Simon Fraser University and Kintec Footlabs Inc.

Feet First: Instrumented Insoles to Examine Workplace Injury Risk

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Point Form Summary

- Plantar foot pain is experienced by 10% of the global population [1].
- It is thought that more time spent on your feet while at work increases your likelihood of experiencing foot pain [2].
- Much of the current research into this relationship uses self-report data to determine a participant's activities throughout the day, which has limited accuracy [3], [4].
- Kintec and SFU have developed an instrumented shoe insole called the Posture Differentiating Insole (PDI) that can accurately measure the amount of time you spend sitting, standing and walking throughout the day.
- Data has been recorded from 34 participants who used these low-cost insoles for up to 5 days while performing their normal work activities. Participants were asked to report their foot pain each day.
- This data was used to train a machine learning algorithm capable of predicting activities at an accuracy of 97.7%, a substantial improvement on self-report data.
- This study has demonstrated that the novel PDI device can be effectively used in a workplace setting for up to 12 hours per day over an extended period.
- The PDI device was able to accurately differentiate standing from sitting which is not possible with most commercial activity trackers.
- Most participants reported not noticing the PDI throughout the day, meaning that true natural environment data was collected.
- Self-reported activity times were shown to have an average classification error of 23%, meaning on average people are reporting just over 2 hours of their work day incorrectly.
- Participants typically underestimated the time they spent standing and overestimated the time they spend walking. They were approximately equal when estimating sitting.
- More time spent standing and walking throughout the work day is likely to increase the occurrence of foot pain.
- The number of times participants changed activities throughout the day appears to be related to an increased occurrence of foot pain
- There is a weak correlation between foot pain and the time spent standing before either sitting or walking to shift weight off your feet, a factor the PDI made possible to research.
- Caution should be used when basing policy or prevention decisions purely on self-reported data. This is particularly true for self-reported activity times.
- It is recommended that objective measurement techniques such as the PDI be used in future studies investigating outcomes related to activities.
- Further research with a large cohort participating over an extended timeframe using the PDI device is recommended to validate the statistical significance of the correlation between foot pain and workplace postures.
- The PDI could also be used to understand the effects of sitting, standing and walking on other conditions commonly linked to prolonged sitting or standing at work such as back pain.

Executive Summary

Purpose: Plantar fasciitis (PF) is a condition that causes foot pain and sometimes even prevents people from walking. Each year, approximately 2.77 million people in the United States report having PF [5]. This costs over $284 million per year [6]. The exact cause of PF is unknown. Research has shown that standing for long periods of time can increase the risk of getting foot pain [7]. Researchers often ask participants to self-report the amount of time spent standing during the work day. This can lead to large errors, as shown in one study where participants incorrectly reported over 3 hours of activity time over a 24 hour period [3]. Current technologies used to track activities are either too expensive or too difficult to use. Without improvements in this technology, it is difficult to develop links between foot pain and specific workplace activities. This is where the Posture Differentiating Insole (PDI) can contribute. The PDI is a prototype smart insole developed by our team at Simon Fraser University. The PDI can evaluate whether a person is sitting, standing or walking at any point during their work day. In this study we have used the PDI to begin to assess the cause of foot pain at work.

Research Question:

1. How does the PDI perform in a workplace for extended duration activity tracking?
2. How do self-reported activity durations compare to the actual activity durations recorded by the PDI?
3. Is there a relation between the amount of foot pain experienced by a worker and the following factors?
    a. Amount of time workers spend standing or walking during their work day
    b. How many times workers switch activities throughout their work day
    c. How long workers stand still before walking or sitting down

Methods: We asked healthy participants both with and without foot pain between the ages of 19 and 60 to participate in our study. A total of 34 participants wore The PDI at work for up to 5 days while they went about their normal workday activities. At the end of each day, participants were asked about their foot pain throughout the day. They were also asked to estimate how much time they spent sitting, standing and walking throughout that day. During the study, each participant completed a 30-minute device calibration procedure. They were asked to sit, stand and walk for two minutes each in a specific order. Then they were asked to include several posture changes such as fidgeting, standing on one foot, and sitting with legs crossed. This was recorded on video so that researchers could tell exactly when the participant changed activities. This data was used to train the PDI to recognize sitting, standing and walking throughout the rest of the workday.

Results: This study showed that the PDI device can be used in a workplace environment for up to 12 hours per day and up to 5 days in a row. Participants reported that they typically forgot they were wearing the insoles. This means we were able to record the participants' natural activities while at work. The computer algorithm was able to correctly determine the participants' activity 97.7% of the time. Sensors in some of the PDIs broke before the end of the study, but most of them worked for the entire study. Data from devices that did not work correctly was not included in the analysis. At completion of the data collection, 96 days of data from 29 participants was able to be analyzed.

The total amount of time each participant spent sitting, standing and walking each day was determined by the PDI. This data was compared to what was self-reported by each participant at the end of each day. We found that the self-reported data had an average classification error of 23%, meaning that participants incorrectly reported an average of 2.15 hours of their working day. Participants usually reported more walking, and less standing than they actually did throughout the day. Sitting was about even.

We looked at how 15 different factors are related to foot pain. We found that more time spent standing and walking throughout the work day is likely to increase the occurrence of foot pain. We were also able to time how long a participant stands before either walking or sitting down. This is something that cannot be measured with self-reported activity data. We found that a longer amount of time spent standing or walking before changing activities is also likely to increase the occurrence of foot pain.

Applications: This study has shown that the PDI can greatly improve on self-reported activity data and provide new accurate information on workplace activity. This study highlighted multiple factors that may increase the occurrence of foot pain. An important next step is to use the PDI in a study with a greater number of participants to further quantify the relationships that may exist between the factors that this study highlighted as being important. Researchers will be able to use this device to study other activity related conditions such as back pain where methods of measuring activity times have shown a need for improvement.

The results of this study show the inaccuracy of self-reported data. We recommend using caution when making decisions (policy or otherwise) based only on self-reported data. This is especially important when looking at self-reported activity data, as shown by this study.

Interests and Biases: Michael Ryan is a salaried employee of Kintec Footlabs Inc.

Keywords: *Plantar Fasciitis; Foot Pain; Self-report Data; Smart Insole; Weight-bearing; Activity Classification; Workplace Injury*

Introduction

It is estimated that 10% of the global population experiences plantar foot pain at some point in their lives [1]. Studies have shown that this number rises substantially in individuals when subjected to prolonged periods of weight bearing (standing or walking) [2]. This can be seen in retail workers where 50% have reported foot pain during work [8]. Approximately 2.77 million people per year in the United States report having plantar fasciitis (PF) [5]. This has an estimated economic burden of $284 million per year [6]. While the exact etiology of PF is unknown, it is thought that prolonged standing is a key contributing factor leading to microtears in the plantar fascia causing pain and inflammation [9], [10]. The US Bureau of Labour Statistics reported that 47% of workers in the US spend over 60% of their workday on their feet, which could put them at risk of developing PF [11]. Research into risk factors of PF typically requires participants to self-report the time spent on their feet throughout the day. However, self-reporting is not an accurate measure of time spent in different activity states, as shown in a recent study where participants incorrectly reported over 3 hours of activity time over a 24 hour period [3]. Importantly, self-reporting also lacks the temporal resolution to track short duration changes in posture which may affect overall plantar tissue loading exposure. While there are commercially available devices capable of human activity recognition, they either lack the ability to differentiate sitting from standing, are too expensive to deploy on a large scale, or are uncomfortable or inconvenient to use [12], [13]. Without improvements in technology, it is extremely difficult to link PF to work-related activities. The challenge is evident in worker compensation claims where an average of 13 claims relating to PF were accepted and 39 denied per year by WorkSafeBC between 2009 and 2013 [14].

Accelerometer based devices such as the activPAL use thigh-mounted accelerometers to track sitting, standing and walking [15]. While these devices are accurate, they are uncomfortable to wear and must be applied to the correct location on the body every day. Devices that measure plantar pressure such as the F-scan System (Tekscan Inc., South Boston, MA, USA) can be used to differentiate activities, however they are bulky to wear and prohibitively expensive to use in a large-scale study. Research has shown that pressure sensors integrated into a shoe insole can be used to track activities, but these devices have not been validated in a workplace environment [16]. Our device uses low-cost pressure sensors in combination with a machine learning algorithm to provide the activity differentiation accuracy of an expensive device at a low cost. With this device capable of tracking activities to over 97% accuracy, we are able to significantly improve on error in current studies using self-report data [17]. The low cost coupled with the unobtrusiveness of having the sensors embedded in a shoe insole allows the PDI to be deployed in large-scale natural environment studies.

The overall research problem is to understand the link between the risk of developing PF and extended weight bearing in the workplace. This project specifically focused on assessing the efficacy of using a novel, low cost, unobtrusive device to objectively and accurately measure the time a participant spends sitting, standing, and walking throughout their work day. To address this problem, the specific objectives of this study were to:

1. Demonstrate that our prototype device can be used effectively in a workplace setting to collect data over extended durations.
    a. Utilize machine learning to classify activities as sitting, standing or walking throughout each participant's workday.
2. Measure and compare self-reported activity to the calculated activity times for the same time period.
3. Measure and compare reported foot pain to participant's activities to investigate the correlations between the occurrence of foot pain and factors including:
    a. Amount of time workers spend weight bearing throughout their work day.
    b. How many times workers switch activities throughout their work day.

c. How long workers stand still before unloading their feet.

Understanding the relationship between weight bearing and PF will enable employers and policy makers to make informed decisions regarding workplace safety. This research has laid the groundwork and demonstrated the feasibility for a larger prospective study that will examine in greater detail the specific impact of workplace exposure to weight bearing postures on the incidence and severity of PF.

Methodology

Participants

Participants were selected based on the inclusion and exclusion criteria listed below and the amount of time they spend on their feet throughout the day. The target was a dataset that ranged from very little time spent weight bearing to most of the day spent weight bearing.

Participant inclusion criteria:

1. Between the ages of 19 – 60
2. Body Mass Index (BMI) less than 30
3. Employed with at least 6 hours of work per shift
4. The ability to walk without the use of an ambulation aid (e.g., walker or cane) or external orthosis
5. Ability and agreement to wear footwear with shoelaces and a removable insole for the duration of the study

Participant exclusion criteria:

1. Any musculoskeletal injury or condition that inhibits the ability to sit, stand or walk.
2. Currently performing modified work tasks due to an existing workers compensation claim of any variety

3. Any lower extremity amputations
4. Any history of lower extremity surgery
5. Any systemic diseases that could affect lower extremity or foot posture
6. Any history of acute trauma to either foot, lower extremity, or lumbosacral region within the past 6 months prior to the start of the investigation
7. Any chronic condition that significantly compromises lower extremity function

A total of 34 participants were recruited for this study (10 males, 24 females, age: 33.1 ± 9.4 (mean, ± standard deviation) years old, mass: 64.9 ± 11.6 kg, height: 1.7 ± 0.1 m). Each participant was asked to participate for their typical work week, usually 4 or 5 days, depending on the length of the work shift. Some participants were not able to complete the entire week due to schedule restrictions, in these instances data from the available days was used.

Study Procedure

This study was approved by the Simon Fraser University Office of Research Ethics and all participants provided informed consent. All participants were required to wear lace up shoes so the electronics case of the device could be attached to their shoelaces. On the first day of the study, the researcher obtained consent, installed the devices into the participant's shoes, turned on the devices and then left the participant to go about their normal work day. At the end of the day, the researcher removed the devices from the participant's shoes and the participant filled out a short end-of-day questionnaire. The researcher then charged the devices and downloaded the data to prepare the devices for the following day. This process was repeated each day for up to 5 days.

Each participant was asked to participate in a calibration procedure. This procedure involved sitting, standing, and walking in a specific order with the devices in their shoes while their lower body was recorded on video. During the calibration sequence, the participant completed the following activities for approximately 1 minute each in this order: Sit, stand, walk, stand, sit, walk, sit, stand on left foot, stand on right foot, stand in self selected position at counter and fill out form (~8 minutes), sit with legs crossed and outstretched, sit with feet tucked under chair, sit and fidget with feet, sit in self selected position. The video recording was used to determine the activity state of the participant at each instant throughout the calibration sequence, providing a solution set for the calibration data. This portion of the study provided data to train and validate the machine learning algorithm for classifying activities.

Posture Differentiating Insole (PDI)

A novel instrumented shoe insole system has been developed by Kintec and SFU researchers to directly measure the time spent sitting, standing and walking over a standard workday. This device is called the Posture Differentiating Insole or PDI. The PDI has several sensors integrated into the insole that measure the pressure applied to the insole at specific locations and the movement of the foot. The insole is flexible and approximately 4mm thick, making it easy to substitute for the standard insole in most shoes. The PDI continually collects data for up to 14h and stores it on a microSD card to be downloaded by a researcher at the end of each day. Figure 1 shows what the PDI looks like installed in a participant's shoes.

Figure 1 - Participant wearing the Posture differentiating Insole (PDI) system

Forms

There were four forms used in this study. The first was a participant profile form that asked questions about personal details such as age, height and weight along with any history of foot pain and occupational aspects (Appendix A). This was filled out only once during the calibration sequence. The other three forms were filled out at the end of each day. The first daily form was the end of day questionnaire which asked participants to self-report the duration of time they spent sitting, standing and walking throughout the day, along with any activities they participated in outside of work (Appendix B). The second form was the EQ5D form which asked a few questions to gauge the overall health of the participant (Appendix C). The final form was the Foot and Ankle Disability Index (FADI) form which asked questions regarding foot and ankle pain (Appendix D).

Activity Classification

The data from the PDI consists of outputs from the pressure sensors in the insole and the accelerometer. This data was broken into samples that resulted in a temporal resolution of 0.7s. Each sample shows a snapshot of the participant's activity. The data from the calibration sequence, along with the solutions attained from the video analysis were used to train a machine learning algorithm to classify each of these snapshots as either sitting, standing or walking. Leave-one-out cross validation was used to determine the accuracy of the algorithm. This trained algorithm was used to determine the activities of each participant throughout their workdays.

Pain Measurement

The dependent variable in this study is the level of foot pain reported by the participant each day. Foot pain was measured using the FADI form. Specifically, questions 23-26 ask participants to rank their general level of pain, pain at rest, pain during normal activity, and pain first thing in the morning on a 5-point scale from '1 - no pain' to '5 - unbearable'.

Since the maximum value of foot pain reported in this study was 2, the presence of foot pain is a binary variable with either some pain being reported, or no pain being reported. To simplify the analysis, an answer of above 1 on any of the questions regarding foot pain in the FADI form was deemed as having foot pain. Therefore; each day of data was classified as either having foot pain or not having foot pain.

Data analysis

Activity times were analyzed in two ways. The first is the total amount of time that a participant spent in each activity throughout the day. This number is a good representation of overall activity level. This was then grouped as time spent weight-bearing (standing or walking) and time spent not weight bearing. The data was also sorted into bins of duration of activity before switching to a different activity. This reflects the variations in posture throughout the workday. The bins selected were based on tertiles for each activity. The data from the forms was digitized to allow for comparison with the activity data.

Statistical Methods

Single variable logistic regression was used to investigate initial correlations between factors and the presence of foot pain. Each day was considered to be an independent sample. The null hypothesis tested was 'there is no correlation between the factor and the presence of foot pain'. Odds ratio was calculated and is based on a 10% increase in the factor. A p-value was attained and pseudo-R^2 was calculated using McFadden's method.

Limitations

This study was designed to be a pilot study laying the groundwork for future research using the PDI device. As such there are some limitations to this study. The major limitation of this study is that data was only collected from relatively healthy participants. While some participants reported pain, it was not severe pain, and none were diagnosed with any foot pain conditions such as Plantar Fasciitis. The relatively small number of participants in this study is a limitation that has an impact on the ability to draw statistical significance from the resulting data.

No data was collected with the PDI outside of work hours. Activities outside of work could impact the participant's level of pain and contribute to the development of musculoskeletal disorders (MSK). To begin to capture the effect of outside activities, participants were asked to self-report their activities outside of work. Each participant only wore the device for up to 5 days. While this gave a relatively good representation of their typical work week, their activities may vary week to week. A longer-term study would be able to pick up these details and may also be able to record the onset of foot pain. The PDI is a novel technology. While the classification of activities produced by this device is quite good, it is not perfect. This can especially be seen in activities such as standing on your toes where the device could benefit from further training data.

Project Findings/Outcomes

Data

These hand-assembled prototype insoles had some instances where more than one sensor was faulty, or data was not recorded correctly. For consistency in the analysis, the data from these days was removed. This resulted in a total of n = 96 days of data from 29 participants. Table 1 below shows the data collected from each participant.

Device Efficacy

A primary objective of this study was to demonstrate that the PDI device can be used effectively in a workplace setting for an extended duration. While there were some instances of sensors breaking or data not being recorded correctly, the majority of the days were a success, and valuable information was gathered. Each device was used for up to 5 days and in most cases showed no major signs of deterioration. The devices captured data for up to 14 hours per day with a temporal resolution for each activity of less than one second. Through verbal conversations with participants we were able to determine that the PDI was not noticed for the majority of the day. Many people completely forgot they were wearing it.

Using leave-one-out cross validation, the machine learning algorithm was shown to have a classification accuracy of 97.7%. The overall durability of the hardware, quality and accuracy of data, and non-interference with footwear demonstrates that the PDI is an effective tool that can be used in a workplace setting for an extended duration.

Table 1 – Participant information

Participant Number	Number of Days Recorded	Number of Days Used	Total Time Used (h)	Avg. Length of Workday (h)	Avg. % of Day Standing / Walking
1	4	0 [1,2]	0	-	-
2	5	0 [1]	0	-	-
3	4	0 [1]	0	-	-
4	3	0 [1]	0	-	-
5	4	0 [1]	0	-	-
6	5	2 [1]	18.0	9.0	5%
7	4	3 [1]	21.3	7.1	7%
8	5	2 [1,2]	13.3	6.7	15%
9	3	3	23.8	7.9	18%
10	5	5	37.7	7.5	18%
11	5	5	38.8	7.8	19%
12	5	5	27.2	5.4	19%
13	5	1 [2]	5.0	5.0	21%
14	4	3 [1]	25.5	8.5	22%
15	5	5	36.2	7.2	23%
16	4	4	30.5	7.6	24%
17	5	5	32.0	6.4	28%
18	5	4 [1]	29.1	7.3	29%
19	4	2 [1]	16.7	8.4	30%
20	5	5	35.4	7.1	33%
21	5	2 [2]	18.3	9.2	36%
22	4	4	33.2	8.3	39%
23	2	2	24.5	12.3	44%
24	5	4 [1]	30.8	7.7	44%
25	4	4	28.1	7.0	49%
26	3	3	37.0	12.3	51%
27	3	3	38.3	12.8	53%
28	4	4	49.9	12.5	54%
29	4	4	46.7	11.7	63%
30	3	3	36.9	12.3	64%
31	4	4	47.7	11.9	74%
32	3	3	36.7	12.2	75%
33	2	1 [1]	12.1	12.1	75%
34	4	1 [1]	10.3	10.3	86%

[1] Data excluded due to more than one sensor no longer functioning correctly

[2] Data excluded because data collection stopped mid-day

Accuracy of Self-Report Data

At the end of each day, participants were asked to self-report how much time they spent sitting, standing and walking throughout the day. They were given the option of what units to report in. Most participants reported time in increments of 30 minutes, with the smallest increment being 5 minutes. This data was compared to the data recorded by the PDI device and the classification error was calculated per activity as the total misclassified time divided by the total time. It was found that participants were worst at self-reporting the time spent walking with an average classification error of 133% (1.3 hours). Participants typically overestimated the time they spent walking as shown in Appendix F by the number of overestimates compared to underestimates. Participants underestimated their time standing with a classification error for standing of 53% (1.3 hours). Participants were about even with regard to overestimating or underestimating the time they spent sitting with an average classification error of 24% (1.5 hours). Participants were not always accurate at reporting the length of their workday, so the sum of the underestimates did not always equal the sum of the overestimates as it should. Overall classification error was therefore calculated as follows:

$$Classification\ Error = \frac{\left(\frac{Sum\ of\ Overestimates + Sum\ of\ Underestimates}{2}\right)}{Measured\ Activity\ Duration} * 100\%$$

When averaged for each participant and then averaged over the number of participants the result was an overall classification error in the self-report data of 23%. This means on average participants are incorrectly classifying 2.15 hours of their workday when asked to self-report their activities. The classification error ranged from 6% to 49% resulting in a range of 19 minutes to roughly 5 hours of misclassified workplace postures when self-reported. A complete breakdown of the classification errors per day is given in Appendix E.

Correlations with Foot Pain

With a relatively small sample size and low pain data it is difficult to draw statistically significant conclusions on correlations between factors related to activities and presence of foot pain. The results of single variable logistic regression are shown in Table 2. This model does not consider relationships that may exist between factors, so cannot conclusively show correlation. It does however give insight into what factors are worth further investigation. The odds ratio (OR) reported is based on a 10% increase in the factor. Factors that are correlated to foot pain ($p < 0.01$) are shown in bold.

Table 2 - Results of single variable logistic regression of each factor in relation to reported foot pain. Odds ratio is the increase in odds of occurrence of foot pain corresponding to a 10% increase in the factor. When considering time weight bearing, the odds ratio of 1.42 means that a 10% increase of the total time spent standing throughout the workday will lead to a 42% increase in the odds of occurrence of foot pain. When looking at standing > 37 seconds, the odds ratio of 1.43 means that if the number of times a participant stands for over 37 seconds increases by 10%, there will be a 43% increase in the odds of occurrence of foot pain. Factors in bold are statistically significant ($p<0.01$).

				95% Confidence Interval	
Factor	Odds Ratio	P-value	Pseudo R^2	2.50%	97.50%
Age	1.08	0.23	0.01	0.95	1.24
Weight	0.96	0.66	0.00	0.82	1.14
Height	0.87	0.08	0.02	0.74	1.02
Time Sitting	0.91	0.40	0.01	0.74	1.13
Time Standing	**1.41**	**0.00**	**0.15**	**1.19**	**1.67**
Time Walking	**1.45**	**0.00**	**0.11**	**1.18**	**1.78**
Time Weight Bearing	**1.42**	**0.00**	**0.15**	**1.19**	**1.69**
Day Duration	**1.48**	**0.00**	**0.17**	**1.23**	**1.79**
No. of Activity Changes	**1.33**	**0.00**	**0.09**	**1.11**	**1.58**
Sit 10 - 48.0 Seconds	1.08	0.52	0.00	0.85	1.36
Sit > 246.0 Seconds	1.05	0.63	0.00	0.87	1.27
Stand 10 - 19 Seconds	**1.32**	**0.00**	**0.08**	**1.11**	**1.58**
Stand > 37 Seconds	**1.43**	**0.00**	**0.15**	**1.19**	**1.70**
Walk 10 - 14 Seconds	**1.30**	**0.00**	**0.09**	**1.11**	**1.52**
Walk > 21 Seconds	**1.49**	**0.00**	**0.12**	**1.19**	**1.86**

Note: Odds ratio is based on a 10% increase in the factor value

The results from this study show that a correlation between the time spent in weight-bearing postures (standing and walking) throughout the workday and reported foot pain exists. This can be seen through the factors time standing, time walking, and time weight bearing. Day duration shows a correlation to foot pain, however it is suspected that this is due to longer shifts for occupations where weight-bearing is most common (e.g. nursing). These participants worked 12-hour shifts and were primarily on their feet during these shifts. This could have resulted in the perceived correlation since no participants in lower percentage weight bearing occupations worked 12-hour shifts.

A boxplot showing time spent sitting, standing and weight bearing (standing or walking) is shown in Figure 2. Each dot represents a day of recorded data. The general trend is that people who spend more time standing or weight-bearing throughout the day are more likely to have foot pain. While there are some outliers, the confidence intervals of the means do not overlap, suggesting that a relationship between these factors is worth further investigation. The time spent sitting does not appear to be related to the occurrence of foot pain.

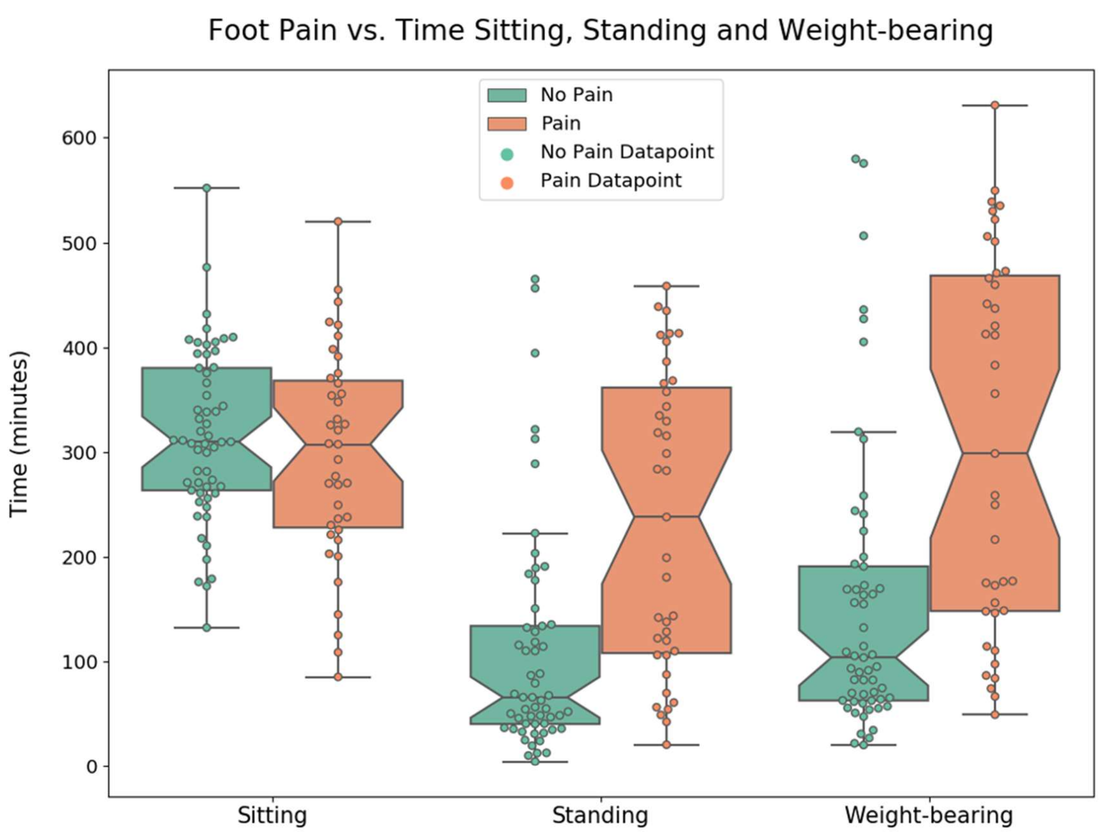

Figure 2 - Boxplots showing the correlation between foot pain and time sitting, standing, weight-bearing throughout the workday. Each dot represents one day of collected data. N=96 for each pair of boxplots. The apparent relation displayed is that increased amounts of time spent standing or weight-bearing throughout the workday are associated with the occurrence of foot pain and the amount of time sitting is not.

The PDI is capable of measuring activity at a temporal resolution of 0.7 seconds. This allows for investigation into many interesting factors that were not previously possible with self-report data. These include the number of changes of activities, and the amount of time spent in an activity before switching to a new activity. The latter is particularly interesting since it is thought that standing still for long periods of time may be related to plantar foot pain. With the PDI, we are now able to tell how long each participant spends standing before they walk or sit down. We are able to break down a work day into 'bins' of activity duration. To eliminate and artifacts from short segments of misclassified activities we have set a lower boundary of 10 seconds for all activity durations in this analysis. This means any activities less than 10 seconds long were not considered for this portion of the analysis. The remaining data was separated into tertile bins based on the duration of time spent in each activity before changing to a different activity. Sitting has a lower tertile boundary of 48 seconds of sitting before changing to a new activity and an upper tertile boundary of 246 seconds. Standing has lower and upper tertile boundaries of 19 and 37 seconds respectively, and walking has lower and upper tertile boundaries of 14 and 21 seconds respectively. Instances above the high tertile boundary and below the low tertile boundary for each activity were investigated for correlation with foot pain as shown in table 2. As an example, if a participant stood still for 15 seconds and then walked, the 15 seconds of standing would be recorded as an instance of standing for between 10 and 19 seconds. If they stood for 45 seconds before sitting down or walking it would be recorded in the standing for over 37 seconds bin. Recording data in this way allows us to investigate relationships between the duration of specific instances of activity, not just the total sum of time over the course of the day. A good example of this impact can be seen in the increase in odds ratio and pseudo-R^2 from standing between 10 and 19 seconds (OR=1.32, R^2=0.08) to standing for over 37 seconds (OR=1.43, R^2=0.15).

Outcomes

The most important outcome of this study was successfully validating the use of the PDI in extended natural environment studies. This device can be used in a workplace setting for up to 12 hours per day over multiple days in a row. Previous studies have typically been limited to measuring workplace exposure over a single day [2], [9], [18], [19]. These studies used a combination of self-report data, video snapshots, and in-person observation which did not capture the entirety of the day. Pederson et. al. used an accelerometer based device, however only measured one day of activity [4]. It is unclear why only one day was used, however it is likely that the process of attaching the accelerometer to the participant's thigh each day was time consuming and inconvenient, preventing a longer duration study. With some minor modifications, the PDI could be used for a much larger cohort study spanning a longer timeframe.

An important element of the PDI technology is that it is unobtrusive and can be easily worn in work environments where traditional activity monitors like watches or pendants would not be allowed (e.g. medical, construction, machining, etc). Existing commercially available technologies include insoles like the F-scan system and accelerometer-based systems like the ActivPAL and the ActiGraph. The F-scan measures foot pressure distribution at a 4 kPa resolution, however it has large components that strap to the ankles and waist which are cumbersome and prohibit use in a natural environment setting. The ActivPAL and ActiGraph have been successfully used for activity classification in natural environment studies with accuracies ranging from 85%-100% depending on the activity [4], [20]. In these studies, the relatively small device is attached to the participants thigh with a waterproof sticker. This method is obtrusive to the participant and would not be possible to wear for more than a week at a time.

Comparison between the self-report and actual activity duration data showed the importance of using the PDI device in quantifying workplace exposure. Without a device to accurately measure activity times, researchers have relied on self-report data, which this study has shown to have a classification error of 23%. As a result, outcomes from research that depends on self-report data may not be completely accurate. This is similar to findings from previous studies investigating the use of the Occupational Sitting and Physical Activity Questionnaire (OSPAQ) for self-reporting activity durations [3],[4]. However, these previous studies used expensive or time-consuming technologies and analysis methods to accurately record workplace activities [2], [21]. The PDI provides a low cost and efficient tool to measure workplace activity for the first time.

A review commissioned by WorkSafeBC and completed by Waclawski et. al. found results to be inconsistent across studies attempting to link PF with suspected risk factors [7]. Three of the four studies reviewed used only self-report data to classify activity times, a potential contributing factor to these inconsistencies. Ku et. al. identified 19 studies relating daily sedentary behaviour with all-cause mortality [23]. Of these 19 studies, 12 relied on self reported activity times. The remaining 7 studies used waist mounted accelerometers to measure sedentary (not moving) and non-sedentary (moving) time. This method has moderate to high accuracy, but misclassifies a significant amount of standing time as sedentary time [24]. The PDI could be used in these types of studies to improving the accuracy of activity classification and expand activity classification to include sitting, standing and walking, not just sedentary and non-sedentary time.

This study provided some insights into the correlation between foot pain and activity related factors. The trends seen in the data show that further investigation is worth pursuing with a larger cohort study including participants with significant foot pain. Notably, this study pointed out that activity duration and variation of activity throughout the day may be important factors for foot pain. These have not previously been explored due to the limitations in self-reporting methods. With a larger subject cohort in a longitudinal study we expect to see greater variations in pain (perhaps even within individual participants) that will assist in drawing stronger conclusions regarding the specific contributing factors to foot pain in the workplace.

Further, the temporal resolution of the PDI allows us to quantify for the first time, activity intervals and the number and frequency of postural changes. This type of analysis is not possible with self-report data. This may have important implications in tissue loading and resulting injury risk as dynamic loading has been shown to alter plantar tissue exposure [22]. Self-reporting misses important observations on activity intervals that may separate at risk individuals in the workplace. Further investigation into these relationships with a larger sample size could yield important new results to differentiate healthy and at-risk individuals.

It is recommended that future studies use an alternate method of measuring pain that is more sensitive and context specific to capture the pain typically experienced at work. The questions in this study asked about average pain over the course of the day. There are two problems with this. First, participants do not report instances of elevated pain that either went away or they were able to relieve by modifying their activities. Second, a 5-point scale did not result in enough resolution in the data. A better question to ask participants would be "Please rank the worst pain you experienced over the course of the day on a scale of '1-no pain at all' to '10-extreme pain'". This question could be used in conjunction with a question about the average pain throughout the day on a 10-point scale to get an even better understanding of the participants' pain levels. Anecdotally, participants reported foot pain and/or fatigue related to work, but these were not captured in the standard foot pain index.

Implications for Future Occupational Health Research

The results of this study show that our device can significantly improve on self-report data and can provide insights far beyond what was previously possible. With a device capable of providing accurate, in depth activity information, researchers will be able to gain a better understanding of the precise activities of workers. Most participants reported that they did not notice the PDI during their workday. This is an excellent outcome as it means that natural activity data was recorded. While there are some minor improvements required for the device design, particularly regarding durability for heavier workers, we are confident that this device could be used effectively in a much larger study over a longer timeframe.

This study has shown that the amount of time spent sitting, standing and walking throughout a workday cannot be accurately captured with self-report data. Future research involving tracking time for any of these activities should use a device such as the PDI to quantify activity times. This study has also highlighted the value of increased temporal resolution on the nature of activities that can be observed in the workplace. This may assist in better differentiating more subtle differences in individual activities instead of only considering overall exposure.

The low-cost and easy to use nature of this device allows it to be used in large cohort natural environment studies. An important next step in research is to use this technology in a large cohort study including participants both with and without significant foot pain and recording pain experiences with a more sensitive scoring tool. This will give researchers a large, representative dataset to further investigate correlations between workplace activity related factors and foot pain. This could also potentially be extended to other injuries such as knee or lower back pain. For example, the PDI could be used in a study similar to the one conducted by Hashimoto et. al. studying the effects of physical activity on low back pain using a uniaxial hip mounted accelerometer [25]. Activities were divided into low, medium and high activity tertiles. The PDI could instead classify activities as sitting, standing or walking, metrics that are more understandable than an activity tertile. The preliminary findings from this study can be used to give researchers an indication of what factors to study in detail and allow them to determine the number of participants required for a statistically significant experiment.

The PDI could also be used to understand the effects of sitting, standing and walking on other conditions such as back pain, which is commonly linked to prolonged sitting or standing at work. Having a device that can accurately capture intervals of activity and the frequency of postural changes in addition to total duration of activity could be an important development in better understanding the impact of daily workplace activity on chronic injury risk.

Additionally, the PDI could be used to measure the effectiveness of policy changes related to activities at work or remind worker to adjust their postures. For instance, if a policy were put in place that gave workers extra break time throughout the day to sit down, the PDI could be used to see if the amount of time workers spent sitting throughout the day actually increases.

Applications for Policy and Prevention

Outcomes from this study show that there is a correlation between time spent standing and weight-bearing throughout the workday and foot pain. Due to a limited sample size, this study could not consider the relationships between factors. This is an important next step. Correlations highlighted in this study should be used to refine the scope of future research, however they should not be used as a basis for policy or prevention at this time. When sharing these findings, care must be taken to ensure the limitations are communicated clearly.

Given the range in error of self-reported activity data seen in Appendix E, building policy based on self-reported exposure data may not be appropriate. Caution should be used whenever basing decisions on research that purely uses self-report surveys. This study has shown this is especially true when self-report data is used for activity classification throughout the workday. The self-report error was largest in people who were on their feet for most of their day.

This project and future studies using this technology will allow workers and employers to better understand what is causing their pain, and what they can modify to prevent it. Importantly, with the new resolution and accuracy provided by this tool, we may be able to better understand the factors that differentiate individual exposures in the same workplace. This is a large reaching goal, but this study brings us a big step closer. In the future, an insole based on this technology and the research enabled by it could monitor workers and prompt them to do something different if their current activities are approaching a dangerous zone. For instance, if a worker is standing in one place for too long the insole could vibrate to remind the worker to move around or sit down for a few minutes. This will help employers save money in lost time and medical insurance claims related to foot pain.

Knowledge Transfer and Exchange

Knowledge transfer is an important part of this research. Workers can only modify their activities if they are aware of how to modify them. So far, we have presented our research at the American Orthotics and Prosthetics Meeting in Vancouver, through multiple WorkSafeBC keynote speeches, a segment on City TV Breakfast Television, and we will present at the Pedorthic Association of Canada Annual Symposium in April 2019. We also plan to share our findings with workers advocate groups such as the BC Nurses Union, and the BCGEU who have a large contact list and thus a large reach to a variety of workers. Kintec will use findings from this research and future experiments to inform their clients who are experiencing foot pain. Kintec is also planning a PR campaign to share our results. Kintec will present this research during their in-store continuing education events presented to 200-300 healthcare professionals.

Each participant involved with this study will receive a personalized report of what their activities were and how our findings relate to their specific activities. This will include a generalized overview of our findings which they will be encouraged to share with their workplace and anyone else who may be interested.

References

[1] P. Gautham, S. Nuhmani, and S. J. Kachanathu, “Plantar fasciitis - An update,” *Bangladesh Journal of Medical Science*, vol. 14, no. 1. pp. 3–8, 2015.

[2] R. A. Werner, N. Gell, M. Pt, A. Hartigan, N. Wiggerman, and W. M. Keyserling, “Risk Factors for Plantar Fasciitis Among Assembly Plant Workers,” *PM&R*, vol. 2, no. 2, pp. 110–116, 2010.

[3] J. L. Urda, B. Larouere, S. D. Verba, and J. S. Lynn, “Comparison of subjective and objective measures of office workers’ sedentary time,” *Prev. Med. Reports*, vol. 8, pp. 163–168, Dec. 2017.

[4] S. J. Pedersen, C. M. Kitic, M.-L. Bird, C. P. Mainsbridge, and P. D. Cooley, “Is self-reporting workplace activity worthwhile? Validity and reliability of occupational sitting and physical activity questionnaire in desk-based workers,” *BMC Public Health*, vol. 16, 2016.

[5] R. L. Nahin, “Prevalence and Pharmaceutical Treatment of Plantar Fasciitis in United States Adults,” *J. Pain*, vol. 19, pp. 885–896, 2018.

[6] K. B. Tong and J. Furia, “Economic burden of plantar fasciitis treatment in the United States.,” *Am. J. Orthop.*, vol. 39, no. 5, pp. 227–31, May 2010.

[7] E. R. Waclawski, J. Beach, A. Milne, E. Yacyshyn, and D. M. Dryden, “Systematic review: plantar fasciitis and prolonged weight bearing,” *Occup. Med. (Chic. Ill).*, vol. 65, pp. 97–106, 2015.

[8] D. Anton and D. L. Weeks, “Prevalence of work-related musculoskeletal symptoms among grocery workers,” *Int. J. Ind. Ergon.*, vol. 54, pp. 139–145, Jul. 2016.

[9] D. L. Riddle, M. Pulisic, P. Pidcoe, and R. E. Johnson, “Risk factors for Plantar fasciitis: a matched case-control study,” *J Bone Jt. Surg Am*, vol. 85–A, no. 5, pp. 872–877, 2003.

[10] R. Puttaswamaiah and P. Chandran, “Degenerative plantar fasciitis: A review of current concepts,” *Foot*, vol. 17, pp. 3–9, 2007.

[11] “Standing or walking versus sitting on the job in 2016,” *United States Bureau of Labour Statistics*. .

[12] O. Aziz, S. N. Robinovitch, and E. J. Park, “Identifying the number and location of body worn sensors to accurately classify walking, transferring and sedentary activities,” *IEEE Trans. Inf. Technol. Biomed. Conf. IEEE Eng. Med. Biol. Soc.*, pp. 5003–5006, Aug. 2016.

[13] M. Ermes, J. Pärkkä, J. Mäntyjärvi, and I. Korhonen, “Detection of daily activities and sports with wearable sensors in controlled and uncontrolled conditions,” *IEEE Trans. Inf. Technol. Biomed.*, vol. 12, no. 1, pp. 20–26, 2008.

[14] Anonymous, “Discussion Paper - Plantar Fasciitis Due to Prolonged Weight Bearing,” 2014.

[15] J. Klenk *et al.*, “Concurrent Validity of activPAL and activPAL3 Accelerometers in Older Adults,” *J. Aging Phys. Act.*, vol. 24, pp. 444–450, 2016.

[16] E. S. Sazonov, N. Hegde, and W. Tang, “Development of SmartStep: An insole-based physical activity monitor,” *Proc. Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. EMBS*, pp. 7209–7212, 2013.

[17] K. Wick, O. Faude, S. Schwager, L. Zahner, and L. Donath, “Deviation between self-reported and

measured occupational physical activity levels in office employees: effects of age and body composition," *Int. Arch. Occup. Environ. Health*, vol. 89, no. 4, pp. 575–582, May 2016.

[18] L. H. Gill, G. M. Kiebzak, P. Charlotte, and N. Carolina, "Outcome of Nonsurgical Treatment for Plantar Fasciitis," *Foot Ankle Int.*, vol. 17, no. 9, pp. 527–532, 1996.

[19] D. B. Irving, J. L. Cook, M. A. Young, and H. B. Menz, "Obesity and pronated foot type may increase the risk of chronic plantar heel pain: a matched case-control study," 2007.

[20] J. A. Steeves *et al.*, "Ability of thigh-worn actigraph and activpal monitors to classify posture and motion," *Med. Sci. Sports Exerc.*, vol. 47, no. 5, pp. 952–959, 2015.

[21] C. L. Edwardson *et al.*, "A three arm cluster randomised controlled trial to test the effectiveness and cost- effectiveness of the SMART Work & Life intervention for reducing daily sitting time in office workers: study protocol," *BMC Public Health*, vol. 18, no. 1, pp. 1–13, 2018.

[22] A. Erdemir, A. J. Hamel, A. R. Fauth, S. J. Piazza, and N. A. Sharkey, "Dynamic Loading of the Plantar Aponeurosis in Walking," *J. Bone Jt. Surg.*, vol. 86, no. 3, pp. 546–552, 2004.

[23] P.-W. Ku, A. Steptoe, Y. Liao, M.-C. Hsueh, and L.-J. Chen, "A cut-off of daily sedentary time and all-cause mortality in adults: a meta-regression analysis involving more than 1 million participants," *BMC Med.*, vol. 16, 2018.

[24] A. Koster *et al.*, "Comparison of Sedentary Estimates between activPAL and Hip- and Wrist-Worn ActiGraph," *Med. Sci. Sports Exerc.*, vol. 48, no. 8, pp. 1514–1522, 2016.

[25] Y. Hashimoto *et al.*, "Association between objectively measured physical activity and body mass index with low back pain: a large-scale cross-sectional study of Japanese men," *BMC Public Health*, vol. 18, 2018.

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Appendix A – Participant Profile Form

Participant Profile Form

Refinement and Deployment of a Low-Cost Device to Classify Human Workplace Activities from Foot Pressure Measures

School of Mechatronic Systems Engineering, 250-13450 102 Avenue, Surrey, BC, V3T 0A3

This work is funded by the Natural Sciences and Engineering Research Council (NSERC) through a Canadian Graduate Scholarships-Master's Program scholarship titled *"Development of an algorithm to accurately interpret signals from an instrumented insole to determine if a wearer is sitting, walking or standing."* and by WorkSafeBC through grant number: WCB RS2017-IG17 titled *"Feet First: Instrumented Insoles to Examine Workplace Injury Risk."*

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Investigator – Dr. Edward Park, Mechatronic Systems Engineering (epark@sfu.ca)
Collaborator – Dr. Michael Ryan, Director of Research and Development at Kintec Footwear and Orthotics (mryan@kintec.net)
Co-op Student – Jonathan de Guzman, Mechatronic Systems Engineering
Co-op Student – Joshua Jessup, Mechatronic Systems Engineering
Co-op Student – Julia Schmidt, Mechatronic Systems Engineering

This section is to be filled out by the test administrator

Subject ID: ____

Date: ____

Test Administrator: ____

Location: ____

The following profile collects personal health information along with selected information about your background as it is relevant to the study. Please fill out the following to the best of your abilities. If you have any questions, please consult the test administrator. If you are not comfortable answering a question, please leave it blank.

Age (years): _____ **Weight** (lbs): ___________ **Height**: _____(ft) ______(in)

Gender: M F Other

Dominant Foot: R L

Shoe Size: ________________________

--HEALTH INFO--

Have you had foot or ankle pain in the last 12 months that has caused you to modify your activities in any way? If so on the image provided below, please indicate the areas where you have felt pain.

Images taken from http://lookfordiagnosis.com/mesh_info.php?term=foot&lang=1 (Left) and http://oppositelock.kinja.com/feet-the-oppo-review-1665703006 (Right)

Do any of the following factors trigger your foot pain as described above? (Please check any that apply)

- ☐ Walking for long periods (>30 min)
- ☐ Walking for short periods (<30 min)
- ☐ Walking on hard surfaces
- ☐ Walking on soft surfaces
- ☐ Jumping
- ☐ Running
- ☐ Hard soled shoes
- ☐ Soft soled shoes
- ☐ Standing (<30 min)
- ☐ Standing (>30 minutes)
- ☐ Walking around after periods of inactivity
- ☐ My feet always hurt
- ☐ Other: ______________________

Have you had any injuries or issues in your toes, ankles, lower legs, knees, thighs, hips or back in the past? If so, please list and explain the severity:

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--OCCUPATIONAL INFO--

Occupation: ____

Choose the type of floor that best describes your *primary* work environment (i.e. the place you spend the most time during an average work day):

- ☐ Wood
- ☐ Concrete
- ☐ Laminate
- ☐ Tile
- ☐ Brick
- ☐ Carpet
- ☐ Sand
- ☐ Grass
- ☐ Other: ________

For an average workday, approximately how long (in hours) do you spend in each of the following postures: (Note: the times should add up to the total length of your typical work day)

Sitting	Standing	Walking	Other (please indicate)

Do you constantly maintain one posture while at work for most of the time? Or do you frequently switch postures (ie. Several times an hour)? Please Describe.

____
____
____
____

Is there any additional information that you would like to provide that you feel would be relevant to this study regarding your occupational demands/circumstances?

____
____
____
____
____
____

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--FOOTWEAR INFO--

Describe your typical 'work' shoes (shoes worn while at work):

- How old are they? (in months): _______________
- Brand and Model: _______________
- Type (Running shoe, dress, construction boot, etc.): _______________
- Are these the shoes you brought with you today? (Circle) Y N

Describe your typical 'active' shoes (if applicable):

- How old are they? (in months): _______________
- Brand and Model: _______________
- Type (Running shoe, dress, construction boot, etc.): _______________
- Are these the shoes you brought with you today? (Circle) Y N

Is there any additional information that you would like to provide that you feel would be relevant to this study regarding your footwear?

____

____

____

____

____

____

____

____

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You have completed the survey. Please inform your test administrator. We thank you for your participation.

The following section is to be completed by the study investigator.

Foot Posture Index (FPI): ____

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Appendix B – End-of-Day Questionnaire

End-of-Day Questionnaire

Refinement and Deployment of a Low-Cost Device to Classify Human Workplace Activities from Foot Pressure Measures

School of Mechatronic Systems Engineering

250-13450 102 Avenue, Surrey, BC, V3T 0A3

This work is funded by the Natural Sciences and Engineering Research Council (NSERC) through a Canadian Graduate Scholarships-Master's Program scholarship titled *"Development of an algorithm to accurately interpret signals from an instrumented insole to determine if a wearer is sitting, walking or standing."* and by WorkSafeBC through grant number: WCB RS2017-IG17 titled *"Feet First: Instrumented Insoles to Examine Workplace Injury Risk."*

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Co-op Student – Joshua Jessup, Mechatronic Systems Engineering
Co-op Student – Julia Schmidt, Mechatronic Systems Engineering

This section is to be filled out by the test administrator

Subject ID: ____

Date: ____

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The following questionnaire collects data about your activities while at work and at home in the past 24hours. Please answer each question to the best of your ability, however if you are not comfortable answering a question, please leave it blank

--WORKDAY ACTIVITIES--

Today, approximately how long (in hours) did you spend in each of the following postures: (Note: the times should add up to the total time you spent at work today)

Sitting	Standing	Walking	Other (please indicate)

Is this representative of a typical work day for you? Yes No

If not, please explain why:

____

____

____

In the last 24 hours, did you participate in any weight bearing activities such as running, yoga, cycling or walking outside of work? Please list the activities and the amount of time spent doing each:

Activity	**Time (please specify units)**
ex. Yoga	ex. 75 min or 1.25h

You have completed the survey. Please inform your test administrator. We thank you for your participation.

Appendix C – EQ5D Form

EQ-5D-5L

Health Questionnaire

English version for Canada

Under each heading, please tick the ONE box that best describes your health TODAY.

MOBILITY

I have no problems in walking about	❑
I have slight problems in walking about	❑
I have moderate problems in walking about	❑
I have severe problems in walking about	❑
I am unable to walk about	❑

SELF-CARE

I have no problems washing or dressing myself	❑
I have slight problems washing or dressing myself	❑
I have moderate problems washing or dressing myself	❑
I have severe problems washing or dressing myself	❑
I am unable to wash or dress myself	❑

USUAL ACTIVITIES *(e.g. work, study, housework, family or leisure activities)*

I have no problems doing my usual activities	❑
I have slight problems doing my usual activities	❑
I have moderate problems doing my usual activities	❑
I have severe problems doing my usual activities	❑
I am unable to do my usual activities	❑

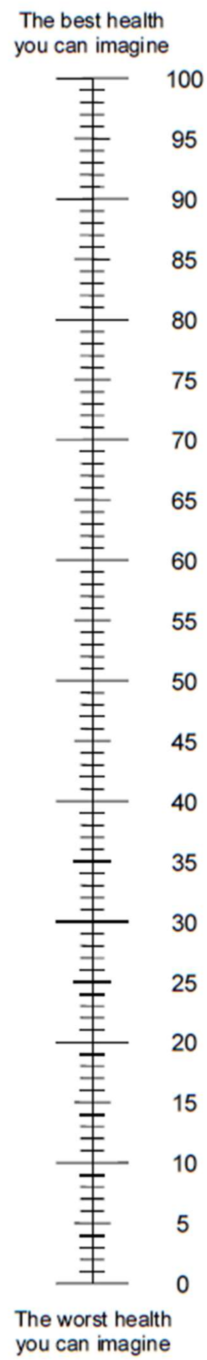
PAIN / DISCOMFORT

I have no pain or discomfort	❑
I have slight pain or discomfort	❑
I have moderate pain or discomfort	❑
I have severe pain or discomfort	❑
I have extreme pain or discomfort	❑

ANXIETY / DEPRESSION

I am not anxious or depressed	❑
I am slightly anxious or depressed	❑
I am moderately anxious or depressed	❑
I am severely anxious or depressed	❑
I am extremely anxious or depressed	❑

- We would like to know how good or bad your health is TODAY.
- This scale is numbered from 0 to 100.
- 100 means the <u>best</u> health you can imagine.
  0 means the <u>worst</u> health you can imagine.
- Mark an X on the scale to indicate how your health is TODAY.
- Now, please write the number you marked on the scale in the box below.



YOUR HEALTH TODAY = [ ]

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Appendix D – Foot and Ankle Disability Index Form

Foot and Ankle Disability Index (FADI)

Refinement and Deployment of a Low-Cost Device to Classify Human Workplace Activities from Foot Pressure Measures

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Co-op Student – Joshua Jessup, Mechatronic Systems Engineering
Co-op Student – Julia Schmidt, Mechatronic Systems Engineering

This section is to be filled out by the test administrator

Subject ID: ______________________________

Date: ______________________________

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Please answer every question with one response that most closely describes your condition within the past week by placing an X in the appropriate box. If the activity in question is limited by something other than your foot or ankle, mark N/A

	No difficulty at all	**Slight difficulty**	**Moderate difficulty**	**Extreme difficulty**	**Unable to do**
1. Standing					
2. Walking on even ground					
3. Walking on even ground without shoes					
4. Walking up hills					
5. Walking down hills					
6. Going up stairs					
7. Going down stairs					
8. Walking on uneven ground					
9. Stepping up and down curves					
10. Squatting					
11. Sleeping					
12. Coming up to your toes					
13. Walking initially					
14. Walking 5 minutes or less					
15. Walking approximately 10 minutes					
16. Walking 15 minutes or longer					
17. Home responsibilities					
18. Activities of daily living					
19. Personal care					
20. Light to moderate work (standing, walking)					
21. Heavy work (push/pulling, climbing, carrying)					
22. Recreational activities					
	No pain	**Mild**	**Moderate**	**Severe**	**Un-bearable**
23. General level of pain					
24. Pain at rest					
25. Pain during your normal activity					
26. Pain first thing in the morning					

Reference for Score: Martin, R. L., Burdett, R. G., Irrgang, J. J. (1999). Development of the Foot and Ankle Disbaility Index (FADI). J Orthop Sports Phys Ther. 1999; 29: A32-33

Appendix E –Self-report Data Analysis Table

Participant Number	Day 1 Classification Error (Minutes / %)								Day 2 Classification Error (Minutes / %)							
	Sit		Stand		Walk		**Total**		Sit		Stand		Walk		**Total**	
6	-13	-2%	4	30%	37	490%	**27**	**5%**	-87	-18%	18	152%	42	233%	**74**	**15%**
7	7	2%	19	166%	18	158%	**22**	**6%**	-49	-12%	6	26%	7	29%	**31**	**7%**
8	177	65%	-21	-100%	9	44%	**104**	**33%**	48	12%	-49	-100%	-3	-10%	**50**	**10%**
9	-237	-57%	144	399%	70	358%	**226**	**48%**	-216	-64%	42	53%	160	323%	**209**	**45%**
10	63	17%	-26	-63%	-9	-26%	**49**	**11%**	53	13%	-28	-65%	-14	-48%	**47**	**10%**
11	77	21%	-37	-71%	-13	-33%	**63**	**14%**	87	24%	-49	-77%	-26	-63%	**81**	**17%**
12	36	12%	-32	-68%	3	13%	**36**	**9%**	24	9%	-25	-63%	-2	-10%	**25**	**8%**
13	-	-	-	-	-	-	-	-	123	52%	18	42%	38	176%	**89**	**30%**
14	-116	-33%	11	10%	82	219%	**105**	**21%**	-112	-27%	-27	-31%	93	349%	**116**	**22%**
15	-49	-12%	12	63%	45	305%	**53**	**12%**	-51	-17%	35	24%	27	84%	**57**	**12%**
16	-99	-25%	9	13%	18	67%	**63**	**13%**	106	34%	-96	-76%	-3	-8%	**102**	**22%**
17	-69	-28%	2	2%	114	174%	**93**	**23%**	-65	-21%	3	3%	75	168%	**72**	**16%**
18	58	27%	-47	-90%	-11	-31%	**58**	**19%**	134	43%	-97	-91%	-36	-64%	**134**	**28%**
19	38	10%	-105	-88%	-7	-19%	**75**	**14%**	70	21%	-104	-87%	5	18%	**89**	**19%**
20	-136	-53%	-66	-52%	176	274%	**189**	**42%**	-32	-12%	-45	-33%	65	119%	**71**	**15%**
21	-109	-42%	37	18%	-35	-28%	**91**	**15%**	-103	-24%	40	78%	32	115%	**88**	**17%**
22	-23	-9%	-58	-33%	64	115%	**73**	**15%**	-35	-10%	-72	-54%	82	213%	**94**	**19%**
23	-162	-57%	-82	-25%	228	172%	**236**	**32%**	-153	-28%	15	14%	182	205%	**175**	**24%**
24	115	34%	-100	-100%	-25	-45%	**120**	**24%**	204	109%	-143	-83%	-4	-6%	**175**	**41%**
25	31	9%	197	191%	140	354%	**184**	**39%**	-99	-45%	-136	-69%	210	353%	**223**	**47%**
26	-166	-48%	-167	-58%	304	261%	**318**	**42%**	-121	-40%	-131	-42%	245	213%	**248**	**34%**
27	-141	-37%	-160	-57%	262	269%	**281**	**37%**	-253	-74%	-189	-61%	310	281%	**376**	**49%**
28	124	53%	-228	-56%	72	66%	**212**	**28%**	90	33%	-186	-51%	77	74%	**176**	**24%**
29	-86	-42%	-236	-80%	366	323%	**344**	**56%**	-62	-26%	-261	-68%	304	262%	**313**	**42%**
30	-143	-44%	-192	-62%	292	228%	**313**	**41%**	-135	-53%	-242	-67%	375	356%	**376**	**52%**
31	-27	-18%	-20	-5%	84	87%	**65**	**10%**	-10	-8%	-91	-20%	65	37%	**83**	**11%**
32	161	117%	-89	-20%	-65	-52%	**158**	**22%**	67	39%	-44	-9%	-51	-46%	**81**	**11%**
33	16	9%	-102	-25%	96	66%	**107**	**15%**	-	-	-	-	-	-	-	-
34	3	4%	-317	-73%	293	301%	**307**	**49%**	-	-	-	-	-	-	-	-

Participant Number	Day 3 Classification Error (Minutes / %)								Day 4 Classification Error (Minutes / %)							
	Sit		Stand		Walk		**Total**		Sit		Stand		Walk		**Total**	
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-61	-14%	13	634%	-2	-9%	**38**	**9%**	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	-184	-43%	17	40%	126	529%	**164**	**33%**	-	-	-	-	-	-	-	-
10	84	23%	-47	-76%	-20	-58%	**76**	**16%**	114	34%	-42	-74%	-22	-60%	**89**	**21%**
11	126	39%	-58	-79%	-26	-63%	**105**	**24%**	41	10%	-34	-70%	-6	-30%	**41**	**9%**
12	-11	-4%	-2	-3%	1	6%	**7**	**2%**	2	1%	-4	-12%	15	95%	**10**	**3%**
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-6	-2%	-26	-47%	7	32%	**20**	**4%**	-	-	-	-	-	-	-	-
15	14	5%	-31	-100%	1	3%	**23**	**6%**	26	9%	-27	-18%	31	107%	**42**	**9%**
16	22	6%	-3	-13%	15	48%	**20**	**5%**	105	35%	-56	-55%	-14	-33%	**87**	**20%**
17	-12	-4%	-33	-53%	48	115%	**47**	**11%**	-39	-11%	3	5%	65	254%	**53**	**13%**
18	130	41%	-98	-91%	-27	-47%	**127**	**27%**	-38	-9%	-53	-84%	13	47%	**52**	**11%**
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	-11	-4%	-6	-9%	42	86%	**30**	**7%**	27	9%	-19	-24%	31	105%	**38**	**9%**
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	-98	-29%	62	52%	20	50%	**90**	**18%**	17	6%	-57	-32%	25	71%	**50**	**10%**
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	228	102%	-181	-100%	-23	-43%	**216**	**47%**	118	39%	-117	-89%	-3	-7%	**119**	**25%**
25	20	9%	-44	-27%	54	81%	**58**	**13%**	72	67%	117	96%	4	8%	**97**	**34%**
26	-206	-46%	-87	-42%	269	297%	**281**	**38%**	-	-	-	-	-	-	-	-
27	-127	-35%	-204	-63%	275	322%	**303**	**39%**	-	-	-	-	-	-	-	-
28	-56	-12%	-38	-17%	61	103%	**78**	**10%**	20	5%	-96	-35%	49	69%	**82**	**11%**
29	-51	-17%	-216	-64%	197	191%	**232**	**32%**	-71	-23%	-194	-62%	205	217%	**235**	**33%**
30	-77	-34%	-231	-56%	297	318%	**302**	**41%**	-	-	-	-	-	-	-	-
31	11	5%	-102	-25%	59	49%	**86**	**11%**	58	24%	-95	-28%	84	88%	**119**	**18%**
32	123	52%	-157	-39%	9	8%	**144**	**19%**	-	-	-	-	-	-	-	-
33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Participant Number	Day 5 Classification Error (Minutes / %)								Overall Classification Error (Minutes / %)	
	Sit		Stand		Walk		**Total**		**Average**	
6	-	-	-	-	-	-	-	-	**50**	**9%**
7	-	-	-	-	-	-	-	-	**30**	**7%**
8	-	-	-	-	-	-	-	-	**77**	**19%**
9	-	-	-	-	-	-	-	-	**199**	**42%**
10	73	19%	-33	-69%	-9	-38%	**58**	**13%**	**64**	**14%**
11	5	1%	-4	-22%	-14	-48%	**12**	**2%**	**60**	**13%**
12	-13	-6%	9	19%	17	123%	**19**	**7%**	**19**	**6%**
13	-	-	-	-	-	-	-	-	**89**	**30%**
14	-	-	-	-	-	-	-	-	**80**	**16%**
15	-24	-6%	-33	-100%	39	185%	**48**	**11%**	**44**	**10%**
16	-	-	-	-	-	-	-	-	**68**	**15%**
17	-56	-32%	-7	-18%	31	109%	**47**	**19%**	**62**	**16%**
18	-	-	-	-	-	-	-	-	**93**	**21%**
19	-	-	-	-	-	-	-	-	**82**	**16%**
20	-10	-4%	-9	-24%	3	4%	**11**	**3%**	**68**	**16%**
21	-	-	-	-	-	-	-	-	**89**	**16%**
22	-	-	-	-	-	-	-	-	**77**	**15%**
23	-	-	-	-	-	-	-	-	**205**	**28%**
24	-	-	-	-	-	-	-	-	**157**	**34%**
25	-	-	-	-	-	-	-	-	**141**	**33%**
26	-	-	-	-	-	-	-	-	**283**	**38%**
27	-	-	-	-	-	-	-	-	**320**	**42%**
28	-	-	-	-	-	-	-	-	**137**	**18%**
29	-	-	-	-	-	-	-	-	**281**	**40%**
30	-	-	-	-	-	-	-	-	**330**	**45%**
31	-	-	-	-	-	-	-	-	**88**	**12%**
32	-	-	-	-	-	-	-	-	**127**	**17%**
33	-	-	-	-	-	-	-	-	**107**	**15%**
34	-	-	-	-	-	-	-	-	**307**	**49%**
								Average:	**129**	**23%**

Note: negative classification error in minutes means underestimation of time, positive value means overestimation

Appendix F – Self-report Data Analysis by Activity

Participant	Sitting			Standing			Walking		
		Classification Error			Classification Error			Classification Error	
Number	Average Time	Minutes	%	Average Time	Minutes	%	Average Time	Minutes	%
6	515	-50	10%	12	11	92%	13	40	309%
7	394	-34	9%	12	13	102%	19	8	41%
8	338	112	33%	35	-35	100%	27	3	11%
9	392	-212	54%	52	68	129%	31	119	383%
10	371	77	21%	50	-35	70%	32	-15	47%
11	381	67	18%	51	-36	71%	34	-17	50%
12	265	8	3%	44	-11	25%	17	7	39%
13	237	123	52%	42	18	42%	22	38	176%
14	398	-78	20%	84	-14	17%	29	61	210%
15	335	-17	5%	75	-9	12%	25	29	113%
16	345	33	10%	79	-36	46%	34	4	12%
17	276	-48	17%	66	-6	10%	41	67	162%
18	310	71	23%	82	-74	89%	44	-15	35%
19	351	54	15%	120	-105	87%	31	-1	4%
20	285	-33	11%	89	-29	33%	51	63	124%
21	346	-106	31%	127	38	30%	76	-1	2%
22	305	-35	11%	151	-31	21%	42	48	113%
23	412	-157	38%	214	-34	16%	110	205	185%
24	261	166	64%	146	-135	92%	55	-14	25%
25	219	6	3%	146	34	23%	55	102	185%
26	364	-164	45%	268	-128	48%	107	273	254%
27	364	-174	48%	304	-184	61%	98	282	289%
28	345	45	13%	317	-137	43%	86	64	75%
29	262	-67	26%	331	-226	68%	107	268	251%
30	268	-118	44%	362	-222	61%	109	321	295%
31	187	8	4%	407	-77	19%	122	73	60%
32	183	117	64%	436	-96	22%	115	-35	31%
33	179	16	9%	402	-102	25%	144	96	66%
34	87	3	4%	437	-317	73%	97	293	301%
	Average*	**76**	**24%**	**Average***	**78**	**53%**	**Average***	**88**	**133%**
	# of Underestimates	**14**		**# of Underestimates**	**23**		**# of Underestimates**	**7**	
	# of Overestimates	**15**		**# of Overestimates**	**6**		**# of Overestimates**	**22**	

Note: negative classification error in minutes means underestimation of time, positive value means overestimation

* Average times are calcualted as the average of the absolute value of the classification error in minutes