professor, Electrical and Computer Engineering, University of Pittsburgh). Surface electrodes (Delsys Trigno Wireless EMG, Delsys, Boston, MA) and subjective discomfort surveys (CR10-Borg, (Borg, 1998)) were provided by the Human Movement and Balance Laboratory at the University of Pittsburgh. Figure 1 displays a typical testing setup. Computer tomography (CT) images of the knee—used for data analysis—were collected at Mercy Hospital.



Figure 1: Typical testing setup at the Orthopaedic Biodynamics Laboratory.

The DSX system was designed and custom built by Dr. Scott Tashman (Director, Biomedical Engineering Program, Steadman Philippon Research Institute) to collect accurate, in vivo skeletal kinematic data (Tashman & Anderst, 2003). The DSX system emits synchronized pulses, creating two radiographs of the knee. From these radiographs, an exact orientation of the bones in the knee can be determined. A 3D model of the knee derived from a CT scan is processed with these x-rays to create a model of the knee. The average distance between the tibial plateaus and femoral condyles can be derived from this data. This process has been validated for measuring gap distance at the knee joint, which is related to cartilage deformation (W. Anderst, Zael, Bishop, Demps, & Tashman, 2009; Tashman & Anderst, 2003; You, Siy, Anderst, & Tashman, 2001).

Behavioral stabilographic characteristics of prolonged standing were measured using two force plates (one for each foot during standing). Force plates collected force and moment data from each leg to determine stabilographic changes over time (Cham & Redfern, 2001). Muscular characteristics of prolonged standing were measured using EMG and NIRS. EMG was measured using surface electrodes to record electrical activity of the muscle tissue. Analysis of this electrical activity estimates muscle fatigue over time (Halim, Omar, Saman, & Othman, 2012). The NIRS device emits low levels of infrared light at discrete wavelengths through a flexible fiber optic cable placed on the soleus muscle (Bakker, Smith, Ainslie, & Smith, 2012).

Two sets of surveys were administered during testing. The first survey was administered at the beginning of each experimental visit, and contained one question, with the following possible responses:

What proportion of the working day do you stand (circle)?
Less than 10% 10% to 25% 25% to 50% 50% to 75% more than 75%

The question was printed on a sheet of paper and subjects were asked to point at the range that they identified with or circle it themselves. Results from this survey were considered as potential covariates for this study. During standing, a discomfort and tiredness survey was

administered every 30 minutes. Figure 2 displays the CR-10 Borg discomfort and tiredness survey that was administered (Borg, 1998). Ratings of floor surface softness, overall tiredness, overall leg tiredness, and perceived discomfort of specific body segments (upper back, lower back, hips, upper legs, knees, lower legs, ankles, and feet) were collected. The set of questions and diagram were taped to the standing desk subjects used during standing. Separate answer sheets were given to each subject to self-report their answers, and answer sheets were immediately collected after completion. Subjects were not allowed to see their prior answers throughout the trial to minimize expectation bias.

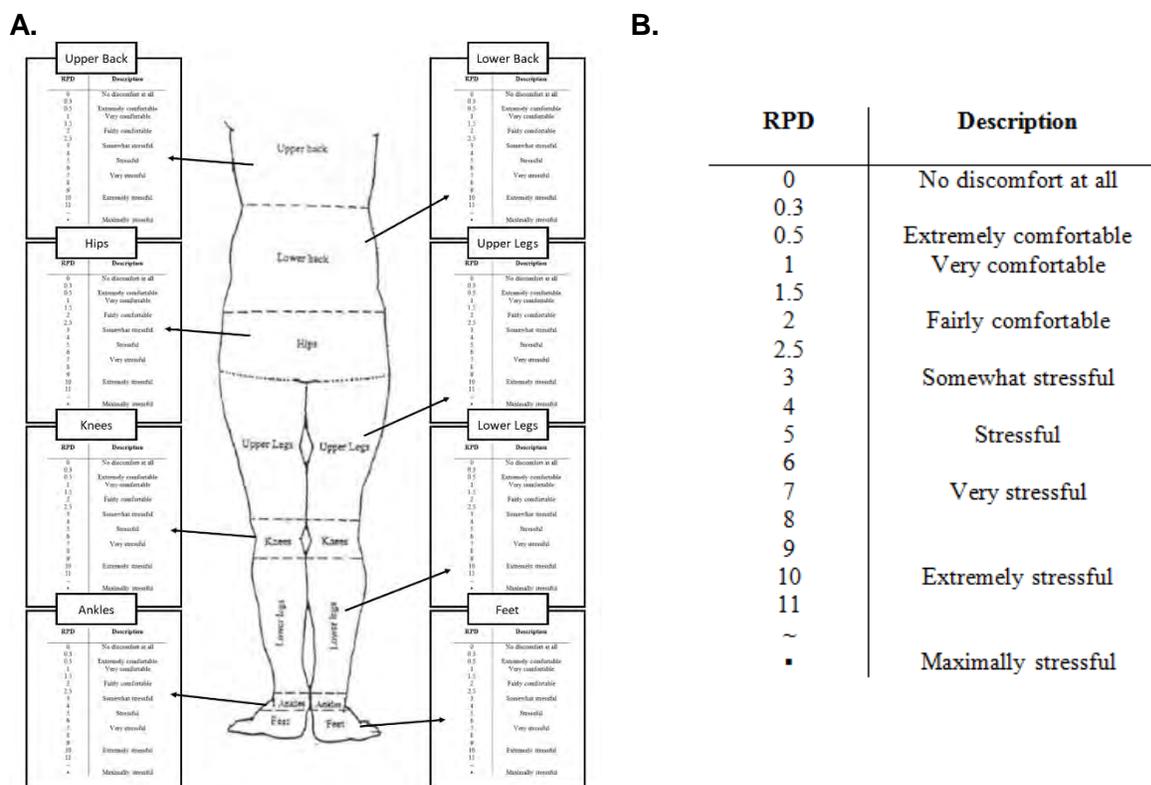


Figure 2: A. Full document provided to subjects to complete their survey. B. Enlarged example of each scale used for separate body parts.

Experimental Protocol

Two standing visits were collected for each subject. Subjects were instructed to refrain from participating in any strenuous exercises 48 hours prior to testing. All testing sessions began between the hours of 6:00 AM and 9:00 AM to control for diurnal musculoskeletal or circulatory changes. Experimental testing duration was approximately four hours, including lab setup, subject setup, testing, and lab takedown. Subjects were provided the same shoes and socks to control for differences in shoe structure. Shoe Shore A hardness properties of the shoe sole have been previously reported as 61.0 (Iraqi, Cham, Redfern, & Beschoner, 2018). Flooring conditions (hard floor, HF; anti-fatigue mat, MT) for each visit were randomly assigned, and the subject was informed of the flooring assignment during subject setup. The HF condition was a Bertec Instrumented Treadmill instrumented with a polyvinyl chloride belt with a material thickness of 4 mm. The MT condition was a standard diamond plated polyvinyl foam mat with a

material thickness of 10 mm. Square sections of the mat (20 in. x 20 in.) were placed over the HF condition.

Subject setup occurred in the following order and took approximately 30-45 minutes to complete.

1. Administration of a pregnancy test (females only)
2. Testing shoe selection
3. DSX alignment
4. Standing desk alignment
5. Reading of subject testing script
6. Safety harness outfitting
7. EMG electrode placement
8. NIRS probe placement

Due to radiation exposure experienced during testing, a pregnancy test was performed on all female participants. Those who tested negative were deemed eligible. Eligible subjects were supplied with black dress shoes (Figure 3) and socks. Shoe sizes were self-selected by subjects, and were consistent between visits.



Figure 3: Shoes and socks used for testing. Subjects self-selected shoe size but all shoes were the same brand and model.

To align the DSX and standing desk to the subject, he or she was asked to place each foot on a separate force plate in a self-selected “comfortable standing position,” which was marked using tape. While standing in their “comfortable standing position,” a standing desk was set to elbow height. Subjects were allowed to do computer work, reading, or watch TV/movies throughout the duration of testing. The activity of choice was not controlled between testing visits. X-ray emitters and image intensifiers were rotated about the subject to capture images of the right knee. After the DSX was positioned, a practice image was collected to ensure proper placement. An image of proper placement is displayed in Figure 4.

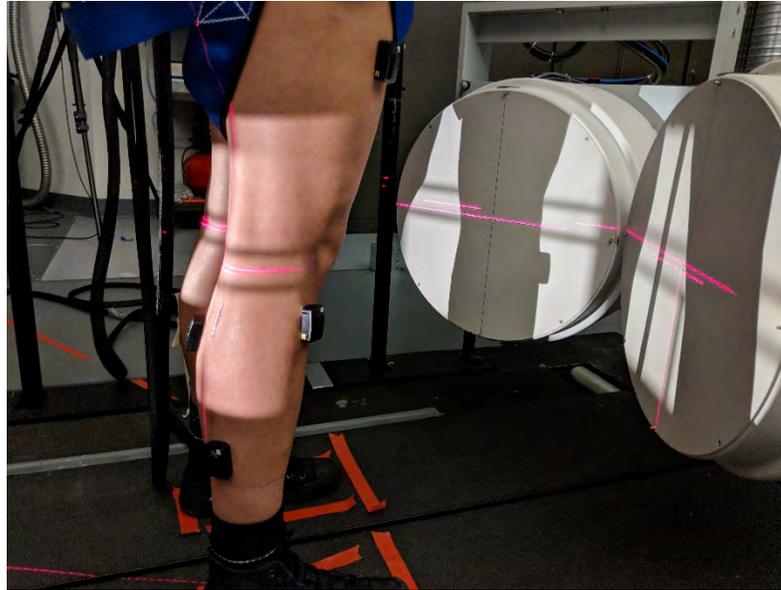


Figure 4: DSX alignment and positioning

A script outlining the main requirements, rules and expectations of the study was read to each subject. The following instructions were provided for each subject:

1. *Every 5-15 minutes today, we will ask you to stand up straight, with equal weight on both legs. I will say 'stand up straight'. You will just stand still for 20 seconds during the x-ray. When I say relax, you can return to what you were doing.*
2. *Try to stand as still as you can with one foot on each plate, keeping both feet on the ground.*
3. *Do not lean on the desk in front of you. When you are using the computer or writing, you are allowed to put your arms on the desk as necessary without leaning.*
4. *You will also be asked to answer a short questionnaire every 30 minutes. The questionnaire will ask you to rate your fatigue or tiredness in different areas of your body.*
5. *We will come out every 30 minutes to take temperature readings of different areas of your legs, lower back, and elbow. During this time, just continue working on whatever you are doing, and we will direct you if we need to.*
6. *Please let us know immediately if you feel dizzy, lightheaded, clammy, or need water.*
7. *Bathroom breaks are highly difficult during testing, so we ask that you use the restroom before we start putting equipment on you. If you need a break though, please let us know.*

A harness was supplied for each subject in case of dizziness or lightheadedness. Subjects were outfitted in their harness and it was adjusted by researchers for a secure fit. Subjects were outfitted with surface electrodes and NIRS probes. EMG electrodes were placed on the right leg, while NIRS probes were placed on the left leg. This was consistent for all subjects and was not dependent on their dominant leg. EMG electrodes were placed on the following muscles: rectus femoris, medial hamstring, tibialis anterior, medial gastrocnemius, and lateral soleus. EMG electrode placement was adapted from validated and published practices (Halim et al., 2012). Prior to electrode placement, the subject's skin was shaved and cleaned using an alcohol swab. Once EMG electrodes were placed, distances between the EMG's to anatomical landmarks were recorded, to ensure accurate similar placement during the second visit. Figure

5 displays a diagram of EMG placement. Table 2 displays the anatomical landmarks that were used for each EMG. A NIRS probe was placed on the left soleus muscle, and placement was analogous to that of the EMG. Placement of the NIRS probe on a subject soleus is displayed in Figure 6.

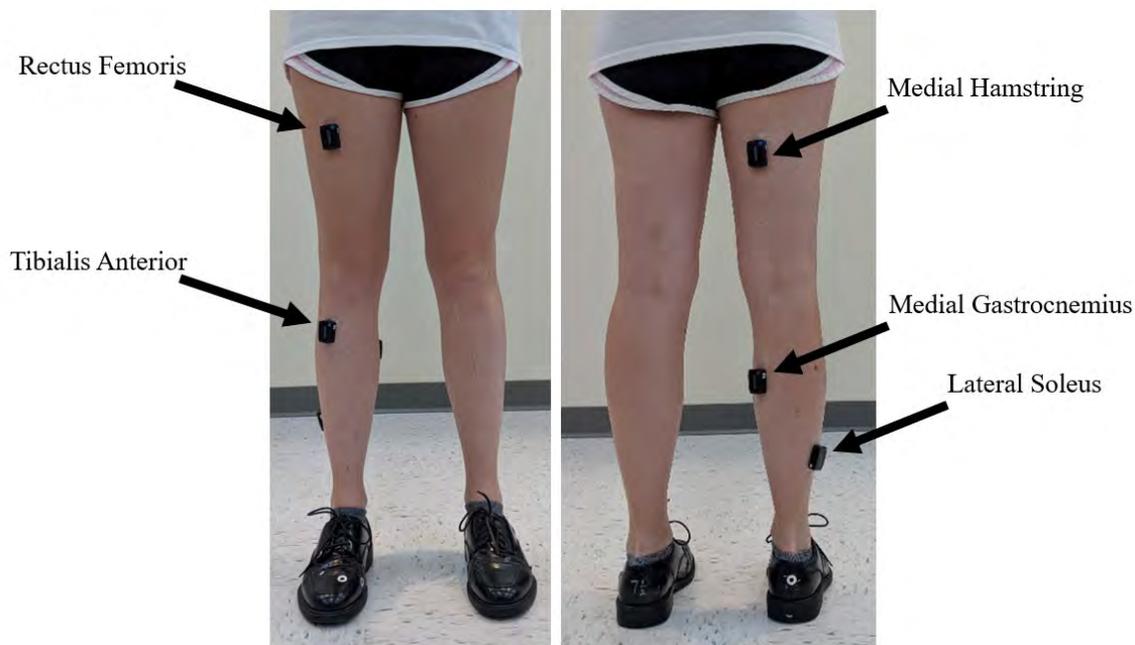


Figure 5: EMG placement locations.

Table 2: Muscles measured using EMG's and accompanying anatomical landmarks. Distances were measured in centimeters to the center of the EMG to the center of the anatomical landmark. Anatomical landmarks were chosen based on the ability to access them for measurement while the subject was seated.

<u>Muscle</u>	<u>Anatomical Landmark</u>
Rectus Femoris (RF)	Patella
Tibialis Anterior (TA)	Tibial Tuberosity
Lateral Soleus (SOL)	Malleolus
Medial Gastrocnemius (GAS)	Popliteal Fossa
Medial Hamstrings (HAM)	Popliteal Fossa

Once subject preparation concluded, subjects completed a 30 minute seated rest prior to testing (Uzuner, Rodriguez, Li, & Kucuk, 2019). The purpose of this seated rest is to relax joint cartilage deformation and blood flow. During this resting period data collection for force plates, NIRS, and EMG was started. An atomic clock was used to note the time of day that the force plates, NIRS, and EMG were started. A custom code was written to temporally align each data type prior to analysis.

When asked to stand, each subject placed their feet in the marked foot locations (see Figure 6) and were reminded to keep all their bodyweight over their feet. They were allowed to move without lifting their feet, but were not directly instructed to do so. Furthermore, subjects were

instructed not to put their weight on the standing desk in any way, other than setting their arms on the desk when using a computer or writing. Once standing, subjects were harnessed as a safety precaution. The addition of a safety harness has not been shown to affect body sway during standing (Freitas, Prado, & Duarte, 2005).

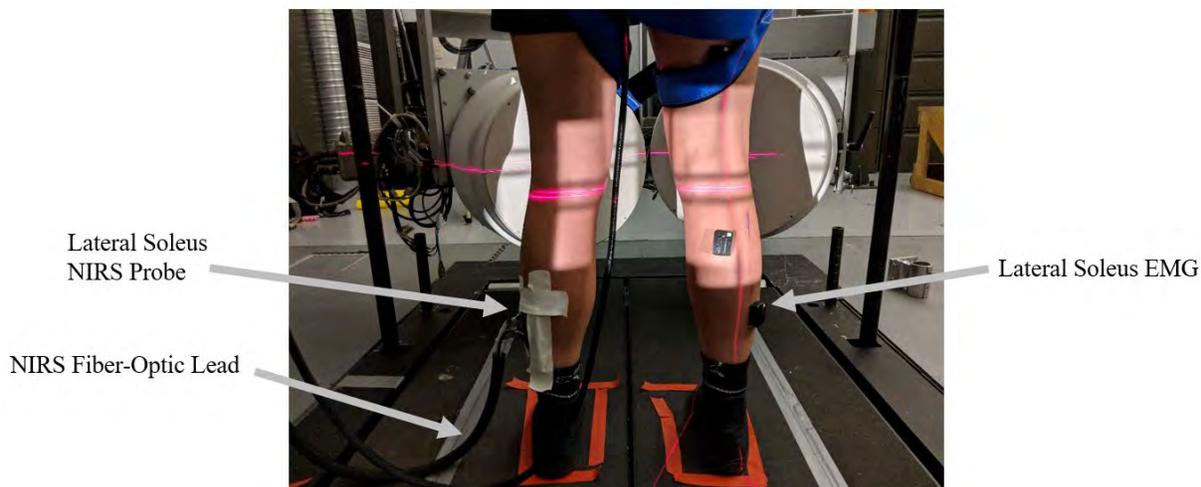


Figure 6: NIRS and EMG placement.

Subjects stood for two hours while data was collected. Force plate, NIRS, and EMG data were collected continuously. DSX image collection and discomfort survey administration were completed at discrete time points during testing. Collection frequency and times for each data type is displayed in Table 3.

Table 3: Collection frequency and times for each data type

Device/Measurement	Data Type	Collection Frequency or Times
DSX	Discrete	0, 5, 10, 15, 20, 25, 30, 40, 50, 60, 75, 90, 105, and 120 minutes
Discomfort	Discrete	0, 30, 60, 90, and 120 minutes
NIRS	Continuous	200 Hz
EMG	Continuous	2000 Hz
Force Plate	Continuous	1000 Hz

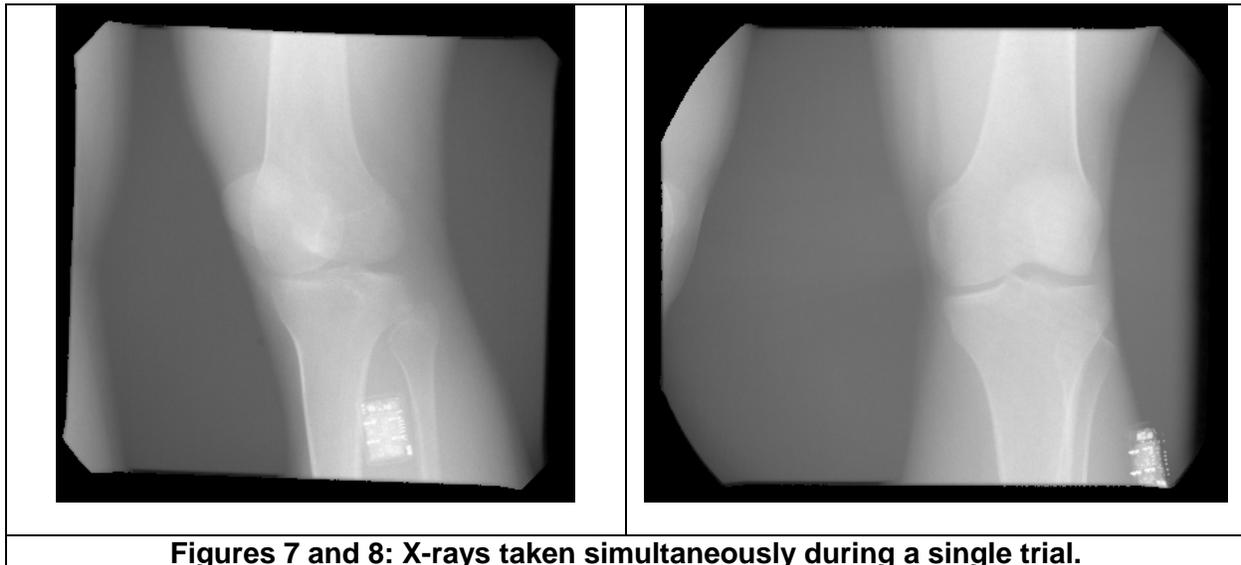
CT scans were completed by a radiologist or technician once for each subject. Axial images of the knee, hip, and ankle were recorded by radiologists and segmented at the Human Movement and Balance Lab using Mimics software (Materialise Inc., Ann Arbor, MI, USA) to create subject-specific bone models using a previously validated method (W. Anderst et al., 2009; W. J. Anderst & Tashman, 2003). A slice through the hip and slice through the ankle were obtained to calculate knee joint kinematics using previously published joint coordinate system methods (Grood & Suntay, 1983). The slice through the hip occurred at the femoral head, and the ankle slices were through the tibiotalar joint. Due to communication errors between radiologists and researchers, some hip slices were through the greater trochanter, and some ankle slices were through the tibiofibular joint. In these cases, the center of the trochanter and center of the

tibiofibular joint were used for kinematics analysis. However, all kinematics analyses are within subject and therefore makes no significant impact on analyses.

Data Processing and Analysis

Completed discomfort and tiredness surveys were obtained for overall tiredness, overall leg tiredness, upper and lower back discomfort, hip discomfort, upper leg discomfort, knee discomfort, lower leg discomfort, ankle discomfort, and feet discomfort throughout standing. Responses were transformed to a linear scale that ranged from 6 – 23, where a rating of 6 represented no discomfort reported by the subject (Borg, 1998). For analysis, discomfort and tiredness ratings were normalized to the first survey response that was collected within the first minute of standing. A repeated measures mixed effects model was performed setting discomfort and tiredness measures as dependent variables; time, BMI, and flooring as fixed effects; and subject as a random effect. Each discomfort site was analyzed separately.

The DSX system generated x-rays of the knee during standing trials with 1 ms pulsed exposures at 90 kV/125 mA. Source to detector distances were approximately 1.8 meters with an inter-beam angle of 60 degrees. However, source to detector distance and inter-beam angle varied slightly given subject preferred standing location and the location of the standing desk. Synchronized x-ray pulses were emitted from two 4 megapixel, 14 bit digital video cameras (Phantom 10, Vision Research, Inc.). X-ray images were converted into visible light by each 40 cm image intensifier (Thales, Inc.). At each discrete collection time (Table 3) images were collected for 0.1 seconds at 100 Hz. A set of example x-rays taken during a single trial are displayed in Figures 7 and 8.



CT scan image specifications are as follows: slice thickness (1.22 ± 0.2 mm), resolution (2.26 ± 0.62 pixels/mm), distance above joint center (146.0 ± 19.5 mm), and distance below joint center (142.4 ± 18.4 mm). Subjects only received one CT scan. Commercially available software (PCXMC, STUK - Radiation and Nuclear Safety Authority, Helsinki, Finland; <http://www.stuk.fi/pcxmc>) was used to estimate total effective dose of 0.097 mSv for prolonged standing visits. Effective dose for the CT scans of each knee were estimated using the CT dosimetry reports (from the CT scanner) from previous knee studies performed in this lab. The average effective exposure from CT (based on 34 previous scans) is 0.98 mSv. Thus, effective dose estimate for the entire study is in the order of 1 mSv (100 mrem). This is well below the

average exposure sustained by United States citizens per year from natural sources such as cosmic rays and radon gas (Mauro, Briggs, & Associates, 2005).

Digitally reconstructed radiographs (DRRs) of segmented bone models were matched to radiographs collected during standing using custom software. Images of these matched radiographs are displayed in Figure 9. Magenta contours are from the x-rays collected during standing trials. Green contours are of the bone models.

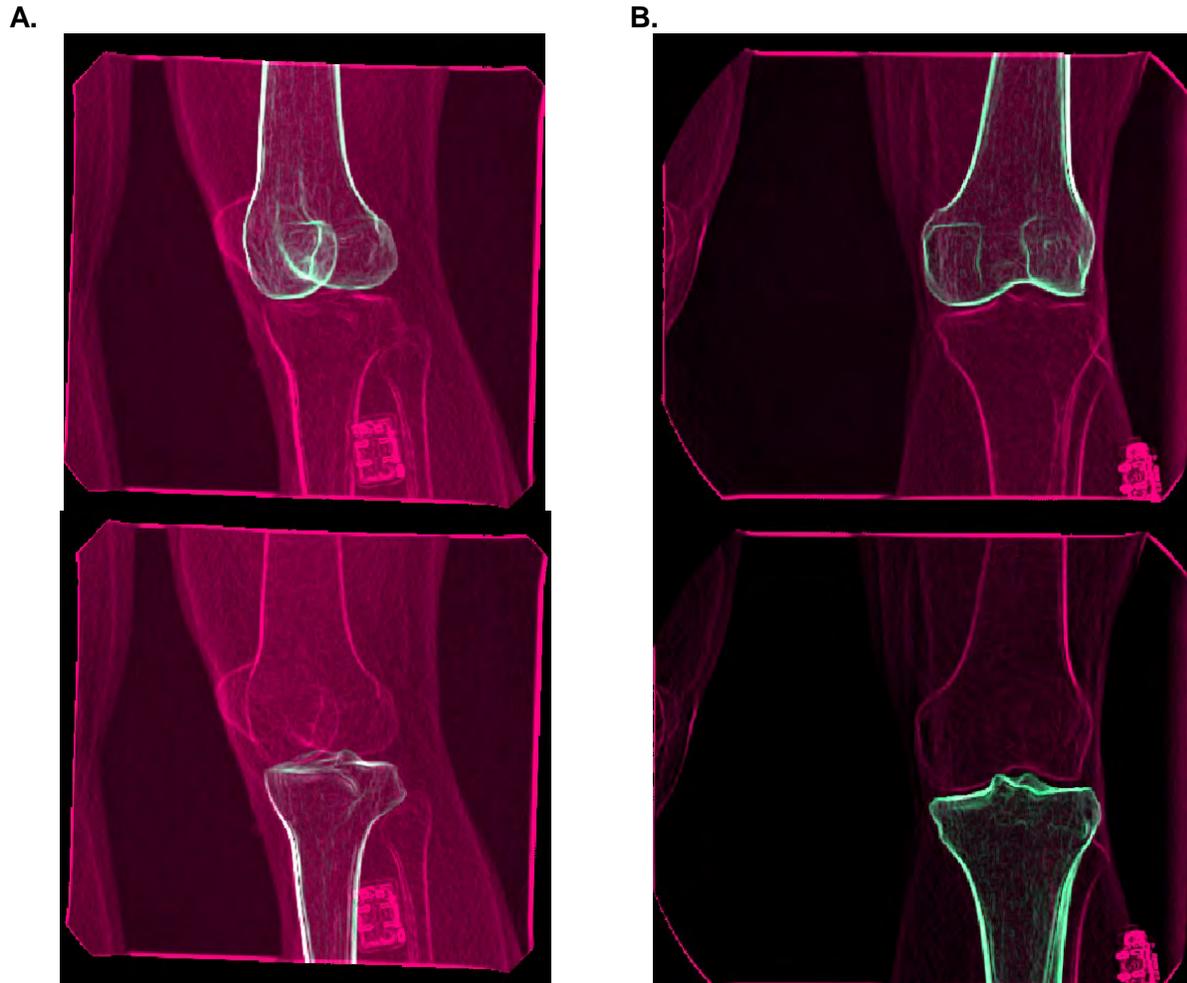


Figure 9: DRRs and x-ray renderings. Top row images are of the femur, and bottom row images are of the tibia. Images on the left (A) and right (B) sides were collected simultaneously using two x-rays.

The researcher provided an initial placement guess within two adjacent frames that an algorithm manipulated to maximize correlations between DRRs and actual radiographs. The two initial frames were then used as an initial guess for subsequent frames, the correlation maximization algorithm was repeated for all frames within a trial (W. Anderst et al., 2009). In situations in which EMG or border noise may interfere with matching, a mask was drawn around the source of the noise. The results of this optimization were then projected into 3D space, allowing for measurement of motions and positions of the knee (W. Anderst et al., 2009). This method has been used extensively. Validation results for static poses are displayed in Table 4 (W. Anderst et al., 2009).

Table 4: Model-based tracking accuracy and precision for individual bones and rotational measurements. Adapted from (W. Anderst et al., 2009).

Axes Measurements (Mean ± STD)						
	<u>Bias</u>		<u>Precision</u>		<u>rms Error</u>	
	<i>Femur</i>	<i>Tibia</i>	<i>Femur</i>	<i>Tibia</i>	<i>Femur</i>	<i>Tibia</i>
x (mm)	-0.01 ± 0.51	-0.14 ± 0.47	0.07 ± 0.02	0.08 ± 0.04	0.18 ± 0.16	0.17 ± 0.06
y (mm)	-0.14 ± 0.18	0.14 ± 0.24	0.04 ± 0.02	0.03 ± 0.14	0.04 ± 0.04	0.06 ± 0.05
z (mm)	-0.18 ± 0.54	-0.37 ± 0.13 ^a	0.04 ± 0.02	0.04 ± 0.01	0.23 ± 0.30	0.15 ± 0.10

Rotational Measurements (Mean ± STD)			
	<u>Bias</u>	<u>Precision</u>	<u>rms Error</u>
F-E (°)	0.60 ± 1.03 ^a	0.21 ± 0.04 ^a	0.85 ± 0.76 ^a
E-I (°)	0.31 ± 0.88 ^a	0.16 ± 0.09 ^a	0.67 ± 0.58 ^a
Ab-Ad (°)	-0.30 ± 0.27 ^a	0.06 ± 0.03 ^a	0.28 ± 0.27 ^a

The primary variables of interest collected include medial tibiofemoral gap (MTFG) and kinematic rotations of the knee in each anatomical plane. MTFG was collected from the central subregion of the medial tibial plateau, due to the increased likelihood of osteoarthritis development at this location. Specifically, the minimum distance between the medial femoral condyle mesh and medial tibial plateau was located and the average gap distance was calculated within a 400 mm diameter of the minimum distance. Kinematics were calculated using methods described by Grood and Suntay (Grood & Suntay, 1983). Average values of MTFG and kinematics were calculated from each separate frame for each trial for analysis. An image of final knee rendering is displayed in Figure 10. Figure 10 A displays a rendering viewed from the posterior to anterior direction. Figure 10 B displays an example rendering of the internal joint, with a color map detailing gap distance between the tibia and femur within the joint.

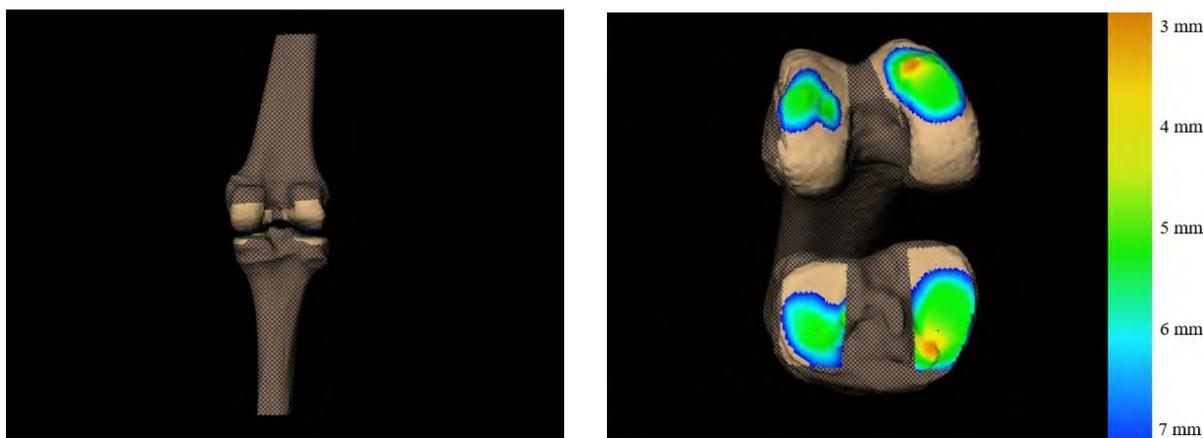


Figure 10: Final right knee rendering for a single subject. A. View is posterior to anterior. B. Color mapping indicates gap distance between the femoral condyles and tibial plateaus. Gap distance is less on the medial side than the lateral side.

MTFG was compared between flooring and BMI groups over time by comparing the coefficients of a fitted piecewise model.

The NIRS device was outfitted with a linear probe specifically designed for the surface anatomy of the soleus muscle. The probe was placed using double sided tape and medical tape. This provided a secure fit without the use of prewrap or elastics that may compress the leg and impede blood flow. Infrared light was emitted at two discrete wavelengths: 690 and 830 nm. Light attenuation was measured at 200 Hz and down sampled to 2 Hz for analysis. Light attenuation was converted to calculate the following hemodynamic variables: concentration of oxygenated hemoglobin (HbO), concentration of deoxygenated hemoglobin (HHb), and total hemoglobin (HbT).

A receiver operating characteristic (ROC) test indicated that a kurtosis filter with a spatial principal component analysis (PCA) was the most effective filter for each hemodynamic variable. Differential path length factor (DPF), a constant that defines the light scattering effects through tissue, was not defined for this analysis. This is because very little research has been performed to identify DPF for muscle and fat tissues (Ferrari, Muthalib, & Quaresima, 2011). Therefore, the units associated with changes in hemoglobin are $\mu\text{M}\cdot\text{cm}$. The concentration of hemoglobin in a volume of blood is assumed for the purposes of this analysis to remain constant. NIRS measures changes in moles of hemoglobin within a constant volume of tissue. Therefore, changes in volume of blood in a constant volume of tissue are reflected in changes of hemoglobin concentration. Raw units ($\mu\text{M}\cdot\text{cm}$) were converted to grams of hemoglobin per 100 grams of muscle tissue, with units of $(\text{gHb}/100\text{g muscle tissue})\cdot\text{cm}$. HbO, HbR, and HbT arrays were exported in 5-minute segments for analysis. DPF is left undefined but expected to be consistent throughout the duration of testing. Therefore, general trends and changes in variables over time may still be analyzed and are clinically relevant, even though true volume measurements of blood are not obtained.

HbO, HbR, and HbT data was combined into five-minute intervals for each subject, and data was normalized to time 0 minutes. Outliers were removed using a Jackknife outlier analysis. Out of the total number of points available (980), 4% were removed. Normality of residuals were checked using a visual analysis of QQ plots. A repeated measures mixed effects model was run on the data setting flooring, BMI, and time as fixed effects; and subject as a random effect. Tukey HSD post hoc analysis was performed on flooring and BMI interactions that were significant.

Surface EMGs collected electrical activity, measured in volts, at 2000 Hz. Data was resampled to 20 Hz prior to analysis. Each subject's root mean square (RMS) and median power frequency (MPF) were calculated for each five-minute interval during testing (Basmajian & De Luca, 1985). RMS and MPF were analyzed for outliers using a Jackknife outlier analysis. Out of all data points (5,554), 2.5% were removed as outliers. Following outlier removal, residuals were analyzed using QQ plots, and transformed to achieve normality. MPF data was normal for all muscles and did not need to be transformed. Boxcox transformations were performed on all RMS data for each muscle separately. Exponent values (λ) for each muscle are displayed in Table 5. RMS and MPF were analyzed using a repeated measures mixed effects model, setting RMS and MPF as dependent variables; flooring, BMI, and time as fixed effects; and subject as a random effect. The analysis was performed within each muscle separately.

Table 5: Boxcox transformations performed on RMS data. Transformed data (<i>RMS'</i>) is a function of original RMS data points and the exponent chosen for each muscle. For $\lambda = 0$, a log transformation is performed.		
<u>Muscle</u>	<u>Exponent</u>	<u>Equation</u>
SOL	$\lambda = 0$	$RMS' = \log RMS$
GAS, TA, HAM	$\lambda = -1$	$RMS' = \frac{(RMS^\lambda - 1)}{\lambda}$
RF	$\lambda = -2$	

H. Results and Discussion

Musculoskeletal discomfort during prolonged standing

Discomfort and tiredness over all body regions surveyed (overall tiredness, leg tiredness, hips, upper legs, knees, lower legs, ankles, and feet) increased significantly with time (Table 6). Results of the repeated measures mixed effects model measuring the effects of flooring, BMI, and time on discomfort is displayed in Table 6.

Table 6: Full factorial repeated measures mixed effects analysis of discomfort. Factors included are flooring (F), BMI (B), and time (T).			
<i>p</i> < 0.0001 ****, <i>p</i> < 0.001 ***, <i>p</i> < 0.01 **, <i>p</i> < 0.05 *, <i>p</i> > 0.05 NS			
	Overall Tiredness	Leg Tiredness	Upper Legs
F	$F_{1,286} = 0.21$ NS	$F_{1,286} = 8.22$ **	$F_{1,285} = 0.03$ NS
B	$F_{1,25} = 0.43$ NS	$F_{1,24} = 0.28$ NS	$F_{1,24} = 0.01$ NS
F x B	$F_{1,286} = 5.68$ *	$F_{1,286} = 0.53$ NS	$F_{1,285} = 0.06$ NS
T	$F_{1,296} = 84.3$ ****	$F_{1,295} = 114.9$ ****	$F_{1,295} = 118.1$ ****
F x T	$F_{1,286} = 0.27$ NS	$F_{1,285} = 11.6$ ***	$F_{1,285} = 0.98$ NS
B x T	$F_{1,296} = 0.00$ NS	$F_{1,295} = 1.11$ NS	$F_{1,295} = 0.00$ NS
F x B x T	$F_{1,286} = 1.86$ NS	$F_{1,285} = 2.12$ NS	$F_{1,285} = 1.12$ NS
	Hips	Lower Legs	Knees
F	$F_{1,285} = 2.96$ NS	$F_{1,286} = 0.86$ NS	$F_{1,285} = 1.88$ NS
B	$F_{1,24} = 0.01$ NS	$F_{1,24} = 1.50$ NS	$F_{1,24} = 1.92$ NS
F x B	$F_{1,285} = 0.76$ NS	$F_{1,285} = 0.49$ NS	$F_{1,285} = 0.93$ NS
T	$F_{1,297} = 97.6$ ****	$F_{1,296} = 123.8$ ****	$F_{1,299} = 128.5$ ****
F x T	$F_{1,285} = 1.10$ NS	$F_{1,285} = 0.04$ NS	$F_{1,285} = 1.48$ NS
B x T	$F_{1,297} = 1.44$ NS	$F_{1,296} = 3.20$ NS	$F_{1,299} = 0.08$ NS
F x B x T	$F_{1,285} = 2.03$ NS	$F_{1,285} = 2.10$ NS	$F_{1,285} = 0.32$ NS
	Ankles	Feet	
F	$F_{1,285} = 0.38$ NS	$F_{1,286} = 14.3$ ***	
B	$F_{1,24} = 0.26$ NS	$F_{1,24} = 0.96$ NS	
F x B	$F_{1,285} = 0.42$ NS	$F_{1,286} = 14.99$ ****	
T	$F_{1,293} = 107.9$ ****	$F_{1,298} = 193.47$ ****	
F x T	$F_{1,285} = 1.46$ NS	$F_{1,285} = 1.34$ NS	
B x T	$F_{1,293} = 0.79$ NS	$F_{1,298} = 0.01$ NS	
F x B x T	$F_{1,285} = 0.06$ NS	$F_{1,285} = 7.53$ **	

Flooring was only significant for leg tiredness and foot discomfort. In both cases, the HF condition showed higher levels of leg tiredness and foot discomfort than the MT condition, displayed in Figure 11.

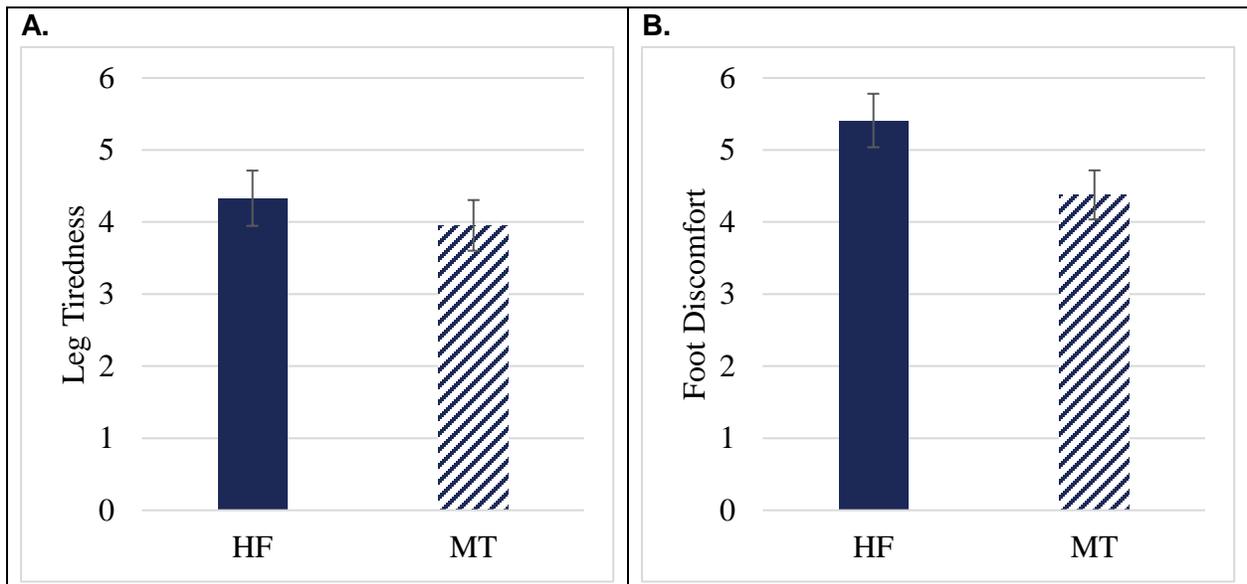


Figure 11: Flooring effects of (A) leg tiredness and (B) foot discomfort. Standing on a HF resulted in increased tiredness and discomfort than the MT.

Flooring x BMI x time was significant for foot discomfort (Figure 12). The mat had the greatest impact on minimizing foot discomfort in an obese population only.

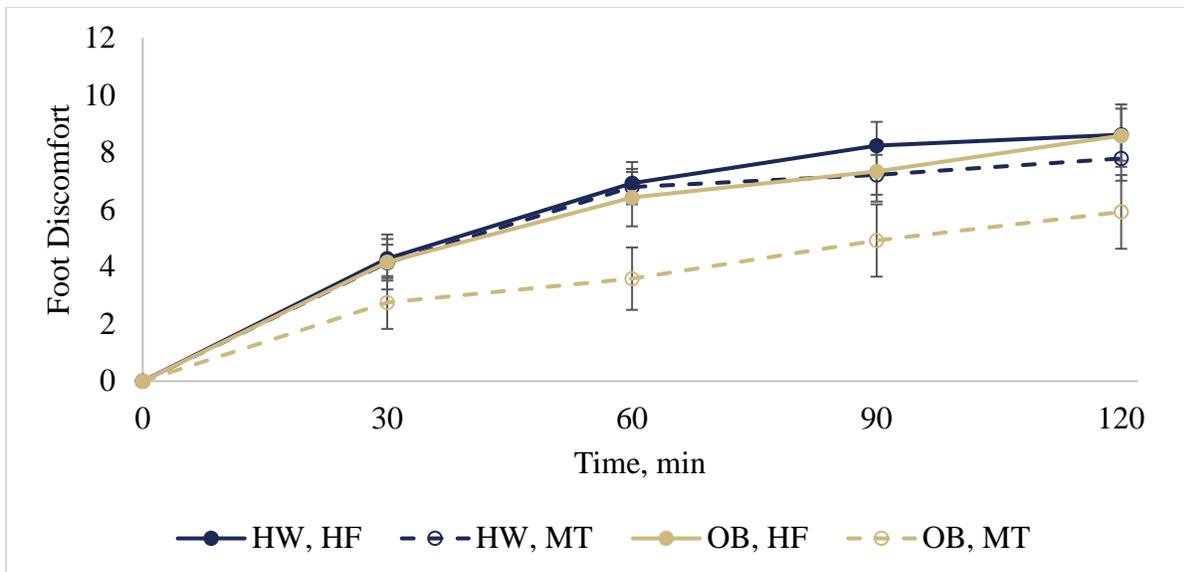


Figure 12: Flooring x BMI x time effect on foot discomfort. The OB, MT condition showed the least increase over time in comparison with the other groups, of which were all similar.

In vivo articular cartilage deformation within the knee joint during prolonged standing

Preliminary analysis of MTFG data indicated a relationship between kinematics and MTFG. Images collected during each trial contained MTFG and kinematics data. While any kinematic changes of the knee during prolonged standing are closed-chain, kinematics measurements represent tibia movements in relation to the femur. Therefore, reported positive knee flexion is associated with flexion of the femur in relation to the tibia; reported positive abduction is associated with adduction of the femur and a valgus rotation of the knee; positive reported external rotation represents internal rotation of the femur over the tibia.

Knee kinematics were not controlled during imaging. Therefore, changes in kinematics between trials introduced variability in the gap distance data. The relationships between kinematics and gap distance were unique to the subject's anatomy and knee morphology, comfortable standing position, and behavior during standing. To accommodate for the impact of varying kinematics on MTFG, an empirically informed piecewise model was fit to the data to observe changes in MTFG over time. Based on previous literature, changes in cartilage compression have displayed a fast elastic response to compression, followed by a slow creep response that behaves asymptotically with time. These changes have also been observed in vivo during walking and standing. To model this behavior, a quadratic function converged with a horizontal linear tail using average MTFG distances at each discrete time point. The statistical convergence was not constrained to a specific time frame. The coefficient describing the quadratic term in the quadratic equation was not constrained to be less than zero. In other words, the model allowed for a quadratic increase rather than decrease, if the data displayed this kind of relationship. The point at which each function converged was considered the "terminal point" in which a minimum gap distance was reached. The values describing the terminal point include terminal gap (GT) and terminal gap time (TT). Figure 13 displays a typical subject, in which the predictive model is plotted with MTFG values used to predict the piecewise model.

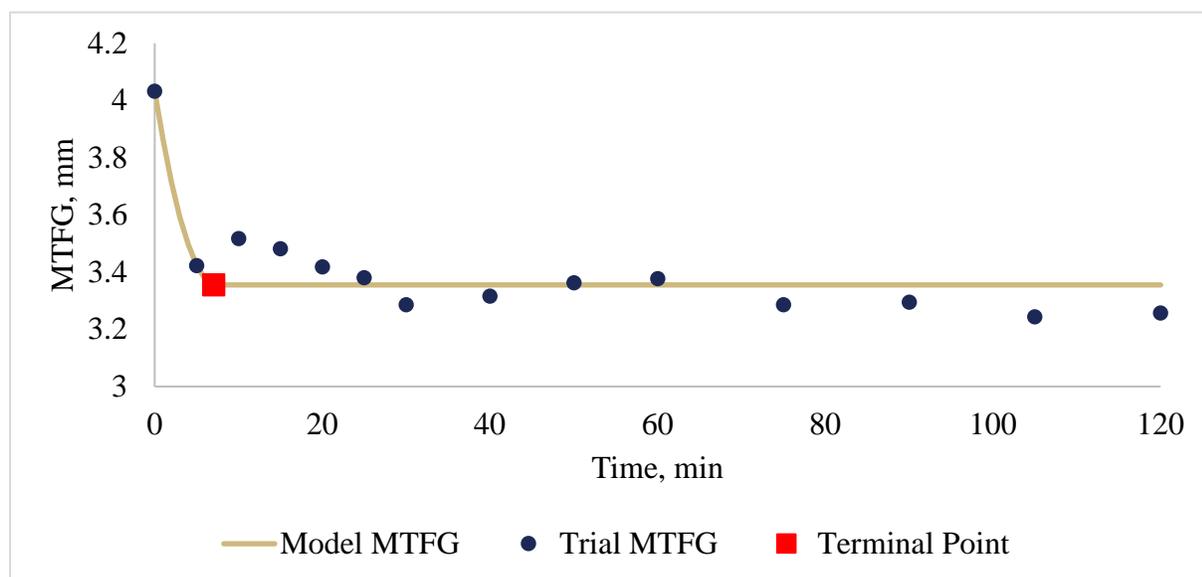


Figure 13: Trial MTFG data and fitted piecewise model MTFG for a typical subject (S01). The terminal point, at (TT,GT) is displayed.

Out of a total 24 subjects considered for this analysis, 13 subjects contained visits that did not converge or converged with errors (6 HW, 7 OB). A typical subject that did not converge is displayed in Figure 14. This subject falls within the obese subgroup and is standing on a hard floor. Figure 14, A displays MTFG collected during trial and the mean MTFG observed throughout the duration of standing. Figure 14, B displays the distance that each MTFG point in Figure 14, A is from the mean observed during standing. Over time, the distance increases and likewise the data becomes more variable over time, which may affect the model's ability to converge.

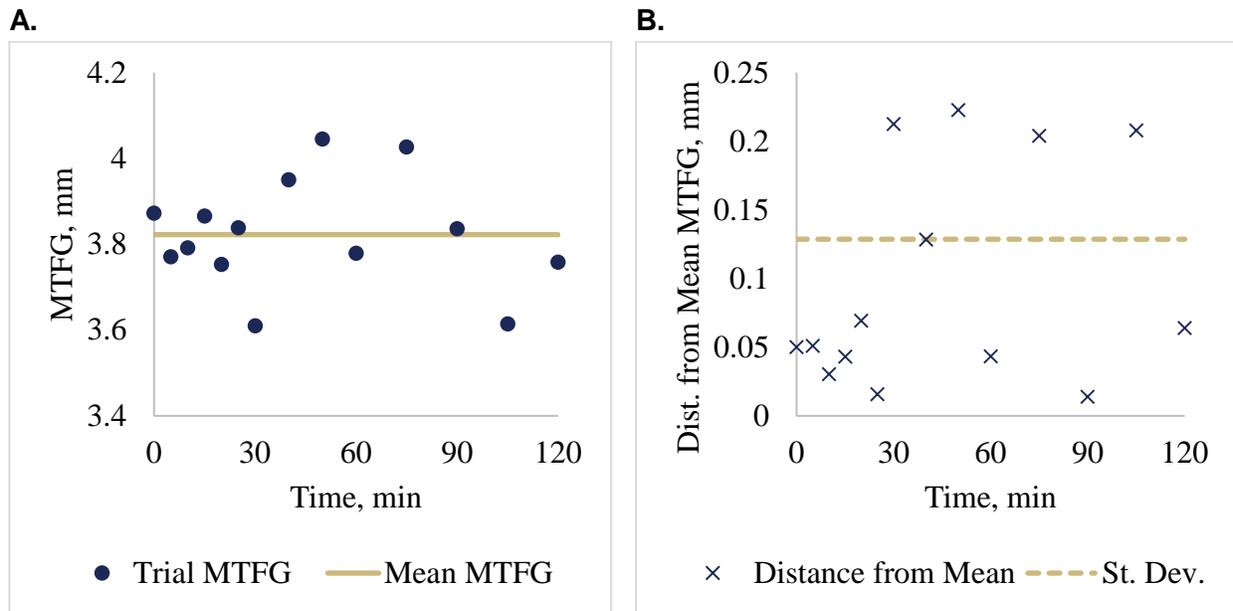


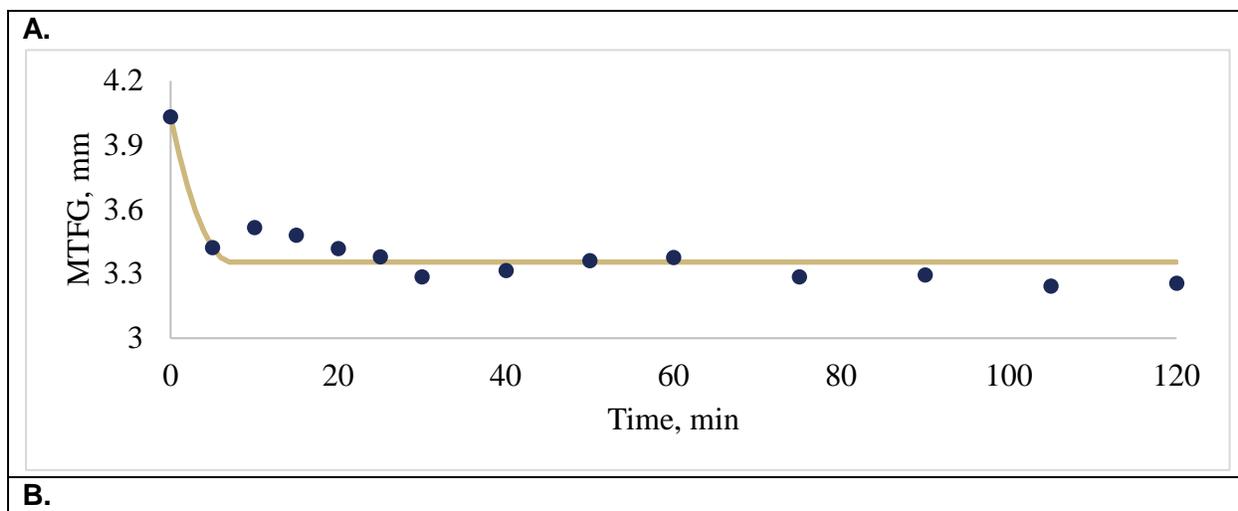
Figure 14: A typical subject that did not converge. Subject (S20) is from the obese subgroup and this data was collected while standing on the hard floor condition. A. Displays MTFG collected during testing, with a solid line indicating mean MTFG. B. Displays the distance each point in A is from the mean value. Distances tend to increase over time but also become more variable.

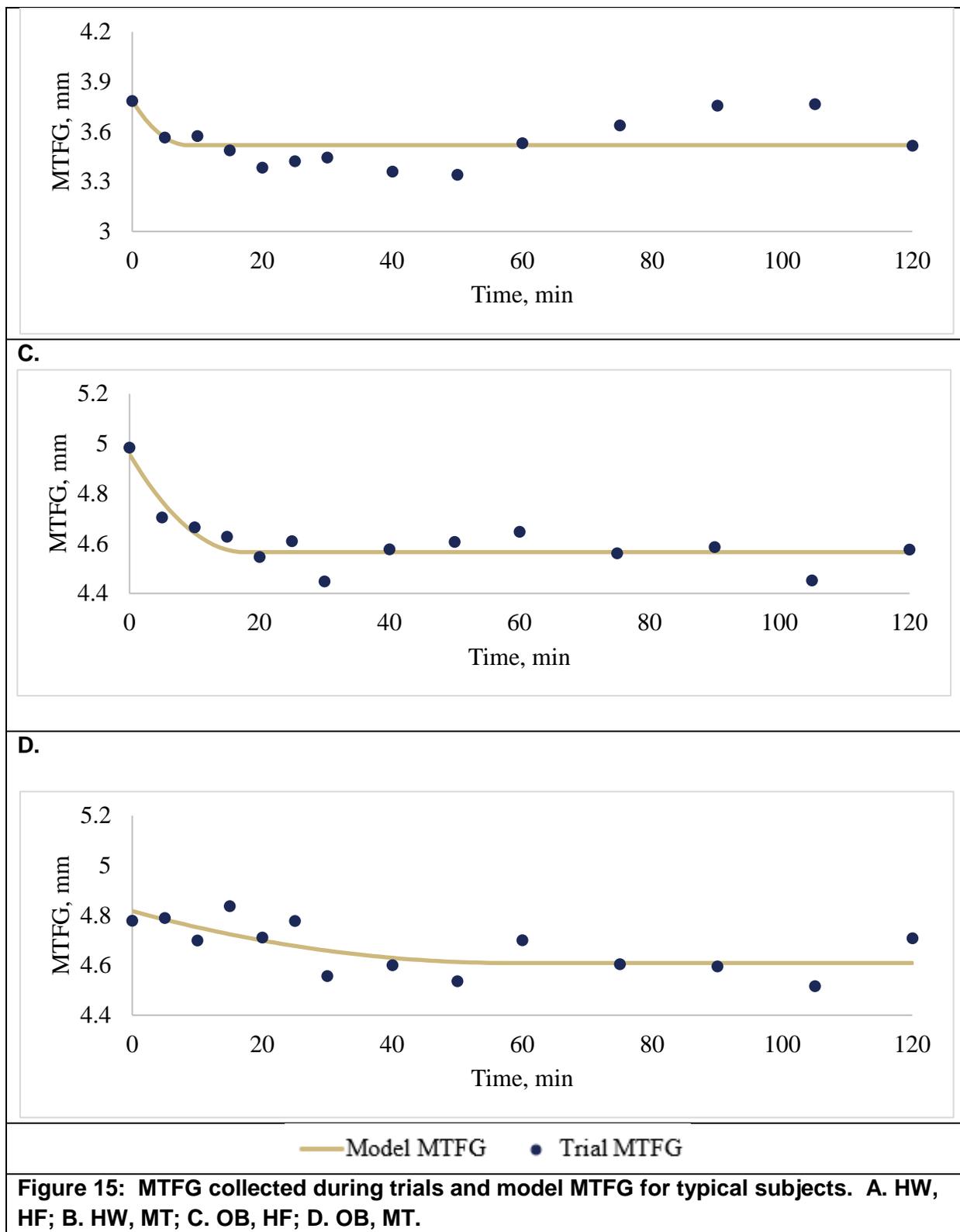
Table 7 displays all TT and GT values, initial MTFG at time zero (G_0), and statistical information for the fits (F , p , and r^2). It is important to note that only 11 subjects are shown here and are considered for analysis. To be considered for analysis, the piecewise fit applied to both HF and MT visits were required to converge—as floor analyses were performed within subject.

Table 7: All converging subjects included in analysis. Terminal gap and time at which terminal gap occurs, gap at time 0, and statistical values are included.						
Non-Obese Subjects						
	Hard Floor			Anti-Fatigue Mat		
	T_T	G_T	G_T/G_0	F	p	r^2
S01	7	3.35	0.83	28.1	****	0.55
	9	3.51	0.93	1.62	NS	0.26

S06	70	5.19	0.96	13.3	***	0.76	22	3.07	0.90	14.6	****	0.56
S07	42	3.13	0.93	0.91	NS	0.86	35	3.34	0.96	3.49	NS	0.46
S13	7	3.38	0.92	7.03	**	0.09	79	3.43	0.96	0.24	NS	0.06
S15	134	3.75	0.96	2.76	NS	0.38	21	3.82	0.93	2.21	NS	0.10
S16	13	4.09	0.83	6.7	**	0.24	27	4.10	0.94	6.25	**	0.36
Avg	45	3.82	0.91				32	3.55	0.94			
STE	20	0.31	0.02				10	0.15	0.01			
Obese Subjects												
Hard Floor							Anti-Fatigue Mat					
	T _T	G _T	G _T /G ₀	F	p	R ²	T _T	G _T	G _T /G ₀	F	p	R ²
S21	18	3.90	0.91	0.39	NS	0.08	69	4.03	4.42	1.32	NS	0.42
S22	18	4.56	0.92	20.2	****	0.42	58	4.61	4.81	5.24	**	0.52
S24	26	3.46	0.96	0.85	NS	0.32	59	3.45	3.89	13.2	***	0.73
S29	27	2.43	0.86	24.4	****	0.50	41	2.56	2.78	2.63	NS	0.39
S31	13	4.91	0.94	1.75	NS	0.40	21	4.81	5.01	1.58	NS	0.27
Avg	20	3.85	0.92				50	3.89	0.93			
STE	2.7	0.43	0.017				8	0.41	0.01			

Changes in MTFG (TT and GT/G0) were correlated with discomfort. Correlations were performed for all subject and split for each subgroup. No significant correlations were found. BMI and flooring were considered as factors to predict TT and GT. Typical NOB and OB subject data are displayed in Figure 15. For each of these subjects, the HF and MT conditions are also displayed. Each graph contains the model output as well as the raw MTFG data that was used as predictors for the model.





Average TT values with standard error are displayed in Figure 16. GT values were normalized for each subject to the starting gap value. It can be seen that the terminal gap reached by the

NOB and OB group when standing on the MT condition may be slightly increased, suggesting less cartilage compression over time. Interestingly, the terminal gap seems to be slightly increased for OB subjects as opposed to NOB subjects. TT did not seem to change between flooring conditions for the NOB group. However, flooring seemed to have a dramatic effect on TT for obese subjects. TT decreased slightly between NOB subjects and OB subjects on the HF condition.

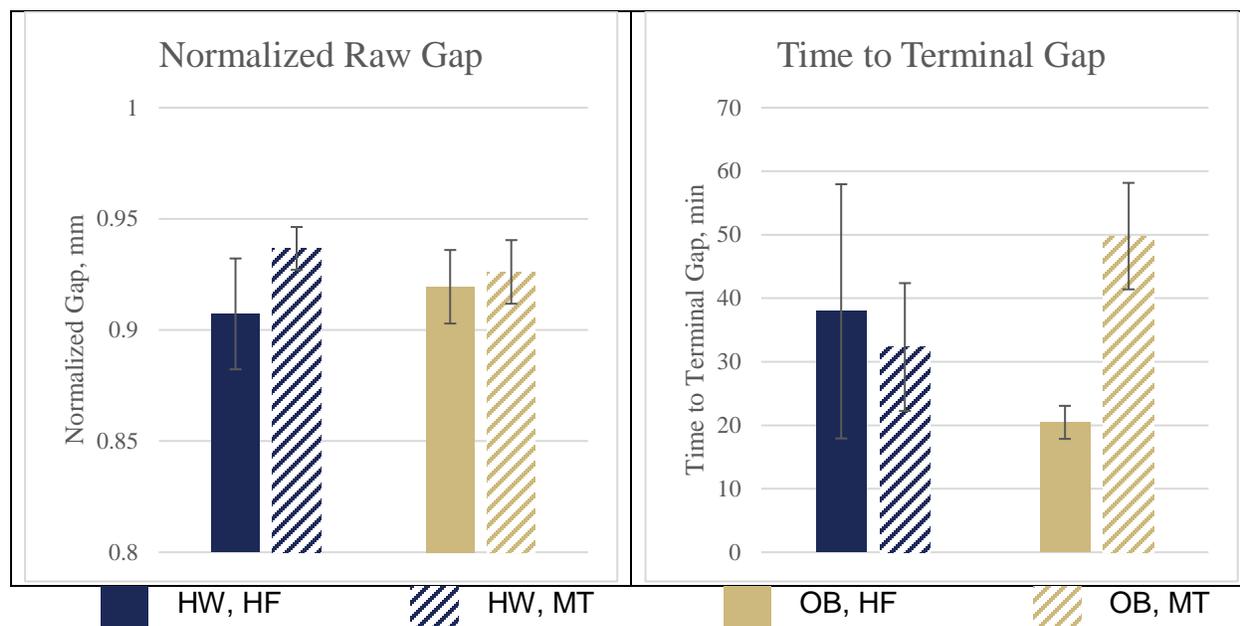


Figure 16: Raw MTFG (GT normalized to starting value) and time to terminal gap.

Lower extremity muscles characteristics during prolonged standing

Statistical analyses of muscle related outcome variables are displayed in Table 8 and 9. EMG outcome variables (MPF and RMS), along with NIRS outcome variables (HbO, HbR, HbT, Flow, and SO₂), were analyzed using a full factorial repeated measure mixed effects model in which time, flooring, and BMI were treated as factors. EMG analyses were run separately for each muscle.

Table 8: MPF results from repeated measures mixed effects model investigating the effects of flooring (F), BMI (B), and time (T). $p < 0.0001$ ****, $p < 0.001$ ***, $p < 0.01$ **, $p < 0.05$ *, $p > 0.05$ NS

	TA	GAS	SOL
F	$F_{1,1022} = 1.14$ NS	$F_{1,1112} = 6.82$ **	$F_{1,1038} = 7.77$ **
B	$F_{1,24} = 0.00$ NS	$F_{1,25} = 5.12$ *	$F_{1,24} = 0.81$ NS
F x B	$F_{1,1022} = 0.68$ NS	$F_{1,1112} = 57.88$ ****	$F_{1,1038} = 3.07$ NS
T	$F_{1,1010} = 1.15$ NS	$F_{1,1104} = 2.87$ NS	$F_{1,1032} = 8.93$ **
F x T	$F_{1,1010} = 1.77$ NS	$F_{1,1103} = 7.94$ **	$F_{1,1032} = 0.01$ NS
B x T	$F_{1,1010} = 0.49$ NS	$F_{1,1104} = 0.02$ NS	$F_{1,1032} = 7.20$ **

F x B x T	$F_{1,1010} = 0.34^{NS}$	$F_{1,1103} = 0.22^{NS}$	$F_{1,1032} = 0.72^{NS}$
	RF	HAM	
F	$F_{1,1002} = 3.14^{NS}$	$F_{1,1130} = 1.18^{NS}$	
B	$F_{1,25} = 0.42^{NS}$	$F_{1,25} = 0.01^{NS}$	
F x B	$F_{1,1002} = 6.09^*$	$F_{1,1130} = 6.37^*$	
T	$F_{1,989} = 2.61^{NS}$	$F_{1,1123} = 0.55^{NS}$	
F x T	$F_{1,989} = 0.44^{NS}$	$F_{1,1124} = 3.03^{NS}$	
B x T	$F_{1,989} = 0.07^{NS}$	$F_{1,1123} = 2.81^{NS}$	
F x B x T	$F_{1,989} = 3.51^{NS}$	$F_{1,1124} = 0.30^{NS}$	

Gastroc	Group Letters	Comparisons		P val
HW, HF	A	HW, HF	OB, HF	0.0006
HW, MT	B	OB, HF	OB, MT	< 0.0001
OB, HF	C	HW, HF	HW, MT	0.0006
OB, MT	AB			
Hamstring	Group Letters	Comparisons		P val
HW, HF	A	HW, HF	HW, MT	0.296
HW, MT	B			
OB, HF	AB			
OB, MT	AB			
Rectus Femoris	Group Letters	Comparisons		P val
HW, HF	A	HW, HF	HW, MT	0.0017
HW, MT	B			
OB, HF	AB			
OB, MT	AB			

Table 9: RMS results from repeated measures mixed effects model investigating the effects of flooring (F), BMI (B), and time (T). Boxcox transformations denoted by superscript values. $p < 0.0001$ **, $p < 0.001$ ***, $p < 0.01$ **, $p < 0.05$ *, $p > 0.05$ NS**

	[TA] ⁻¹	[GAS] ⁻¹	[SOL] ⁰
F	$F_{1,1029} = 3.35^{NS}$	$F_{1,1107} = 22.84^{****}$	$F_{1,1132} = 107.07^{****}$
B	$F_{1,23} = 4.03^{NS}$	$F_{1,25} = 0.92^{NS}$	$F_{1,28} = 2.09^{NS}$
F x B	$F_{1,1029} = 9.55^{**}$	$F_{1,1107} = 6.06^*$	$F_{1,1132} = 3.66^*$
T	$F_{1,1011} = 40.07^{****}$	$F_{1,1103} = 19.54^{****}$	$F_{1,1119} = 0.17^{NS}$
F x T	$F_{1,1011} = 6.39^*$	$F_{1,1103} = 0.31^{NS}$	$F_{1,1119} = 1.88^{NS}$
B x T	$F_{1,1011} = 1.64^{NS}$	$F_{1,1103} = 6.25^*$	$F_{1,1119} = 0.00^{NS}$
F x B x T	$F_{1,1011} = 5.10^*$	$F_{1,1103} = 0.15^{NS}$	$F_{1,1119} = 2.11^{NS}$
	[RF]⁻²	[HAM]⁻¹	
F	$F_{1,999} = 0.47^{NS}$	$F_{1,1127} = 3.54^{NS}$	

B	$F_{1,25} = 0.94$ ^{NS}	$F_{1,25} = 1.77$ ^{NS}
F x B	$F_{1,999} = 0.08$ ^{NS}	$F_{1,1127} = 72.42$ ^{****}
T	$F_{1,988} = 3.91$ [*]	$F_{1,1123} = 8.13$ ^{**}
F x T	$F_{1,988} = 5.07$ [*]	$F_{1,1123} = 3.05$ ^{NS}
B x T	$F_{1,988} = 7.26$ ^{**}	$F_{1,1123} = 23.89$ ^{****}
F x B x T	$F_{1,988} = 1.02$ ^{NS}	$F_{1,1123} = 0.78$ ^{NS}

Gastroc	Group Letters	Comparisons		P val
HW, HF	AB	OB, HF	OB, MT	< 0.0001
HW, MT	AB			
OB, HF	A			
OB, MT	B			
Hamstring	Group Letters	Comparisons		P val
HW, HF	AC	HW, HF	HW, MT	< 0.0001
HW, MT	BD	OB, HF	OB, MT	< 0.0001
OB, HF	CD			
OB, MT	AB			
Tibialis Anterior	Group Letters	Comparisons		P val
HW, HF	A	HW, MT	OB, MT	0.0425
HW, MT	B	HW, HF	HW, MT	0.0003
OB, HF	AB			
OB, MT	A			
Soleus	Group Letters	Comparisons		P val
HW, HF	AB	OB, HF	OB, MT	< 0.0001
HW, MT	C	HW, HF	HW, MT	< 0.0001
OB, HF	A			
OB, MT	BC			

Figures 17 and 18 demonstrate the impact of prolonged standing on leg muscle fatigue. Soleus MPF increased with time. In addition, the RMS of lower extremity muscles decreased after initiation of standing, then increased with time approximately about 20 minutes.

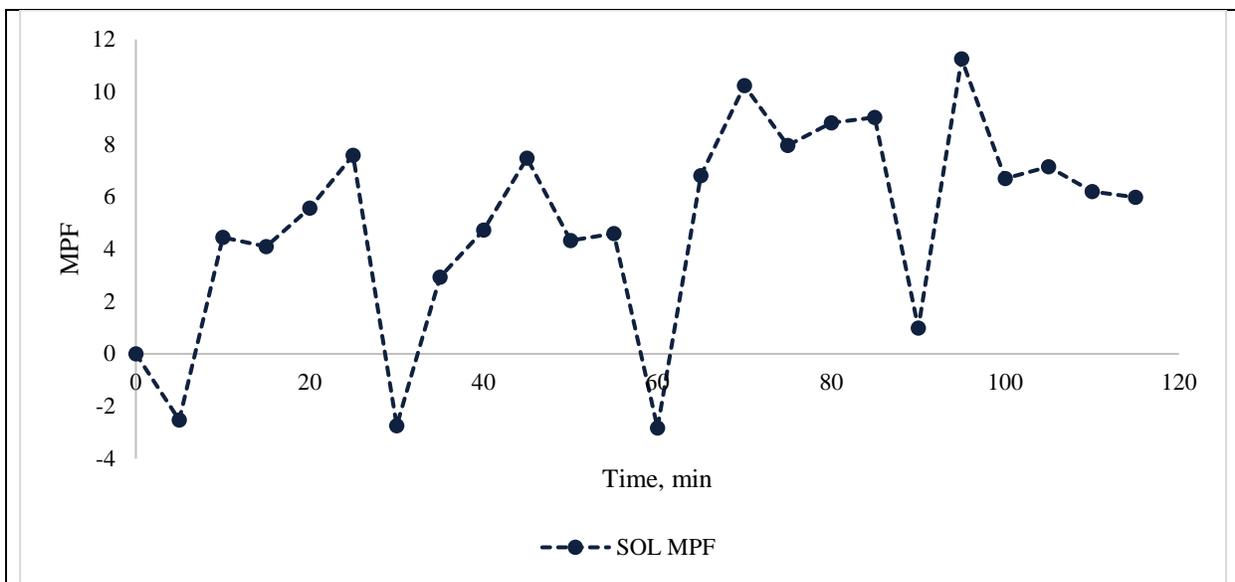


Figure 17: Soleus MPF increases with time.

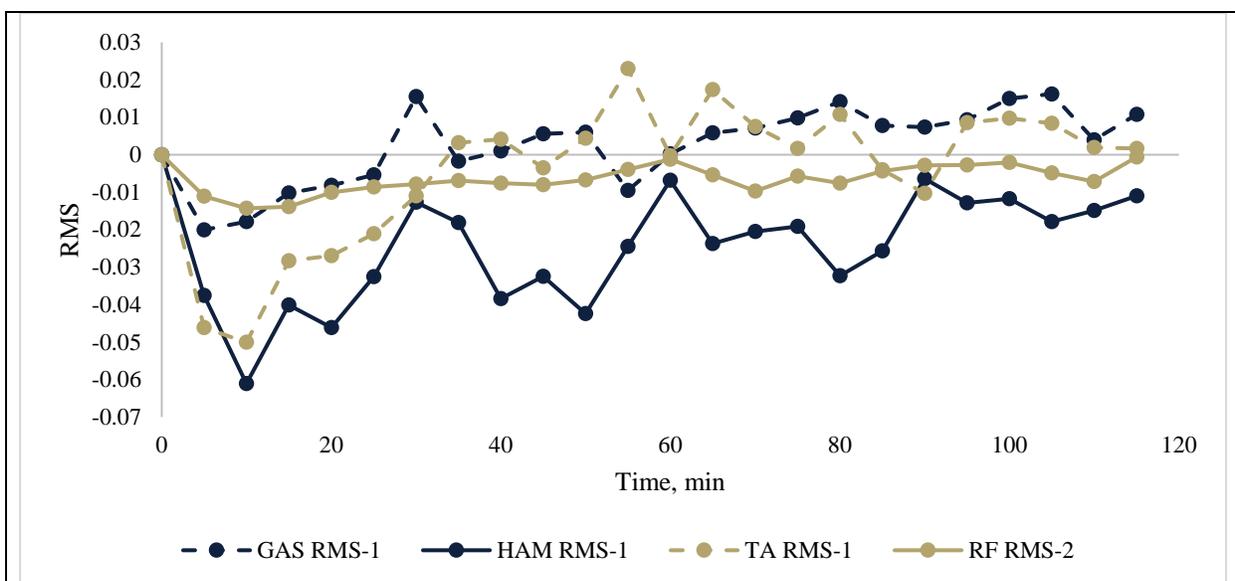


Figure 18: RMS of gastrocnemius, hamstring, rectus femoris, and tibialis anterior decreases after time 0, then increase with time.

Figures 19 and 20 demonstrate the impact of flooring and obesity on lower extremity muscle fatigue. Mat significantly decreased soleus muscle fatigue.

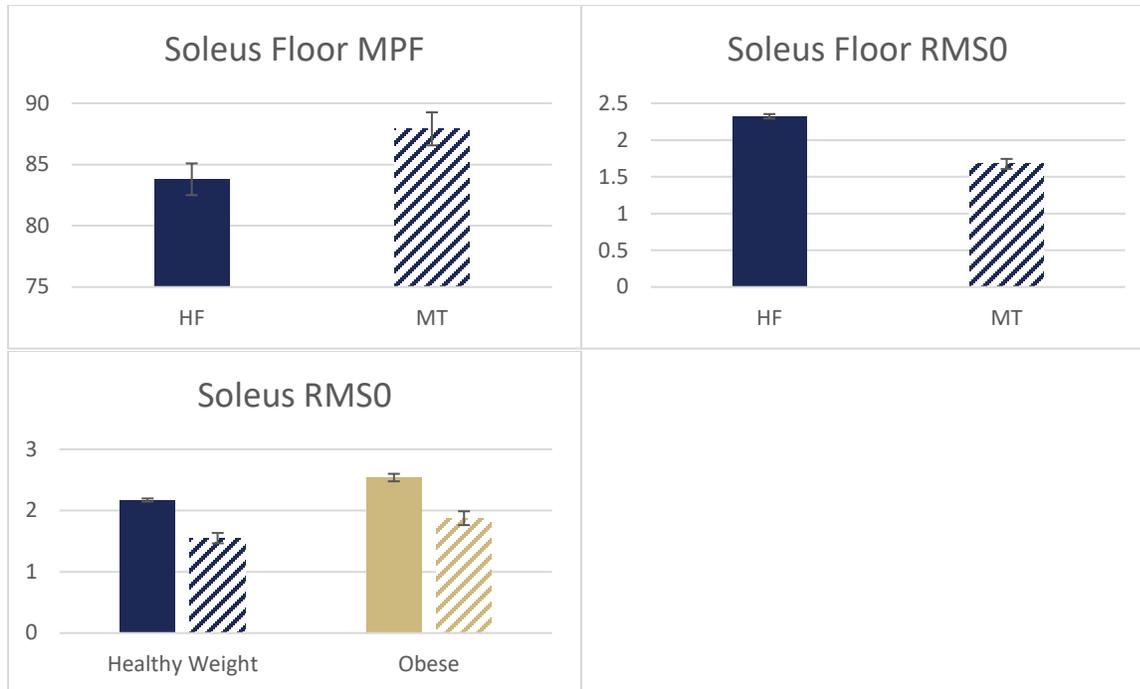


Figure 19: Fatigue characteristics of the soleus muscle across flooring conditions and obesity groups. HF is plotted in a solid bar and MT in a dashed bar.

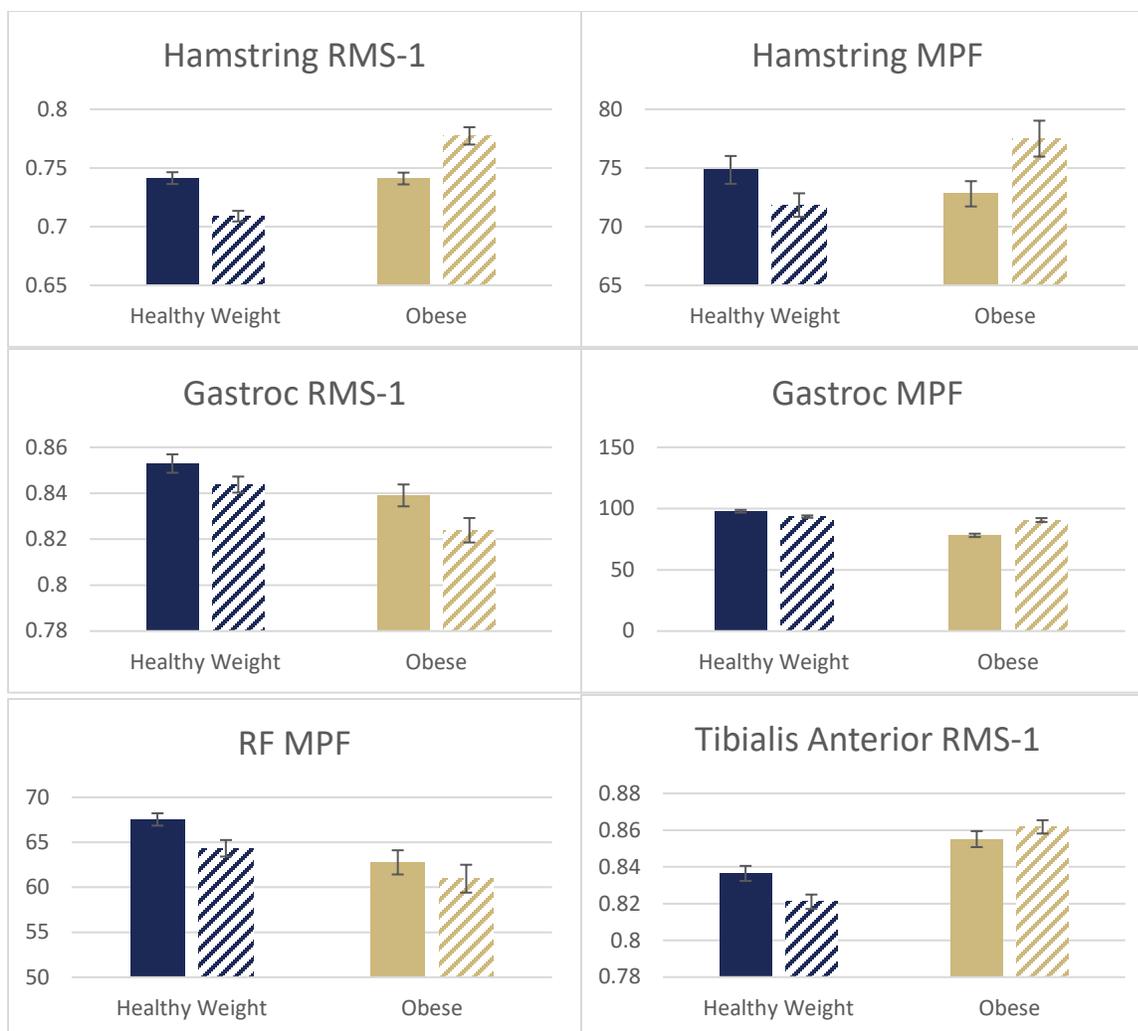


Figure 20: Fatigue characteristics of the hamstring, gastrocnemius, rectus femoris and tibialis anterior across flooring conditions and obesity groups. HF is plotted in a solid bar and MT in a dashed bar.

Figures 21 and 22 demonstrate the impact of prolonged standing on leg muscle HbO, HbR and HbT and on blood flow in the soleus muscle. Considering the relationship between HbO and HbR. The amount of HbO in the tissue region of interest is associated with arterial supply of HbO (positive inflow) and the metabolism of oxygen (negative effect). Likewise, the use of HbO is directly related to HbR. The amount of HbR in the tissue region of interest is associated with metabolic use (positive effect) and the venous outflow (negative effect). Therefore, an increase in HbO over time is likely due to a greater supply than demand. Likewise, an increase in HbR is associated with metabolism that is higher than the venous outflow. If we make the assumption that flow is overall flow, this means that the overall movement of blood over time through the region of interest is measured. An increase would mean that blood is moving quickly into and out of the region of interest. This is given that the flow into and out of the region of interest must be equal—this is a standard requirement of flow into a “pipe” system. Though, because the vessels are compliant, flow into and out of the system might not be the same until the vessels stop expanding. As seen in the below figures, HbO, HbR, HbT and Flow all increased with time.

HbT is the sum of both HbO and HbR. Increases tended to occur rapidly at the beginning of the standing trial and then plateau.

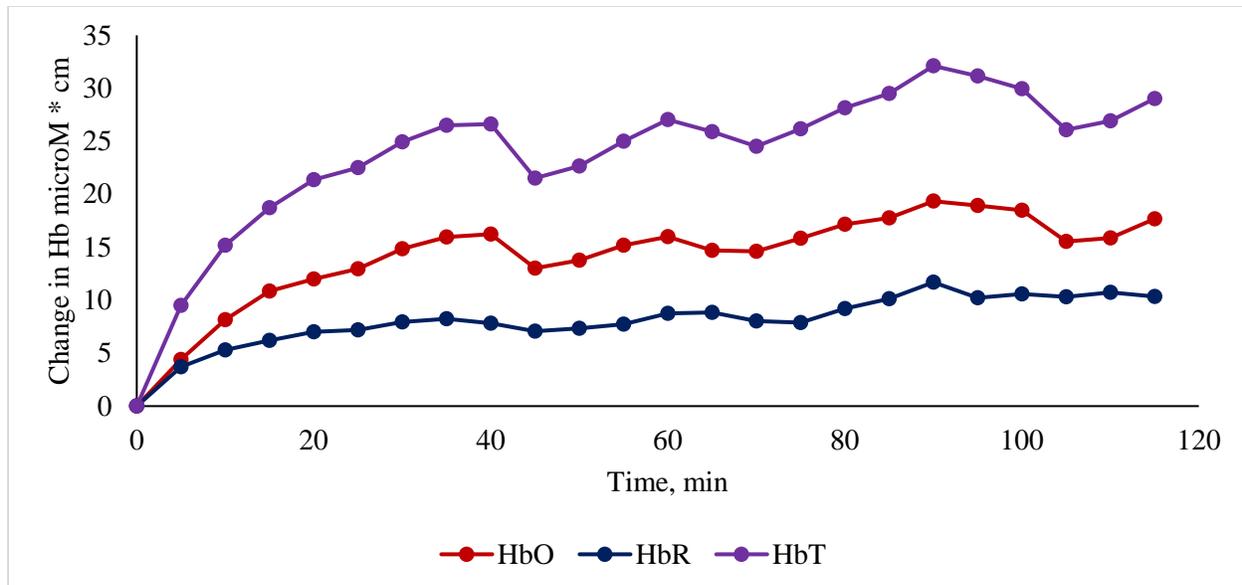


Figure 21: Soleus muscle HbO, HbR, and HbT during prolonged standing. All parameters increased with time spent standing.

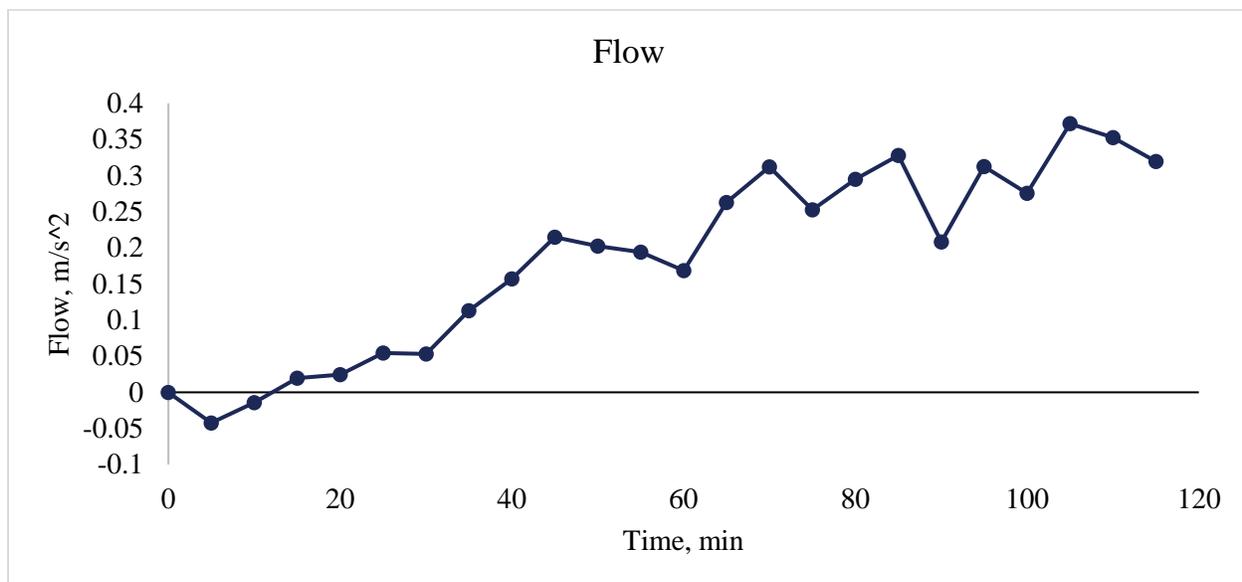


Figure 21: Soleus muscle blood flow during prolonged standing. Flow increased with time spent standing.

Soleus muscle blood flow shows similar tendencies within the first 30 minutes of standing on either a HF or MT (Figure 22). Then, MT tends to stabilize after about 40 minutes, while HF tends to continue increasing. In addition, HbR shows similar tendencies to flow (Figure 22). The HF indicates that it is likely that the relationship between flow out of the region of interest is less

than that being metabolized. Therefore, this indicates that standing on the HF might require more movement and muscle use. When muscles are used, the body sends more blood to that area and therefore the higher flow might substantiate these results.

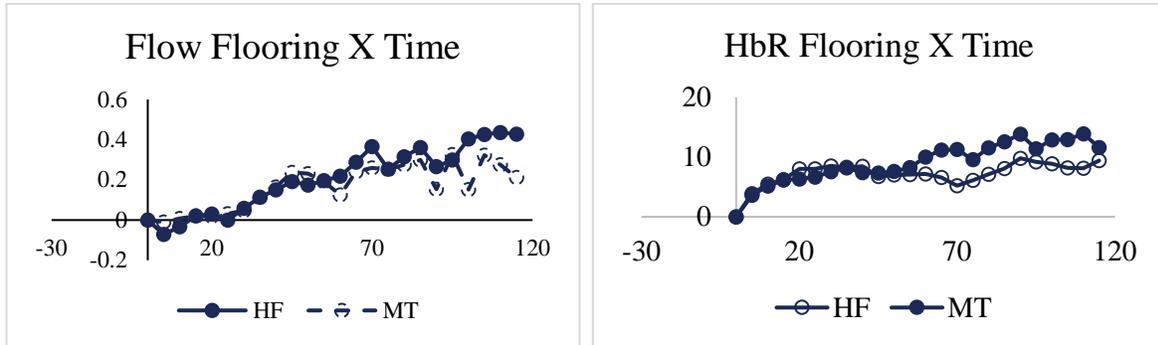
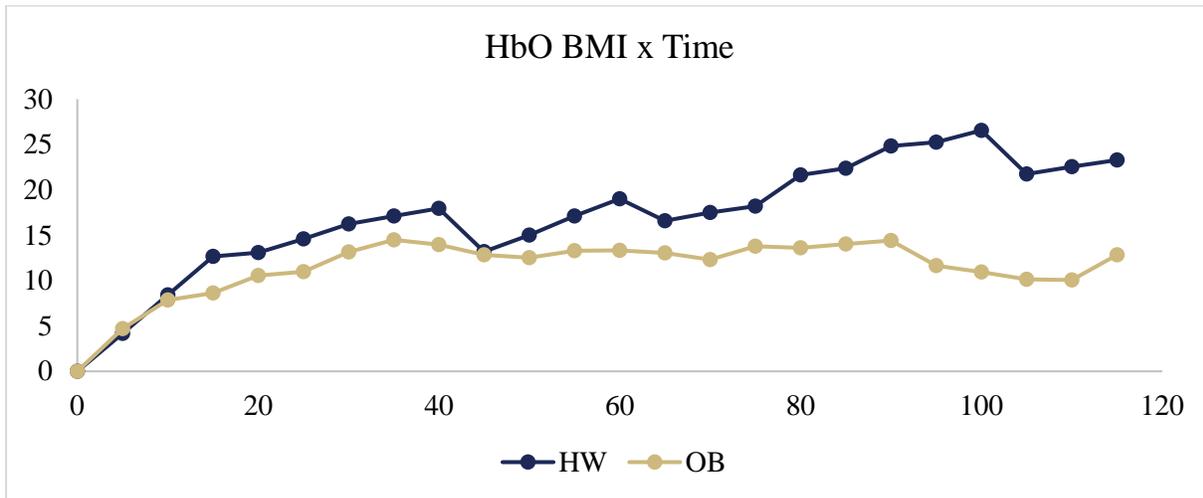


Figure 22: Soleus muscle flow and HbR on HF and MT.

HW subjects show increased HbT and HbO in comparison to OB subjects (Figure 23). Interestingly, change in flow does not change much for HW subjects in comparison to OB. This may indicate that HW subjects are able to maintain homeostasis better, despite increases in volume. Further work needs done to examine these physiological effects.



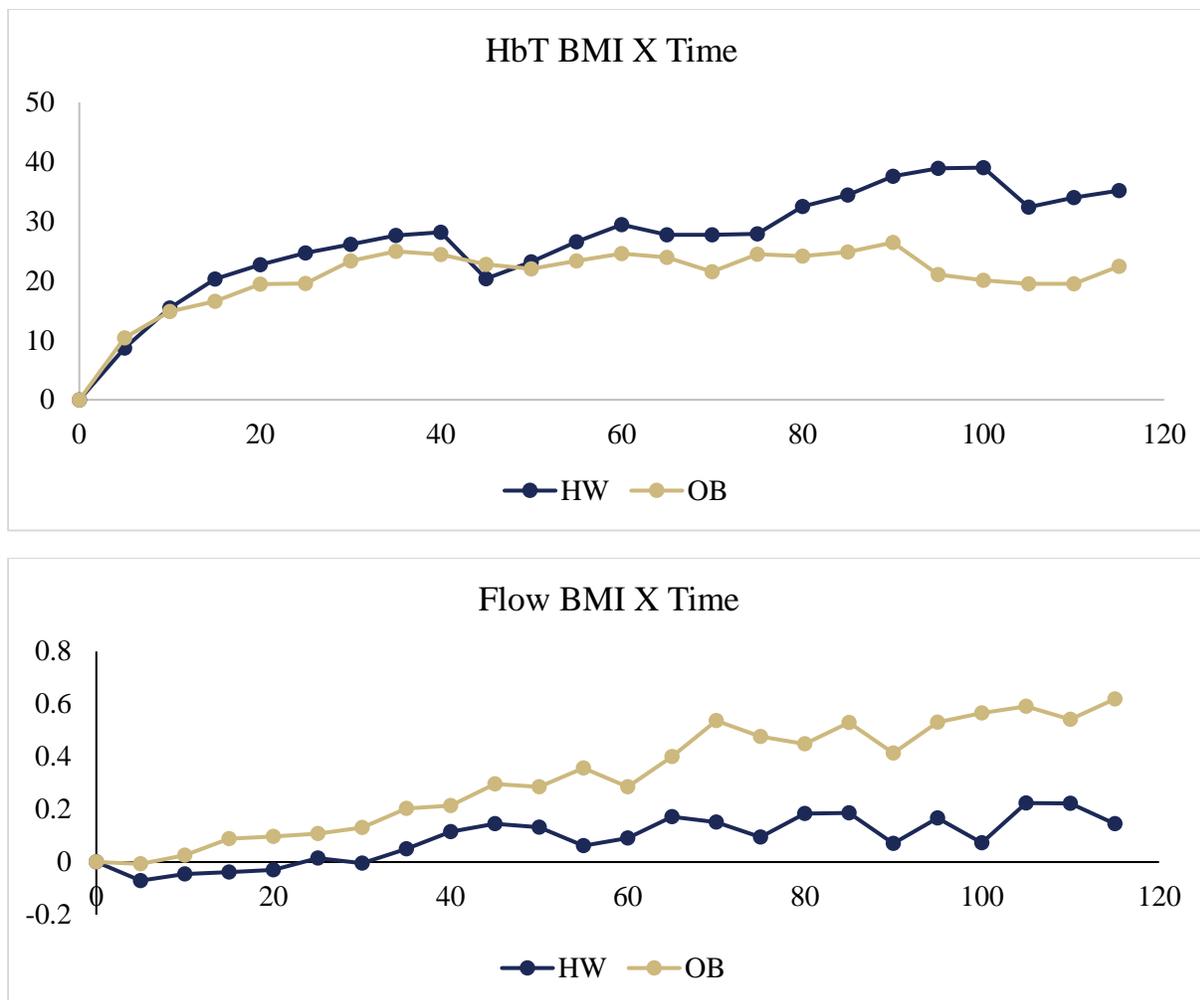


Figure 23: Soleus muscle HbO, HbT and blood flow during prolonged standing for HW and OB participants. Obese adults demonstrated differences in these parameters.

Increases in HbO, HbR, and HbT over time are consistent with prior literature. These increases show significantly different results at the same time points between the MT and HF conditions, suggesting that the MT does have an effect on circulatory mechanisms during standing. HbT and HbO increased expectedly as a result of standing. When a person moves from a resting position to standing, blood moves more rapidly towards the lower extremities as a result of increased blood flow due to gravity effects. Increased flow to the lower extremities exerts an internal pressure on the capillaries, resulting in a large pressure gradient between the internal capillary and the interstitial hydrostatic pressure. As blood volume in the lower extremities continues to increase and edema occurs, external pressures on the capillaries increase and the pressure gradient reaches equilibrium. These results, especially the increase in HbO observed in this study, suggest that muscle fatigue over time is not due to a lack of oxygen, but may be a result of some other circulatory mechanism.

This study has multiple limitations. Subjects were young and healthy. It is expected that outcomes observed during this study will become more extreme for at risk populations,

including physically inactive obese or middle aged populations. Unlike normal working conditions in which workers can lift their legs or shake out their feet, testing conditions controlled for extraneous movement, which required that subjects leave their feet in contact with the ground throughout the full duration of testing. DSX data was still very impacted by changes in knee kinematics as subjects shifted their weight. This limited the originally intended analysis and a statistical model was utilized to assist with interpretation. Additional more controlled data collection is needed to understand the underlying mechanisms of prolonged standing and cartilage deformation. This step would assist in better interpretation of applied data. Data was only included for two hours. Nevertheless, interesting changes were observed given this standing period. Finally, only one anti-fatigue mat was used during this study. It has been shown in prior studies that the mechanical properties of anti-fatigue mats may change physiological outcomes of standing. Therefore, this study may not reflect outcomes measured using other anti-fatigue mats.

I. Conclusions

Time was found to be the most prominent predictor of all outcomes, including discomfort, gap distance, EMG, and NIRS. Flooring tended to display a beneficial physiological effect on prolonged standing. The response to different flooring varied depending on BMI group. This implies that human factors should be taking into account in future work including evaluation and design of discomfort, injury and fatigue reducing products. This will ensure that interventions are tailored to the individual and more successful in preventing injury and discomfort during prolonged standing. The results collected during this study will inform future endeavors to make standing more comfortable in the workplace and prevent the associated injuries. Understanding the underlying mechanisms behind musculoskeletal injuries during prolonged standing, through direct, objective measurements, will reduce injury and inform future occupational regulations. The career development and training offered by this award have provided me with training in state of the art techniques and methodologies that are not typically used in the field of ergonomics and resulted in investigator independence. This project provided critical knowledge regarding musculoskeletal changes in the lower extremities due to prolonged standing that could result in injury. This research, in addition to a series of studies that are naturally following in its path, has led to new methods of evaluating injury risk and more effective interventions to reduce musculoskeletal injuries in the workplace. Since prolonged standing is common in the workplace, the results of this research can impact multiple industry sectors including Healthcare and Social Assistance, Manufacturing, Mining, Public Safety, Transportation, Warehousing and Utilities, Wholesale and Retail Trade. The NIOSH cross-sector programs being addressed are Engineering Controls, Musculoskeletal Disorders, Prevention through Design, and Training Grants.

J. References

- Aiyangar, A., Zheng, L., Tashman, S., Anderst, W., & Zhang, X. (2013). Capturing three-dimensional in vivo lumbar inter-vertebral joint kinematics using dynamic stereoradiographic imaging. *Journal of Biomechanical Engineering*, *accepted*.
- Anderst, W., Baillargeon, E., Martin, D., & Tashman, S. (2009). *A non-invasive technique to precisely measure three-dimensional vertebral movement in the lumbar spine*. Paper presented at the Orthopaedic Research Society, Las Vegas, NV.
- Anderst, W., Zauel, R., Bishop, J., Demps, E., & Tashman, S. (2009). Validation of three-dimensional model-based tibio-femoral tracking during running. *Med Eng Phys*, *31*(1), 10-16. doi:10.1016/j.medengphy.2008.03.003
- Anderst, W. J., Les, C., & Tashman, S. (2005). In vivo serial joint space measurements during dynamic loading in a canine model of osteoarthritis. *Osteoarthritis Cartilage*, *13*(9), 808-816. doi:10.1016/j.joca.2005.04.019
- Anderst, W. J., & Tashman, S. (2003). A method to estimate in vivo dynamic articular surface interaction. *J Biomech*, *36*(9), 1291-1299.
- Bakker, A., Smith, B., Ainslie, P., & Smith, K. (2012). Near-infrared spectroscopy. In *Applied Aspects of Ultrasonography in Humans*: IntechOpen.
- Basmajian, J. V., & De Luca, C. J. (1985). *Muscles alive, their functions revealed by electromyography* (5th ed.). Baltimore: Williams & Wilkins.
- Beck, T. W., Stock, M. S., & Defreitas, J. M. (2013). SHIFTS IN EMG SPECTRAL POWER DURING FATIGUING DYNAMIC CONTRACTIONS. *Muscle Nerve*. doi:10.1002/mus.24098
- Bey, M. J., Zauel, R., Brock, S. K., & Tashman, S. (2006). Validation of a new model-based tracking technique for measuring three-dimensional, in vivo glenohumeral joint kinematics. *J Biomech Eng*, *128*(4), 604-609. doi:10.1115/1.2206199
- Blagojevic, M., Jinks, C., Jeffery, A., & Jordan, K. P. (2010). Risk factors for onset of osteoarthritis of the knee in older adults: a systematic review and meta-analysis. *Osteoarthritis Cartilage*, *18*(1), 24-33. doi:10.1016/j.joca.2009.08.010
- Borg, G. (1998). *Borg's perceived exertion and pain scales*: Human kinetics.
- Capodaglio, P., Castelnuovo, G., Brunani, A., Vismara, L., Villa, V., & Capodaglio, E. M. (2010). Functional limitations and occupational issues in obesity: a review. *Int J Occup Saf Ergon*, *16*(4), 507-523.
- Cham, R., & Redfern, M. S. (2001). Effect of flooring on standing comfort and fatigue. *Hum Factors*, *43*(3), 381-391.
- Chou, R., & Shekelle, P. (2010). Will this patient develop persistent disabling low back pain? *Jama*, *303*(13), 1295-1302. doi:10.1001/jama.2010.344
- Eckstein, F., Lemberger, B., Stammberger, T., Englmeier, K. H., & Reiser, M. (2000). Patellar cartilage deformation in vivo after static versus dynamic loading. *J Biomech*, *33*(7), 819-825.
- Engels, J., Van Der Gulden, J., Senden, T. F., Hertog, C., Kolk, J., & Binkhorst, R. (1995). Physical work load and its assessment among the nursing staff in nursing homes.
- Ferrari, M., Muthalib, M., & Quaresima, V. (2011). The use of near-infrared spectroscopy in understanding skeletal muscle physiology: recent developments. *Philosophical Transactions: Mathematical, Physical and Engineering Sciences*, *369*(1955), 4577-4590. doi:10.1098/rsta.2011.0230
- Freitas, S. M. S. F., Prado, J. M., & Duarte, M. (2005). The use of a safety harness does not affect body sway during quiet standing. *Clinical Biomechanics*, *20*(3), 336-339. doi:10.1016/j.clinbiomech.2004.12.002

- Grazio, S., & Balen, D. (2009). [Obesity: risk factor and predictor of osteoarthritis]. *Lijec Vjesn*, 131(1-2), 22-26.
- Grood, E. S., & Suntay, W. J. (1983). A joint coordinate system for the clinical description of three-dimensional motions: application to the knee. *Journal of biomechanical engineering*, 105(2), 136-144.
- Halim, I., Omar, A. R., Saman, A. M., & Othman, I. (2011). A review on health effects associated with prolonged standing in the industrial workplaces. *IJRRAS*, 8(1), 14-21.
- Halim, I., Omar, A. R., Saman, A. M., & Othman, I. (2012). Assessment of muscle fatigue associated with prolonged standing in the workplace. *Safety and health at work*, 3(1), 31-42. doi:10.5491/SHAW.2012.3.1.31
- Helmick, C. G., Felson, D. T., Lawrence, R. C., Gabriel, S., Hirsch, R., Kwoh, C. K., . . . Stone, J. H. (2008). Estimates of the prevalence of arthritis and other rheumatic conditions in the United States. Part I. *Arthritis Rheum*, 58(1), 15-25. doi:10.1002/art.23177
- Herberhold, C., Faber, S., Stammberger, T., Steinlechner, M., Putz, R., Englmeier, K. H., . . . Eckstein, F. (1999). In situ measurement of articular cartilage deformation in intact femoropatellar joints under static loading. *J Biomech*, 32(12), 1287-1295.
- Hitt, H. C., McMillen, R. C., Thornton-Neaves, T., Koch, K., & Cosby, A. G. (2007). Comorbidity of obesity and pain in a general population: results from the Southern Pain Prevalence Study. *J Pain*, 8(5), 430-436. doi:10.1016/j.jpain.2006.12.003
- Iraqi, A., Cham, R., Redfern, M. S., & Beschorner, K. E. (2018). Coefficient of friction testing parameters influence the prediction of human slips. *Applied Ergonomics*, 70, 118-126. doi:10.1016/j.apergo.2018.02.017
- Janssen, I., Bacon, E., & Pickett, W. (2011). Obesity and its relationship with occupational injury in the canadian workforce. *J Obes*, 2011, 531403. doi:10.1155/2011/531403
- Kell, R. T., & Bhambhani, Y. (2008). Relationship between erector spinae muscle oxygenation via in vivo near infrared spectroscopy and static endurance time in healthy males. *Eur J Appl Physiol*, 102(2), 243-250. doi:10.1007/s00421-007-0577-6
- Kim, J. Y., Stuart-Buttle, C., & Marras, W. S. (1994). The effects of mats on back and leg fatigue. *Appl Ergon*, 25(1), 29-34.
- King, P. M. (2002). A comparison of the effects of floor mats and shoe in-soles on standing fatigue. *Appl Ergon*, 33(5), 477-484.
- Krijnen, R. M., de Boer, E. M., Ader, H. J., Osinga, D. S., & Bruynzeel, D. P. (1997). Compression stockings and rubber floor mats: do they benefit workers with chronic venous insufficiency and a standing profession? *J Occup Environ Med*, 39(9), 889-894.
- L, R., SE, Y., & DN, K. (2013). Non-pharmacological interventions for preventing venous insufficiency in a standing worker population. *Cochrane Database of Systematic Reviews*, 10. doi:10.1002/14651858
- Leboeuf-Yde, C. (2000). Body weight and low back pain. A systematic literature review of 56 journal articles reporting on 65 epidemiologic studies. *Spine (Phila Pa 1976)*, 25(2), 226-237.
- Lin, Y. H., Chen, C. Y., & Cho, M. H. (2012). Influence of shoe/floor conditions on lower leg circumference and subjective discomfort during prolonged standing. *Appl Ergon*, 43(5), 965-970. doi:10.1016/j.apergo.2012.01.006
- Macfarlane, G. J., Thomas, E., Papageorgiou, A. C., Croft, P. R., Jayson, M. I., & Silman, A. J. (1997). Employment and physical work activities as predictors of future low back pain. *Spine (Phila Pa 1976)*, 22(10), 1143-1149.
- Mancini, D. M., Bolinger, L., Li, H., Kendrick, K., Chance, B., & Wilson, J. R. (1994). Validation of near-infrared spectroscopy in humans. *J Appl Physiol (1985)*, 77(6), 2740-2747.
- Marr, S. J., & Quine, S. (1993). Shoe concerns and foot problems of wearers of safety footwear. *Occup Med (Lond)*, 43(2), 73-77.

- Mauro, J., Briggs, N. J. M., VA: S. Cohen, & Associates. (2005). Assessment of variations in radiation exposure in the United States.
- McGill, S. M., Hughson, R. L., & Parks, K. (2000). Lumbar erector spinae oxygenation during prolonged contractions: implications for prolonged work. *Ergonomics*, *43*(4), 486-493. doi:10.1080/001401300184369
- Meijssen, P., & Knibbe, H. J. (2007). Prolonged standing in the OR: a Dutch research study. *Aorn j*, *86*(3), 399-414. doi:10.1016/j.aorn.2007.08.007
- Ogden, C. L., Carroll, M. D., Kit, B. K., & Flegal, K. M. (2012). Prevalence of obesity in the United States, 2009-2010. *NCHS Data Brief*(82), 1-8.
- Quaresima, V., Ferrari, M., Franceschini, M. A., Hoimes, M. L., & Fantini, S. (2004). Spatial distribution of vastus lateralis blood flow and oxyhemoglobin saturation measured at the end of isometric quadriceps contraction by multichannel near-infrared spectroscopy. *J Biomed Opt*, *9*(2), 413-420. doi:10.1117/1.1646417
- Redfern, M. S., & Cham, R. (2000). The influence of flooring on standing comfort and fatigue. *AIHAJ*, *61*(5), 700-708.
- Rekant, J. S., Wiltman, S. A., Chambers, A. J. J. I. T. o. O. E., & Factors, H. (2019). A Novel Method of Analysis for Prolonged-Standing Data: Accounting for Joint and Muscle Discomfort. *7*(2), 142-152.
- Sabharwal, S., & Root, M. Z. (2012). Impact of obesity on orthopaedics. *J Bone Joint Surg Am*, *94*(11), 1045-1052. doi:10.2106/jbjs.k.00330
- Schouten, J. S., van den Ouweland, F. A., & Valkenburg, H. A. (1992). A 12 year follow up study in the general population on prognostic factors of cartilage loss in osteoarthritis of the knee. *Ann Rheum Dis*, *51*(8), 932-937.
- Shuford, H., & Restrepo, T. (2010). *How obesity increases the risk of disabling workplace injuries*.
- Statistics, B. o. L. (2013). *Occupational employment statistics: largest occupations in each area, May 2012*.
- Statistics, B. o. L. (2016). Standing or walking versus sitting on the job in 2016. *The Economics Daily*. Retrieved from www.bls.gov
- Tashman, S. (2012). Arthrokinematic biomarkers for early osteoarthritis after meniscal injury. In University of Pittsburgh: Arthritis Foundation.
- Tashman, S., & Anderst, W. (2003). In-vivo measurement of dynamic joint motion using high speed biplane radiography and CT: application to canine ACL deficiency. *J Biomech Eng*, *125*(2), 238-245.
- Tomei, F., Baccolo, T. P., Tomao, E., Palmi, S., & Rosati, M. V. (1999). Chronic venous disorders and occupation. *Am J Ind Med*, *36*(6), 653-665.
- Uzuner, S., Rodriguez, M. L., Li, L., & Kucuk, S. (2019). Dual fluoroscopic evaluation of human tibiofemoral joint kinematics during a prolonged standing: A pilot study. *Engineering Science and Technology, an International Journal*. doi:10.1016/j.jestch.2018.12.014
- Waters, T. R., & Dick, R. B. (2015). Evidence of Health Risks Associated with Prolonged Standing at Work and Intervention Effectiveness. *Rehabilitation Nursing*, *40*(3), 148-165. doi:10.1002/rnj.166
- You, B. M., Siy, P., Anderst, W., & Tashman, S. (2001). In vivo measurement of 3-D skeletal kinematics from sequences of biplane radiographs: application to knee kinematics. *IEEE Trans Med Imaging*, *20*(6), 514-525. doi:10.1109/42.929617
- Zander, J., King, P., & Ezenwa, B. (2004). Influence of flooring conditions on lower leg volume following prolonged standing. *Int J Ind Ergon*, *34*, 279-288.
- Zhang, X. (2011-2013). In Vivo Dynamic Lumbar Vertebral Motion and Disc Deformation during Lifting Tasks. In University of Pittsburgh: NIOSH.
- Zhang, X., Xiong, J., & Bishop, A. M. (2003). Effects of load and speed on lumbar vertebral kinematics during lifting motions. *Hum Factors*, *45*(2), 296-306.

K. Publications

Journal Articles

Chambers AJ, Robertson M, Baker N: [2019] The effect of sit-stand desks on office worker behavioral and health outcomes: A scoping review. *Applied Ergonomics* 78:37-53.

Rekant J, Wiltman S, Chambers AJ: [2019]. A Novel Method of Analysis for Prolonged-Standing Data: Accounting for Joint and Muscle Discomfort. *IIE Transactions on Occupational Ergonomics and Human Factors* 7(2):142-152.

Chambers AJ, Haney J, Huppert T, Redfern M: [2019]. The Effect of Prolonged Walking on Erector Spinae and Soleus Muscle Oxygenation and Discomfort. *Journal of Sports Science and Medicine* 18:337-343.

Proceedings

Wiltman S, Pechtl K, Huppert T, Chambers AJ: [2019] Influence of Flooring on Lower Extremity Blood Oxygenation and Volume during Prolonged Standing. *Proceedings of the 2019 Human Factors and Ergonomics Society, Seattle, WA, October 28-November 1.*

Wiltman S, Chambers AJ [2019] Measuring Medial Compartment Tibiofemoral Gap Distance Due to Prolonged Standing. *Proceedings of the 2019 Regional Meeting of the American Society of Biomechanics, State College, PA, April 12-13.*

Wiltman S, Chambers AJ: [2018] Effect of Standing on Tibiofemoral Gap Distance over Varying Flexion Angles. *Proceedings of the 2018 National Occupational Injury Research Symposium (NOIRS), Morgantown, WV, October 17.*

Wiltman S, Rekant J, Chambers AJ: [2018] A Novel Method for Identifying Weight Distribution Changes during Prolonged Standing. *Proceedings of the 2018 Annual Regional Meeting of the American Society of Biomechanics, State College, PA, April 20-21.*

Wiltman S, Chambers AJ [2017] Weight Shifting Strategies and Discomfort during Prolonged Standing. *Proceedings of the 2017 the Annual Meeting of the Human Factors and Ergonomics Society, Austin, TX, October 9-13.*

Bottorff E, Wiltman S, Chambers AJ: [2017] Effect of knee rotations on articular cartilage compression during knee flexion exercise. *Proceedings of the 2017 the Annual Meeting of the American Society of Biomechanics, Boulder, Co, August 8-11.*

Driggers J, McMurtry S, Wiltman S, Chambers AJ: [2017] Validating a novel 3D scanner for measuring leg swelling during prolonged standing. *Proceedings of the 2017 the Annual Meeting of the American Society of Biomechanics, Boulder, Co, August 8-11.*

Chambers AJ, Wiltman S: [2017] Time dependency of bilateral weight distribution during prolonged standing. *Proceedings of the 2017 Annual Meeting of the International Society of Posture and Gait Research, Fort Lauderdale, FL, June 25-29.*

Dissertation/Thesis

Wiltman SA: [2019] Using Objective Methods to Measure the Underlying Mechanisms of Discomfort during Prolonged Standing, Ph.D. Thesis, University of Pittsburgh.

L. Career development and training activities during award period

My career development consisted of research, coursework, and mentored training. These provided me with the skills and knowledge necessary to become an independent investigator. Coursework and research training was used to increase my knowledge of ergonomics and injury prevention. I enrolled and took courses in the University of Pittsburgh's Graduate Program in Safety Engineering. In addition to this, I acquired a certificate in Occupational Ergonomics from Colorado State University. These programs broaden my ability to recognize, evaluate, and control ergonomic risk factors in a wide range of workplace settings. I was mentored by and collaborated with experts in occupational biomechanics, orthopedics, radiology and obesity research. I also received training in state of the art techniques and methodologies that are not typically used in the field of ergonomics. I successfully lead this study that investigated the impact of prolonged standing on in vivo changes in articular cartilage deformation with the knee joint and lower extremity muscles. The career development and training offered by this award have resulted in investigator independence. Since the start of this award, I have submitted or served as a principal investigator or co-investigator on over 10 external grants, 7 internal grants, and 4 corporate research agreements, with a funding rate of better than 60%. Additionally, I have published (or currently under review) 17 journal articles and 13 proceedings while mentoring numerous undergraduate and graduate students.

M. Cumulative Inclusion Enrollment Table

[View Burden Statement](#)

PHS Inclusion Enrollment Report

This report format should NOT be used for collecting data from study participants.

OMB Number: 0925-0001 and 0925-0002
 Expiration Date: 10/31/2018

***Study Title (must be unique):** In vivo changes in lower extremity joints and muscles during prolonged standing

* Delayed Onset Study? Yes No

If study is not delayed onset, the following selections are required:

- Enrollment Type Planned Cumulative (Actual)
- Using an Existing Dataset or Resource Yes No
- Enrollment Location Domestic Foreign
- Clinical Trial Yes No
- NIH-Defined Phase III Clinical Trial Yes No

Comments:

Racial Categories	Not Hispanic or Latino			Hispanic or Latino			Unknown/Not Reported Ethnicity			Total
	Female	Male	Unknown/ Not Reported	Female	Male	Unknown/ Not Reported	Female	Male	Unknown/ Not Reported	
American Indian/ Alaska Native	0	0		0	0					0
Asian	1	2		0	0					3
Native Hawaiian or Other Pacific Islander	0	0		0	0					0
Black or African American	4	2		0	0					6
White	11	4		3	0					18
More than One Race	1	3		0	0					4
Unknown or Not Reported										
Total	17	11		3	0					31

Report 1 of 1

[< Previous Report](#)

[Delete Report](#)

[Next Report >](#)

N. Inclusion of Children

Children under 21 years of age were not eligible and did not participated in this study.

O. Materials available for other investigators

None



University of Pittsburgh

*Department of Bioengineering
Swanson School of Engineering*

326 Benedum Engineering Hall
Pittsburgh, PA 15260
412-624-9019

November 26, 2019

To whom it may concern,

I served as Dr. Chambers' primary mentor during the award period of the grant entitled, "In vivo changes in the lower extremity joints and muscles during prolonged standing". Dr. Chambers successfully completed all phases of this career award. She independently led the research portion of this award while mentoring numerous undergraduate and graduate students. She received training in state of the art techniques and methodologies that are not typically used in the field of ergonomics. Dr. Chambers has already been able to apply these techniques to other projects. This award allowed Dr. Chambers to collaborate with experts in occupational biomechanics, orthopedics, radiology and obesity research. Several of these experts have continued collaborations with Dr. Chambers outside of this project. These collaborations have resulted in a funded R01 grant, a funded R03 grant, two funded internal grants and several other grants and fellowships that are currently under review. Dr. Chambers' career development also consisted of coursework. Dr. Chambers enrolled and took courses in the University of Pittsburgh's Graduate Program in Safety Engineering. Additionally, she acquired a certificate in Occupational Ergonomics from Colorado State University. I believe this coursework broadened her ability to recognize, evaluate, and control ergonomic risk factors in a wide range of workplace settings.

Dr. Chambers successfully led this award that investigated the impact of prolonged standing on in vivo changes in articular cartilage deformation with the knee joint and lower extremity muscles. The career development and training offered by this award have resulted in investigator independence. Since the initiation of the award, Dr. Chambers has submitted or served as a principal investigator or co-investigator on over 10 external grants, 7 internal grants, and 4 corporate research agreements, with a funding rate of better than 60%. Dr. Chambers has published, or currently has under review, 17 journal articles and 13 conference proceedings. Dr. Chambers recently accepted a permanent position in the Department of Health & Physical Activity at the University of Pittsburgh. She hopes to continue her research in occupational health and safety in this position. This department also specializes in obesity research, a population of interest also included in this career award. Dr. Chambers is already contributing to their department goals of improving health and wellness, with her focus being occupational health and wellness. I believe this career award directly contributed to her ability to acquire this position and will continue to aid in her future successes.

Sincerely,

A handwritten signature in blue ink that reads "Mark S. Redfern".

Mark S. Redfern, PhD
William Kepler Whiteford Professor
Professor, Departments of Bioengineering, Otolaryngology, and Physical Medicine and Rehabilitation

Please wait...

If this message is not eventually replaced by the proper contents of the document, your PDF viewer may not be able to display this type of document.

You can upgrade to the latest version of Adobe Reader for Windows®, Mac, or Linux® by visiting http://www.adobe.com/go/reader_download.

For more assistance with Adobe Reader visit <http://www.adobe.com/go/acrreader>.

Windows is either a registered trademark or a trademark of Microsoft Corporation in the United States and/or other countries. Mac is a trademark of Apple Inc., registered in the United States and other countries. Linux is the registered trademark of Linus Torvalds in the U.S. and other countries.

I. OUTCOMES**I.1 What were the outcomes of the award?**

Outcomes/Impact

Potential Outcomes

- The findings about time having the most consistent impact on have the potential to lead to improved workplace practices. Specifically, the finding that time is the most determining factor related to injury risk can be used by employers and employees to better limit long periods of standing or provide controls to alternate position more frequently.
- It was shown that using an anti-fatigue mat displayed musculoskeletal physiological benefits during prolonged standing. The methods used here, novel to ergonomics, can be used in future work to evaluate mats and floors for effectiveness and improve design.
- Lastly, the impact of flooring varied with obesity group. It was shown that traditional interventions may have different physiological impacts depending on the BMI of the individual using them. This implies that human factors should be even more prominent in future work in this area. This is an important finding that should be taking into account in future work including evaluation and design of discomfort, injury and fatigue reducing products.

Intermediate Outcomes

- Novel evaluation techniques of musculoskeletal discomfort and potential injury mechanism applied in this study have been used, in collaboration with flooring companies, by to evaluate floors for comfort under foot. In addition, these novel methods are being used to develop best dosage practice for sit stand desks in collaboration with sit stand desk companies and the office for ergonomics research committee.

End Outcomes

- No end outcomes are noted at this time. Future research is required to determine the effectiveness of the intermediate outcomes on end outcomes.