

THESIS

OCCUPATIONAL PHYSICAL ACTIVITY IN SEDENTARY AND  
ACTIVE WORKERS

Submitted by

Janalee Thompson

Department of Environmental and Radiological Health Sciences

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Master's Committee:

Advisor: John Rosecrance

Brooke Anderson

Tori Crain

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## ABSTRACT

### OCCUPATIONAL PHYSICAL ACTIVITY IN SEDENTARY AND ACTIVE WORKERS

With the increasing use of technology in the workplace, many jobs are becoming more sedentary. The purpose of this study was to establish a quantitative baseline measure of occupational physical activity (OPA) in active and sedentary workers. Two activity trackers (Fitbit Charge HR<sup>TM</sup> and Hexoskin) were used to assess activity measures (step count, heart rate and energy expenditure) among workers during their work shift. The first objective of the study was to assess the agreement between two types of accelerometer-based activity trackers as measures of OPA. The second objective of this study was to assess differences in measures of OPA among workers in physically active and sedentary work environments. There was a statistically significant difference in measures of total step counts between the two devices. When comparing active and sedentary workers there were also statistically significant differences in measures of step counts, mean percent heart rate increase, maximum heart rate range and energy expenditure. Conclusion: The Fitbit Charge HR<sup>TM</sup> and Hexoskin had significant differences in measures of step counts and heart rate. When comparing active and sedentary workers, there were significant differences in measures of step counts, mean heart rate, maximum heart rate range required by job, and energy expenditure. The results of the present study provide quantitative evidence that active workers require greater physiologic demands than sedentary workers.

## TABLE OF CONTENTS

|   |    |
|---|----|
| ABSTRACT.....                                     | ii |
| CHAPTER I: INTRODUCTION.....                      | 1  |
| Background.....                                   | 1  |
| Purpose of study.....                             | 3  |
| Hypotheses.....                                   | 5  |
| CHAPTER II: REVIEW OF LITERATURE.....             | 6  |
| CHAPTER III: Methods.....                         | 16 |
| Subjects.....                                     | 16 |
| Daily activity logs.....                          | 17 |
| Procedures.....                                   | 18 |
| Statistical Analysis.....                         | 21 |
| CHAPTER IV: RESULTS.....                          | 25 |
| Subjects.....                                     | 25 |
| Daily activity logs.....                          | 26 |
| Comparison of Fitbit Charge HR™ and Hexoskin..... | 27 |
| Comparison of Active and Sedentary Workers.....   | 31 |
| CHAPTER V: DISCUSSION.....                        | 34 |
| Limitations.....                                  | 40 |
| Implications.....                                 | 43 |
| CHAPTER VI: CONCLUSION.....                       | 45 |
| REFERENCES.....                                   | 46 |

# CHAPTER I

## INTRODUCTION

### Overview

This chapter provides the background and summarizes the significance of the study. Chapter I includes the aim of the study, purpose, hypotheses and relevant definitions.

### Background

The benefits of a healthy balance of physical activity inside and outside of the workplace are numerous, as reported by the World Health Organization (WHO) (2016). The 2016 WHO report indicated that highly active adult men and women have lower rates of all-cause mortality, coronary heart disease, depression, and numerous other adverse health outcomes. Consequently, active individuals maintain a healthier weight and exhibit improved signs of muscular fitness (WHO, 2016). Maintaining good physical and mental health is essential to prolonging life, yet our modern day work life may not be conducive to a healthy lifestyle. Conversely, some occupations often inherently require workers to perform excessive physical activity throughout their workday, putting these workers at risk for disorders associated with physical overexertion. According to the Centers for Disease Control and Prevention (2013), Americans who work full-time spend about one-third of their lives in the workplace. If a work environment does not provide an adequate amount of physical activity, or overloads workers with physical demands, the effects of work may contribute to adverse health outcomes.

Physically active workers can potentially have an increased risk for becoming fatigued and physically exhausted (Yamazaki, Fukuhara, Suzukamo, Morita, Okamura, Tanaka, &

Ueshima, 2007), whereas sedentary workers may be susceptible to health conditions associated with sedentary lifestyles (Owen, Healy, Matthews, & Dunstan, 2010). There is likely a range or level of occupational physical activity (OPA) that is safe for the majority of all workers, although an optimal level is likely dependent on individual characteristics and lifestyles of workers. It may be just as hazardous for workers to overwork themselves and become fatigued as it is for workers to be stationary for entire shifts (Krause, 2010; Hamilton, Healy, Dunstan, Zderic, & Owen, 2008). The concerns regarding low physical activity in the workplace are now recognized by organizations that are beginning to develop cultural norms encouraging OPA among employees (National Institute for Health and Clinical Excellence, 2008). Workplace health could improve with the implementation of job and task designs that promote OPA, or in some cases reduce excessive OPA.

The recent trend in physical activity trackers, specifically popular activity monitors like the Fitbit<sup>®</sup>, have made activity tracking more “user friendly” and appealing to the general public. With increasing popularity and acceptance of wearable technology such as accelerometer-based activity trackers, it is no surprise that these devices are making appearances in the workplace. In addition to trendy wrist-worn wearable activity trackers, wearable smart clothing is also becoming popular among athletes and health enthusiasts. According to the website CCS Insight (2016), the wearable technology market is expected to grow from 84 million units in 2015 to 245 million units in 2019. Given the public demand and availability of wearable technology, researchers have started testing a variety of wearable activity trackers to assess an individual’s physical activity (Diaz, Krupka, Chang, Peacock, Ma, Goldsmith, Schwartz, & Davidson, 2015; Noah, Spierer, Gu, & Bronner, 2013; Scott & Browning, 2016; Takacs, Pollock, Guenther, Bahar, Napier, & Hunt, 2014).

## Purpose of the Study

With increasing use of technology in the workplace, OPA may continue to decline as a result of being sedentary. Conversely, workers in active jobs (manufacturing) may receive too much physical activity and be at risk for physical overexertion injuries and inefficient work practices. OPA across occupational groups has not yet been quantified. Therefore, this study is one of the first to evaluate physical activity in the workplace through the use of activity trackers. This study was developed to quantify a baseline measure of OPA among workers in sedentary and active jobs. We anticipated that the baseline measures of OPA can assist in the evaluation of design of workplaces that promote a healthier work life.

The first objective of this study was to determine the level of agreement of two types of accelerometer based activity trackers for assessing occupational physical activity. The second objective of this study was to assess differences in OPA among workers in physically active and sedentary work environments. The wrist-worn Fitbit Charge HR<sup>TM</sup> and Hexoskin wearable shirt were used to assess OPA in this study. Although very high and very low OPA can be detrimental to human health, quantitative assessments are seldom used to determine the degree to which physical work actually impacts overall health. Thus, OPA levels are often unidentified and not given much attention (Scott & Browning, 2016). Having an understanding of OPA will allow us to target specific job tasks and work processes for redesign. By modifying work design and work processes, we may have the ability to influence the OPA to optimal levels among active and sedentary workers. The goals of the present study are consistent with the program goals of the NIOSH Total Worker Health<sup>®</sup> (TWH) program. As described by the CDC (2015), “Total Worker Health<sup>®</sup> is defined as policies, programs, and practices that integrate protection from work-related safety and health hazards with promotion of injury and illness prevention efforts to

advance worker well-being.” Occupational and personal health are both emphasized in Total Worker Health. As with TWH, the present study addresses issues pertaining to employee health inside and outside of the workplace. Specifically, this study addresses the following NIOSH TWH goals:

NIOSH Total Worker Health<sup>®</sup> Program Goals for Intramural and Extramural Research:

- Strategic Goal 1: Increase the adoption of integrated health protection and health promotion programs and activities to reduce the risk of occupational illness and injury and advance the overall health and well-being of workers.
- Strategic Goal 2: Protect and promote the overall safety, health, and well-being of the workforce through research that investigates the joint effects of work and non-work factors and evaluates interventions that integrate health protection with health promotion.



## Hypotheses

The following hypotheses were developed to address the study objectives.

First objective of the study: To determine the agreement of two types of accelerometer based activity trackers (Fitbit Charge HR™ and Hexoskin) for assessing occupational physical activity:

H1: Hexoskin and Fitbit Charge HR™ measures of step counts will be significantly different, such that the Fitbit Charge HR™ will over count steps.

H2: The Fitbit Charge HR™ and Hexoskin will both have at least good inter method reliability ( $r \geq 0.5$ ) for step counts.

H3: Hexoskin and Fitbit Charge HR™ measures of heart rate will be significantly different, such that the Fitbit Charge HR™ will overestimate heart rate.

H4: The Fitbit Charge HR™ will have poor inter-method reliability ( $r \leq 0.3$ ) for heart rate measures.

Second objective of the study: To assess differences in OPA among workers in physically active and sedentary work environments:

H5: Active workers will take significantly more steps throughout their work-shift than sedentary workers.

H6: Active workers will have a greater mean percent heart rate increase during a work-shift than sedentary workers.

H7: Active workers will have a significantly greater mean percent maximum heart rate range required by the job than sedentary workers.

H8: Active workers will have significantly greater energy expenditure (more calories burned, higher METs) during a work-shift than sedentary workers.

## CHAPTER II

### REVIEW OF LITERATURE

#### Overview

The following chapter addresses the literature relevant to OPA, wearable technology, Fitbit Charge HR™ and the Hexoskin. Additionally, justifications for using self-reported daily activity logs in both manufacturing and office workers will be included and addressed.

#### Occupational Physical Activity

Physical activity in the workplace is an important factor for supporting and maintaining a healthy lifestyle. However, as proposed in the “Goldilocks model” (Goldenhar, Hecker, Moir, & Rosecrance, 2003) there is likely a level of work (based on overtime and economic considerations) that is optimal. This hypothesis may also likely be true for OPA, meaning that a reasonable level of OPA is somewhere between too little and too much. The ability to measure OPA of individuals in their work environment quickly and with simple instrumentation would be a significant step towards promoting a healthier workplace. There is extensive evidence that high intensity and or prolonged OPA (e.g., highly repetitive tasks, prolonged or heavy physical loads, awkward postures, and lack of rest breaks) is associated with increased risk of muscle fatigue and musculoskeletal disorders (Putz-Anderson, Bernard, Burt, Cole, Fairfield-Estill, Fine, Grant, Giessing, Jenkins, Hurrell, Nelson, Pfirman, Roberts, Stetson, Haring-Sweeny, & Tanaka, 1997). There is also extensive evidence that too little OPA (as in the case with sedentary office work) is associated with adverse health outcomes (Booth, Roberts, & Laye, 2012; Owen et al., 2010).

With growing use of technology inside and outside of the workplace, people are becoming increasingly less physically active and more sedentary. Twenty years ago, sedentary jobs (office work) were fundamentally more physically active than sedentary jobs we see today as a result of technology. Computers, tablets and e-mail allow workers instantaneous communication without leaving a desk, but physical activity has been sacrificed as a result. Church, Thomas, Tudor-Locke, Katzmarzyk, Earnest, Rodart, Martin, Blair, & Bouchard (2011) analyzed Bureau of Labor Statistics data from over the last five decades and reported that energy expenditure has reduced by over 100 calories burned per day in sedentary jobs. Church et al. (2011) further explained that this reduction in calories burned has contributed to the increased mean body weights for both men and women in the last 50 years. McCrady and Levine (2009) reported that workers sit more in the workplace than they do when away from work. Unfortunately, the amount of physical activity that individuals perform in sedentary jobs is expected to continue to decrease (Ng & Popkin, 2012).

The World Health Organization (WHO, 2017) reported that physical activity is the fourth leading risk factor for worldwide mortality. The Centers for Disease Control and Prevention (CDC) (2016) reported that only 1 in 5 adults (20%) meet the CDC physical activity guidelines. To put this into perspective, adults 18-64 years old only need a minimum of 150 minutes of moderate-intensity aerobic activity (e.g. power walking) and two days of muscle strengthening activities per week to maintain a healthy body. As people become more sedentary, it puts current generations at risk of developing chronic health conditions attributable to sedentary lifestyles, like “sitting disease”, which had previously never been a serious concern for human health (Owen, Healy, Matthews, & Dunstan, 2010). According to the American Cancer Society (2016), one-third of all types of cancers are preventable through increased physical activity, a nourishing

diet, and maintaining a healthy weight. Though sedentary workers often sit 8 to 12 hours a day in the workplace, which contributes to the low physical activity statistics.

Body mass index (BMI) and gender may also indicate increased risk of developing adverse health effects from sedentary lifestyles. Researchers from the American Cancer Society's Cancer Prevention Study II reported that women who spent more than six hours a day sitting were at a 37% greater risk of early mortality from cancer than women who sat for less than three hours per day. Whereas men who spent more than six hours a day sitting were at a 17% increased risk of early mortality attributable to being sedentary compared to men who were more active throughout the day. The American Cancer Society's Cancer Prevention Study II also reported that above average BMI and gender is associated with adverse health outcomes. Women who did not normally participate in any physical activity or exercise during the day were at a 94% increased risk of early mortality (due to adverse health outcomes) and inactive men were at a 48% increased risk. Patel, Bernstein, Deka, Feigelson, Campbell, Gapstur, Colditz, & Thun (2010) also reported that sitting longer than six hours per day was associated with early mortality.

Conversely, some occupations may increase employee odds of being physically overworked and overexerted. Mulhern and Putz-Anderson (2009) reported that "An overexertion injury occurs when a person works beyond his or her physical capacity or, more specifically, when the physical forces required to perform a task exceed the tolerances of the body's soft tissues." According to the Bureau of Labor Statistics (2015), injuries resulting from physical overexertion are 33 per 100,000 full time employees per year. Consequently, work-related musculoskeletal symptoms commonly develop as a result of physical overexertion, which yield exorbitant worker compensation costs (CDC, 2016). Work-related musculoskeletal symptoms are injuries that

affect muscles, bones, tendons, and nerves and cause acute or chronic pain. Musculoskeletal symptoms can be attributable to daily work tasks involving repetitive motion, sustaining awkward postures, vibration, and sudden exertion (Canadian Centre for Occupational Health and Safety, 2016; CDC, 2016).

Overwork can also lead to cardiac fatigue and exhaustion. Karoshi, a Japanese term that means death by overwork, is a concern primarily in western cultures (Ke, 2012). To keep up with the excessive product demands of western cultures, workers are often pushed to their physical limit in order to do their job (Nishiyama & Johnson, 1997). Rhoads (1977) reported that overwork is defined as “...working beyond one’s endurance and recuperative capacities;” he further states that some people lack the ability to determine when they need rest. If people cannot determine when they are being overworked, they may ignore preliminary physiological symptoms leading to heart attack or stroke (Rhoads, 1977). The potential health risks associated with low and high OPA are too serious to be overlooked; therefore, the upcoming sections discuss a few non-invasive physiological monitoring systems that may be used to address this area of concern.

### Wearable Technology

Technologies are now available to precisely assess occupational movements that are based on videography, reflective sensors and inertial measurement units. However, these systems are relatively expensive, time consuming, require experienced researchers and are not practical in occupational settings. Recently, there has been a growing public interest in the use of commercially available and relatively low cost accelerometer-based physical activity monitors (e.g., Fitbit, Jawbone, and Polar) commonly referred to as “wearables.” Wearables are types of

technology devices that can be worn on the wrist, around the neck, hip, or even as a piece of clothing.

According to the International Data Collection (IDC), the wearables market grew 67.2% from 2015 to 2016. This market growth is projected to continue to grow from 84 million units in 2015 to 245 million units by 2019. With the recent popularity and trendiness of wearables, people wear them to work and on social outings. Some workplaces have even begun incorporating wearables into corporate wellness programs. ABI Research (2013), a market intelligence company, projects that corporate wellness programs will incorporate over 13 million wearable devices into workplaces within the next five years. Given the public demand and availability of these devices, researchers have also started testing wearable activity trackers to assess individual physical activities (Diaz et al., 2015; Noah et al., 2013; Scott & Browning, 2016; Takacs et al., 2014). Recent studies assessing individual physical activities are primarily used in controlled, laboratory settings. Unfortunately, there are few studies that have assessed the reliability and validity of measurement systems that quantify OPA in the actual workplace. Though Healy, Clark, Winkler, Gardiner, Brown, & Matthews (2011) have suggested that free-living sedentary behavior should be measured using both activity tracking devices and self-report measures.

### Fitbit<sup>®</sup>

Fitbit<sup>®</sup> is the leading manufacturer of wearable devices in the world (IDC, 2016). The popularity of these devices has prompted many researchers to investigate the feasibility of using these for research purposes. Fitbit<sup>®</sup> devices have been used in several physical activity validation studies measuring energy expenditure, step counts, and heart rate (Evenson, Goto, & Furberg,

2016). Research has demonstrated that the Fitbit® accelerometer-based devices are the most valid and reliable commercially available activity monitors (Diaz et al., 2015; Evenson et al., 2015; Noah et al., 2013; Paul, Tiedmann, Hassett, Ramsay, Kirkham, Chagpar, & Sherrington, 2015). Consumer Reports (2016) recently conducted a validity study comparing the Pure Pulse™ photoplethysmography (optical heart rate monitoring) heart rate feature of Fitbit Charge HR™ to an electrocardiogram (ECG) monitored chest strap system. The Consumer Reports study found that the variance between the Fitbit Charge HR™ and ECG monitored chest strap system did not differ more than three heartbeats per minute. Wallen Gomersall, Keating, Wisloff, & Coombes (2016) conducted a controlled laboratory treadmill study and reported that the Fitbit Charge HR accurately reported user heart rate. In addition, Dooley (2016) reported that the Fitbit Charge HR™ accurately tracked heart rate results in a laboratory treadmill setting assessing physical activity at the moderate physical activity level based on the Borg's Rating of Perceived Exertion Scale (RPE). The RPE measures physical activity levels through self-report on a scale of 6-20. Subjects then completed exercises that were categorized into one of four physical activity categories: sedentary, light, moderate, or vigorous. In the Dooley (2016) study, the Fitbit Charge HR™ significantly overestimated heart rate at the light activity level and underestimated heart rate at the vigorous intensity level when compared to a Polar heart rate monitor.

In terms of step counts, the hip worn Fitbit® devices are the most accurate when compared to visually counting steps or research accelerometers in controlled and free-living settings (Ferguson, Rowlands, Olds, & Maher, 2015; O'Connell, O'Laighin, Kelly, Murphy, Beirne, Burke, Kilgannon, & Quinlan, 2016). However, hip worn activity trackers are only limited to step counts and distance traveled, whereas wrist-worn activity trackers are capable of measuring heart rate. There are numerous studies that have evaluated the validity and reliability of the hip

worn Fitbit® devices for step counts (Dontje, de Groot, Lengton, van der Schans, & Krijnen, 2015; Evenson et al., 2016; Kooiman, Dontje, Sprenger, Krijnen, van der Schans, de Groot, 2015; O’Connell et al., 2016; Takacs et al., 2014; Singh, Farmer, Van Den Berg, Killington, & Barr, 2016), but not nearly as many studies have been conducted estimating wrist-worn activity tracker step count validity and reliability due to their fairly recent presence in the wearables market. Research has demonstrated that the Fitbit® is a reliable and validated device in controlled settings (Noah et al., 2013; Takacs et al., 2014), as in monitored treadmill studies, but there is paucity of literature utilizing commercial accelerometer-based activity trackers to assess physical activity in occupational environments.

The Fitbit Charge HR™ is a wrist-worn device. Thus, upper limb activity while stationary may overestimate physical activity and steps. An example of overestimating physical activity is if people are more active with their arms than the rest of their body, or if individuals are resistance training. Bai, Welk, Nam, Lee, Lee, Kim, Meier, and Dixon (2015) reported that the Fitbit® had reasonable energy expenditure (calories burned) estimates in their study of controlled and free-living activity assessments, although there was greater error and variability during individual resistance exercise assessments. The researchers of the Bai et al. (2015) study proposed that future studies be directed toward evaluating the Fitbit® under free-living conditions. Thus, the proposed research represents a relatively novel approach in the assessment of OPA.

The Fitbit Charge HR™ directly measures heart rate and steps. Consumers are required to program their Fitbit Charge HR™ before use entering data including height, weight, age, and gender. Heart rate is measured through optical heart rate monitoring, photoplethysmography, which detects a pulse by shining a light through the skin to detect blood flow. Steps are measured



using a three-axis accelerometer and an algorithm that uses a motion threshold, user height, and subsequent acceleration to determine what will be counted as a step. Using the direct measures of heart rate and steps, Fitbit® activity trackers estimate metabolic equivalence of task (METs) and calories burned. METs represent the intensity of exercise and range from .99, a sleeping or resting state, to 23, which is equivalent to running about a four-minute mile. Fitbit® calculates METs using heart rate, calorie expenditure, height, weight, age, and gender. Ergonomists commonly use METs to evaluate physiologic energy expenditure and intensity. Calories burned are calculated from user basal metabolic rate (BMR). BMR is the rate at which calories are burned to maintain vital body functions such as breathing, heart rate, and brain activity. Fitbit® calculates BMR based on physiological data including age, gender, height, and weight.

#### Hexoskin

The Fitbit Charge HR™ will be compared to the Hexoskin activity tracker to assess OPA. Hexoskin is a relatively new type of “smart clothing,” which includes a biometric shirt that has physiological sensors placed within the fabric to measure heart rate, respiration rate, and activity. Smart clothing like the Hexoskins are commonly worn by athletes who use state of the art sensor technology to track their physiological performance. Hexoskin is becoming an extremely popular physiological monitoring device and has recently monitored Redbull-sponsored and Olympic athletes (Hexoskin, 2016). Hexoskin has been reported as a valid and reliable measure of daily tasks, which include activities such as lying, sitting, standing, and walking (Villar, Beltrame, & Hughson, 2015). According to Banerjee, Anantharam, Romine, Lawhorne and Sheth (2015), Hexoskin was validated in a study evaluating cadence (e.g., steps, distance) while performing activities consisting of running, walking, and sprint intervals. Banerjee et al. (2015) suggested

that Hexoskin has strong potential to be used as a tool for discriminating between varying tasks or activities.

Though there are not many published research studies using Hexoskin to date, major companies and government organizations are utilizing this technology. Analog Devices, Inc. (ADI), a signal processing company, recently collaborated with Hexoskin and Microsoft to extensively evaluate and improve athlete and team performance management. The ADI project utilized Hexoskin cloud-based technology and the Hexoskin proprietary e-textile platform (Hexoskin blog, 2016). Additionally, the Hexoskin space medicine team has been working with the Canadian Space Agency and NASA since 2011 (Hexoskin blog, 2016). NASA is using Hexoskin technology for the Human Exploration Research Analog (HERA) mission to physiologically monitor and prepare astronauts for long-term space missions. Although the Hexoskin is considered a cutting-edge research tool, the only published research has been conducted in controlled laboratory studies. Villar, Beltrame, & Hughson (2015) reported that the Hexoskin was consistent, had low variability, and had good agreement when compared to a standard electrocardiogram on lying, sitting, standing, and walking tests. However, Montes (2015) reported that the Hexoskin heart rate monitoring was inconsistent when compared to a Polar T-31 heart rate monitor. Additionally, Montes (2015) stated that the Hexoskin was only reliable for step counts at faster (3.5 miles per hour) walking speeds.

Hexoskin smart clothing uses sensors built into a spandex shirt to measure physiological variables. The physiological variables measured by the Hexoskin include: heart rate, heart rate variability, breathing rate, breathing volume, activity (steps, cadence, calories), and sleep. Before wearing the Hexoskin, each user is required to log basic physiological information into the

device. These variables are used for increased accuracy of measures and include: height, weight, date of birth, and gender.

Heart rate is measured real-time using an electrocardiogram (ECG) and is capable of detecting user heart rate maximum and resting heart rate. Heart rate maximum (HRmax) represents the highest heart rate reached during exercise. Resting heart rate is the lowest heart rate measured when the user is relaxed. Many variables such as age, gender, physical fitness and heart medications can influence HRmax and resting heart rate. For example, athletes will usually have lower resting heart rates than non-athletes. Breathing/respiratory rate and minute ventilation is detected by the inflation and deflation of your lungs. Breathing rate is measured in respirations per minute (rpm). Minute ventilation is the volume of air inhaled during one minute. From these measures, Hexoskin estimates maximum volume of oxygen ( $VO_2$  max).  $VO_2$  max is used to determine the aerobic fitness of the user. Lastly, Hexoskin utilizes a three-axis accelerometer to measure steps, steps per minute (cadence), and calories burned. The step counts, steps per minute, and calories burned are estimated based on your length of stride, which is based on basic physiologic information and subsequent acceleration.

## CHAPTER III

### METHODS

#### Overview

Chapter III describes the study participants, the procedures, and methodology associated with the Fitbit Charge HR™ and the Hexoskin, as well as the daily activity logs. The physiological variables that each device measured are described as are the study procedures and statistical analysis.

#### Subjects

Participants in the moderate to high physically active work group were recruited from the brewing service sector while sedentary participants from the low physically active work group were recruited from a call center and a manufacturing office work environment. The active work group included subjects who packaged bottled beer, distributed packaged beer to liquor stores, loaded delivery trucks with custom pallets, poured beverages in tap rooms and gave brewery tours. A call center is an office that accepts large capacity customer service phone calls. Management at each company recruited participants internally by informing employees about the study in employee meetings and via e-mail announcements. Once management obtained names of interested participants, a list with potential subject names was given to the study investigators. The study investigators entered participant information into an Excel spreadsheet in which each participant received a unique identifying code rather than name. The study investigators were the only researchers involved in the study to have access to the spreadsheet linking names to unique

identifiers. Other researchers involved in the study only had access to anonymous data. IRB approval was obtained for all aspects of the study.

Data was collected from 50 active workers and 51 sedentary workers. All participants 18 years of age or older and all genders were invited to participate. Participants were offered monetary compensation of \$20 cash for their participation. One organization did not want their employees compensated. Therefore, 24 subjects were not compensated. All participant data collected was confidential and only aggregated group data was shared with the employer. All subjects had the opportunity to see their personal results (step counts, average heart rate, average amount of calories burned) for the shift in which they participated. All subjects signed an informed consent document, and demonstrated an understanding that participation in this research was voluntary. If subjects decided to participate in the study, they understood that they could withdraw their consent and stop participating at any time without penalty or loss of benefits to which they are otherwise entitled. Letters of support from the companies participating were not obtained and data was not collected until Institutional Review Board (IRB) approval was determined.

### Daily Activity Logs

Workers were asked to complete a daily activity log to be completed every half hour during their work shift. Daily activity logs were used to compare data collected from the activity trackers to self-reported activity. In addition, activity logs were used to determine when the participant took breaks or went to lunch. The activity log included the following information:

- Time of day/shift in 30 minute increments
- What type of equipment/tools were used in the last 30 minutes

- The majority of time in the last 30 minutes was spent:
  - Sitting
  - Standing
  - Walking
  - Lifting
  - Carrying
  - Climbing (stairs, etc.)

For every item selected, five minutes was assigned to that activity. For example, if sitting and standing were both selected for a single 30 minute time period, 15 minutes would be assigned to sitting and 15 minutes assigned to standing. On the back of the daily activity logs, the user was asked to provide their height, weight, date of birth, gender, and shirt size. There was one question asking the participant if they used any medications affecting their heart rate (e.g. beta blockers). Subjects were not excluded from the study if they claimed to be taking medications that affected their heart rate. This information was only intended to be useful to the researchers when evaluating heart rate data.

## Procedures

The following details the procedures that took place at the beginning of each day that data collection occurred.

1. Introduction to the study and IRB consent for each participant.

A brief greeting and verbal introduction to the study was presented to participants. The Fitbit Charge HR<sup>TM</sup>, the Hexoskin and daily activity logs<sup>TM</sup> were described (i.e., what they are).

Before use, the Fitbit Charge HR<sup>TM</sup> and Hexoskin were programmed to each user by entering the subject's height, weight, date of birth, and gender. This information was only obtained once and used for both the Fitbit Charge HR<sup>TM</sup> and Hexoskin. From this information, both activity trackers were programmed and sizes of Hexoskin shirts to be worn by participants

were determined. The IRB written consent was distributed to all participants. At least one researcher was always present to answer questions or address concerns. All participants read and signed the IRB consent document.

## 2. Daily Activity Logs

Daily activity logs were distributed and explained to all participants. On the back of the paper daily activity logs, the user was asked to provide their height, weight, date of birth, gender, and shirt size. Additionally, there was one question asking the participant if they consume any medications that affect their heart rate (e.g., beta blockers).

## 3. Fitbit Charge HR™

Each participant was asked to wear a Fitbit Charge HR™ on their non-dominant wrist, as suggested by the manufacturer. Participants wore the activity tracker for one entire work shift. The instructions given to each participant on how to wear the device included the following:

- Do not to submerge the activity tracker in water (light splashing okay)
- Do not tamper with the device once applied (e.g., do not loosen or tighten the wristband)
- Do not remove before the completion of your shift.
- The Fitbit Charge HR™ can withstand sweating, but if you feel the wristband slipping, just wipe the extra sweat away from your wrist and continue forward with your day.

#### 4. Hexoskin Instructions

Each participant was also asked to wear a Hexoskin shirt beneath their work clothing. This is a lightweight, quick-dry material that looks like a fitted tank top. Physiological sensors are located within the shirt material. The participant was instructed to use a restroom or changing area to remove their shirt and put on the Hexoskin shirt. Hexoskin shirts for women have built-in bras, so women participants were asked to remove their bra or any other undergarment from the waist up that may interfere with the sensors. Before putting on the shirt, the researcher would moisten the sensors with a water spray bottle. Three silver colored material square sensors on the inside of the shirt were dampened. Moistening these sensors improved the conducting of the sensor with the skin. After putting on the Hexoskin shirt, participants wore their usual work clothes over the Hexoskin shirt.

For all participants, elastic bands were wrapped around the shirt to prevent any movement of the sensors. These bands were adjustable and added a very minimal amount of pressure to the areas where the sensors were located (two on ribcage below, one on the abdomen). Once participants were wearing the Hexoskin shirt, researchers attached the participant data logger. This was a small battery that attached to the shirt and was zipped into the Hexoskin shirt pocket located on the waist. Instructions given to each participant on how to wear the device included the following:

- Do not remove the Hexoskin shirt before the completion of your work shift.
- Do not shower with the Hexoskin shirt on.
- Do not tamper with the shirt or sensors while wearing.
- Do not remove the battery located in the shirt pocket.
- The Hexoskin is a made of material that can withstand sweat and physical activity.



Researchers were present at the end of each work shift to collect the Fitbit Charge HR™, Hexoskin, and thank the participant for being in the study. Researchers instructed each participant on how to remove the shirt. Participants were asked to remove the shirt in a changing room or restroom. Participants were then instructed to remove the shirt carefully by grabbing the bottom of the shirt and removing it over their head, inside out. After all activity trackers were removed and activity logs collected, participants were offered \$20 in monetary compensation.

Once activity trackers and activity logs were collected, activity trackers were synced to online Fitbit® and Hexoskin accounts to store and save their respective data. Individual identifiers were matched between the Fitbit Charge HR™, Hexoskin, and activity logs. Both activity trackers were connected via Bluetooth or direct connection to their respective platform after each work shift. This enabled the data to be transferred from the activity tracker to their respective platforms. To ensure that the data from both devices was synced, time codes generated from each tracking device were matched.

### Statistical Analysis

Individual level Fitbit Charge HR™ data was synced to computers and data was recorded in one-second and one-minute intervals on Excel spreadsheets by a third party software program (Fitabase). Fitabase company is a research platform and a Fitbit partner that allows users to easily export and analyze Fitbit® data with customizable features. Hexoskin data was downloaded into Excel spreadsheets directly from the Hexoskin online dashboard.

Workers were categorized into sedentary or active groups. These groups were statistically analyzed using a two-sample t-test. Two variables (heart rate and steps) were compared to the daily activity logs on a half hour basis during the workday. Predicted maximum heart rate was

calculated using the age-predicted formula: 220 – age (Astrand & Rodahl, 1986). Percent maximum heart rate range (Rogers, 1986) was determined for each subject based on the following formula:

$$100 \times \frac{(\text{Average HR on Job} - \text{Resting HR})}{(\text{Predicted HR max} - \text{Resting HR})} = \text{Percent Maximum HR Range Required by the Job}$$

The percent maximum heart rate range is an estimate of the percent of aerobic capacity (oxygen consumption) (Rogers, 1986). Each participant’s resting heart rate at work was defined as the lowest mean heart rate for a 60 second time period during the work shift.

Energy expenditure was estimated with metabolic equivalence of task (METs) and calories burned. METs are a measure of intensity during physical activities. METs range from .99 (sleeping) to 23 (running approximately a four minute mile) and were assigned hourly based on observation, self-report (activity logs), and physiological measures such as heart rate and breathing rate. Table 1 provides examples of activities in METs.

**Table 1.**  
*Harvard T.H. Chan School of Public Health Metabolic Equivalence of Task*

| Light <3.0   | Moderate 3.0-6.0  | Vigorous >6.0   |
|--|---|---|
| Walking- slowly= 2.0                                       | Walking- very brisk (4mph)= 5.0                                   | Walking/Hiking (4.5mph)= 7.0<br>Jogging at 6mph= 10.0 |
| Sitting- using computer= 1.5                               | Cleaning- heavy= 3.0-3.5<br>(washing windows, vacuuming, mopping) | Shoveling= 7.0-8.5                                    |
| Standing- light work= 2.0-2.5<br>(cooking, washing dishes) | Mowing lawn= 5.5<br>(walk power mower)                            | Carrying heavy loads= 7.5                             |
| Fishing- sitting= 2.0                                      | Bicycling- light effort (10-12mph)= 6.0                           | Bicycling- fast (14-16mph)=10                         |
| Playing most instruments= 2.0-2.5                          | Badminton- recreational= 4.5                                      | Basketball game= 8.0                                  |
|  | Tennis- doubles= 5.0  | Soccer= 7.0<br>Tennis-singles= 8.0                    |

Additionally, basal metabolic rate (BMR) was evaluated based on height, weight, age, and gender. BMR represents the amount of calories that are burned at rest, which are approximately half of the calories that are burned each day. When estimating calories, each device accounts for BMR in the calories burned estimation. The Hexoskin does not directly estimate BMR; therefore, BMR will be calculated using the Mifflin St. Jeor equation (Mifflin, St. Jeor, Hill, Daugherty, & Koh (1990):

For men:  $BMR = 10 \times \text{weight (kg)} + 6.25 \times \text{height (cm)} - 5 \times \text{age (years)} + 5$

For women:  $BMR = 10 \times \text{weight (kg)} + 6.25 \times \text{height (cm)} - 5 \times \text{age (years)} - 161$

Both the Fitbit Charge HR<sup>TM</sup> and Hexoskin estimate caloric expenditure, which was also used in determining energy expenditure. Caloric expenditure is based on subject height, weight, age, gender, heart rate, and step counts. The Fitbit Charge HR<sup>TM</sup> and Hexoskin both use proprietary algorithms to make estimates of calories burned.

A one-way repeated measures analysis of variance (ANOVA) was used to assess step counts. Similarly, a one-way longitudinal repeated measures ANOVA was used to determine significance of heart rate for the Fitbit Charge HR<sup>TM</sup> and the Hexoskin. To assess step count and heart rate reliability as measured by the Hexoskin and Fitbit Charge HR<sup>TM</sup>, a concordance correlation coefficient (CCC) was used. A longitudinal repeated measures one-way ANOVA was preferable to a basic one-way ANOVA because the groups were not independent of one another. The longitudinal repeated measures ANOVA was used to test differences between the Hexoskin and Fitbit Charge HR<sup>TM</sup> on measures of step counts and heart rate while controlling for gender. Gender is a potential confounding variable when evaluating heart rate, thus a longitudinal repeated measures ANOVA, was used to control for this binary variable. Concordance correlation coefficients were estimated based on intra-class correlation coefficients (ICC) to

measure agreement between the Hexoskin and Fitbit Charge HR™. A CCC is useful in addition to a longitudinal repeated measures ANOVA when comparing agreement between quantitative instruments (Kwiecien, Kopp-Schnieder, Blettner, 2011).

Similar to a study assessing the validity of a Fitbit Flex (Sushames, Edwards, Thompson, McDermott, & Gebel, 2016) to an Actigraph GT3x accelerometer, two-way mixed methods intra-class correlation coefficients (ICC) were used to assess reliability between the two activity trackers using these correlation coefficient values: poor ( $r = 0.1-0.3$ ), moderate ( $r = 0.3-0.5$ ), good ( $r = 0.5-0.7$ ), and very good ( $r = 0.7-1.0$ ). The same reliability standards for CCC were used in the present study using the CCC one-way longitudinal repeated measures ANOVA. Bland-Altman plots were also generated to evaluate device agreement between the Fitbit Charge HR™ and Hexoskin quantitative measurements. In a Bland-Altman analysis, 95% of the mean differences between measurements must lie within the limits of agreement (mean difference +/- SD) to satisfy the requirement of quantitative measurement agreement (Bland & Altman, 1986; Giavarina, 2015). To compare active and sedentary workers on measures of step counts, heart rate, mean percent maximum heart rate range and energy expenditure, two sample t-tests were used to assess differences between groups. All statistical tests were run using R version 3.2.5. Statistical significance was determined at the alpha 0.05 level.

## CHAPTER IV

### RESULTS

#### Overview

This chapter explains the results of the data analysis including Fitbit Charge HR™ and Hexoskin comparisons and active and sedentary worker comparisons. Repeated measures one-way ANOVA, two sample t-tests and concordance correlation methods were used in the statistical analysis.

#### Subjects

Data was collected from 50 brewing and 51 sedentary subjects in a manufacturing company and call center, respectively. Data from two subjects in the active group were removed from the analyses due to device failure to collect data. The Hexoskin device data loggers for these two subjects failed to track activities because devices were not attached to the shirt correctly. Additionally, the data from one subject in the sedentary group was not part of the data analysis due to consumption of medication (Ritalin) that affected their heart rate. Two subjects in the sedentary group reported in their activity logs that they had walked around the adjacent neighborhood during their lunch break. After speaking with these two subjects at the end of their work shift, it was determined that the lunch walk was not part of their normal daily work activity. They explained that since they were being recorded for physical activity they wanted to walk to increase their step count. This was an abnormal activity for them and only performed on this occasion. Thus, we removed the data for the period of time that these two subjects were walking on the lunch break. Three subject's Fitbit Charge HR™ data was not used in the

analysis because we were unable to extract the data from the platform. Data from these subjects was removed to provide an equal comparison of Hexoskin and Fibt Charge HR<sup>TM</sup> data.

Therefore, the final sample was 94 in total: 47 active and 47 sedentary workers. The mean age of all subjects was 38 years (SD=8.88) and consisted of mean age for active workers was 37 years (SD=7.32) as compared to 39 years (SD=9.99) for sedentary subjects. There was not a statistically significant difference in subject age. Subjects included 34 women: 5 active and 29 sedentary subjects. Additionally 60 men participated: 42 active and 18 sedentary subjects. Active and sedentary subjects were categorized as either “active” or “sedentary” by management based on the nature of work. After observation and informal conversations with participants, the researchers agreed with management on their active and sedentary job classifications. Work shifts ranged from five hours to 12 hours.

### Daily Activity Logs

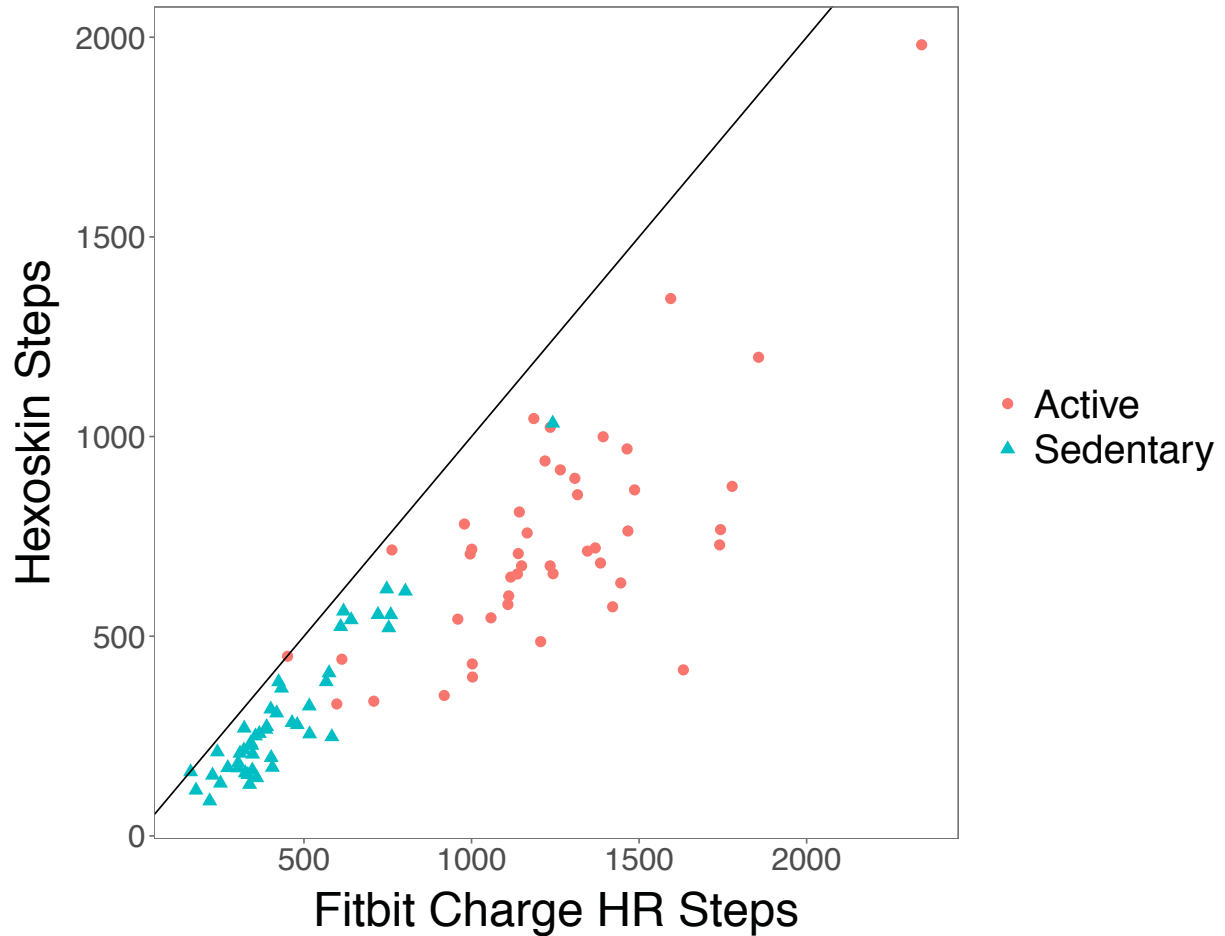
Daily activity logs were completed by each subject every 30 minutes. The activity logs were only used for qualitative information (e.g., comparing self-reported activities to physiological data). Active workers did not complete activity logs as thoroughly as sedentary workers. The response rate was low for answering the heart rate medication question in the daily logs such that 42% (24 active, 17 sedentary) of subjects did not answer the question. However, 9% (4 active, 5 sedentary) of subjects answered yes to taking medication that affects heart rate and 1% (1 active) answered yes to taking medication that affects heart rate; though upon medication research, the answer should have been no. Subjects who reported taking medication affecting heart rate also voluntarily provided their medication type and dose. Type of medication and dose were evaluated by the researchers in order to determine whether heart rate would be

affected. From this information, only one subject was removed for stimulant medication consumption.

### Comparison of Fitbit Charge HR™ and Hexoskin

The Hexoskin measured heart rate and step counts and made estimates of calories burned. The Hexoskin mean heart rate during the work shift was 89 beats per minute (bpm) (SD= 13.45) for active subjects and 84 bpm (SD= 13.77) for sedentary subjects. The mean step count per work shift hour was 728 steps (SD = 294.86) for active subjects and 302 steps (SD = 181.92) for sedentary subjects. Mean predicted maximum heart rate was 183 bpm (SD = 7.33) for active subjects and 180 bpm (SD = 9.99) for sedentary subjects. Mean calories burned were 2,235 calories (SD = 727.63) for active subjects and 1,409 calories (SD = 640.33) for sedentary subjects. METs were not calculated from Hexoskin data.

As measured by the Fitbit®, the mean heart rate during the work shift was 84 bpm (SD = 13.16) for active subjects and 76 bpm (SD =12.18) for sedentary subjects. The mean step count per work shift hourly was 1,219 steps (SD = 363.84) for active subjects and 76.48 steps (SD = 12.18) for sedentary subjects. Step counts during the work shift were significantly different as measured by the Hexoskin and Fitbit Charge HR™. Table 2 displays the means, standard deviations, p-values and CCC for the comparison of the Fitbit Charge HR™ and Hexoskin on measures of step counts and mean heart rate. H1, comparing measures of step counts between the two devices was statistically significant with a p-value of <0.001 and the null hypothesis was rejected. H2, evaluating inter-method reliability was statistically significant with a good concordance correlation coefficient value (CCC = .53) and the null hypothesis was rejected.



**Figure 1.** Correlation of hourly step counts for each participant in the study as measured by the Fitbit Charge HR™ and Hexoskin.

Fitbit® and Hexoskin measures of heart rate, H3 were significantly different. Gender was controlled for by using a longitudinal repeated measures ANOVA. H3 was statistically significant at the alpha 0.05 level with a p-value of <0.001 and therefore rejected the null. However, the concordance correlation coefficient for H4, there will be poor inter-method reliability was not statistically significant with a good correlation (CCC= 0.61) and failed to reject the null. Figure 2 illustrates a scatterplot of mean heart rates for each participant in the study as measured by the Fitbit Charge HR™ and Hexoskin.

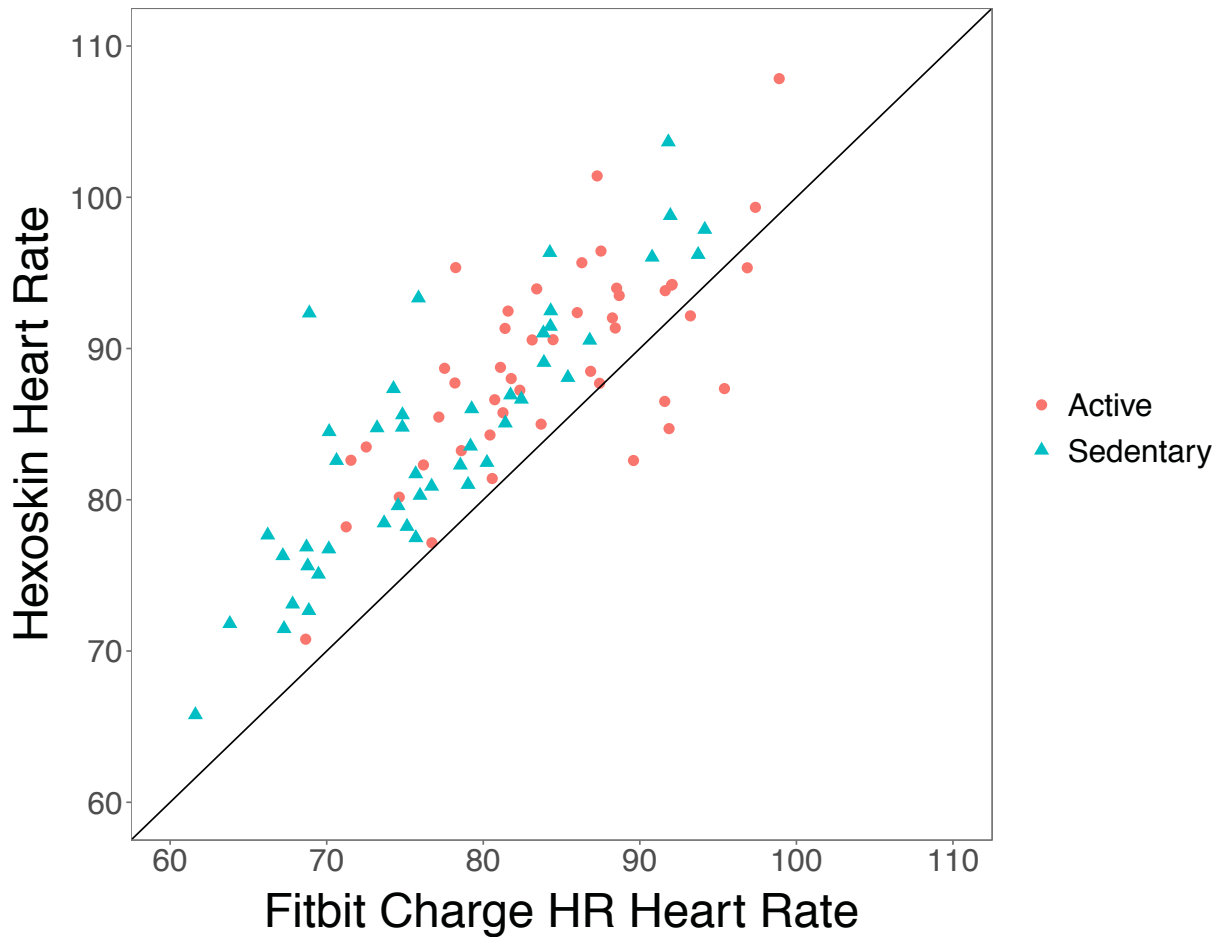


**Table 2.**

*Comparison of Fitbit Charge HR™ and Hexoskin.*

*Note: p-values refer to repeated measures one-way ANOVA testing Hexoskin and Fitbit Charge HR™ step counts and heart rate. \*Significant p-value < 0.05.*

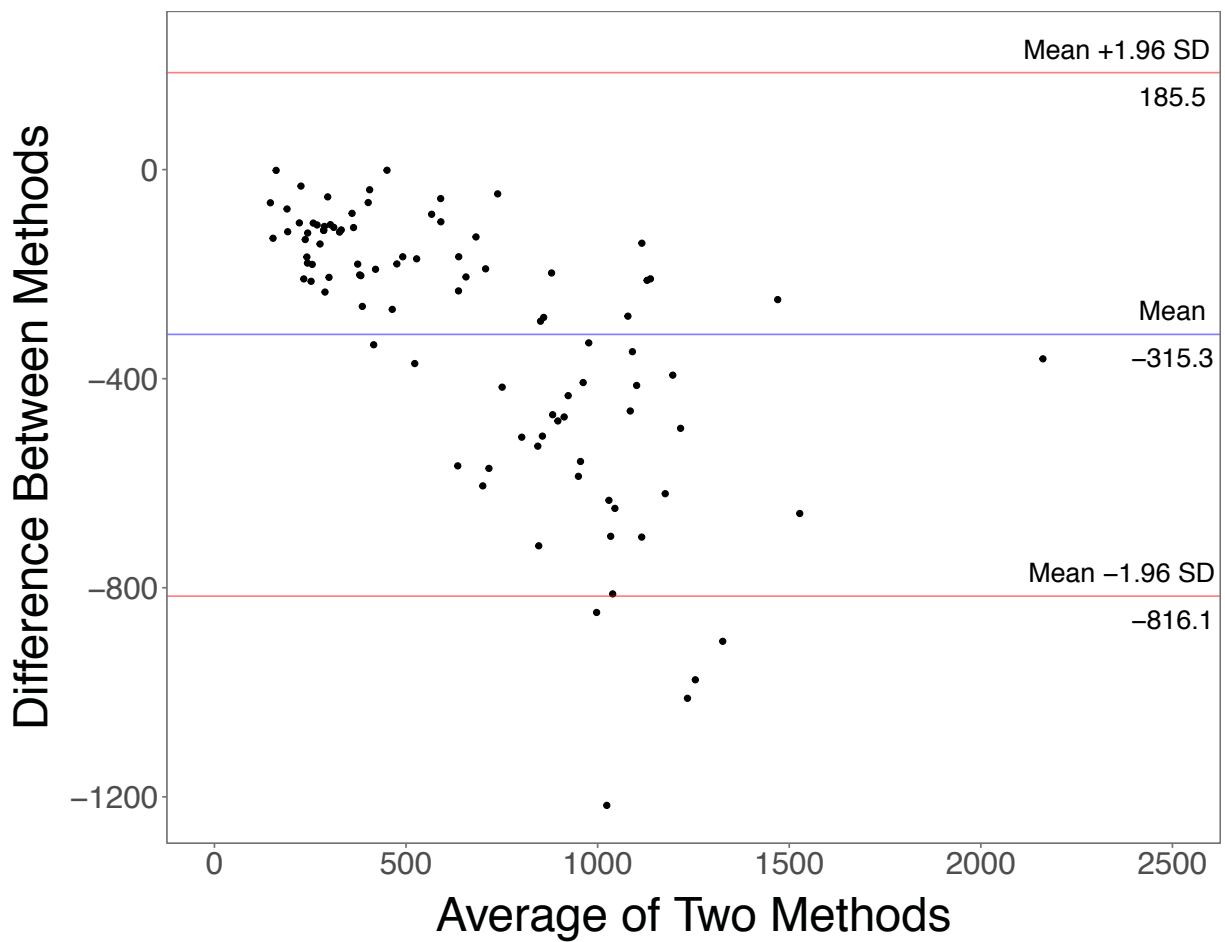
|                       | Hexoskin |        | Fitbit |        | Difference between means | p-value | CCC  |
|-----------------------|----------|--------|--------|--------|--------------------------|---------|------|
|                       | Mean     | SD     | Mean   | SD     |                          |         |      |
| Step Count (per hour) | 514.93   | 324.13 | 830.22 | 487.83 | -315.29                  | <0.001* | 0.53 |
| Heart Rate (bpm)      | 86.47    | 7.84   | 80.33  | 8.75   | 6.14                     | <0.001* | 0.61 |



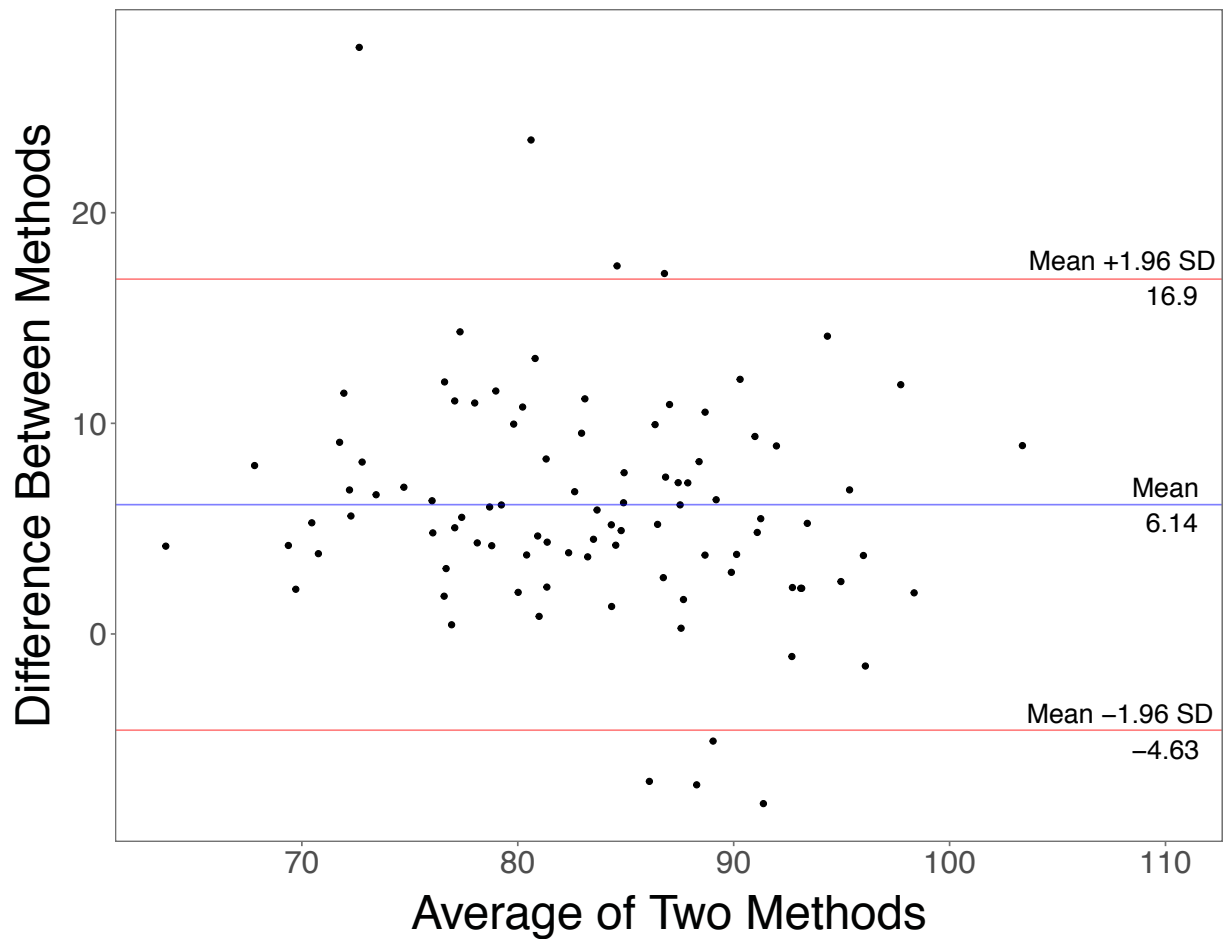
**Figure 2.** Correlation of mean heart rate for each participant in the study as measured by the Fitbit Charge HR™ and Hexoskin.

Bland-Altman plots were created to illustrate quantitative measurement agreement between the Fitbit Charge HR™ and Hexoskin. Bland-Altman analysis for step count and heart

rate agreement between the two activity trackers was satisfied if 95% of the mean differences were within the limits of agreement (mean  $\pm$  SD) (Bland & Altman, 1986). Bland-Altman plot analysis of Fitbit Charge HR™ and Hexoskin displayed agreement in quantitative measures of step counts with 95% of the differences within the limits of agreement. Figure 3 illustrates the Bland-Altman step count agreement. However, Bland-Altman plot analysis of Fitbit Charge HR™ and Hexoskin did not display agreement in quantitative measures of heart rate with 91% of differences within the limits of agreement. Figure 4 displays the results of the Bland-Altman analysis.



**Figure 3.** Bland-Altman plot analysis of hourly step counts.



**Figure 4.** Bland-Altman plot analysis of mean heart rate.

#### Comparison of Active and Sedentary Workers

Total step counts were significantly greater in active subjects than sedentary subjects.

The mean hourly step count for the active work group was 728 steps (SD =294.86) and the mean step count for the sedentary work group was 302 steps (SD =181.92). H5, comparing active and sedentary workers on measures of step counts was statistically significant at the alpha 0.05 level with a p-value < 0.05 and the null was rejected.

The mean heart rate for active subjects was greater than sedentary subjects. The mean heart rate for the active work group was 89 beats per minute (SD =13.45), and the mean heart rate for the sedentary work group was 84 beats per minute (SD =13.77). H6, comparing active and sedentary workers on measures of mean heart rate was statistically significant at the alpha 0.05 level with a p-value=0.002 and the null was rejected. Additionally, H7, comparing active and sedentary workers on measures of mean percent maximum heart rate range was statistically significant at the alpha 0.05 level with a p-value < 0.001 and the null was rejected.

Basal metabolic rate (BMR) was calculated based on subject height, weight, age, and gender using the Mifflin St. Jeor calculation:

For men:  $BMR = 10 \times \text{weight (kg)} + 6.25 \times \text{height (cm)} - 5 \times \text{age (years)} + 5$

For women:  $BMR = 10 \times \text{weight (kg)} + 6.25 \times \text{height (cm)} - 5 \times \text{age (years)} - 161$

The active and sedentary workers yielded similar BMR values. In the active subject group, women had a mean BMR of 1,333 calories (SD = 108.70) and men had a mean BMR of 1,805 calories (SD = 175.40). The sedentary subject group had fairly similar BMR values: women had a mean BMR of 1,317 calories (SD = 133.40) and men had a mean BMR of 1,755 calories (SD = 219.82).

The Fitbit Charge HR<sup>TM</sup> and the Hexoskin estimated caloric expenditure, which was also used to determine energy expenditure. The Fitbit Charge HR<sup>TM</sup> estimated that mean calories burned for active subjects was 1,871 calories (SD = 598) and the mean for sedentary subjects was 885 calories (SD = 272). The mean METs estimated for active subjects was 3 (SD = 0.92) and the mean MET's for sedentary subjects was 1.81 (SD = 0.59). The Hexoskin estimated that mean calories burned for active subjects was 2,209 calories (SD = 769.14) and the mean calories burned for sedentary subjects was 1,387 calories (SD = 611.9). For calories burned in H8, the p-

value was statistically significant at the alpha 0.05 level with a p-value <0.05. For METs, the p-value was statistically significant at the alpha 0.05 level with a p-value <0.05 and the null hypothesis was rejected.

**Table 3.**

*Comparison of Active and Sedentary Work Groups.*

*Note: p-values refer to two-sample t-test testing for whether differences between the two groups are significant. \*Significant p-value < 0.05.*

|                 | Active                |         | Sedentary |         | Difference between means | p-value |         |
|-----------------|-----------------------|---------|-----------|---------|--------------------------|---------|---------|
|                 | Mean                  | SD      | Mean      | SD      |                          |         |         |
| <b>Hexoskin</b> | Step Count (per hour) | 727.53  | 294.86    | 302.34  | 181.92                   | 425.2   | <0.001* |
|                 | Heart Rate (bpm)      | 88.9    | 13.45     | 84.11   | 13.77                    | 4.79    | 0.002*  |
|                 | Percent Max HR Range  | 23.04   | 4.96      | 17.88   | 5.09                     | 5.16    | <0.001* |
|                 | Calories              | 2209.15 | 769.14    | 1387.28 | 611.9                    | 821.87  | <0.001* |
| <b>Fitbit</b>   | Step Count (per hour) | 1218.73 | 363.84    | 441.72  | 200.77                   | 777     | <0.001* |
|                 | Heart Rate (bpm)      | 84.17   | 13.16     | 76.48   | 12.18                    | 7.7     | <0.001* |
|                 | Percent Max HR Range  | 14.95   | 4.42      | 9.87    | 2.66                     | 5.09    | <0.001* |
|                 | Calories              | 1871    | 598       | 885     | 272                      | 985     | <0.001* |
|                 | METs                  | 3       | 0.92      | 1.81    | 0.59                     | 1.19    | <0.001* |

Hexoskin data was used for the comparison of active and sedentary workers because it utilizes a hip worn accelerometer and is equipped with an electrocardiogram. Previous studies have indicated that hip worn accelerometers and electrocardiograms are more valid and reliable than other methods. Two-sample t-tests were also generated for the Fitbit Charge HR™ in the comparison of active and sedentary workers, and all tests were statistically significant.

## CHAPTER V

### DISCUSSION

#### Overview

Attention concerning physical activity in the workplace has become increasingly important and popular as evidenced by the fairly recent published research and media attention on the adverse health effects associated with physical inactivity. Employers are becoming increasingly aware that improving the overall health and wellbeing of their employees is good for their business. Thus, in the last five years there has been greater implementation of worker health promotion programs, some of which encourage employees to use fitness tracking technology like the Fitbit<sup>®</sup>. The purpose of this study was to quantify a baseline measure of OPA across active and sedentary workers. Though an optimal level of occupational physical activity has not been identified to date, this study contributes to the literature pertaining to activity levels in the work environment. The “Goldilocks model” (Goldenhar, et al., 2003) proposed that optimal levels of work (based on economic realities) are somewhere between too much and too little. It is also likely that the same principle of “not too much but not too little” applies to OPA. Both high and low OPA are potentially harmful to the health and wellbeing of workers, but quantitative measures of OPA are seldom used in the workplace. The present study addressed this issue by quantitatively measuring OPA through measures of heart rate, step counts, and energy expenditure. Studies quantitatively assessing OPA using activity trackers had not been conducted prior to the present study. Thus, comparing the results of the present study to other

studies of OPA among work groups is very limited. There are, however, studies on the use and validity of activity trackers for monitoring activity in a variety of settings.

State of the art technology is available to assess physical activity, but this technology is often invasive, expensive, and requires a high level of knowledge to use. Additionally, this technology is not always practical or feasible, especially for the general public. However, trendy activity trackers like Fitbit<sup>®</sup> and Jawbone are relatively inexpensive and come in a variety of colors and shapes making them aesthetically attractive to the average consumer. The immense public interest in these activity trackers has compelled exercise physiologists and other researchers to conduct validation studies comparing these trackers to validated technology.

Fitbit<sup>®</sup> devices have undoubtedly become the most popular activity trackers and have been used in several validation studies evaluating step counts, heart rate and calories burned (Evenson et al., 2016). Other studies have reported that Fitbit<sup>®</sup> activity trackers are the most valid and reliable of the commercially available devices (Diaz et al., 2015; Evenson et al., 2016; Noah et al., 2013; Paul et al., 2015). Specifically, Consumer Reports (2016) compared the Fitbit Charge HR<sup>™</sup> optical heart rate monitoring (PurePulse<sup>™</sup>) to a validated ECG chest strap in a validation study and reported that the heartbeats differed no more than three beats per minute. Wallen et al. (2016) and Stahl, An, Dinkel, Noble, & Lee (2016) reported that the Fitbit Charge HR<sup>™</sup> accurately tracked heart rate in their validation studies. Additionally, Dooley (2016) found that the Fitbit Charge HR<sup>™</sup> tracked heart rate accurately for moderate activities, however it tracked heart rate inaccurately for light and vigorous activities when compared to a Polar heart rate monitor.

Though the present study was consistent with literature supporting the inaccuracy of optical heart rate monitoring. There was a statistically significant difference in the Fitbit<sup>®</sup> optical

measures of heart rate when compared to the Hexoskin electrocardiogram in the present study. The heart rate finding in the present study is in agreement with literature comparing electrocardiograms to the Fitbit Charge HR™. Jo, Lewis, Directo, Kim & Dolezal (2016) compared a Fitbit Charge HR™ to an electrocardiogram in a controlled treadmill setting and reported that the Fitbit Charge HR™ was not a valid device to track heart rate data. Additionally, Lee, An, Kang, & Kim (2016) reported that the Fitbit Charge HR™ was inaccurate when compared to a Polar electrocardiogram chest strap. Reasons for the significant findings of the present study could be attributable to the free-living environment. In the present study, the devices were significantly different in measures of heart rate but had good correlation. The Hexoskin consistently overestimated mean heart rate during the work shifts. Though varying activity levels in the workplace may yield different findings than controlled treadmill settings.

Previous research has suggested that hip worn tri-axial accelerometers are more accurate than wrist-worn accelerometers in tracking step counts. Specifically, the hip-worn Fitbit® devices have demonstrated to be valid and reliable for tracking step counts as compared to research grade accelerometers (e.g. Actigraph, Omron) (Dontje et al., Ferguson et al., 2015; 2015; Evenson et al., 2016; Kooiman et al., 2015; O'Connell et al., 2016; Takacs et al., 2014; Singh et al., 2016). The use of a hip worn accelerometer, however, is far less appealing than a colorful and stylish wristband that will not only track step counts but also heart rate. The popular use of wrist-worn accelerometers is a relatively recent phenomenon, with little research on their validity in the literature. The few studies that evaluated the wrist-worn Fitbit® activity trackers have reported that the Fitbit® is a reliable and moderately valid device for measuring steps and heart rate in controlled treadmill walking and jogging settings (Bai et al., 2015; Kooiman et al., 2015; Sushames et al., 2016; Stahl et al., 2016).



For measurement, devices with hip worn accelerometers (e.g. Hexoskin) are reported to be the most valid and reliable. However, wearable technology like the Hexoskin is not always practical to wear in the daily office environment, and other hip worn accelerometers are typically less invasive. Therefore, other validated hip worn accelerometers (e.g. Actigraph, Fitbit Zip) may be superior methods to measure steps at work. Wrist-worn activity trackers are stylish, but are likely to only be useful for approximations of activity levels. Though if inexpensive wrist-worn accelerometers like the Fitbit Charge HR™ encourage users to be more physically active, then they may serve their intended purpose.

Though the results of the present study are in contrast to some of the literature evaluating wrist-worn Fitbit® accelerometers. In the present study, we determined that there was a significant difference in total step counts as measured by the Hexoskin (with an accelerometer located near the hip) and the wrist-worn Fitbit Charge HR™. The Fitbit Charge HR™ measured a greater number of total steps as compared to the Hexoskin. One possible explanation for this difference may be that upper extremity motion, which activates the accelerometer, records step counts when the individual is actually stationary. Thus, normal work activities that involve upper extremity motion (e.g., reaching for the tap to fill a glass with beer) may be falsely measuring step counts when the worker is only standing or sitting. Three-axis accelerometers are coded to record steps when there are changes in directional acceleration as with the swinging motions of the arms or with the vertical movement of the pelvis with walking. Examples of non-step situations where a wrist-worn accelerometer could record a step(s) include being excessively active with arms while talking, pulling a beer tap handle, moving boxes, steering a forklift, etc. In all of the previous examples, an accelerometer positioned on the trunk or in proximity to the pelvis would not have recorded steps.

Although subjects were categorized into sedentary and active work groups a priori, the active group was less active than expected based on the investigators' observations and worker activity logs. As expected, the present study determined statistically significant differences in total step counts taken during the work shift between active and sedentary workers. Total mean steps for active workers were much greater than total mean steps taken for sedentary workers. This was likely due to a difference in activity levels based on the nature of their job tasks (e.g., some tasks requiring more physical exertion than others). As expected, mean heart rates and the percent maximum heart rate range required for the job tasks were both greater among active workers than among sedentary workers. This finding indicated that active workers had job tasks that required greater cardiovascular effort than sedentary workers. The mean percent of maximum heart rate required by the job was 22.57% for active workers and 17.49% for sedentary workers. Rogers (1989) stated that if percent maximum heart rate range required by the job exceeds 33%, workers are likely to become physically fatigued. Statistically significant differences were found for both heart rate hypotheses (H6: Active workers will have a greater mean heart rate than sedentary workers and H7: Active workers will have a greater mean percent maximum heart rate range than sedentary workers) when comparing active and sedentary workers. In addition, statistically significant differences between the two work groups supported the hypothesis that active workers would participate in job tasks requiring greater energy expenditure (as estimated by calories burned and METs) than sedentary workers.

Church et al. (2011) reported that gradually over the last 50 years, mean body weight for both men and women has increased as a result of less activity, and subsequently burning fewer calories. Additionally, Bergouignan, Legget, De Jong, Kealey, Nikolovski, Groppe, Jordam, O'Day, Hill & Bessesen (2016) reported that sedentary workers who participated in physical

activity during their workday had decreased fatigue and food cravings. Thorp, Healy, Winkler, Clark, Gardiner, Owen & Dunstan (2012) found that time spent at work was more sedentary than time spent away from work. The literature surrounding sedentary behavior and the results of this study suggest that interventions should be implemented into sedentary work environments to improve worker health and wellbeing.

Recent research has supported the benefits increases in OPA through short bouts of activity (five minutes or less) among sedentary workers. That research indicated that short bouts of activity periodically throughout the day may reduce feelings of fatigue and other adverse health affects associated with being inactive (Dunstan, Kingwell, Larsen, Healy, Cerin, Hamilton, Shaw, Bertovic, Zimmet, Salmon, & Owen, 2012; Swartz, Squires, & Strath, 2011; Wennberg, Boraxbekk, Wheeler, Howard, Dempsey, Lambert, Eikelis, Larsen, Sethi, Occleston, Hernestal-Boman, Ellis, Owen, & Dunstan, 2016). Additional studies should look further into the long-term benefits as well as the sustainability of frequent short bouts of activity among employees throughout the workday. More passive interventions that increase the natural movement of workers through better design of work environments should also be explored, as they may be more sustainable. If workplaces were designed to promote rather than restrict physical movement, we may have a healthier workforce.

Some simple examples of workplace design that promote physical activity include: 1) Relocating recycling and trash bins to a central location that workers would have to walk some distance to use. This would not only design activity into the employee's workday, but also save on the expense of custodial staff making many trips to the central recycling/trash area. 2) Placing filtered water drinking fountains / water stations in a central area of the building. This centralized one location design would encourage employees to walk for a healthy beverage. The

centralized design also encourages serendipitous meetings between employees that may not normally meet and potentially fostering cross-disciplinary interactions. 3) Displaying signage / posters that indicate distances and calories burned by modifying routes through the office or using stairs instead of elevators. 4) Redesign could even include building a gym area for activities such as yoga, treadmill walking, stationary cycling that also has computer access for those that need to stop and check email or text messages. To encourage maximum use, these activity areas should be very attractive with an abundance of natural light and scenic views. 5) Active design may also include developing a culture where meetings are designed as active experiences rather than the current norm of continuous sitting. For example, a meeting in which each person speaking must get out of their chair and walk to the podium or microphone to stand and speak.

## Limitations

### *Daily Activity Logs*

The daily activity logs were only useful when completed thoroughly by subjects. Some subjects would forget about the activity logs during their shift and consequently fill them out at the end of the day. Forgetfulness with the activity logs was especially prevalent for subjects in the active group because they had to set their activity log down while they worked as opposed to having the log in front of them at their desk. In addition, the question on the back of the activity log asking subjects about whether they regularly consumed heart rate limiting medication was often unanswered. These logs were not very beneficial to the present study because the majority of logs were incomplete.

### *Hexoskin*

The Hexoskin was minimally invasive because it was worn beneath all clothing and undergarments. However, women were sometimes hesitant to wear the Hexoskin due to concerns with built-in bra support. Two female subjects decided against participating in the study due to this concern. The Hexoskin women's shirt sizes were also an issue because sizing was limited to extra-small to large. There were five potential sedentary women subjects who could not participate because extra large and extra-extra large shirt sizes were unavailable from the manufacturer. Though breathing rate was not a focus in the present study, the breathing rate sensor that extended across the abdomen was obstructed on some subjects because women's pants usually have a higher waist-band than men's. The high waist-band would work itself under the Hexoskin shirt during the work shift. Once this was identified as an issue, women were asked to tuck their Hexoskin shirt into their pants. Moreover, men would comment on the tight fit of the Hexoskin. This is most likely attributable to the nature of men's and women's clothing because men may be used to wearing loose fitted shirts. Lastly, the Hexoskin is designed for athletes, who typically have a lean and athletic build. The average worker is not usually the shape of an athlete, therefore there were sensitivity issues related to the breathing rate sensor located across the abdomen.

### *Fitbit Charge HR™*

Overall the Fitbit Charge HR™ was less invasive than the Hexoskin. However, when programming the devices before use, the Fitbit took longer to set up. The Fitbit would normally take longer to sync and program than the Hexoskin. This was inconvenient when setting up subjects on-site because they would have to stand and wait for the Fitbit to program before they

could start working. Both the Fitbit and Hexoskin required individual e-mail accounts for each user registration, therefore alias e-mails were created using an alias e-mail account generator on Google GSuite. On the final day of data collection, Fitbit and Fitabase would not allow alias e-mail accounts to log data. Therefore Fitbit data for two subjects was not recorded.

### *Heart Rate*

A resting heart rate was not measured during this study, yielding a limitation. Resting heart rate is the least amount of blood that your heart pumps at rest, or while not exercising (American Heart Association, 2015). Traditionally resting heart rates are measured in a cool, quiet location with limited distractions. Though in the work environment, quiet and distraction-free locations can be difficult to find. Additionally, it is often not feasible in the workplace to ask subjects to rest in a quiet room while a resting heart rate measurement is taken. To address this limitation, a working resting heart rate was measured for each participant by defining the lowest mean heart rate at work for a 60-second time period. Additionally, device fit of both the Hexoskin and Fitbit Charge HR<sup>TM</sup> devices could potentially yield a limitation. Hexoskin sensor-embedded shirts are designed for athletes, yet most workers are not athletes, nor are they anatomically structured like an athlete. Thus, the majority of subjects in the present study did not always fit well into the small, medium and large Hexoskin shirts. Additionally, the Fitbit Charge HR<sup>TM</sup> is worn on the wrist like a watch and “good” consistent fit is necessary since the heart rate is read optically from the device to the surface of the skin. Both movement of the Fitbit<sup>®</sup> over the skin and moisture between the device and skin may affect consistent readings of heart rate.

## Implications

Researchers can apply several strategies to improve the measurement of OPA.

By continuing to evaluate additional occupations and activity levels, measures and methodology associated with OPA will improve. Highly active occupations such as firefighting, professional logging and construction roofing are jobs require highly intensive physiological demands of workers. Having the capacity to accurately measure heart rate among highly active workers with non-invasive activity tracking would be an important step toward understanding and redesigning high physical activity tasks in the workplace. Similarly, additional research should be directed toward measuring OPA among moderately active and sedentary workers. By continuing to assess OPA across a variety of activity levels and job types, it is likely that an optimal level of OPA per occupation can be identified. Additionally, evaluating worker activity in different types of environmental climate (e.g. extremely hot and humid or cold weather) could be useful for regulating safe working activity levels.

Additional research should also be focused on evaluating the accuracy of new wearable technology on the market. There have been many studies evaluating activity trackers, though future research should continue to assess devices as they are developed and released to the general public. Fitbit<sup>®</sup> wrist-worn devices should undergo additional accuracy testing. This can be accomplished through the continued comparison of the Fitbit<sup>®</sup> algorithms to state of the art physiological measurement devices, like the Zephyr<sup>™</sup> Bioharness chest strap and Hexoskin. The Hexoskin was a user-friendly activity tracker, however it may not a feasible measurement option due to invasiveness of the shirt. The Hexoskin would be uncomfortable and include additional maintenance (e.g. washing every day) if worn for multiple days in a research study. However, a chest strap may be less invasive and noticeable to a consumer. Persistent validity and reliability

testing of wearables could advance the development of activity tracking algorithms, in addition to potentially improving the measurement of OPA. Also, product fit should be considered when assessing the accuracy and consistency of activity tracking devices. The average workforce is comprised of people who vary in shape, size and height making it challenging to find wearable devices that fit every individual perfectly. Identifying an optimal level of OPA across different occupations could be plausible with additional research and measurement methods.



## CHAPTER VI

### CONCLUSION

The purpose of the present study was to quantify a baseline of OPA among active and sedentary workers using measures of steps, heart rate, and energy expenditure. To date, there is no published research quantifying OPA with activity trackers. The first objective of the present study was to determine the agreement between two types of accelerometer based activity trackers for assessing OPA. The Fitbit Charge HR<sup>TM</sup> recorded a statistically significant greater number of total steps during an employee's workday as compared to the Hexoskin wearable. There were no statistically significant differences in measures of mean heart rate for two devices. The second objective of the study was to evaluate measures of OPA among groups of active and sedentary workers. As compared to sedentary workers, active workers had statistically significant greater total step counts, mean heart rate, percent of maximum heart rate and energy expenditure during the work day. These results indicated that physiologic demands of active workers are greater than for sedentary workers. Additional research is needed to determine how to design and sustain more physically active work environments into traditionally sedentary work.

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