The Pennsylvania State University
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THE BIOMECHANICAL, PHYSIOLOGICAL, AND COGNITIVE EFFECTS OF ACTIVE WORKSTATIONS AND UTILIZING ANTHROPOMETRIC DATA TO IMPROVE THE USABILITY

A Dissertation in
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Abstract

The benefits of a physically active lifestyle are well known, such as reducing the risks of developing type 2 diabetes, cardiovascular diseases, obesity, and some cancer types. However, many adults in high-income and developed countries work in sedentary jobs and report lack of time for physical activity. Studies have shown that prolonged sedentary behavior has been contributing significantly to the obesity epidemic. To prevent the spread of this, researchers have studied the use of active workstations to help accomplish light physical activity during office work. However, further investigation is needed to validate and better understand the use of active workstations.

To further understand the possibility of using active workstations to improve health while maintaining work efficiency, this study investigates the physiological, biomechanical, and cognitive effects of using active workstations and discusses ways to improve the usability. The objectives include: (1) Investigating the ergonomic characteristics associated with using an under desk bike; (2) Comparing office related work performance while using an under desk bike to working in a seated position; (3) Comparing the energy expenditure of using active workstations (under desk bike, under desk elliptical trainer, and treadmill desk) to a seated or standing position; and (4) Comparing the muscle demands and joint kinematics of using active workstations to a seated or standing position.

The findings for each research question are the following: (1) Recommended workstation measurements were proposed to accommodate 95% of the general U.S. population in using under desk bikes; (2) Under desk cycling had no significant effect on reading, logical reasoning, and phone call answering performances, but typing performance was significantly different, with a modest deterioration, compared to the traditional seated posture; (3) Using active workstations at light physical activity level could significantly increase energy expenditure by 67.5 (under desk bike) or up to 122.5 (treadmill desk) more kilocalories per hour compared to sitting or standing at the desk; and (4) Normative values regarding the muscle demands of eight lower extremity muscles and sagittal plane kinematic measures of the hip, knee, and ankle joints during the use of active workstations were determined to help guide clinical decision making related to lower extremity training and rehabilitation through active workstations.

This study presents a range of topics on the physiological, biomechanical, and cognitive effects of using active workstations in a controlled lab setting to support the research on promoting light physical activity in the workplace. Future studies may conduct a longitudinal field study and include diverse populations to obtain more widely applicable results.

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Chapter 1
Introduction

1.1 Problem Statement

Prevalence of overweight and obesity has definitely become one of the most significant epidemics in many countries (Ng et al., 2014). In 2012, the prevalence of obesity was approximately 34% for both U.S. adult males and females (Ogden et al., 2014). At the same time, approximately 1.46 billion adults worldwide were estimated to be overweight with 502 million being obese (Finucane et al., 2011). The dramatic rise of obesity is not only threatening the wellbeing of humanity, but also becoming an economic burden due to high health-care costs (Yusuf et al., 2005; Wang et al., 2011; Wardle and Cooke, 2005).

Although numerous studies have been conducted to understand and restrain this growth, it is still not fully understood due to the etiology of obesity being highly complex (Barness, Opitz, and Gilbert-Barness, 2007; Wang and Lobstein, 2006). Factors such as genetics, psychological, physiological, environmental, social, and economical can all affect the progression of obesity (Finkelstein, Ruhm, and Kosa, 2005; Wright and Aronne, 2012). However, the most common cause known is the excess energy consumption (dietary intake) compared to energy expenditure (calories burned via physical activity; Ogden et al., 2007; Aronne, Nelinson and Lillo, 2009).

Food supply trends have changed and the consumption rate of energy-dense foods have significantly increased. With weekly works hours increasing and processed food items being more accessible and affordable, reliance on these pre-prepared foods have increased (Drewnoski and Specter, 2004). These may save time and reduce diet costs, but they are typically high in sugar, fat and sodium, which may lead to an increase in energy intake (Drewnowski, 2004). Hence, the increase of dietary intake will affect the development of obesity. Swinburn, Sacks and Ravussin (2009) even stated that the increase in energy consumption is more than enough to explain the weight gain in the United States population.

Excess energy intake is considered one of the main reasons for the growth of obesity, nonetheless, lack of physical activity exacerbates this situation (Kruger, Kohl III, and Miles, 2007). The majority of the working environment has altered to a sedentary computer based setting in developed and high-income countries (Ma, Xiao, and Stafford, 2009). Typically, U.S. adults employed in these sedentary occupations remain deskbound for approximately 11 hours a day (Tudor- Locke et al., 2011). This prolonging seated posture in the office requires little movement, leading to minimal physical activity in a day's work, and eventually increasing the chances of weight gain.

To prevent this epidemic from spreading, researchers have investigated ways to accomplish simultaneous caloric expenditure and productive office work by using active workstations. However, research supporting active workstations is still young and heterogeneous. For example, the ergonomics of using active workstations have not been evaluated, the validity and reliability of these devices have not been fully tested, implementation issues related to both the employers' and the workers' perspective needs further investigation, and other potential use needs examination.

1.2 Study Objectives

This study investigates the physiological, biomechanical, and cognitive effects of using active workstations and discusses ways to improve the usability. The four detailed objectives are the following:

- Objective 1 - Evaluate ergonomic factors associated with of using an under desk bike in the office workplace by investigating the preferred office workstation settings (e.g., desk height and depth) with respect to anthropometric measurements and user preferences and, in addition, to determine preferred cycling intensity when performing reading comprehension and typing tasks.
- Objective 2 - Evaluate work performance of four tasks commonly seen in the office (reading, typing, logical reasoning, and phone call answering) during the use of an under desk bike at two intensities 17 and 25 W and compare to a traditional sitting position on a broader demographic.
- Objective 3 - Determine the physiological effects of sitting and standing at the desk and using three different active workstations while writing on the computer and, in addition, to determine the validity and reliability of low-cost consumer-oriented active workstations.
- Objective 4 - Determine the biomechanical effects of sitting and standing at the desk and using three different active workstations while writing on the computer.

Chapter 2
Background

2.1 Obesity

Obesity has become a worldwide health problem and is definitely considered as one of the most greatest health challenges in this era. Substantial amount of healthcare resources have been devoted, such as from the World Health Organization (WHO), to emphasize the global prevalence and secular trends for this pandemic (World Health Organization, 2000). One of the main reasons for this is that excess bodyweight can be a risk factor for mortality and morbidity from diabetes, coronary heart diseases, cancer and etc., which is causing nearly 3 million deaths every year worldwide (Ezzati et al., 2002; Wang et al., 2011; Flegal et al., 2013). Even though the impacts of obesity (e.g., health, social and economical impacts) are well known, many are still not aware of the magnitude and the consequences. The number of individuals that are unaware, or even being negligent, to this issue is increasing, which has the potential to negatively affect the aspects of one's well-being.

2.1.1 Definitions of Obesity

The World Health Organization (WHO) defines obesity as "abnormal or excessive fat accumulation in the body that may impair health" (World Health Organization, 2000). Body Mass Index (BMI) is a measure of body fat based on height and weight that applies to adult men and women and is typically used as an estimator of obesity to distinguish people from this normal to abnormal fat accumulation in the body. BMI was developed by Adolphe Quetelet in 1832 as the Quetelet Index back then and renamed to its current name (BMI) in 1972 by Anoel Keys (Eknoyan, 2008). The following equation shows how BMI is calculated in metric units.

$$BMI = \left(\frac{kg}{m^2}\right) \tag{2.1}$$

According to the United States Centers for Disease Control and Prevention (CDC) and the WHO, adult individuals can be categorized under the terms underweight, normal, overweight and obese based on their BMI (Centers for Disease Control and Prevention, 2014, World Health Organization, 2000, Table 2.1).

Table 2.1. Classification of adults according to BMI

Classification	BMI
Underweight	< 18.5
Normal	$18.5 - 24.9$
Overweight	$25.0 - 29.9$
Obese	≥ 30.0

Whilst BMI can easily be calculated, there are a few limitations in using it as a means of estimating adiposity. BMI depends on the weight (kg) and the square of the height (m^2) of an individual. Therefore, even if two individuals had the same body shape and relative composition, the taller person will have a greater BMI (Rothman, 2008). Also, BMI would overestimate adiposity in those individuals with more lean body mass (e.g. athletes or muscle-fit individuals). Because of BMI not being able to capture one's muscle mass, the muscular weight will simply add to the overall weight. Hence, this would classify those fit or athletic people into the overweight category, even though their body fat percentages would be less than the average person (Stevens, McClain, and Truesdale, 2008). Using BMI for children and teens can even be more complex, since children cannot use the adult calculator directly and need a age- and sex-specific percentile chart that is used to compare and interpret BMI (Kuczmarski et al., 2002). In spite of the duality, BMI is still a fair estimator of body fat and the simple calculation of BMI has made it a standard for recording obesity statistics in the U.S. and around the world (World Health Organization, 2014).

2.1.2 Obesity trend

Increased prevalence of overweight and obesity has become one of the most significant epidemics in the U.S. In the year 2008, the prevalence of obesity was almost 34% for both U.S. adult males and females, which is approximately twice the percentage compared to the 1970s (Freedman, 2011). It was also found that approximately 68% of U.S. adults are considered either overweight or obese (Flegal et al., 2010). Figure 2.1 shows the trends in adult overweight, obesity, and extreme obesity among men and women aged 20 through 74 in the U.S. for the selected years between 1960 – 1962 through 2011 – 2012 (Fryar, Carroll, and Ogden, 2014).

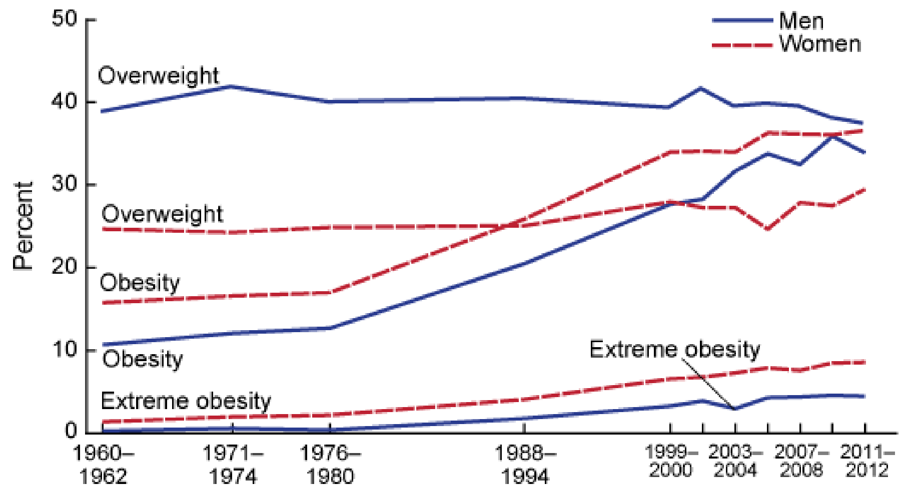


Figure 2.1. Increasing Overweight, Obesity and Extreme Obesity Trend in U.S. Adults. (Adapted from Fryar et al., 2014)

Not only is this spreading in the U.S., but prevalence of overweight and obesity has also become a worldwide threat (Prentice, 2006). In the year 2008, approximately 1.46 billion adults worldwide were estimated to be overweight with 502 million of these being obese (Finucane et al., 2011). The obesity increase rate was higher in nations with higher economic growth, such as Europe, Australia and North America (Swinburn et al., 2011). However, this trend was not only limited to developed countries, but also in the urban areas of developing nations, e.g., many countries in Africa and Latin America and some in Asia (Popkin, Adair, and Ng, 2012).

The rising number of overweight and obese individuals entails a huge burden for a nation, especially in terms of healthcare costs (Finkelstein et al., 2009). Wang et al. (2008) estimated that, if this rising pattern were to continue through 2030, approximately 86.3% of U.S. adults may be at least overweight with 51.1% being obese. Not only would this epidemic itself be a concern, but they also stated that healthcare costs could be an issue since the estimated costs on obesity could reach $900 billion. On the other hand, Finkelstein et al. (2012) stated that this pattern will not continue to increase in a linear manner and estimated that approximately 42% of the U.S. adult population will be obese by 2030. They also claimed that if the current prevalence of overweight and obesity were to remain, an estimated savings of $549 billion could occur by 2030.

2.1.3 Effects of sedentary behavior on obesity

As the majority of the working or studying environment altered to a sedentary setting, lack of physical activity has become more common in adults (Ma, Xiao, and Stafford, 2009). Typically, U.S. adults employed in these sedentary occupations remain deskbound for approximately 11 hours a day (Tudor- Locke et al., 2011). Matthews et al. (2008) also reported that children and adults in the United States spent an average of approximately 55% of their day in a sedentary posture. This prolonging seated posture requires little movement (i.e., minimal physical activity) and is significantly contributing to the current obesity epidemic (Hamilton, Hamilton and Zderic, 2007).

Although the etiology of obesity is complex and the exact causes are still unknown, it is typically narrowed down to three major factors: metabolic factors, diet and physical activity, each influenced by genetic traits (Aronne, Nelson and Lillo, 2009; Weinsier et al., 1998). This study focuses on the lack of physical activity from the perspective of prolonged sedentary behavior. Since prolonged sitting is detrimentally associated with obesity (and other several adverse health outcomes such as cardiovascular disease, Type 2 diabetes, or cancer; Katzmarzyk et al., 2009).

2.2 Workplace physical activity interventions

A sedentary lifestyle entailed with insufficient physical activity has become common in Americans and other industrialized populations (Kruger, Ham, and Kohl III, 2005). This prolonged sedentary behavior has been recognized as a health threat due to it increasing the risks for obesity, type 2 diabetes, coronary heart diseases and other chronic disease (U.S. Department of Health and Human Services, 2000). Since physical activity can improve health and prevent chronic diseases, numerous studies have attempted to promote physical activity by introducing workplace wellness programs or providing workstation alternatives (Dishpan et al., 1998; Osilla et al., 2012).

2.2.1 Workplace wellness programs

A workplace wellness program is a health promotion activity or a entity-based policy designed to improve health outcomes by increasing physical activity at the workplace (Centers for Disease Control and Prevention, 2014). Various studies have been conducted to promote physical activity in the workplace through wellness programs, such as recommending the use of stairs, forming structured exercise programs or providing access to workplace fitness facilities (To et al., 2013).

Teh and Aziz (2002) found that climbing stairs can be a viable exercise activity for additional energy expenditure throughout a workday. They tested over 100 participants and found that the approximate caloric cost of stepping up and down a step was 0.11 and 0.05 kcal, respectively, which met the minimum requirements for cardiorespiratory benefits. They also stated that this has the potential to be a universal workplace physical activity due to staircases being easily accessible. Point-of-decision prompts (i.e., motivational signs; Figure 2.2) near elevators or escalators to promote stair use have also been used to enhance this encouragement (Soler et al., 2010).

Figure 2.2. Sample point-of-decision prompt to promote stair use (Adapted from Soler et al., 2010)

Faghri et al. (2008) introduced a 10-week pedometer walking program combined with internet-based motivational messages to 206 participants, which were employees of two worksites, to increase physical activity during a workday. Employees were encouraged to maximize the number of steps in a workday by taking the stairs, parking their cars further or using break times to walk. Results indicated that there was significant increase in the number of steps per week and was inferred that the walking program can be effective at increasing physical activity in sedentary employees, which might help them maintain or even lose their weight.

Work-related musculoskeletal disorders also occur in sedentary workers because of prolonged repetitive muscle activity only in particular regions and almost no activity in others (Hägg, 1991). Henning et al. (1997) investigated the effects of frequent short breaks during continuous computer tasks and concluded that workers can benefit with respect to productivity and well-being. Galinsky et al. (2007) found that supplementary breaks and stretching exercises can be beneficial in terms of alleviating discomfort and eyestrain for data entry operators. Samani et al. (2009) have used electromyography in the trapezius muscle to examine the activity during computer work. They found that active breaks, where employees perform stretching or strength exercises, can have functional implications with respect to work-related musculoskeletal disorders.

2.2.2 Workstation alternatives

Modifications have been made to traditional workstations (i.e., a seated office chair and desk) to promote physical activity and also reduce sedentary behavior in the workplace. These changes include using a stability ball chair instead of a traditional office chair, replacing the desk to a standing or sit-stand desk, replacing both chair and desk to a treadmill or to a cycling device (Neuhaus et al., 2014). Studies have shown that the energy expenditure of these workstation alternatives can range from approximately 1 kcal/min to 4 kcal/min (Figure 2.3; Tudor-Locke et al., 2013).

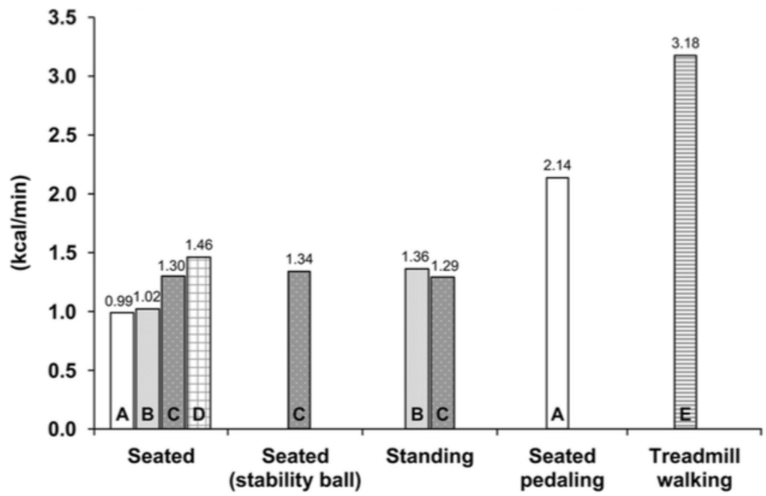


Figure 2.3. Energy expenditure for different workstation alternatives: A - Carr et al. (2014); B - Reiff et al. (2012); C - Speck and Schmitz (2011); D - Swartz et al. (2011); E - Levine and Miller (2007). (Adapted from Tudor-Locke et al., 2013)

Beers et al. (2008) compared heart rate and energy expenditure for three working conditions: (1) sitting on an office chair, (2) sitting on a therapy ball, and (3) standing. To test these conditions, they recruited 24 clerical workers (12 females and 12 males) that were sedentary for at least 4 hours throughout an 8 hour workday. The participants were required to complete a typing task and rank their comfort, fatigue and preference of each working condition and were also asked to perform an additional 20 minutes of clerical work in their preferred working condition. Results showed that sitting on a therapy ball (Figure 2.4) or standing increased energy expenditure by approximately 4.0 kcal/h compared to sitting in an office chair. The participants also liked sitting on a therapy ball as much as sitting in an office chair, but preferred the therapy ball than that of standing. They concluded that these methods can increase passive energy expenditure with minimal behavioral changes.

Figure 2.4. Using an exercise ball chair in the office (Retrieved from "Does an Exercise Ball Chair Actually Give You Any Health Benefits?", 2013)

Alkhajah et al. (2012) compared the time spent sitting, standing and stepping for an intervention group (i.e., those given a sit-stand workstation; Figure 2.5) and a comparison group (i.e., no treatment). Participants were recruited from two academic institutions in Brisbane, Australia with 18 and 14 participants for the intervention and comparison groups, respectively. Participants underwent three assessment phases: baseline, 1-week follow up, and a 3-month follow up. They were equipped with an activPAL3 activity monitor (PAL Technologies Ltd., Glasgow, UK) and completed a self-administered questionnaire. From the three month assessment period, it was found that the introduction of a sit-stand workstation significantly reduced sitting time. The self-reported outcomes showed the many agreed the workstation was easy to use and comfortable, but did have insufficient support for their hands/wrist and space for mouse movement. Despite this, none of the participants indicated that they would return to their original workspace setup.

Figure 2.5. Ergotron WorkFit-S, Single LD Sit-Stand Workstation (Ergotron Inc., St. Paul, MN, USA)

Although the above methodologies have had some impact on reducing sitting time and increasing energy expenditure, they are still workstation alternatives that follow more of a static manner. Other studies have investigated the effects of active workstations that require more dynamic motions, hence increasing the energy expenditure during work. Carr et al. (2013) tested the practicality and feasibility of a portable pedaling exercise machine called the MagneTrainer (3D Innovations LLC., Greeley, CO, USA; Figure 2.6). They studied 40 middle-aged participants, primarily female, working in sedentary environments and divided them into an intervention and controlled group. The intervention group received the MagneTrainer, a real-time activity tracking software, a pedometer, and an internet website based intervention program on reducing sedentary time for 12 weeks (Figure 2.6). The control group, on the other hand, maintained their regular behaviors for that same period. Results indicated that the intervention group pedaled approximately 31 minutes per day, reduced daily sedentary time by roughly an hour a day, and the majority of the participants frequently checked the internet based intervention program. The authors claim that the compliance with the internet based invention program was high, but the pedaling device was moderate. However, considering the relatively low cost for the device, software, pedometer and website access (≈$180) these findings can be promising.

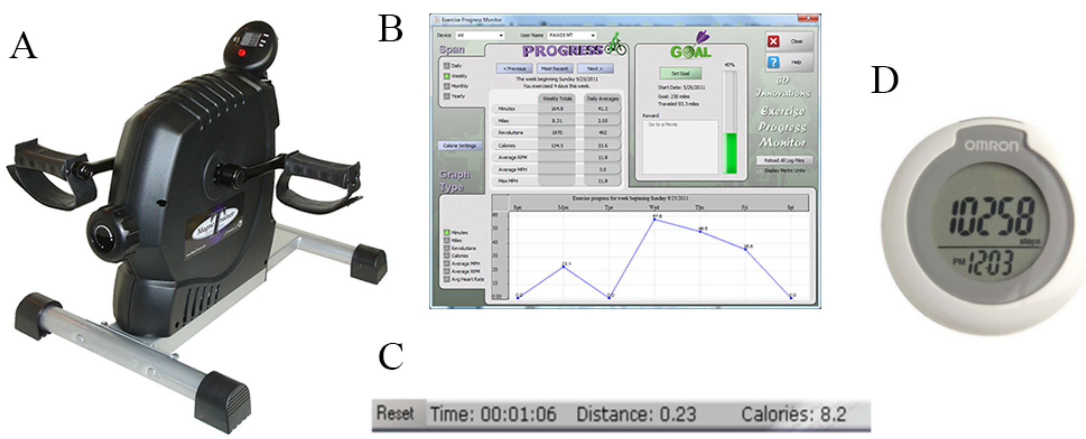


Figure 2.6. (A) MagneTrainer; (B) Real-time activity tracking software; (C) MagneTrainer monitor feedback; (D) Pedometer. (3D Innovations LLC., Greeley, CO, USA; Omron, Kyoto, Japan)

Levine and Miller (2007) experimented the use of a vertical workstation along with a treadmill at the workplace and compared the effects to that of a traditional seated workstation (Figure 2.7). They recruited 15 sedentary individuals (14 female and 1 male) with obesity and measured the energy expenditure for three conditions: at rest, seated in an office chair, and walking at a self-selected speed on the treadmill workstation. The mean energy expenditure for the seated condition was approximately 72 kcal/h (σ: 10), whereas the walking at a pace of 1.1 mph (σ: 0.4) was 191 kcal/h (σ:29). Results indicated that increase in energy expenditure for the treadmill workstation over the deskbound condition was 119 kcal/h (σ: 25) and concluded that energy expenditure could increase by approximately 100 kcal/h if the sitting was replaced by walking-and-working. The authors stated that if obese people replaced the seated condition to a walking-and-working setting a weight loss of 20-30kg per year could occur (assuming all other conditions remained constant).

Figure 2.7. Vertical workstation and in use with the treadmill (Adapted from Levine and Miller, 2007; "Lose Weight While You Work", 2008)

Straker et al. (2009) observed the effects of two active workstation designs, a treadmill and a cycle ergometer, on three different computer tests: typing, mouse-pointing, and a combined task (Figure 2.8). Thirty office workers were recruited and performed the standardized computer tasks in six different conditions: sitting, standing, walking at 1.6 km/h, walking at 3.2 km/h, cycling at 5 watts and cycling at 30 watts. Results indicated that the performance on mouse related tasks were affected more for both active workstations and the participants had lower performance on the tests when using the treadmill. The authors concluded that this can be related to the biomechanical and cognitive processes occurring simultaneously.

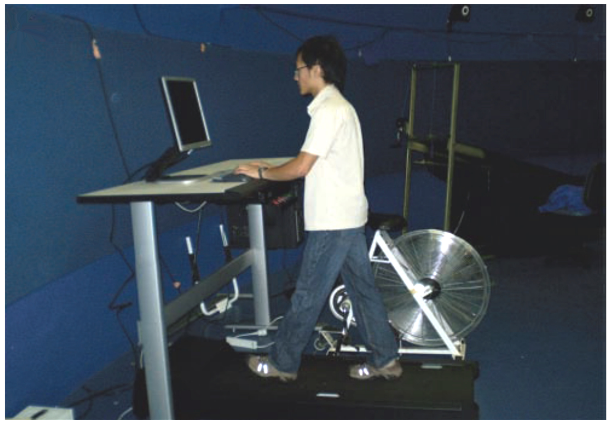


Figure 2.8. Walking workstation and the cycle ergometer (Adapted from Straker et al., 2009)

Workstation alternatives have the potential to directly reduce sedentary time and increase energy expenditure. However, adapting these methodologies have tradeoffs between energy expenditure and work performance. Static workstations enable workers to add a slight more to energy expenditure without sacrificing too much performance. While active workstations increase the energy expenditure to a noticeable level that can prevent weight gain or even lose weight, but might hinder the work performance due to these being more of a dual task (Beurskens and Bock, 2012). Further studies are needed to find methodologies that would maximize energy expenditure but have minimal effect on work performance.

2.3 Anthropometry

Anthropometry refers to the measurements of human body shape, size, strength, mobility and flexibility and working capacity (Pheasant and Haslegrave, 2005). Originally, it was used to identify and understand the physical variation in the human body and to investigate the correlation between physical and psychological traits (Hrdlička, 1920). Nowadays, anthropometry plays an important role in creating user-centered designs for industries such as automotive, clothing, electronics, architecture and furniture (Oh and Radwin, 1993; Reed and Flanagan, 2000). In this context, anthropometric measurements are typically gathered, formed into a collection of data, and statistically analyzed to identify the distribution of certain body segments to optimize the product for the target population (Garneau and Parkinson, 2009). However, it is critical to acknowledge the importance of regularly updating these anthropometric data collections since changes in lifestyles, nutrition, and ethnic composition of populations can eventually lead to changes in the distribution of body dimensions (Fryar, Gu and Ogden, 2012).

2.3.1 Anthropometric databases

One of the most widely used anthropometry databases is the 1988 U.S. Army Anthropometry Survey (ANSUR) due to its rigorous methodology and comprehensive collection of measurements (Gordon et al., 1989). The database consists of over 200 measurements taken from thousands of U.S. Army personnel from different racial groups, which makes this useful when analyzing relationships between body segments. Gordon et al. (1989) also defined standard measurements with explanation and illustrations, which many researchers adapt (Figure. 2.9; Robinette et al., 2002; Untaroiu et al., 2007). Although this data can be quite versatile, as with any anthropometric data, caution must be exercised when using anthropometric measurements extracted from a particular population to make conclusions on a different population (Garneau and Parkinson, 2009).

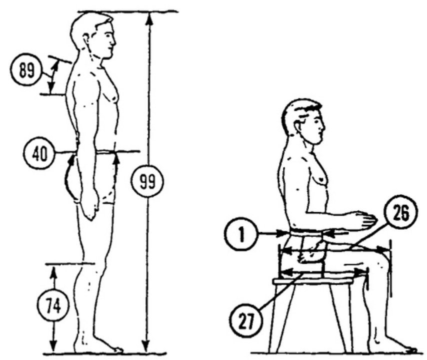


Figure 2.9. Standard measurements for standing and sitting. (Adapted from Gordon et al., 1989)

The United States government has conducted surveys to assess the health and nutritional status of adults and children in the United States since the early 1960s (Centers for Disease Control and Prevention, 2014). The first set of surveys were the National Health Examination Surveys (NHES I, II and III) that were conducted from 1960 to 1970 and the second were the National Health and Nutrition Examination Survey (NHANES I, II and III) that were conducted from 1971 to 1994 (Ogden et al., 2004). Beginning in 1999, the NHANES became a continuous survey and started releasing in 2-year groupings. Even though the primary purpose of these surveys were to evaluate the current health and nutritional status of U.S. population they also included overall human body measurements (e.g., stature and weight) and therefore have been used in various studies that require anthropometric data (Parkinson and Reed, 2010).

Anthropometric surveys have typically served as a means of investigating the summary statistics (e.g., mean, standard deviations and percentiles) for a population. However, the Civilian American and European Surface Anthropometry Resource (CAESAR) data consortium was the first anthropometric survey to be conducted using 3-D scanned images of civilians for engineering application purposes (Robinette et al, 2002). CAESAR was conducted in three regions North America, The Netherlands and Italy and approximately measured 4,400 subjects which included anthropometric data (e.g., stature, weight), demographic data (e.g., income) and 3-D full body scanned images.

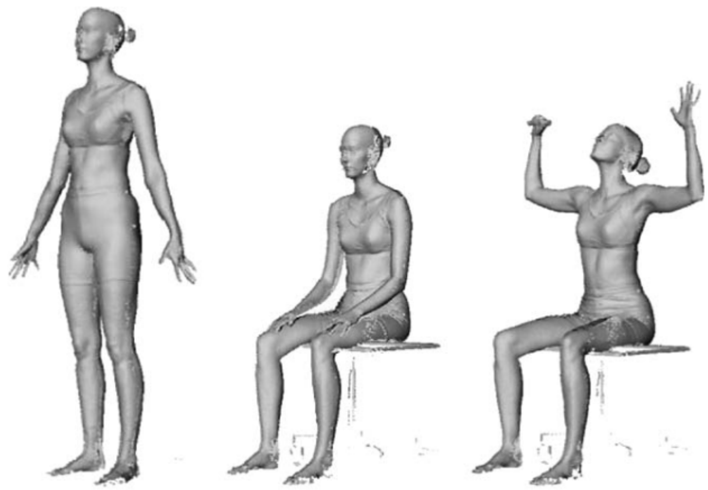


Figure 2.10. Scanned images of standing, seated (comfortable) and seated (coverage). (Adapted from Robinette et al., 2002)

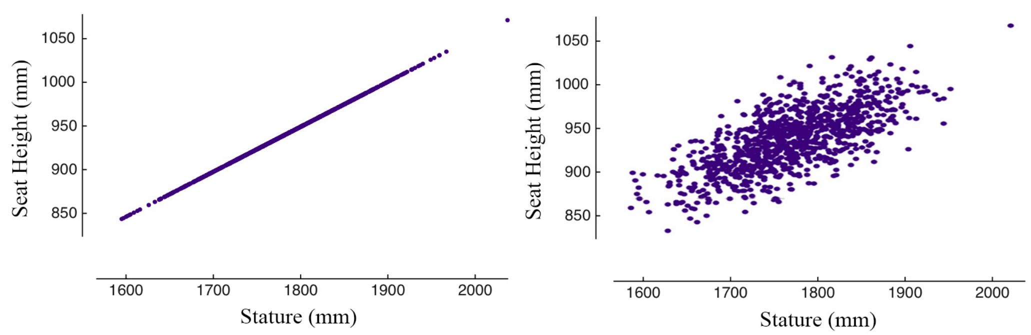
2.3.2 Anthropometric measurements when designing artifacts

In the design of artifacts interacting with human users, the understanding of body dimensions and capabilities of the target population is critical in terms of maximizing fit, safety, and performance (HFES 300 Committee, 2004). Body measures have been used in various product design processes such as workstation designs, bicycle handle designs, aircraft designs and etc. (Das and Sengupta, 1996; Chang et al., 2010; Joslin, 2014).

One of the early studies in anthropometry was analyzing the mechanism of limb joints and determining the space requirements of a seated operator (Dempster, 1955). Dempster (1955) investigated the structure of the limbs joints and the range and type of their motions by cadaver dismemberment methodologies and supporting these findings with living subjects. These findings were applied to two types of manikin designs: (1) a three-dimensional manikin emphasizing on the joints and links of the upper and lower limbs and (2) a two-dimensional (sagittal-plane) manikin created by using drafting board. These manikin designs allowed duplicating the dimensions and movements of an average individual which helped determine the required work space with respect to a seated position. Dempster (1995) also found the distribution of body mass and the center of gravity for certain body segments.

Das and Sengupta (1996) explained the procedure for determining the dimensions and layout of a single-user workstation and, as an example, applying this methodology to the design process of a supermarket check stand workstation for females. Relevant anthropometric measures with respect to reach (e.g., arm length, shoulder height and maximum reach) and lateral clearance (e.g., hip breadth and elbow to elbow) were obtained to determine adequate posture, work height, work area, clearance and visual requirements. Scaled drawings of the workstation and relevant body segments were sketched to determine space availability and the boundary limits. Last, the importance of creating a prototype of the workstation and testing with representative subjects to increase the usability was emphasized.

Although the spatial dimensions of the target user population are typically employed when designing artifacts that interact with the human user, sometimes it is not sufficient enough to satisfy the designated user. For example, two drivers with identical body dimensions might adjust their seats to different positions. Garneau and Parkinson (2009) discussed that this is due to preference in users actually having two components: the anthropometrics measurements and the remaining variability. They stated that if both of these components were quantified, the accuracy of the prediction model could increase and would allow designers to create products that are safer, cost effective and accessible to more people. In an effort to accomplish this, they introduced the hybrid with residual variance model and applied this to determine the seat height adjustability range of an upright exercise cycle. The hybrid with residual variance model (Figure 2.11) is a regression model with a stochastic component added (i.e., based on the residual variance of the regression model) that predicts the user preference (considering both the body size and user variability).



Preferred Seat Height $= 0.515 \cdot$Stature$+22.1$
(A)

Preferred Seat Height $= 0.515 \cdot$Stature$+22.1 + N(0, 35.2)$
(B)

Figure 2.11. Preferred seat height predicted using (A) a regression model and (B) the hybrid with residual variance model. (Modified from Garneau and Parkinson, 2009)

Mahoney, Kurczewski and Froede (2015) also incorporated both anthropometric and preference distributions in the design of group interaction workstations, which offers personal work area for each user and a shared space for adjacent users. First, a virtual population was created based on the demographics of the target population (i.e., college-aged students in this case study).

Next, an extended-reach zone was defined for each member and was randomly paired with other members using a Monte Carlo simulation to test for accommodation. A pair of members were defined as accommodated if their normal-reach zones did not overlap and the extended-reach zones did overlap. An example of accommodating pairs for a polygonal workstation is shown in Figure 2.12 with each members' normal- and extended-reach zones.

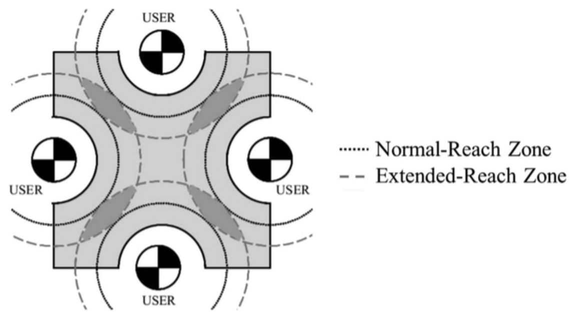


Figure 2.12. Accommodating pairs in a polygonal group workstation (Modified from Mahoney, Kurczewski and Froede, 2015)

2.4 Office Work Performance Measures

The Occupational Outlook Handbook from the Bureau of Labor Statistics defines the duties of general office clerks as the following (Bureau of Labor Statistics, 2014):

- Telephone - Answering, taking messages, and transferring calls
- Mail - Sort and deliver incoming and send outgoing mail.
- Appointments - Schedule appointments and receive customers or visitors
- Announcements - Provide general information internally or externally
- Memo - Type, format or edit memos or reports
- Documentation - Copy, file and maintain paper/electronic documents
- Travel - Prepare or process vouchers
- Information - Obtain information, send correspondence, or perform data entry

Most office tasks are not focused to a single task, but rather require performing tasks that often change daily. The following tasks are used to evaluate the performance of typical office work: Typing, reading comprehension, and logical reasoning.

2.4.1 Typing

Taking messages, scheduling appointments, preparing reports, and performing data entry all require the skill of typing on a computer. Typing is one of the fundamental skills that is required in most, if not all office tasks and are functioned by central and peripheral control mechanisms (Gentner, 1983). Typing tasks have been used to see if particular stressors or factors affected the worker's typing performance.

Salthouse (1984) investigated the effects of age and skill in typing by administering several tasks such as copying a document, typing sentences and then backwards, choice reaction time tasks and tapping tasks. Results indicated that typing skill was related to the temporal consistency of performing similar keystrokes, the efficiency of overlapping successive keystrokes, the speed of hand tapping in an alternate manner, and the number of characters for the next immediate word/phrase that needs to be typed to maintain a normal typing pace. It was also concluded that the tapping rate and the choice reaction time tests were slower for older typists, but were not slower in typing speed.

Evans and Johnson (2000) examined the effect of low-intensity noise in typing performance (including the main objectives such as urinary epinephrine, norepinephrine, and cortisol levels). Forty female clerical workers were recruited and were randomly assigned to either a control group or to a 3-hour exposure to low-intensity noise designed to simulate open-office noise levels. Although the participants in the office-noise condition perceived the environment as significantly noisier, the typing performance (i.e., error rate) nor the speed was affected. Chronic exposure to aircraft noise had no significant effect on reading comprehension for the eight schools.

2.4.2 Reading comprehension

Haines et al. (2001) investigated the effects of chronic aircraft noise exposure on approximately 300 students from seven elementary schools around London Heathrow airport (one school was excluded due to procedural error). Four schools were in a high-aircraft noise-impact urban area (16 hour outdoor $\leq$66 dBA) while three schools were in a low-aircraft noise-impact urban area (16 hour outdoor $\leq$57 dBA). The stress responses, mental health and cognitive performance were measured. One method of assessing cognitive performance was to evaluate the reading comprehension scores, using the Suffolk Reading Scale Level 2 (Hagley, 1987). Children in the four high noise exposed schools had poorer reading comprehension that this in the three low noise schools.

Wang and Boubekri (2010) assessed how the distance between a person and sunlight in a room is related to behavioral responses and cognitive performance (e.g., reading comprehension). One hundred subjects participated in a controlled experiment in a fairly small work setting. It was found that people were not always aware of the fact that environmental factors can influence their behaviors. Another finding was that people were generally attracted to sunlight and outdoor views, but did not necessarily have better performance in these areas.

2.4.3 Logical reasoning

One of the essential skills that employers want most in their workers is logical reasoning (Carnevale, 1990). Logical reasoning skills are primarily linked with fluid intelligence, which is the ability to analyze and solve novel problems, independent of acquired knowledge (Cattell, 1971). The Baddeley Reasoning Test (also known as Baddeley's Grammatical Reasoning Test or Baddeley's Logical Reasoning Test) is a 64-item test that can be administered in three minutes and measure this fluid intelligence through logical reasoning (Baddeley, 1968). The test involves noting whether a statement is true or false with scores ranging from 0 to 64 (Figure 2.13).

Examples	True	False
1. A follows B—BA	√	
2. B precedes A—AB		√
3. A is followed by B—AB		
4. B is not followed by A—BA		
5. B is preceded by A—BA		
6. A does not precede B—BA		

Figure 2.13. Six examples (out of 64) of the Baddeley Reasoning Test (Adapted from Baddeley, 1968)

Baddeley (1968) examined test-retest reliability on 18 subjects and showed a mean correlation of .8 between performance on two successive days. Validity resulted with a correlation of .59 on 29 subjects with respect to the performance on the British Army verbal intelligence test. Based on the 29 subjects, the practice effect was reasonably small after the first trial with average scores of 32.9, 37.5, 39.1, 39.6, and 41.9. The Baddeley Reasoning Test has been extensively used in many studies due to its reliability and sensitivity to various stress factors (Furnham and McClelland, 2010).

Sheehy, Kamon and Kiser (1982) examined the effects of different levels of carbon dioxide inhalation on psychomotor and mental performance during a treadmill exercise and its recovery period. The Baddeley Reasoning Test was administered to measure the participants' reasoning skill after running 10 minutes on a treadmill at 80% of aerobic capacity. They recorded the number of statements completed, the number of errors occurred, and the average response time per question. However, no significant difference were found for the number of statements completed or errors occurred in the different CO_2 inhalation conditions. Vercruyssen, Kamon and Hancock (2007) also looked at this effect, but with different carbon dioxide levels and treadmill exercise for 15 minutes at 70% maximal aerobic capacity. They also found no significant difference in the logical reasoning performance with respect to the level of carbon dioxide exposure.

The effect of moderate cold stress (10°C for 4 hours) on cognitive function and mood was investigated in 15 male volunteers after an intense U.S. Army Ranger training (Lieberman, Castellani and Young, 2009). The volunteers were tested on three separate points: immediately after training, 2 days after training when they had partially recovered, and 108 days later after full recovery. The Baddeley Reasoning Test was facilitated to test the volunteers' grammatical reasoning skills and showed improvement as time passed ($p < .05$). Other tests such as visual vigilance, four-choice reaction time, pattern recognition, symbol-digit substitution and word list learning also showed improvement as time passed (all $p < .05$).

Chapter 3

Utilizing anthropometric data to improve the usability of desk bikes, and influence of desk bikes on reading and typing performance[1]

3.1 Abstract

This study investigated the feasibility of using a desk bike in an office setting. Workstation measurements were introduced to accommodate 95% of the general U.S. population in using desk bikes. Reading and typing performances were compared at three different cycling conditions (no cycling, 10 and 25 W). Thirty healthy individuals (15 female and 15 male; Age mean: 23.1, σ: 4.19) were recruited based on 5/50/95th percentile stature. Participants were required to select preferred workstation settings and perform reading and typing tasks while pedaling. According to anthropometric measurements and variability from user preference, recommended adjustable ranges of workstation settings for the general U.S. population were derived. Repeated measures ANOVA showed that pedaling had no significant effect on reading comprehension ($p > .05$), but had significant effect on typing performance ($p < .001$). A preferred level of cycling intensity was determined (mean 17.3 W, σ: 3.69).

3.2 Introduction

Excess body weight is considered a risk factor for mortality and morbidity from diabetes, heart diseases and cancer (Flegal et al., 2013; Wang et al., 2011). Despite the substantial efforts from healthcare practitioners, the weight-gain epidemic continues to accelerate (Finkelstein et al., 2012; World Health Organization, 2000). Studies have shown that one of the largest contributors to the weight gain epidemic has been the trend for work environments to require less physical activity in industrialized populations (Hamilton, Hamilton, and Zderic, 2007).

As most working environments in developed and developing countries now require prolonged

[1]Cho, J., Freivalds, A., & Rovniak, L. S. (2017). Utilizing anthropometric data to improve the usability of desk bikes, and influence of desk bikes on reading and typing performance. Applied Ergonomics, 60, 128-135.

seated postures, physical inactivity has become more common in adults (Ma, Xiao, and Stafford, 2009). Tudor-Locke et al. (2011) reported that workers employed in sedentary occupations (≤ 1.5 metabolic equivalent) were sedentary for approximately 11 hours a day. In addition, more than one third of U.S. adults do not meet recommended physical activity guidelines (Hallal et al., 2012). Healthcare researchers have been emphasizing the importance of physical activity and suggest that even low intensity exercise may have beneficial health outcomes (Neuhaus et. al., 2014; Tudor-Locke et al., 2014).

Despite the known health benefits of regular exercise, in terms of practicality, it is difficult for most adults to invest additional time in exercise. Researchers have also found that regardless of physical activity, prolonged sedentary behavior can be independently associated with poor health and mortality (Parry and Straker 2013; Biswas et al., 2015). Therefore, introducing health promotion interventions to the workplace can be ideal in reducing prolonged sitting time (Carnethon et al., 2009; Van Uffelen et al., 2010).

Recent experimental studies have found that replacing excessive sedentary behavior with light physical activity may be beneficial to one's health (Levine and Miller, 2007; Dunstan et al., 2012). Carr et al. (2013) tested the practicality and feasibility of a portable pedaling exercise on middle-aged female participants working in sedentary environments. Results indicated that approximately an hour of daily sedentary time was replaced with pedaling at a moderate speed. Similarly, Rovniak et al. (2014) found that compact pedaling devices could help expend approximately 90 extra kilocalories per hour above sedentary sitting.

Although studies have been conducted to investigate the effects of simultaneous pedaling on work productivity (Elmer and Martin, 2014; Torbeyns et al., 2015), research on the ergonomic factors that may impede or facilitate use of these pedaling devices is limited. In the design of artifacts interacting with human users, the understanding of body dimensions and capabilities of the target population is critical in terms of maximizing fit, safety, and performance (HFES 300 Committee, 2004). Body measures have been used in various product design processes such as workstation designs, bicycle seat designs, and aircraft designs (Das and Sengupta, 1996; Garneau and Parkinson, 2011; Joslin, 2014). The concept of incorporating anthropometric measures should not be an exception for using exercise equipment in the office workplace.

The primary purpose of this study was to evaluate ergonomic factors associated with of using a desk bike in the office workplace by investigating the preferred office workstation settings (e.g., desk height and depth) with respect to anthropometric measurements and user preferences. In the authors' earlier research, the preferred workstation settings were established based on twelve undergraduate students (Cho et al., 2014). The current study is an outgrowth to that by broadening the sample to include the general U.S. adult population and increasing the sample size. Additional goals included: (a) Extending the limited literature on measuring cognitive performance when using a desk bike in the office by testing reading comprehension and typing tasks and (b) Finding the preferred exercise intensity on a desk bike while working on these tasks. The results from this study can be used to help understand the implications for and improve the usability of compact under-the-desk bikes at workstations and eventually improve health, safety and well-being.

3.3 Methods

3.3.1 Participants

Thirty participants (15 female) were recruited from The Pennsylvania State University and Centre County of Pennsylvania, U.S. All participants were healthy with an average age of 23.1 ($\sigma = 4.19$). Participants were recruited based on 5th, 50th and 95th percentile stature according to NHANES 2007-2010 (each with 5 participants for each gender; Fryar et al., 2012). All participants reported some experience in using a computer mouse and keyboard. The study was approved by the Human Subject Research Institutional Review Board at The Pennsylvania State University. All participants read and signed the informed consent prior to participation in the study and received compensation ($14 for 2 hours).

3.3.2 Anthropometric Measurements

The nine anthropometric measurements in this study adopted the standards from the Anthropometric Survey of U.S. Army Personnel (Gordon et al., 1989; Figure 3.1).

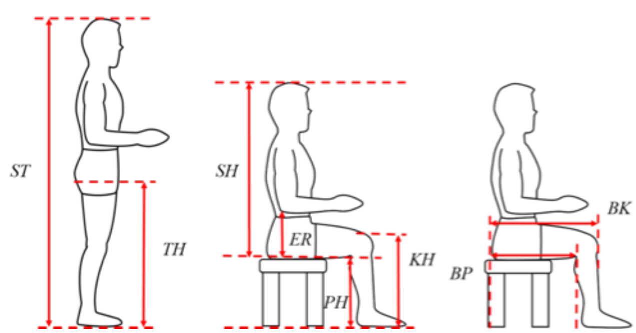


Figure 3.1. Representation of the anthropometric measures

- Stature (ST): The vertical distance between the floor and the top of the head.
- Trochanterion height (TH): The vertical distance between the floor and the trochanterion (upper side of the thigh).

- Sitting height (SH): The vertical distance between the sitting surface and the top of the head.
- Elbow rest height (ER): The vertical distance from the sitting surface and the olecranon (bottom of the tip of the elbow).
- Popliteal height (PH): The vertical distance from the footrest and the posterior surface of the knee.
- Knee height (KH): The vertical distance from the footrest surface and the suprapatella (top of the knee).
- Buttock-popliteal (BP): The horizontal distance from the posterior point of the buttock to the popliteal fossa (back of the knee).
- Buttock-knee (BK): The horizontal distance from the posterior point of the buttock and the anterior point of the knee.
- Weight (WT): Body mass measured to the nearest 0.1 kg on a digital scale.

The measurements were collected using an anthropometer (Model 101, GPM, Switzerland) on the right side of participants (with the exception of ST and WT). For ST and TH, participants were standing erect looking straight ahead without shoes. Other measures were taken with participants seated on a horizontal surface, elbows and knees flexed 90 degrees (verified with a goniometer), and feet set parallel to thighs on a height adjustable flat horizontal surface (footrest) in a relaxed and upright posture. The weight factor was evaluated by calculating the Body Mass Index (BMI) based on ST and WT.

3.3.3 Experimental Setup

An office workstation with a standard computer (Windows 7) and a 24 inch monitor (16:9 ratio and resolution of 1920 x 1080 at 60Hz) was set up in a controlled lab (54.1 m^3; 3.6 x 4.7 x 3.2 m) with the temperature set to 23.3°C (Figure 3.2). The simulated workstation consisted of an office chair (Aeron Chair, Herman Miller, Zeeland, MI, USA) and a customized workstation desk (two adjustable industrial workstations connected with a flat plywood table top; 2.2 x 125 x 70 cm).

Figure 3.2. The simulated office workstation in the laboratory

The desk bike DeskCycle (3D Innovations LLC., Greeley, CO, USA; Figure 3.3) was used in this study and was set to the intensity level of 2. Participants were required to pedal at 10 and 25 W, which is approximately 45 and 90 RPM, respectively.

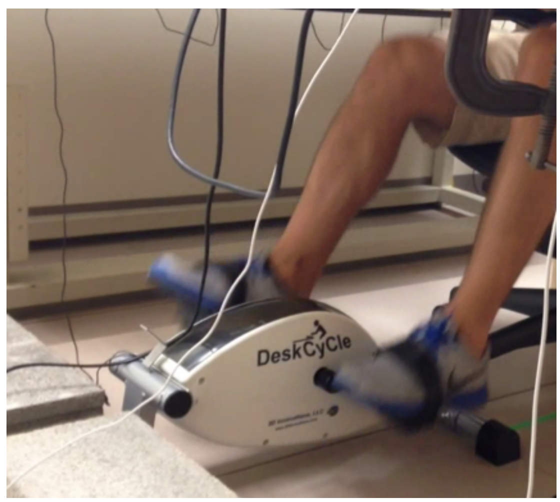


Figure 3.3. Participant pedaling the DeskCycle in the lab setup

Participants were able to adjust the seat height pneumatically, while the desk height and depth were adjusted by the facilitators according to participants' request. Figure 3.4 shows the dimensions of the workstation that were measured.

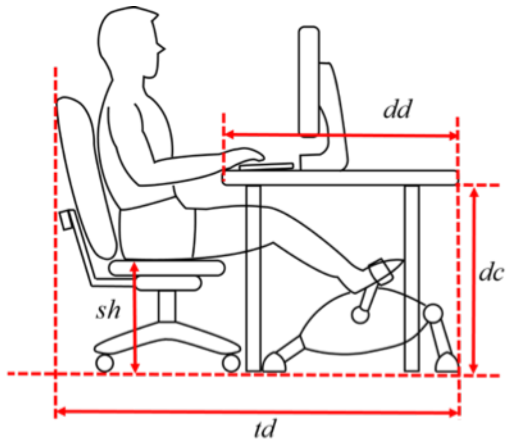


Figure 3.4. Representation of the workstation measures

- Seat height (*sh*): The vertical distance between the floor and the lowest point of the buttock in contact with the seat.
- Desk clearance (*dc*): The vertical distance between the floor and the lowest point of the table top.
- Desk depth (*dd*): The horizontal distance between the back of the DeskCycle to the front edge of the table top.
- Required minimum total distance (*td*): The horizontal distance between the back of the DeskCycle to the back of the chair.

3.3.4 Reading Comprehension and Typing Task Outcomes

Reading accuracy and times were measured through reading comprehension problems. Participants were required to read a passage (approximately 280 words) and answer five multiple-choice questions (each with four choices) on the computer. Eight passages were prepared with all written at the average U.S. adult reading level (Kirsch, 1993).

Typing speed (adjusted words-per-minute; AWPM) was measured using TypingMaster Pro Lite (TypingMaster Inc., Helsinki, Finland). Participants were required to copy a passage presented on the screen for two minutes as quickly and as accurately as possible. To ensure that the difficulty is consistent across the typing passages, eight passages with a syllabic intensity of approximately 1.3 was prepared (Straker et al., 2009).

3.3.5 Subjective Readings

The intensity of cycling condition was evaluated subjectively with the Borg Rating of Perceived Exertion (Borg RPE; Borg 1982). Two additional questions were asked at the end of the study to assess the desk bike:

1. Do you think the DeskCycle would be possible to use at your desk?
2. How did you feel about completing the office tasks while pedaling the DeskCycle?

3.3.6 Procedure

An overview of the study was provided and all participants provided written informed consent. The nine anthropometric measures were obtained three times and the median score was computed. An introduction to the simulated office workstation and DeskCycle was provided. Participants were requested to adjust the desk and seat to their preference until they felt comfortable and were instructed on how to properly use the DeskCycle. The participants were guided through the procedure of completing the reading comprehension and typing tasks to eliminate any learning effects. The reading comprehension task was practiced for one passage and the typing task was practiced for one minute. After the practice session, the participants stepped aside and the workstation was set to a random setting. Last, the participants were guided through the experimental procedure that consisted of four cycling levels: no cycling (seated), low level cycling (10 W), high level cycling (25 W), and preferred level cycling. Each condition had two replicates with a total of eight sessions. The two preferred level conditions were assigned to the first and last sessions and the six remaining sessions were in between (Figure 3.5). To randomize the six sessions, random 6×6 Latin Squares were generated and each subject was assigned to each row. An example of one trial could be, preferred level cycling (practice) – no cycling – low level cycling – no cycling – high level cycling – high level cycling – low level cycling – preferred level cycling. The study took approximately two hours for each participant.

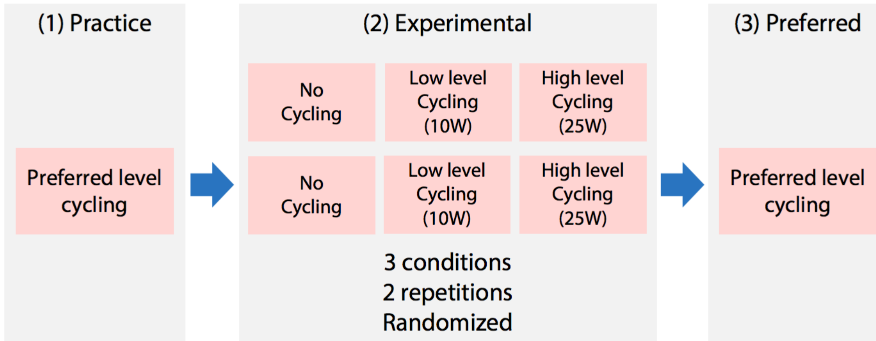


Figure 3.5. Flow diagram of the overall procedure

Each session (red block) in Figure 3.5 took approximately 10 minutes and is described in Figure 3.6. First, the participants adjusted the workstation to their preferred settings. Next, they started pedaling and steadily increased to the assigned intensity and reached steady state within 2 minutes (excluded for seated condition). Then they completed the reading and typing task while pedaling. When participants started to lose pace an auditory signal (a small beep) was presented to bring the pace back to the designated level by briefly checking the monitoring device. For the preferred level intensity, the average wattage was recorded at every minute. After each session, participants rated perceived exertion (Borg RPE) followed by a two-minute rest to reduce the possibility of any fatigue effect. The settings on the workstation (e.g., desk height and depth) were set back to random settings and participants were prompted to readjust each component before the next 10-minute session.

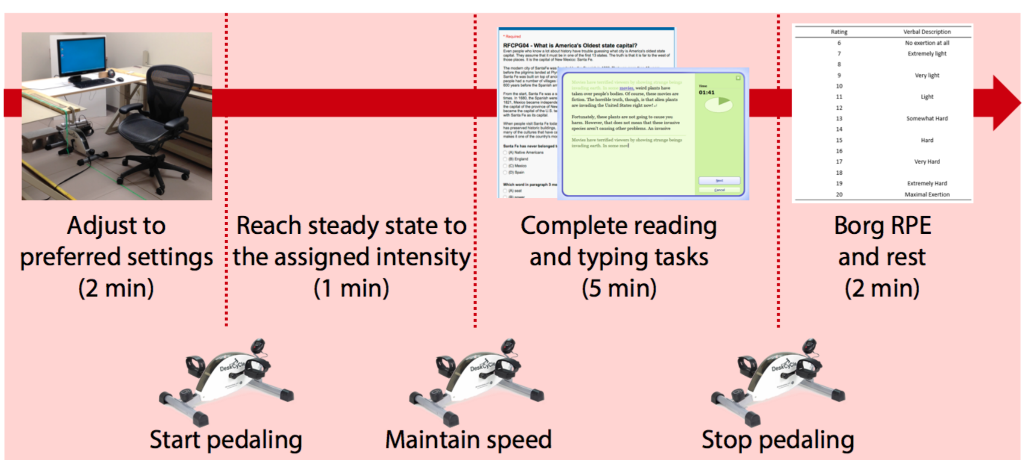


Figure 3.6. Procedure of each condition in Figure 3.5

3.3.7 Data Analysis

Statistical analysis of the data was performed with SPSS software version 22 (SPSS Inc., Chicago, IL, USA) and Minitab 17 (Minitab Inc., State College, PA, USA). In all analyses, $p-$values less than 0.05 were considered statistically significant.

3.4 Results

3.4.1 Anthropometry and Preference for Workstation Settings

The summaries of the data collected from the sample are shown in Tables 3.1 and 3.2.

Table 3.1. Summary of Age and Anthropometric Measurements

	Age	$ST\ (mm)$	$BMI\ (kg/m^2)$	$KH\ (mm)$	$PH\ (mm)$
Mean	23.1	1688.23	23.92	513.83	417.07
σ	4.19	115.24	4.06	42.3	35.48

Table 3.2. Summary of Preferred Workstation Settings (mm)

	sh	dc	dd	td
Mean	429.91	760.84	719.25	1343.22
σ	21.33	40.07	47.46	61.25

Regression models of preferred workstation settings (3.1) - (3.4) were determined by best-subset regression analyses and the addition of stochastic variables (normal distribution with a mean of zero and a standard deviation equal to the root mean squared error of each regression model). The stochastic variables were added to ensure that the variability for each workstation setting can be explained by both anthropometric measurements and user preferences. For further details, refer to Garneau & Parkinson (2011). The four regression models (3.1) - (3.4) have an R^2 value of 0.47, 0.8, 0.44, and 0.66, respectively (all $p < .001$). ANCOVA showed no significant difference between males and females.

$$sh = 0.413 \times PH + 257.8 + N(0, 15.79) \tag{3.1}$$

$$dc = 1.009 \times PH + 340 + N(0, 18.32) \tag{3.2}$$

$$dd = 0.386 \times TH + 378.3 + N(0, 36.31) \tag{3.3}$$

$$td = 0.432 \times ST + 614.3 + N(0, 36.35) \tag{3.4}$$

PH, TH, and ST measures of the general U.S. adult population were required to calculate the preferred office workstation settings. ST was obtained from the NHANES 2007-2010 anthropometric database (Centers for Disease Control and Prevention, 2014). However, NHANES 2007-2010 did not record PH and TH values for their sample. Therefore, PH and TH were obtained by first finding the relations between (i) PH and ST and (ii) TH and ST for both genders from the U.S. Army data (Gordon et al., 1989). The regression models (3.5) - (3.8) have an value of 0.74, 0.78, 0.69, and 0.77, respectively (all $p < .001$). The regression models include residual variance since people with the same stature may contain varying length in popliteal height (and trochanterion height). The subjects in the U.S. Army database were weighted to match 2010 U.S. Census distributions.

$$PH_m = 0.314 \times ST_m - 118.93 + N(0, 12.54) \tag{3.5}$$

$$TH_m = 0.623 \times ST_m - 169.7 + N(0, 22.23) \tag{3.6}$$

$$PH_f = 0.295 \times ST_f - 95.27 + N(0, 13.16) \tag{3.7}$$

$$TH_f = 0.583 \times ST_f - 96.9 + N(0, 21.61) \tag{3.8}$$

Then, a virtual population of PH and TH were estimated by using the ST of males and females (5647 and 5971, respectively) from the NHANES 2007-2010 data (weights carried out appropriately) into the above proportionality equations (Garneau and Parkinson, 2011).

Finally, preferred workstation settings were estimated by using equations (3.1) - (3.4) with the ST data from NHANES 2007-2010 and the PH and TH from the virtual population. Figure 3.7 shows an example of estimating seat height (sh) using PH, resulting in seat height ranges from 396.23 mm (15.6 inches) to 465.99 mm (18.3 inches) for 2.5th to 97.5th percentile popliteal heights, respectively. Table 3 shows the final results of the recommended adjustable ranges of the workstation settings that would accommodate 95% of the general U.S. population when using the DeskCycle.

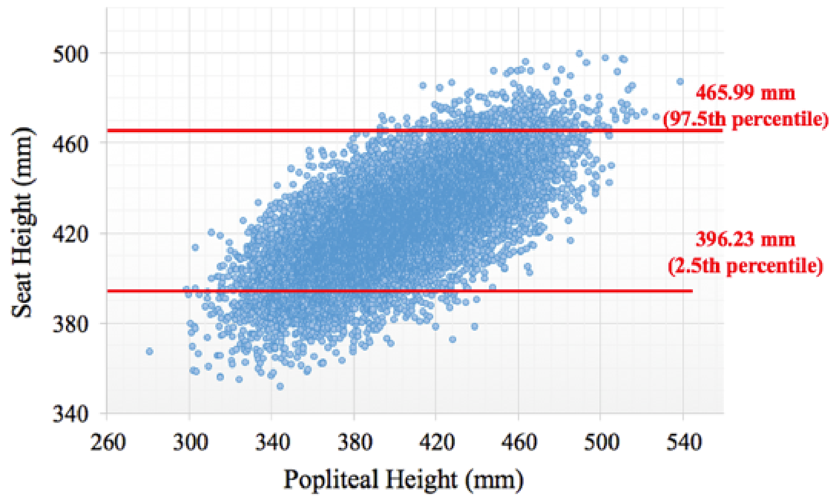


Figure 3.7. Recommended seat height (sh) adjustable range to accommodate 95% of the general U.S. population

Table 3.3. Recommended Adjustable Ranges of Workstation Settings when using the DeskCycle (mm)

	2.5th percentile	97.5th percentile
seat height	396.23 (15.6 inches)	465.99 (18.3 inches)
desk clearance	677.83 (26.7 inches)	813.71 (32 inches)
desk depth	668.75 (26.3 inches)	784.71 (30.9 inches)
required minimum total distance	1272.63 (50.1 inches)	1454.09 (57.2 inches)

3.4.2 Effects of Cycling on Reading Comprehension and Typing

Repeated measures ANOVAs showed that cycling condition had no significant effect on reading comprehension time ($F(1.59, 44.43) = 1.45, p = .246$; Figure 3.8 and 3.9) and accuracy ($F(1.6, 44.82) = .469, p = .586$; Figure 3.10 and 3.11). Because the sphericity assumption was violated for reading time and accuracy, the Greenhouse-Geiser adjustment was used. Data from one participant was discarded for failure to follow task instructions on the reading task.

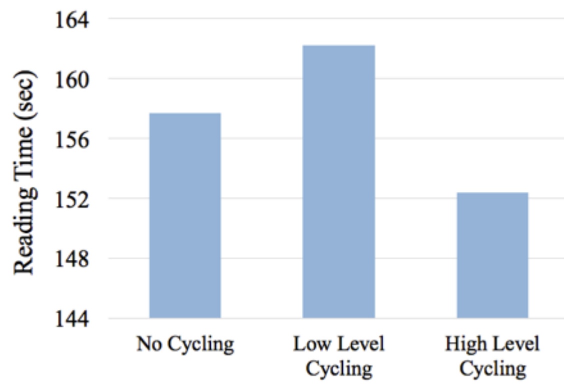


Figure 3.8. Mean reading time (sec) of each cycling condition

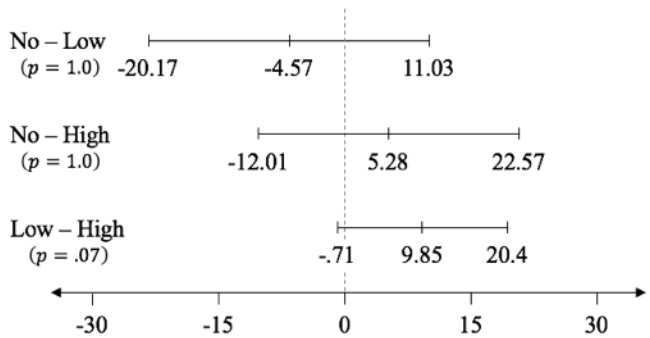


Figure 3.9. Bonferroni corrected 95% confidence intervals for the difference between mean reading times (sec)

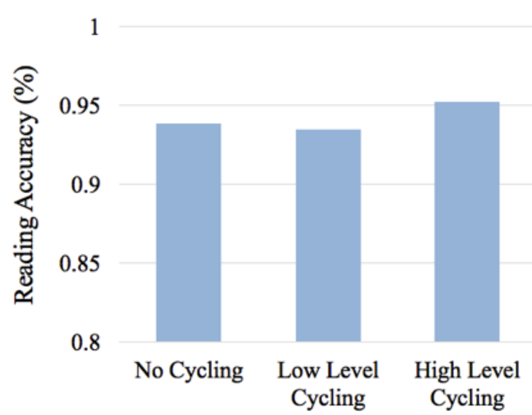


Figure 3.10. Mean reading accuracy (%) of each cycling condition

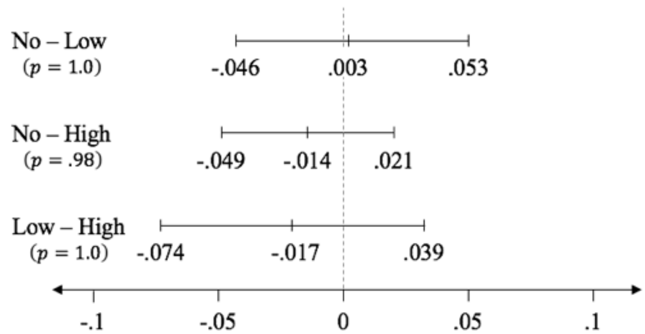


Figure 3.11. Bonferroni corrected 95% confidence intervals for the difference between mean reading accuracies (sec)

Repeated measures ANOVA showed that cycling condition had significant effect on adjusted words-per-minute (AWPM) values ($F(2,58) = 16.17, p < .05$; Figure 3.12). Post hoc analysis with Bonferroni correction showed that typing performances were significantly different across all three cycling conditions (all $p < .05$; Figure 3.13).

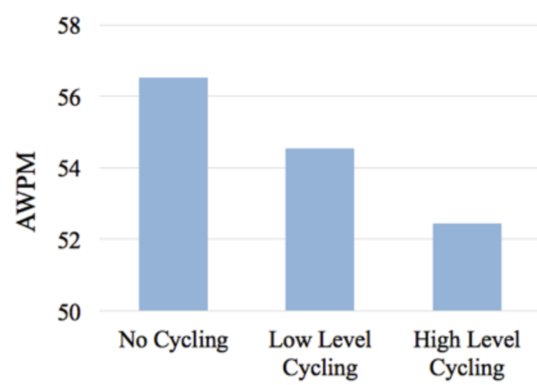


Figure 3.12. Mean typing performance (adjusted words-per-minute; AWPM) of each cycling condition

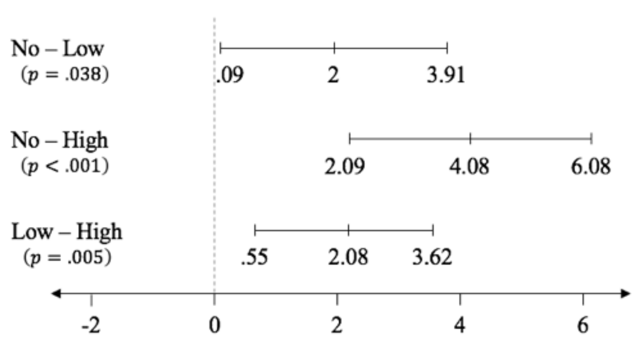


Figure 3.13. Bonferroni corrected 95% confidence intervals for the difference between mean typing

3.4.3 Borg Rating of Perceived Exertion (RPE)

Repeated measures ANOVA showed that cycling condition had significant effect on Borg RPE ($F(2,58) = 131.76, p < .05$; Figure 3.14). Post hoc analysis with Bonferroni correction showed that Borg RPE ratings were significantly different across all three cycling conditions (all $p < .05$; Figure 3.15).

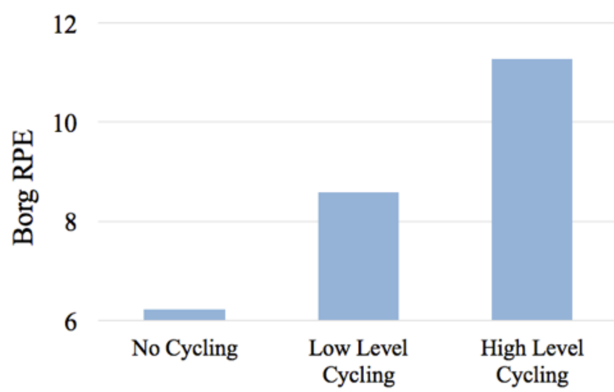


Figure 3.14. Mean Borg RPE of each cycling condition

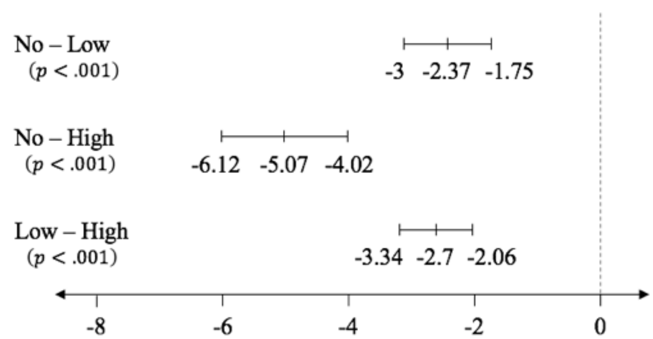


Figure 3.15. Bonferroni corrected 95% confidence intervals for the difference between mean Borg RPE

3.4.4 Preferred level of cycling

During the preferred level session, average speed was recorded every minute. The arithmetic mean, of these recorded times, was computed for each participant. The preferred level had an average of 17.3 W (σ: 3.69), which is approximately 67 RPM.

3.5 Discussion

This study has investigated the ergonomic characteristics associated with using a desk bike (i.e., the DeskCycle for this study) in an office workstation. The results determined: (1) the recommended adjustable ranges of workstation settings when using the DeskCycle for the general U.S. population; (2) that cycling did not have significant effect on reading comprehension (time and accuracy); (3) that cycling had significant impact on typing performance; and (4) that the preferred cycling intensity was 17.3 W (σ: 3.69), on average, when performing the reading comprehension and typing tasks. To our knowledge, this is the first study to investigate the ergonomic features of using a desk bike in a workstation setting, as well as determine preferred cycling speeds during office work tasks.

The required adjustable range of seat height (*sh*), for the general U.S. population to use the DeskCycle was in compliance with the ANSI/HFES 100-2007 (2007) office chair minimum height adjustable range (Table 3.4). However, the preferred desk clearance and depth determined in this study were much greater than the ANSI/HFES 100-2007 recommended guidelines. This was due to the increased range of motion from pedaling beneath the desk.

Table 3.4. Comparison of Adjustable Ranges of Workstation Settings with respect to ANSI/HFES 100-2007 (mm)

	Study Results	ANSI/HFES 100-2007
seat height	396.23 – 465.99 (15.6 – 18.3 inches)	381 – 558.8 (15 – 22 inches)
desk clearance	677.83 – 813.71 (26.7 – 32 inches)	500.38 – 718.8 (19.7 – 28.3 inches)
desk depth	668.75 – 784.71 (26.3 – 30.9 inches)	At least 600 (At least 23.6 inches)

Based on these data, only a small portion of the general U.S. population will be able to use the DeskCycle with standard desks. Assuming we have a standard desk with a clearance of 718.8 mm (max value of ANSI/HFES 100-2007 recommended range), females up to the 25th percentile stature and males shorter than the 5th percentile stature (i.e. approximately 160 cm or 63 inches) will be able to use the DeskCycle with no interference based on the required desk clearance ranges from this study (Centers for Disease Control and Prevention, 2014). Therefore, an alternative to the traditional desk (e.g., height adjustable desk) will be required for the general U.S. population to use the DeskCycle and similar devices at the workplace.

Although this study established guidelines in using the DeskCycle at workstations by employing anthropometry and user preference, two limitations were identified. First, the sample did not entirely represent the general U.S. population due to the stratification considering only length (stature) and not weight. Evidently, the average BMI for the sample (23.92 kg/m^2) was different from that of the general U.S. population (27.5 kg/m^2; Centers for Disease Control and Prevention, 2014). Second, the popliteal height (PH) and trochanterion height (TH) of the U.S. population were synthesized by utilizing the U.S. army data due to the lack of civilian popliteal and trochanterion height data (Gordon et al., 1989). However, the U.S. army data was collected approximately 25 years ago from the military population, which brings two drawbacks: (1) it does not represent the civilian population and (2) secular trends could have contributed to the change in proportionalities (Malina, Bouchard, and Bar-Or, 2004). Although, the Civilian American and European Surface Anthropometry Resource (CAESAR) does provide popliteal height and trochanterion height the research team did not have access to this database. Therefore, incorporating weight in the stratification and obtaining (or collecting) recent data on PH and TH could have the potential to improve the accuracy of study findings.

Reading comprehension performance (i.e., accuracy and efficiency) was not compromised by cycling condition. Similar to prior findings, four subjects commented that it was difficult to pedal on the DeskCycle while performing the reading comprehension tasks even though their performances were not significantly different compared to the seated condition (Commissaris et al., 2014). However, some have commented that it was difficult to select the correct answer (i.e., clicking the radio button) on the computer due to the simultaneous physical movement in the lower and upper limbs. This finding agrees with previous reports that pedaling could result in a decline in performance related to mouse tasks (Straker et al., 2009; Neuhaus et. al., 2014; Tudor-Locke et al., 2014).

Typing performance was inversely proportional to cycling speed. This coincides with previous studies (Straker et al., 2009; Thompson and Levine, 2011), but contrasts with other studies which indicated that active workstations do not have significant effect on typing performance (Elmer and Martin, 2014). These opposing findings may be due to the availability of resources that an individual can allocate towards both the physical and cognitive task. Dynamic movements (e.g., walking and pedaling) would require more attention towards controlling/balancing the lower limbs and result in having more effect on typing performance compared to a static/secure movement (e.g. standing or secured seat pedaling; Winter, 1995).

In the authors' earlier research, a pilot study was conducted to test the desk bike with a standard office desk. However, most participants complained it was awkward to pedal in the current setup. Knees kept bumping against the desk as pedal strokes required more clearance than what standard desks provided. Unlike the responses from the pilot study, most of the participants in the current study have commented that they could see themselves using the desk bike setup for tasks that are not too mentally demanding, especially at the preferred intensity level (17.3 W). This could indicate that this intervention has the potential to decrease sedentary behavior on some aspect.

Based on participant feedback, maintaining the pedaling speed at the lower level (10 W) was difficult, which was mainly due to the pace being unnaturally slow. This led to the audio indicator (i.e., a small beep) signaling more often compared to the preferred and high level cycling and hence lose attention on the task due to checking the speed monitor more often. Future studies could employ the preferred level intensity (17.3 W) as a ‘moderate’ level cycling, which could potentially allow the subjects to pedal at a more natural pace and minimize attention loss.

Currently, the speed monitor is an external device, which requires users to switch attention from the computer screen to the DeskCycle information display. If the speed were to be displayed on the computer screen (e.g., as a small indicator) it could potentially minimize unnecessary movements, cause less mental stress and increase the attention span of the users to the task. That approach is similar to that of the benefits from using a head-up display compared to using a head-down display while driving (Liu and Wen, 2004). Future studies should examine ways to improve the notification system, which minimizes disruption effects.

Overall, this study has investigated the ergonomics features of using a desk bike, specifically the DeskCycle, in an office workstation. Recommended adjustable ranges of workstation settings for the general U.S. population were provided and a preferred cycling intensity was determined. This study also extends prior research by measuring reading and typing tasks when using a desk bike. These findings can help inform compact under-the-desk bike workstation design guidelines to improve health, safety, work performance, and user satisfaction.

3.6 Acknowledgements

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Chapter 4
Effects of an under desk bike on office related tasks

4.1 Abstract

This study investigated the feasibility of increasing physical activity while working on office related tasks by using an under desk bike in an office setting. Ninety-three healthy sedentary participants were recruited and were stratified into eight groups based on sex, age (25–44 vs. 45–65), and BMI (18.5–24.9 vs. 25–34.9 kg/m^2). Reading, typing, logical reasoning, and phone call answering performances were compared at three different cycling conditions (no cycling, 17 and 25 W). Performance of reading, logical reasoning, and phone call answering were not significantly different between the cycling conditions. Typing performance was significantly different compared to the traditional seated posture, but only a modest deterioration was shown. Under desk bikes could increase physical activity with minimal disruption on office work performance.

4.2 Objective

The findings from this chapter extends the previous chapter by further evaluating the feasibility of accomplishing simultaneous caloric expenditure with office work on a broader demographic.

4.3 Methods

4.3.1 Participants

Ninety-three healthy sedentary participants were recruited and were stratified into eight groups (Table 4.1) according to sex, age (20–44 vs. 45–65), and BMI (18.5–24.9 vs. 25–34.9 kg/m^2). Inclusion criteria included being sedentary, that is, less than 150 mins/week of moderate/vigorous physical activity and at least 6 hours of sitting per day; a touch typist to maintain a fixed gaze on the computer screen; and a native English speaker to minimize confounding errors from reasoning tests being administered in English for non-natives (Furnham, 2010; Furnham and McClelland, 2010). Potential participants were excluded if they were pregnant or had health risk associated with physical activity, which was screened using the Physical Activity Readiness Questionnaire (Thomas, Reading, and Shephard, 1992). The Pennsylvania State University Institutional Review Board approved the study and all participants provided written informed consent prior to testing.

Table 4.1. The eight strata according to sex, age, and BMI

	Male		Female	
	Overweight BMI 25-34.9 kg/m	Normal BMI 18.5-24.9 kg/m	Overweight BMI 25-34.9 kg/m	Normal BMI 18.5-24.9 kg/m
20-44 years	Stratum 1 (N=12)	Stratum 2 (N=12)	Stratum 3 (N=12)	Stratum 4 (N=12)
45-65 years	Stratum 5 (N=12)	Stratum 6 (N=9)	Stratum 7 (N=12)	Stratum 8 (N=12)

4.3.2 Experimental Setup

An electrically height adjustable desk (Jarvis Desk, Ergo Depot, LLC., Portland, OR, USA) and a non-swivel height-adjustable chair (Bevco 1200 Stationary Plywood Chair, Bevco Precision Manufacturing Company, Waukesha, WI, USA) was set up in the Human Factors Lab at the Pennsylvania State University. The under desk bike (DeskCycle, 3D Innovations LLC., Greeley, CO, USA) used in this study was set to the intensity level of 2 and participants were required to pedal at 17 and 25 W, which is approximately 67 and 90 RPM.

4.3.3 Speed Monitoring System

A speed monitoring system was developed to ensure a consistent pedaling speed at each intensity level. A 3 mm disc neodymium magnet was attached to the flywheel of the pedaling device and a hall effect sensor A3144 module along with a microcontroller (Arduino Uno R3, Ivrea, Italy) was used to count every revolution as the magnet passed the hall effect sensor. The microcontroller computed the current under desk bike RPM, using the time difference between consecutive revolutions, and transmitted this to the computer. An app was developed (Objective-C, Apple Inc., Cupertino, CA, USA) to read the RPM data and presented a banner notification, which popped up on the top right corner of the computer screen (in the status menu of macOS, Apple Inc., Cupertino, CA, USA), when participants substantively deviated from the targeted speed. The banner notification remained there until the participant pedaled at the designated speed for three consecutive cycles (Figure 4.1).

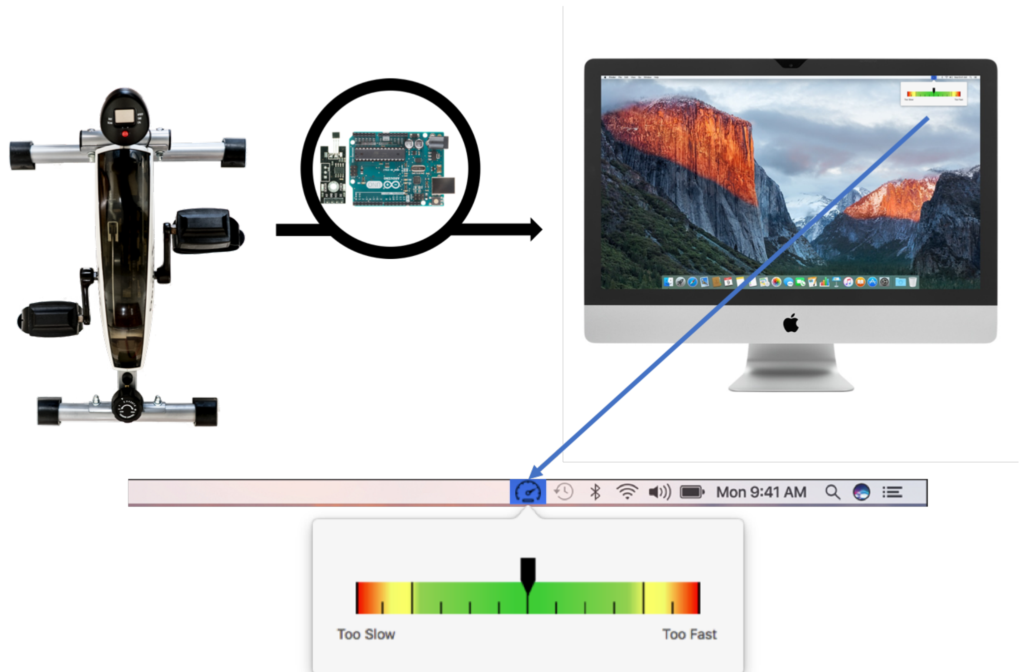

Figure 4.1. Speed monitoring system setup

4.3.4 Tasks and performance measurement

The tasks selected for this study included a reading comprehension task, a typing task, and a combined logical reasoning and phone call task. These were aimed at simulating the tasks that are typically performed by general office clerks (Bureau of Labor Statistics, U.S. Department of Labor, 2015). Prior to this study, the authors conducted a 30-participant pilot study on the learning effects of the cognitive tasks and found that only the first two trials were significant. Therefore, all participants practiced at least two practice sessions.

Reading time and accuracy were measured through reading comprehension problems. Participants were required to read a passage (approximately 280 words) and answer five multiple-choice questions (each with four choices) on the computer. Two practice passages and five main passages were prepared, with all written at the average U.S. adult reading level (Kirsch, 1993). The passages were from Reading for Comprehension Level H (published by Continental Press Inc. and approved by New York State Textbook Law) and were used with permission (Appendix B).

Typing speed (adjusted words-per-minute; AWPM; MacKenzie and Tanaka-Ishii, 2010) was measured using a typing tutor program (TypingMaster Pro Lite, TypingMaster Inc., Helsinki, Finland). Participants were required to copy a passage presented on the screen for 5 min as quickly and as accurately as possible. Two practice passages and five main passages were prepared, all at a syllabic intensity of approximately 1.3 to ensure that the difficulty is consistent across the typing passages (Straker et al., 2009).

The logical reasoning task for this study was the Baddeley Reasoning Test, which is a 64-item test (32 possible items each represented twice) that can be administered in three minutes and measure fluid intelligence (i.e., the ability to analyze and solve novel problems, independent of acquired knowledge; Baddeley, 1968; Cattell 1971). The test involves noting whether a statement is true or false with scores ranging from 0 to 64. For this study, a computer-based Baddeley Reasoning Test battery was developed to be administered for 5 minutes with a total of 128 items (32 possible items each represented four times; Figure 4.2). The order of the questions was randomized based on a constrained randomization approach and participants were required to select the answer on the computer using a mouse. Performance was measured based on the number of correct answers.

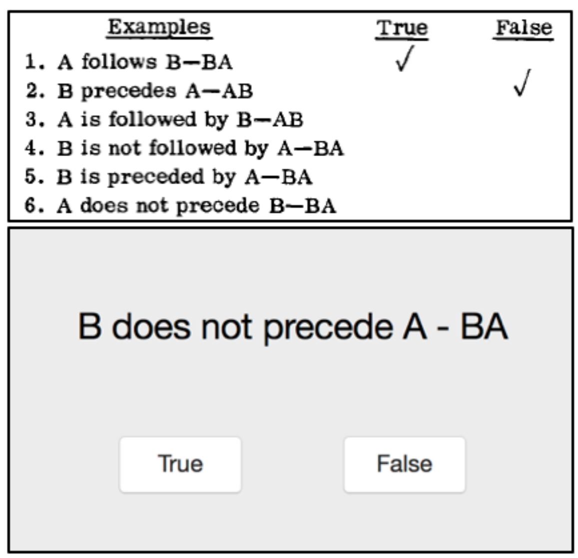

Figure 4.2. Six examples of the original Baddeley Reasoning Test (Adapted from Baddeley, 1968) and one example on the computer-based Baddeley Reasoning Test

For the phone call task, a cognitive task battery that simulates phone call transfer requests, typically received in office settings, was developed for a tablet device (iPad, Apple Inc., Cupertino, CA, USA). The task required users to answer an incoming call, listen to a pre-recorded request, and select the correct department and extension number with respect to the recording (Figure 4.3).

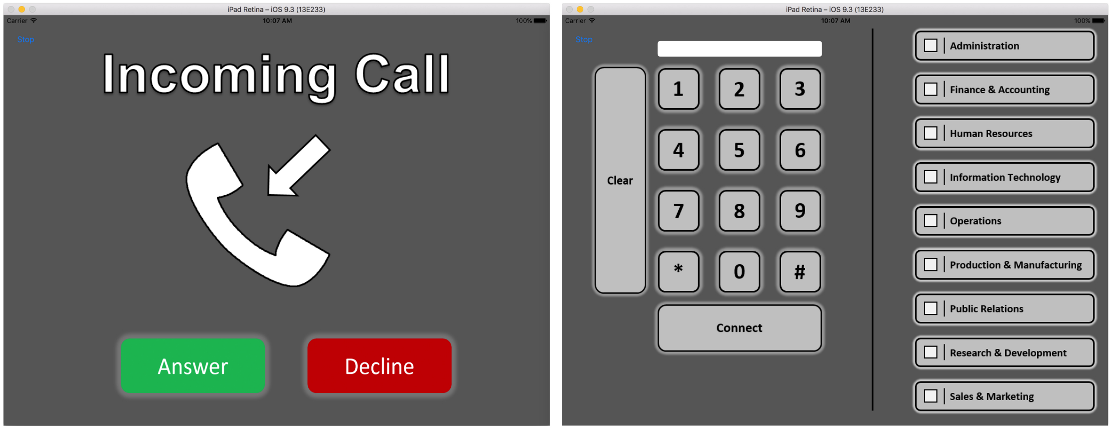

Figure 4.3. Example screens of the phone call task

The duration of the phone call task was set to 5 minutes with one phone call per minute (total of 5 phone calls). Phone calls arrived somewhere between the first 0 and 20 seconds (uniformly distributed) within every one minute time frame. When a phone call arrived, participants had 15 seconds to respond. They may answer the call, decline the call, or the call may stop ringing due to timeout. If the call was answered, a pre-recording was played for 5 seconds and requested an employee (by first and last name) from one of nine departments. An example of a pre-recording would say "Hi, I'd like to speak to Arnold Perry in Administration please." The participants were given 20 seconds to look up the particular employee from a 3-page directory list and enter the appropriate department and 3-digit extension number on the iPad. Figure 4.4 shows the structure of the one minute time frame that repeats 5 times and an example of the phone call task.

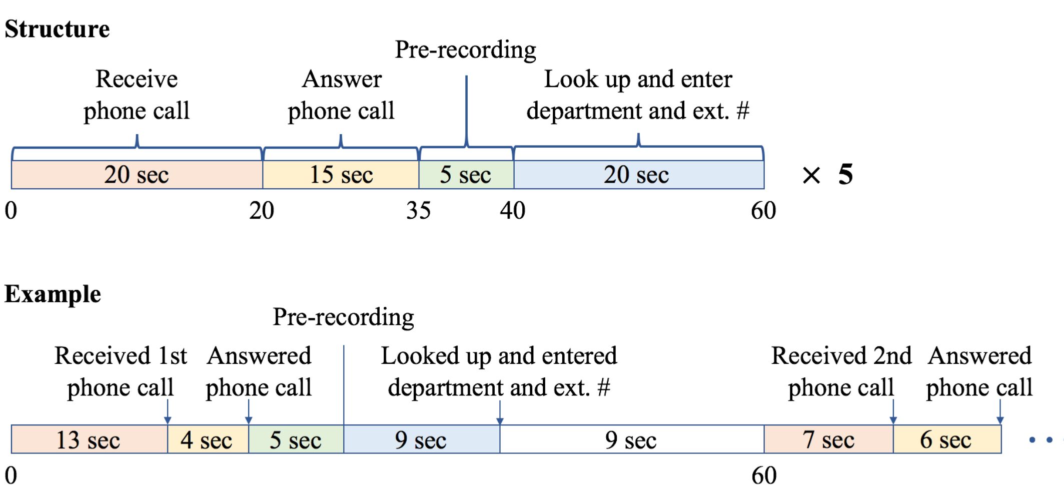

Figure 4.4. The structure and an example of the phone call task

The 3-page directory list consisted of nine departments: Administration, Finance & Accounting, Human Resources, Information Technology, Operations, Production & Manufacturing, Public Relations, Research & Development, and Sales & Marketing (Figure 4.5). Each department consisted of 37 random names that were common in the U.S. (names were created from http://www.random-name-generator.info), giving a total of 333 employees $(9 \times 37 = 33)$. Each of the 333 employees were randomly assigned with a unique 3-digit extension number that was a multiple of 3 between 003 and 999. The full 3-page directory is shown in the appendix.

Administration			Finance & Accounting		
First Name	**Last Name**	**Ext. #**	**First Name**	**Last Name**	**Ext. #**
Antoinette	Ward	654	Alberto	Saunders	060
Arnold	Perry	207	Allan	Cross	408
Aubrey	Bell	435	Amy	Mcdonald	396
Ben	Rowe	414	Anthony	Moreno	150

Figure 4.5. A short excerpt from the 3-page directory list

Each phone call consisted of 2 points, one for department name and the other for extension number. Selecting the correct department and entering the correct extension number yielded a score of 2 points. Performance was measured based on the total score from five phone calls (max score 10).

4.3.5 Procedure

An overview of the study was provided and all participants provided written informed consent. A balance beam metric scale (Detecto Scales, Inc., Webb City, MO, USA) was used to measure the participants' height and weight to the nearest 0.1 cm and 0.1 kg, respectively. Prior to the participants' arrival, the height of the desk and chair were adjusted to recommended settings based on Cho, Freivalds, and Rovniak (2017). If needed, however, participants were able to readjust the settings to their preference. First, participants were introduced to the three office tasks (reading comprehension, typing, and the combined logical reasoning and phone call), three cycling conditions (sitting and pedaling at 17 and 25 W), and the speed alert banner notification. To eliminate learning effects, all participants performed two practice sessions. The first practice session required participants to start pedaling and steadily increase to the low intensity 17 W within 30 sec. Then they completed the three tasks, each for approximately 1 min, with short 30-second breaks between tasks. Participants were requested to continue pedaling for these short breaks to minimize attention loss. After a 3-min break, the second practice session was administered, at the moderate intensity 25 W, following the same steps. A 5-min break was given after the two practice sessions to rest to reduce the possibility of any fatigue effect. Next, the participants were guided through the experimental procedure that consisted of the seated and cycling conditions. The procedure was similar to that of the practice sessions, but the tasks were administered for 5 min. After each cycling condition, participants rated perceived exertion (Borg RPE; Borg, 1982). The order of the tasks and the order of pedaling levels were randomized based on a Graeco-Latin squares design.

4.4 Results

Descriptive statistics for the task performances are given in Table 4.2. Two-way mixed-design analysis of variance (ANOVA) were performed on comparing task performance while sitting and under desk cycling at low (17 W) and moderate (25 W) intensities (Table 4.3). Test results showed that only the main effects strata and cycling condition were significant on typing performance. Because the sphericity assumption was violated for reading comprehension accuracy and phone call score, the Greenhouse-Geiser adjustments were used. Data from one participant for the typing task and three participants for the phone call task were discarded for excessive errors and failure to follow task instructions, respectively. During the experimental procedure, all participants showed high adherence (mean: 97.7%) to the assigned pedaling speed based on the speed monitoring system.

Table 4.2. Mean (SD) task performance results while sitting and under desk cycling at low (17 W) and moderate (25 W) intensities

	Sit	Low (17 W)	Moderate (25 W)
Reading time (sec)	126.21 (34.44)	125.05 (38.86)	124.92 (37.74)
Reading Accuracy (score)	4.8 (0.52)	4.76 (0.6)	4.77 (0.55)
Typing (AWPM)	56.54 (14.1)	54.75 (13.95)	53.55 (14.66)
Logical reasoning (score)	49.74 (15.9)	48.27 (16.64)	48.84 (16.38)
Phone call (score)	9.67 (0.76)	9.5 (0.95)	9.74 (0.71)

Since the interaction of strata and cycling condition was not significant for typing, the main effects of strata and cycling condition were analyzed separately. The p-value $= .006$ for strata and p-value $< .001$ for cycling condition. Tukey HSD post-hoc test revealed that the typing performance (AWPM) for strata 5 and 6 were significantly different from stratum 2 (Figure 4.6). Post hoc analysis with Bonferroni correction showed that typing performances were significantly different between all but the low and moderate intensities (Figure 4.7).

Table 4.3. Two-way mixed-design analysis of variance (ANOVA) results, comparing task performance while sitting and under desk cycling at low (17 W) and moderate (25 W) intensities. Significant differences marked bold.

		F-test	p-value
Reading time	strata	$F(7,85) = 0.901$	.51
	cycling condition	$F(2,170) = 0.133$	.876
	strata * cycling condition	$F(14,170) = 0.647$	.822
Reading Accuracy	strata	$F(7,85) = 1.16$	.344
	cycling condition	$F(1.853,157.538) = 0.145$	.85
	strata * cycling condition	$F(12.974,157.538) = 1.376$	.176
Typing	**strata**	$\boldsymbol{F(7,84) = 3.113}$	**.006**
	cycling condition	$\boldsymbol{F(2,168) = 16.022}$	**<.001**
	strata * cycling condition	$F(14,168) = 1.291$	.218
Logical reasoning	strata	$F(7,85) = 0.466$	.857
	cycling condition	$F(2,170) = 1.273$	.283
	strata * cycling condition	$F(14,170) = 0.466$	.957
Phone call	strata	$F(7,82) = 1.281$	.270
	cycling condition	$F(1.766,144.805) = 2.46$	.096
	strata * cycling condition	$F(12.361,144.805) = 1.035$	.421

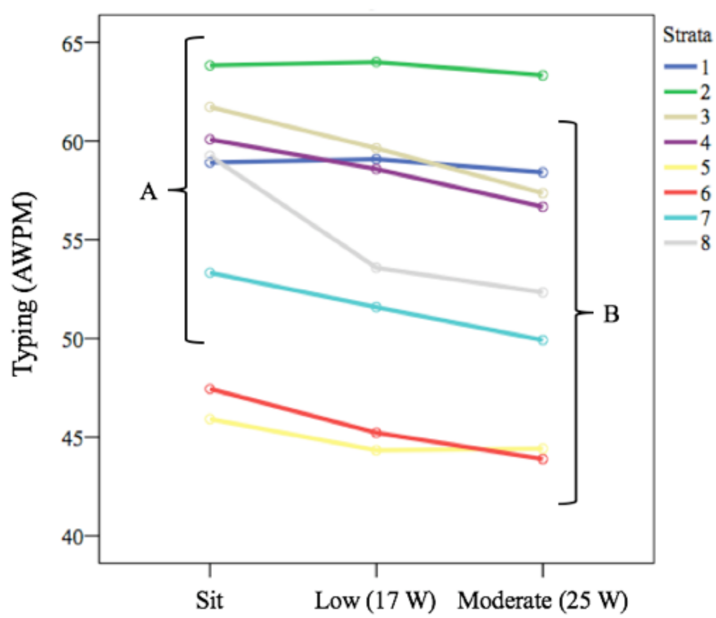

Figure 4.6. Mean typing performance (AWPM) for the 8 strata.

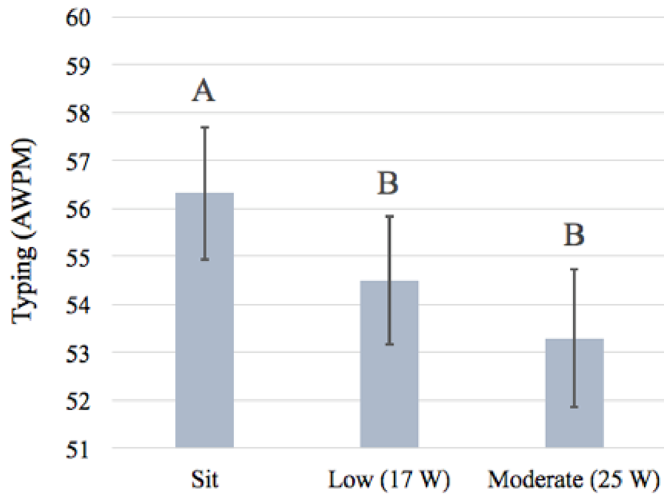

Figure 4.7. Mean typing performance (AWPM) while sitting and under desk cycling at low (17 W) and moderate (25 W) intensities (based on estimated marginal means).

A paired t-test showed that the difference in the mean Borg RPE responses between the two cycling conditions was statistically significant $(t = -12.841, df = 92, p < .001)$, with the lower intensity at 9.35 (1.73) and the moderate intensity at 11.32 (1.97).

4.5 Discussion

This study evaluated work performance of four tasks commonly seen in the office while using the DeskCycle at two intensities 17 and 25 W and compared to a standard sitting position. The current study is an outgrowth to the work performance measurement conducted in the previous chapter by broadening the sample to include the general office-working population, investigating additional tasks, and selecting the intensity levels of 17 and 25 W based on previous findings.

Pedaling while performing an office task is a dual-task scenario where attention is required on both tasks. However, simultaneously accomplishing both tasks might lead to a cognitive overload that could eventually result in performance decrement, especially if the office task requires continuous upper limb fine motor movements with the underlying lower extremity motions (Ohlinger, Horn, Berg and Cox, 2011, Winter 1995). This could be why typing performances were statistically significant at the low and moderate intensities compared to the sitting condition. These results are consistent with those of previous controlled studies showing that cycling workstations had impact on typing performance (Cho, Freivalds, and Rovniak, 2017; Straker et al., 2009). Although the decrement in typing performance was significant, only a modest deterioration of 2-3 AWPM occurred (Figure 4.7) and it is not likely for general office workers to write in this manner where they perceive the text on the screen, be cognizant of the text to copy (type), and type the text using the keyboard. Writing mainly requires three cognitive processes (planning, translating, and reviewing) along with a motor execution process for typing that do not occur in a simple linear sequence (Flower and Hayes, 1981; Kellogg, 1988). This might explain why some studies did not find significant differences in typing performance during cycling conditions (Elmer and Martin, 2014; Commissaris et al., 2014). The typing task selected in these studies were a bit more lenient compared to the current study that resembled more of a natural writing environment. These results could indicate that office workers could use the DeskCycle at the low and moderate intensities with minimal performance impact, on typing related tasks, as long as the attentional resources can be divided.

Results from the reading comprehension, logical reasoning, and phone call tasks were not significantly different among all conditions, which are in line with previous under desk cycling studies (Cho, Freivalds, and Rovniak, 2017; Commissaris et al., 2014). For these tasks, the attentional resources were being strategically allocated to the cognitive aspect of the task and the under desk cycling, whereas the typing task additionally required resources for constantly typing the text using upper limb fine motor movements. Although the reading comprehension, logical reasoning, and phone call tasks required some movements like mouse pointing or looking through the phone directory, the frequency of these movements was much less compared to the continuous finger movement for typing. Previous studies on treadmill desks have also shown similar results on reading comprehension and phone call tasks, and other cognitive tests that resembles the logical reasoning task in this study (Commissaris et al., 2014, John et al., 2009). Although these findings were based on treadmill desks, studies have shown that task performances were similar, if not better, at seated active workstations due to higher stability in the upper body (Botter et al., 2016; Straker et al., 2009).

Many studies have attempted to determine the effects of active workstations on work productivity by selecting a combination of one exercise condition and one office-like task (Tudor-Locke, Schuna, Frensham, and Proenca, 2014). However, office workers are typically engaged in more than one office task and are required to switch between multiple tasks (Bureau of Labor Statistics, U.S. Department of Labor, 2015). The logical reasoning and the phone call task simulated a task-switching environment on top of under desk cycling and found that performances were not significantly different from a traditional seated position. To our knowledge, this is the first study to investigate a task-switching environment while using an under desk bike, and opens up new possibilities to improve the use of active workstations while performing multiple office tasks.

Several limitations of this study should be noted. The standardized tasks used for performance measurement may not adequately represent every day office work performance. The tasks were administered in short durations (5 min) that would only comprise a small portion of the workday. The testing was also conducted in an office-like laboratory setting with minimal disturbance. Future studies should conduct longitudinal field studies to investigate the effects of under desk bikes on the participants' daily work routines and see if this can sustain increases in energy expenditure and improve health outcomes.

4.6 Conclusion

Lack of physical activity and prolonged sedentary behavior is associated with adverse health effects. An under desk bike, specifically the DeskCycle, offers the possibility to increase physical activity at the workplace during daily office work. Performance of reading, and a task-switching setting with logical reasoning and phone call answering tasks were hardly affected while pedaling the under desk bike. Typing performance was significantly different compared to the traditional seated posture, but only a modest deterioration was shown. Future studies should investigate the long term effects of using an under desk bike in a real office environment.

Chapter 5

Energy expenditure of sitting, standing, and using three active workstations

5.1 Abstract

This study aimed to determine the physiological effects of sitting and standing at the desk and using three different active workstations while writing on the computer and, in addition, to determine the validity and reliability of low-cost consumer-oriented active workstations. Energy expenditure and heart rate were measured in 10 healthy males (ages 21-31 and BMI 22.7-26.6 kg/m^2), while writing on the computer at eight different conditions: sit, stand, under desk cycling at 15 and 35 W, under desk elliptical training at 15 and 35 W, and treadmill desk walking at 2.5 and 3.2 km/h. A power output measurement system was developed to obtain the required power to drive the cranks of the under desk bike and under desk elliptical trainer. Using the active workstations in this study could increase energy expenditure by 67.5 (DeskCycle 15 W) or up to 122.5 (treadmill 3.2 km/h) more kilocalories than they would expend per hour of sedentary sitting and writing on the computer. Using the under desk cycle and the under desk elliptical trainer at 35 W resulted in higher energy expenditure, however, participant feedback indicated that it would not be possible to use these at this intensity for longer periods. At 60 RPM, the power displayed on the under desk bike was overestimated at higher resistance levels compared to the actual power, and the actual power required to drive the cranks on the under desk elliptical trainer was much lower (max 13 W) than that of most exercise devices. Using active workstations at light physical activity level could significantly increase energy expenditure compared to sitting or standing at the desk. The inaccuracy of under desk bikes and under desk elliptical trainers could be misleading to users.

5.2 Introduction

Physical inactivity is associated with several diseases such as type 2 diabetes, cardiovascular diseases, obesity and some cancer types (Lee et al., 2012; Blair, 2009). It is also identified as the fourth leading risk factor for global mortality (WHO, 2009). Accordingly, promoting physical activity has become a priority to improve and maintain health (Artinian et al., 2010; Nelson et al., 2007; Warburton, Nicol, and Bredin, 2006). Research has shown that adults are advised to perform moderate-intensity physical activity for at least 30 min on most, if not all, days of the week (Haskell et al., 2007). However, the level of physical activity undertaken in most populations is insufficient despite the expected health benefits from such activity. In 2010, self-reported findings shown that more than 32% of U.S. adults were insufficiently active (WHO, 2012).

Furthermore, as occupations in developed and high-income countries require seated computer-based work, along with other sedentary lifestyle trends, adults spending the majority of waking hours in sedentary behavior ($\leq$1.5 metabolic equivalent) has been brought to attention (Healy et al., 2011). Reports have shown that U.S. adults employed in sedentary occupations are sitting approximately 11 hours a day (Tudor-Locke et al., 2011). Considering this prolonged sitting behavior, even when adults meet physical activity recommendations this may not be enough to reduce health risk factors (Owen et al., 2010; de Rezende et al., 2014).

Innovatively, researchers have recently found that replacing the conventional seated workstation to an active workstation can promote light intensity exercise, reduce sedentary behavior, and still maintain work productivity. John et al. (2009) investigated the effects of treadmill desk walking on fine motor skills and cognitive performances. Cho, Freivalds and Rovniak (2017) studied the effects of using a compact under desk bike on typing and reading comprehension performance. Straker, Levine, and Campbell (2009) determined the effects of treadmill desk walking and desk cycling on various computer input tasks.

Although a burgeoning number of studies have evaluated the effects of active workstations on work productivity, the research that justifies the use of these from the physiological standpoint is limited. Elmer and Martin (2014) found that a recumbent cycling workstation can facilitate physical activity without compromising typing performance. However, the setting required a large amount of space and resembled an exercise device that did not seem feasible for the office. Rovniak et al. (2014) measured the energy expenditure of participants using a compact elliptical device while watching television. However, using an elliptical device at the desk on top of office work could have different physiological effects (Hjortskov et al., 2004). Levine and Miller (2007) evaluated the walk-and-work setup at a self-selected velocity 1.77 (0.64) km/h, but studies have reported that there was no significant difference in typing performance between walking conditions up to a certain level (Straker, Levine, and Campbell, 2009). Therefore, it could be beneficial to see the energy expenditure at higher walking speeds, since walking at approximately 4.5 km/h is considered most efficient from the energy consumption perspective (Waters and

Mulroy, 1999).

To better evaluate the efficacy of using minimally invasive and cost-efficient active workstations while performing a writing task on the computer, this study investigates the energy expenditure of using three different types of active workstations (under desk bike, under desk elliptical trainer and treadmill desk) and compares them to sitting and standing at the desk. The energy expenditures were measured based on indirect calorimetry (oxygen consumption and carbon dioxide production). Additionally, because the validity and reliability of power determined by commercial exercise cycling and elliptical training devices are not well known (or not given at all), a power measurement system was constructed to (a) validate the power displayed on the under desk bike and (b) document the actual power for the under desk elliptical trainer. The results from this study provide normative values for the energy expenditure of under desk cycling, under desk elliptical training, and treadmill desk walking while working at the desk, and may also assist in selecting the appropriate device for users.

5.3 Methods

5.3.1 Participants

Ten healthy male participants, with mean age 24 (σ: 3.7) years, height 177.6 (σ: 3) cm, and weight 75.7 (σ: 5.7) kg, were recruited. All participants reported some experience in using a stationary bike, elliptical trainer and a treadmill. Participants were asked not to exercise on the test day and to not eat or consume caffeinated beverages for at least three hours before the study. The study was approved by the Human Subject Research Institutional Review Board at The Pennsylvania State University (STUDY00005567) and written informed consent was obtained from participants prior to testing. All participants received a compensation for their participation ($20 for 2 hours).

5.3.2 Experimental Setup

Data were collected in a controlled laboratory setting (54.1 m^3; 3.6 $\times$ 4.7 $\times$ 3.2 m) equipped with an under desk bike (DeskCycle, 3D Innovations LLC., Greeley, CO, USA), under desk elliptical trainer (Cubii, FitnessCubed, Inc., Chicago, IL, USA), under desk treadmill (LifeSpan TR1200-DT3, PCE Fitness, Salt Lake City, UT, USA), a height adjustable desk (SmartDesk 2 Business Edition, Autonomous, Mentone, CA, USA), an office chair (Aeron Chair, Herman Miller, Inc., Zeeland, MI, USA) and a standard computer (Figure 5.1). The temperature of the laboratory was maintained at 23.3°C. Energy expenditure measurements were collected using a metabolic analysis system.

Figure 5.1. The laboratory setting with the under desk bike, under desk elliptical trainer, and under desk treadmill

5.3.3 Power output and speed measurement

Participants were required to exercise at a light intensity of 15 and 35 W (for the DeskCycle and Cubii) at a cadence of 60RPM, which was reported as the most economical and efficient cadence for a natural pace with minimal attention loss (Cho, Freivalds, and Rovniak, 2017; Marsh and Martin, 1997; Schuna et al., 2016; Stach, Graham, Yim, and Rhodes, 2009). The DeskCycle and Cubii provided estimates of calories burned and pedaling/stride rates with respect to the selected resistance level. The DeskCycle also displayed the amount of power output with respect to pedaling rates on their product website (Cubii did not provide power values). However, the validity and reliability of power determined by commercial exercise cycles are not well known. Therefore, prior to data collection a power output measurement system was constructed to verify and obtain the required power to drive the cranks at 60 RPM for each resistance level.

The power output measurement system recorded the torque and cadence using a (A) variable transformer (POWERSTAT, Superior Electric, Bristol, CT, USA), (B) high torque drill (Bosch 1034VSR Drill, Bosch, Stuttgart, Germany), (C) rotary torque sensor (RSS-20, Transducer Techniques LLC, Temecula, CA, USA), (D) digital display (DPM-3, Transducer Techniques LLC, Temecula, CA, USA), (E) DeskCycle, (F) Cubii, (G) microcontroller (Arduino Uno R3, Ivrea, Italy) and (H) hall effect sensor A3144 module (Figure 5.2).

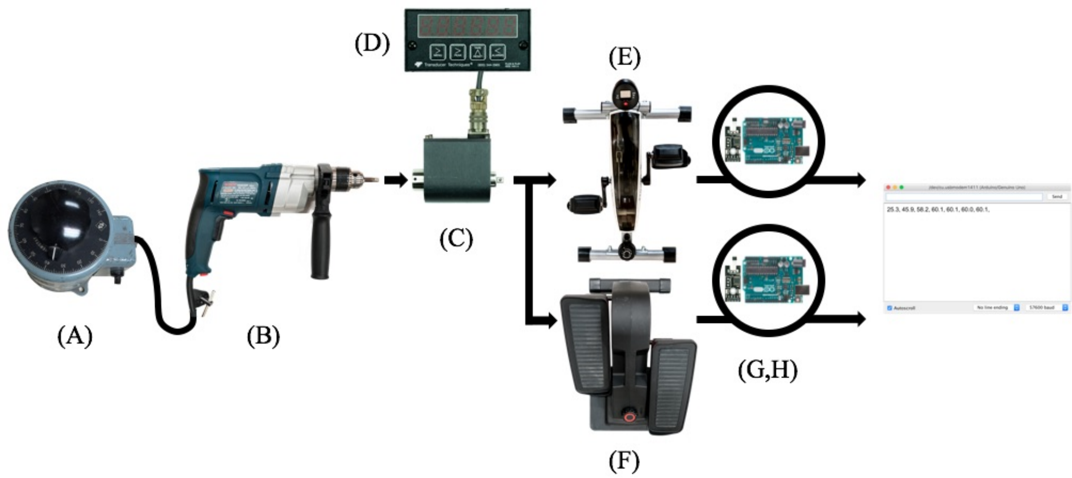

Figure 5.2. Power output and speed measurement system

The torque and cadence obtained from the above power output measurement system were used to calculate the power using $P = \tau \cdot \omega$, $\tau = P/\omega$, and $\omega = (2\pi \cdot RPM)/60$. Where P is power (W), τ is torque (Nm) from the rotary torque sensor, ω is the angular velocity (radians per second), and RPM (revolutions per minute) is the cadence obtained from the Arduino and hall effect sensor A3144 setup.

The amount of power to drive the cranks of the Cubii at 60RPM was lower than the designated 15 and 35 W at all resistance levels. Therefore, additional magnets were attached to increase the magnetic force between the bracket and the flywheel in the magnetic braking system of the Cubii (Figure 5.3).

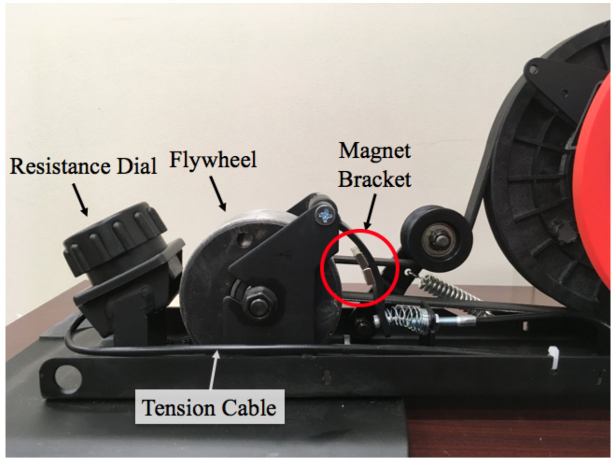

Figure 5.3. Modifications made to the Cubii for higher resistance

Participants were required to walk on the treadmill at a light intensity of 2.5 and 3.2 km/h, which were reported as possible walk-and-work speeds as long as fine motor skills (e.g., precise mouse pointing) are not required and cognitive overload does not occur (Alderman, Olson, and Mattina, 2014; Straker, Levine, and Campbell, 2009). To check the accuracy of the speed 2.5 and 3.2 km/h, velocity was computed based on the distance traveled over the course of time. Distance was determined by the product of the belt length and number of rotations, which was done using a colored piece of tape marked on the belt. The movement intensities for the walking was chosen to be comparable with the cycling and elliptical training, but were not individually determined.

5.3.4 Energy expenditure and heart rate data acquisition

Energy expenditure was measured using a metabolic analysis system (BBB1LP Breath by Breath Metabolic Analysis System, Qubit Systems Inc., ON, Canada; Figure 5.4), which consisted of a laser diode O2 and nondispersive infrared CO2 analyzer (S147 Rapid Response O2/CO2 Analyzer, Qubit Systems Inc., ON, Canada), an interface (LabPro, Vernier Software & Technology, OR, USA) and an analysis software (LoggerPro, Vernier Software & Technology, OR, USA). The O2/CO2 analyzer was calibrated prior to each participant testing with calibrated gas (5% CO2, 16% O2 and balanced N2; GASCO Affiliates, LLC., Oldsmar, FL, USA). Expired gas from the participants was collected using a face mask (Economy anaesthetic mask, Intersurgical Ltd., Wokingham, UK). The instrument measured ventilation and expired concentrations of oxygen and carbon dioxide breath-by-breath and estimated energy expenditure using the modified Weir equation $EE = (3.94 \times \dot{V}O_2) + (1.1 \times \dot{V}CO_2)$.

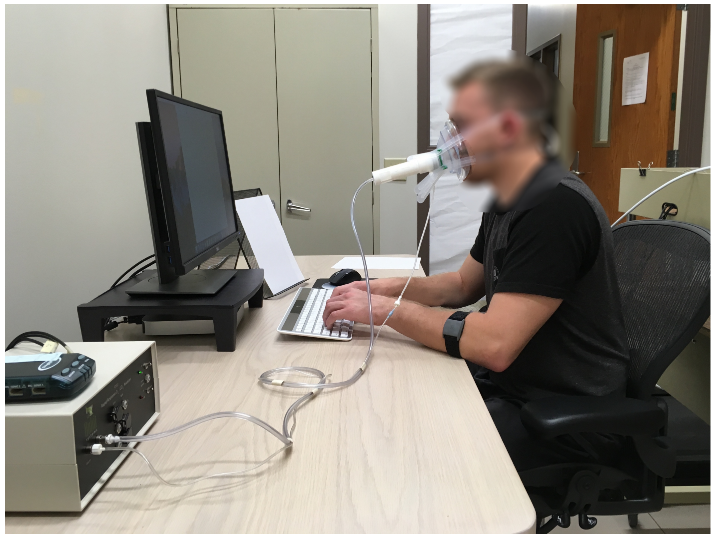

Figure 5.4. Metabolic analysis system and heart rate sensor

Heart rate was assessed using a forearm strap type heart rate measurement device (Scosche RHYTHM+, Schosche Industries, Oxnard, CA, USA; Figure 5.4). The readings from RHYTHM+ were found to be accurate compared to chest strap transmitters (Stahl et al., 2016).

5.3.5 Writing task

For each exercise condition (including sitting and standing), participants were required to choose one among three random topics and write about the particular topic during the experiment. A total of 27 topics were prepared and the order was randomized. The topics were similar to those given in the speaking test of the International English Language Testing System (IELTS) owned jointly by the British Council, Cambridge English Language Assessment, and IDP Education. For example, "Describe a trip you want to take." or "Describe a childhood memory." The attachment of the face mask prevented participants to work in a natural behavior, and therefore, work performance was not measured (Botter et al., 2016; Burford et al., 2013). However, participants were instructed to write as if they were writing for a test or composing an important email.

5.3.6 Procedure

An overview of the study was provided and participants provided written informed consent. Age was self-reported, and a balance beam metric scale (Detecto Scales, Inc., Webb City, MO, USA) was used to measure height and weight to the nearest 0.1 cm and 0.1 kg, respectively.

First, participants were familiarized with the exercise devices (along with the adjustable seat and desk) and the writing task. Participants were requested to adjust the seat and desk to their preference for the seated condition and practice the writing task. This step was repeated for the standing condition (the chair was removed by the facilitators). For the under desk cycling (DeskCycle) and under desk elliptical training (Cubii) conditions, participants were first instructed on how to properly use these exercise devices. Then they were requested to adjust the seat and desk for pedaling and stepping, and practice the exercise (at 15 and 35 W) along with the writing task. They were also informed of the speed alert notification, which alerted the users when they were significantly beyond the designated 60RPM. This familiarization process was repeated for the treadmill desk walking condition (at 2.5 and 3.2 km/h; the chair and speed alert notification was removed by the facilitators). At the end of the familiarization stage, participants wore the face mask that was secured with an elastic strap and the heart rate transmitter was attached to the forearm.

Next, the participants were guided through the experimental procedure that consisted of 8 conditions: sit, stand, under desk cycling at 15 and 35 W, under desk elliptical training at 15 and 35 W, and treadmill desk walking at 2.5 and 3.2 km/h. Participants performed the writing task for all 8 conditions. The sit and stand conditions were collected first and the remaining six exercise conditions were collected in a randomized order. Data were collected for 5 minutes per condition, but the exercise conditions required an extra minute at the beginning for the participants to reach steady state according to the assigned intensity level. Participants were given a 5-minute rest between conditions. After completing all eight conditions, participants were asked questions relating to their experiences on the active workstations. Finally, they were debriefed, paid, and released. The study duration was approximately 2 hours.

5.3.7 Data Analysis

SPSS version 22 (SPSS Inc., Chicago, IL, USA) was used to perform statistical analyses of the collected data. The independent variable in this study were the sit, stand, and the six exercise conditions. The dependent variables were energy expenditure (kcal/h) and average heart rate (BPM). Repeated measures ANOVAs were performed to test for significant differences in the effect of sit, stand, and the six exercise conditions on energy expenditure and average heart rate. Statistical significance for all analyses was set at $p < .05$.

5.4 Results

5.4.1 Power Measurement

Table 5.1 shows the DeskCycle and Cubii power values at 60RPM. The DeskCycle power values were the displayed power value from the manufacturer and the measured power value using the power output measurement system from this study. The Cubii power values were the measured power value using the power output measurement system and the modified power values, which was done by increasing the magnetic force by adding magnets. The measured treadmill speed of 2.5 and 3.2 km/h were equivalent to the speed displayed on the console.

Table 5.1. DeskCycle and Cubii power values at 60RPM

	DeskCycle		Cubii	
Resistance Level	Displayed Power (W)	Measured Power (W)	Measured Power (W)	Modified Power (W)
1	12	9	7	7
2	**15**	**15**	7	8
3	22	23	7	9
4	**35**	**35**	8	12
5	56	47	**8**	**15**
6	79	58	9	23
7	106	66	**11**	**35**
8	130	73	13	N/A

5.4.2 Energy expenditure and heart rate

Repeated measures ANOVAs showed that sit, stand and exercise conditions had significant effect on energy expenditure ($F(2.96, 26.63) = 199.31, p < .001, \eta_p^2 = .957$) and average heart rate ($F(3.16, 28.46) = 42.79, p < .001, \eta_p^2 = .826$). Because the sphericity assumption was violated for energy expenditure and average heart rate, the Greenhouse-Geiser adjustment was used. Post hoc analysis using Bonferroni correction showed significant differences in the energy expenditure and average heart rate for sit, stand, and exercise conditions (Figure 5.5).

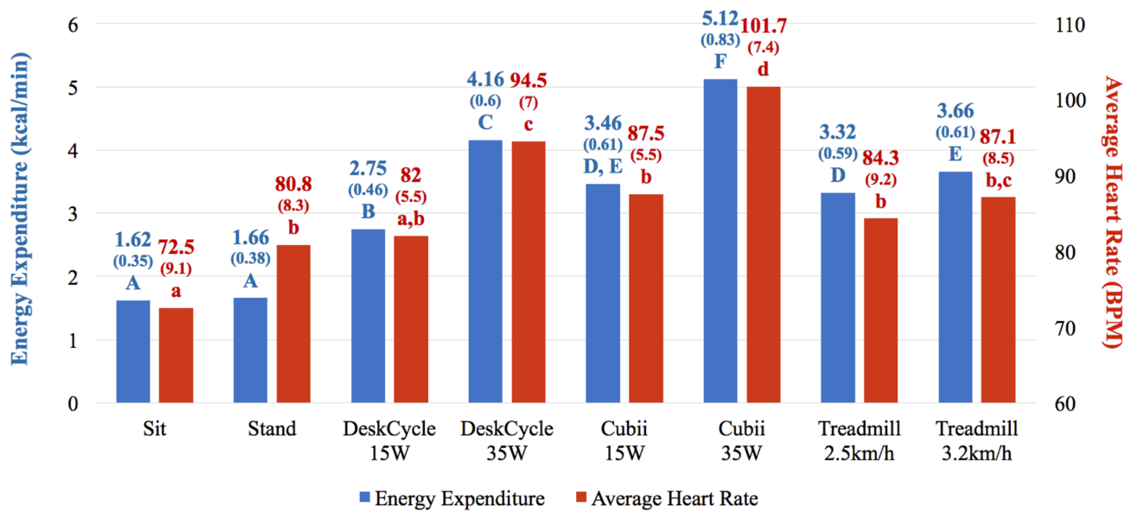

Figure 5.5. Mean (SD) energy expenditure and average heart results based on sit, stand, and exercise conditions

A general linear model analysis was performed on energy expenditure with average heart rate as a covariate and participant as a random factor. Results showed a positive correlation between energy expenditure and average heart rate ($energy\ expenditure = 6.595 \times average\ heart\ rate - 337; R^2 = 80.7\%, p < .001$; Figure 5.6) with no significant interaction between the participant and average heart rate ($F(9,60) = 0.78, p = .638$).

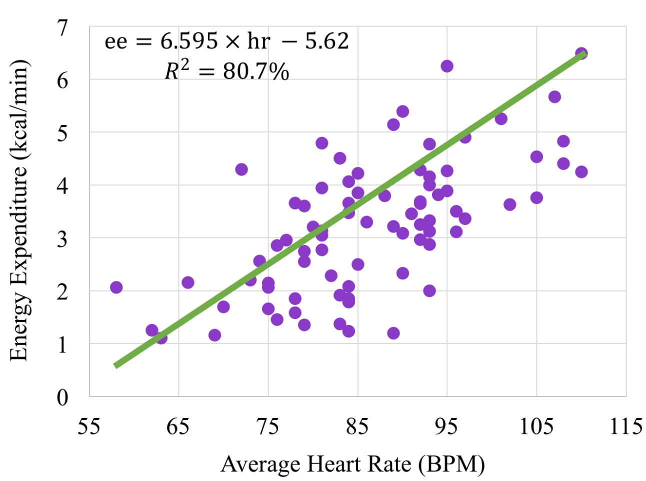

Figure 5.6. Energy expenditure (ee) versus average heart rate (hr)

5.5 Discussion

The present study explored the energy expenditure and average heart rate of sitting, standing, and using three types of active workstations: DeskCycle (under desk bike), Cubii (under desk elliptical trainer) and Lifespan treadmill (under desk treadmill). Participants were required to pedal at two different intensity levels for each device and complete a writing task on the computer. Results showed that using these devices at the intensities suggested from this study could help expend at least 67.5 (DeskCycle 15 W) or up to 210 (Cubii 35 W) more kilocalories than they would expend per hour of sedentary sitting and writing. These results are in line with previous reports documenting the energy expenditure of using a treadmill desk (Levine and Miller, 2014) and a cycling workstation (Elmer and Martin, 2014).

Although results suggested that users could potentially increase energy expenditure up to 210 kcal/h compared to sitting at the desk, six (out of ten) participants commented that it would be difficult to continue writing while using the DeskCycle at 35 W for more than 5 minutes due to being physically fatigued, even though they said they did not perceive performance decrease in writing during this period. Additionally, three participants commented that using the Cubii at 35 W was interfering with their writing performance. In this aspect, it is possible to determine that writing on the computer and simultaneously exercising on the DeskCycle or Cubii at 35 W is not the best option for sustained use and conclude that energy expenditure could increase up to 122.5 (treadmill 3.2 km/h) more kilocalories per hour compared to sedentary sitting.

The power values of the Cubii was not provided by the manufacturers and therefore was measured using the power output measurement system (Figure 5.2). The required power to drive the cranks at 60 RPM for the Cubii turned out to be much lower than expected (max resistance required 13 W) and therefore was calibrated to match the DeskCycle. However, as mentioned above, participants commented that the Cubii was difficult to use at 35 W and that they were mainly using their ankles to pedal than utilizing the entire lower extremity. This could be due to the crank arm being attached to the front end of the pedal, which would require plantarflexion motions for under desk elliptical training. Further investigation on the muscle demands and kinematics should be studied to understand and evaluate whether this intensity would be suitable for light physical activity.

An increase in energy expenditure within the individual was associated with an increase in average heart rate ($p < .001$), with approximately 81% of variation in energy expenditure explained by average heart rate. These results are consistent with previous findings that energy expenditure and heart rate are correlated and that heart rate can be used to estimate energy expenditure if physiological differences in individuals were incorporated in the calculation

(Keytel et al., 2005; Spurr et al., 1988). However, the energy expenditure and heart rate measures were formed in short 5-minute durations, which is no more than a fraction of a typical workday, and were based on young adult males with fairly similar physiological and anthropometric characteristics. Since these do not represent the average workday and the whole population, further testing may conduct a longitudinal study and include more diverse populations to obtain widely applicable results.

5.6 Conclusion

This study has investigated the energy expenditure of the DeskCycle (under desk bike), Cubii (under desk elliptical trainer), and Lifespan Treadmill (under desk treadmill) that could potentially reduce sedentary behavior and increase energy expenditure throughout the workday. Results showed that using these exercise devices at the desk even at the light physical activity level could significantly increase energy expenditure. Although the findings from this study has the potential to improve the wellbeing of human health, promoting health behavior change in individuals and support from employers is critical to make it successful.

Chapter 6

Lower extremity muscle demands and joint kinematics of under desk cycling, under desk elliptical training, and treadmill desk walking

6.1 Abstract

The objective of this study was to compare the lower extremity muscle demands and joint kinematics while sitting at the desk, standing at the desk, under desk cycling, under desk elliptical training, and treadmill desk walking to provide evidence-based data and guide clinical decision making in lower extremity training and rehabilitation. Eleven healthy male participants (Age mean: 24, σ: 3.6) were required to complete a writing task at the desk based on eight different conditions: sitting, standing, under desk cycling (15 and 35 W), under desk elliptical training (15 and 35 W), and treadmill desk walking (2.5 and 3.2 km/h). Surface electromyography data of eight lower extremity muscles and sagittal plane kinematic data of the hip, knee and ankle joints were recorded. A method of measuring joint angle using inertial measurement units and radio modules was also presented. Repeated measures ANOVAs showed significant differences in the effect of sit, stand, and six exercise conditions on (1) mean and peak EMG activity on eight lower extremity muscles and (2) maximum flexion/extension and range of motions of the hip, knee and ankle angles. Results indicated that the treadmill desk walking condition showed similar patterns to regular treadmills and overground walking, which have been proven to be effective gait training methods. The under desk elliptical trainer showed minimal hip motion, greater ankle motion, and large muscle demands in the lower leg. The under desk bike muscle demands and joint kinematics were balanced compared to the elliptical trainer and showed similarity to the treadmill. Participant feedback indicated that it would be difficult to use the under desk bike and the elliptical trainer at the 35 W intensity level for longer periods. All the participants selected either the under desk bike or treadmill as the preferred active workstation. However, the majority of participants chose the under desk bike considering workplace feasibility. The findings from this study provides evidence-based data to help guide clinical decision making related to the use of active workstations in lower extremity training and rehabilitation.

6.2 Introduction

Exercise machines have become particularly popular in the past few decades as a means to improve walking ability. They support the accomplishment of therapeutic goals, such as strengthening muscles or simulating muscle activity patterns during walking, and other advantages include that they can be done in a small area, the intensity can be controlled, and considered safe if used properly (Buchner et al., 1997; Macko et al., 2005). Numerous studies have been conducted to provide insight into the clinical efficacy of using exercise machines to improve walking ability. Muscle activation and joint kinematics during overground walking have been compared to walking on a treadmill and to elliptical training (Burnfield, Shu, Buster, and Taylor, 2010; Lee and Hidler, 2008). Stationary cycling has also been investigated and compared with treadmill/overground walking and elliptical training (Damiano, Norman, Stanley, and Park, 2011; Hamzaid, Smith, and Davis, 2013; Prosser et al., 2011).

Although these exercise machines may be available in the physical therapy setting, people often face barriers to continue training after discharge from rehabilitation. The average U.S. adult employed in the workforce spend 11 hours per day in sedentary behavior (Tudor-Locke, Leonardi, Johnson, and Katzmarzyk, 2011). Therefore, lack of time could be an issue for employees that require extra time investment in physical activity (Robroek, Van Lenthe, Van Empelen, and Burdorf, 2009). Another reason could be that fitness centers or appropriate exercise machines might not available. Even if they were available, many people with physical activity limitations are not able to use these due to unfamiliarity with certain equipment or the requirement for special needs (Miyai et al., 2000; Shu et al., 2010). This is unfortunate because physical activity is essential to promoting health, alleviating chronic conditions, and reducing functional declines (Hesse et al., 1995; Warburton, Nicol, and Bredin, 2006).

Recent research has reported the feasibility of using active workstations to replace sedentary behavior with low-intensity physical activity to increase energy expenditure with minimal effect on office work productivity (Cho, Freivalds, and Rovniak, 2017; Levine and Miller, 2007; Tudor-Locke, Schuna, Frensham, and Proenca, 2014). The expansion of active workstations could create opportunities for rehabilitation and gait training, especially because exercise can be accomplished without requiring extra time investment, can be minimally invasive in the work environment, are cost-efficient, and resemble some of the traditional exercise machines offered during rehabilitation. However, active workstations were recently introduced to the market and are still burgeoning (Neuhaus et al., 2014). Therefore, the muscle demands and joint kinematics of active workstations are not systematically documented, which can be critical information in guiding lower extremity rehabilitation.

To better evaluate the efficacy of using active workstations and understand its potential on lower extremity rehabilitation, this study investigates the muscle demands and joint kinematics recorded, using surface electromyography (EMG) and an inertial-based measurement system, during static postures (sitting and standing at the desk) and when using active workstations (under desk cycling, under desk elliptical training and treadmill desk walking). We hypothesized that these different types of active workstations would have different effects on muscle demands and motion patterns in the lower extremity while working at the desk. The findings from this research will provide health care practitioners and physical therapists with information critical to guiding exercise interventions for people seeking to improve walking ability or remaining physically active.

6.3 Methods

6.3.1 Participants

Eleven healthy male participants with mean age 24 (σ: 3.6) years, of mean height 177.3 (σ: 3) cm, and mean weight 76.7 (σ: 6.5) kg were recruited. All participants reported at least 150 min/week of moderate physical activity and some experience in using a stationary bike, elliptical trainer and a treadmill. Participants were asked to not eat a meal or consume caffeinated for at least three hours before the study and avoid any intense physical activity the day before the test and on the test day. The institutional review board of the Pennsylvania State University approved the study; all participants provided written informed consent and received $20 for compensation for their 2 hours of participation.

6.3.2 Experimental Setup

Data were collected in the human factors lab (54.1 m^3; 3.6 $\times$ 4.7 $\times$ 3.2 m; Figure 6.1) at the Pennsylvania State University equipped with an under desk bike (DeskCycle, 3D Innovations LLC., Greeley, CO, USA), under desk elliptical trainer (Cubii, FitnessCubed, Inc., Chicago, IL, USA), and under desk treadmill (LifeSpan TR1200-DT3, PCE Fitness, Salt Lake City, UT, USA). A height adjustable desk (SmartDesk 2 Business Edition, Autonomous, Mentone, CA, USA) and chair (Aeron Chair, Herman Miller, Inc., Zeeland, MI, USA) was also prepared to control confounding ergonomic factors. Although the DeskCycle and Cubii are currently in the market, the validity and reliability of commercial exercise machines are not well known. Therefore, prior to data collection the power output of the DeskCycle and Cubii were measured and properly calibrated to ensure participants pedal at a light intensity of 15 and 35 W at 60RPM, which was reported as the most economical and efficient cadence for a natural pace and would minimize attention loss (Schuna et al., 2016). The temperature of the laboratory was maintained at 23.3°C. Muscle demands and joint kinematics were collected using surface electromyography (EMG) and an inertial-based measurement system, respectively.

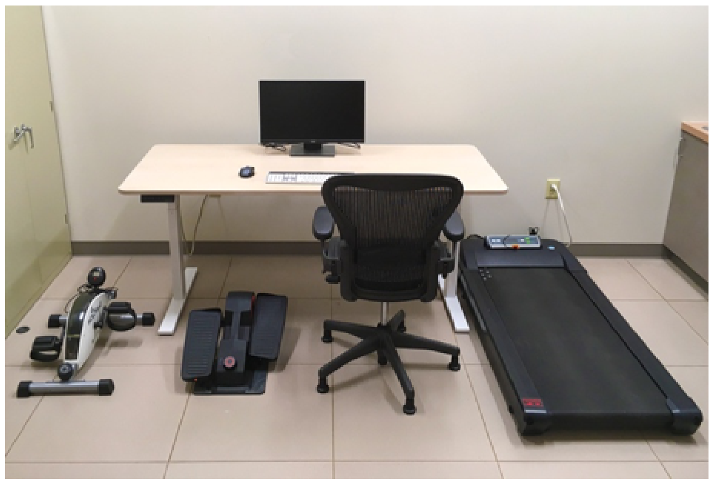

Figure 6.1. The laboratory setting with the under desk bike, under desk elliptical trainer, and under desk treadmill

6.3.3 Muscle demand data acquisition

Surface Electromyography (EMG) activity was continuously recorded from 8 superficial muscles of the right lower extremity comprising Rectus Femoris (RF), Vastus Lateralis (VL), Vastus Medialis (VM), Biceps Femoris (BF), Gastrocnemius Lateral (GL), Gastrocnemius Medial (GM), Soleus (S), and Tibialis Anterior (TA; Hermens et al., 1999; Kasman and Wolf, 2002; Perotto, Delagi, Iazzetti, and Morrison, 2011). EMG data were collected using pre-gelled single use surface electrodes (T3425, Thought Technology Ltd., Montreal, QC, Canada), EMG extender cables (T8720M, Thought Technology Ltd., Montreal, QC, Canada), EMG sensors (MyoScan SA9503M, Thought Technology Ltd., Montreal, QC, Canada), an encoder (FlexComp Infiniti SA7550, Thought Technology Ltd., Montreal, QC, Canada) and an analysis software (BioGraph Infiniti version 6.1, Thought Technology Ltd., Montreal, QC, Canada).

The pre-gelled single use surface electrodes were attached over each muscle belly parallel to the direction of the underlying muscle fibers. Before attaching the electrodes, the skin area was shaved and cleaned with isopropyl alcohol swabs to minimize skin impedance. The electrodes and cables were carefully secured all-purpose support wraps to maintain good skin-to-electrode contact and prevent cables from interfering with lower extremity movements (Figure 6.2).

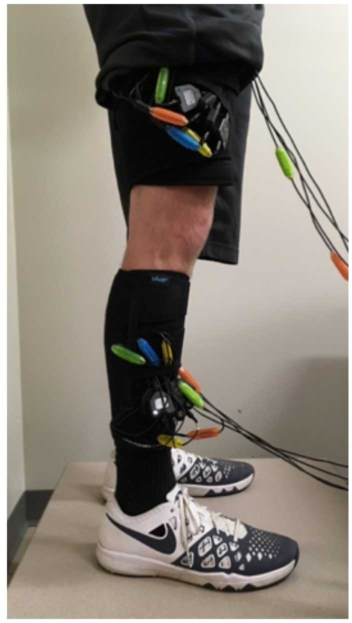

Figure 6.2. Surface EMG setup on the right leg for muscle demand measurement

The MyoScan EMG sensors were used as a differential amplifier to sense and amplify the EMG signals (with a gain of 500). The FlexComp Infiniti encoder was used to digitize the analog signal acquired from the MyoScan EMG sensors. In the data acquisition, a 4th-order Butterworth bandpass filter was applied with a 10 to 500 Hz cutoff frequency and the sampling rate was set to 2048 Hz. The EMG signals were converted to root mean square (RMS) data using the non-sliding-window algorithm with an averaging factor of 50 and a time period of 0.4 seconds for signal smoothing.

6.3.4 Kinematic data acquisition

The joint angles (anatomical position as zero degrees) and range of motions of the right hip, knee, and ankle were continuously recorded in the sagittal plane using a wearable inertial-based measurement system made up of four small inertial measurement units (IMU; 9DoF Razor IMU M0, Sparkfun electronics, Boulder, CO, USA). Each IMU was connected to an XBee 802.15.4 module (XB24-API-001, Digi International Inc., Minnetonka, MN, USA) and a 1200 mAh lithium polymer battery, and were all tightly fixed inside an ABS plastic case ($7 \times 4.6 \times 1.9$ cm; Figure 6.3).

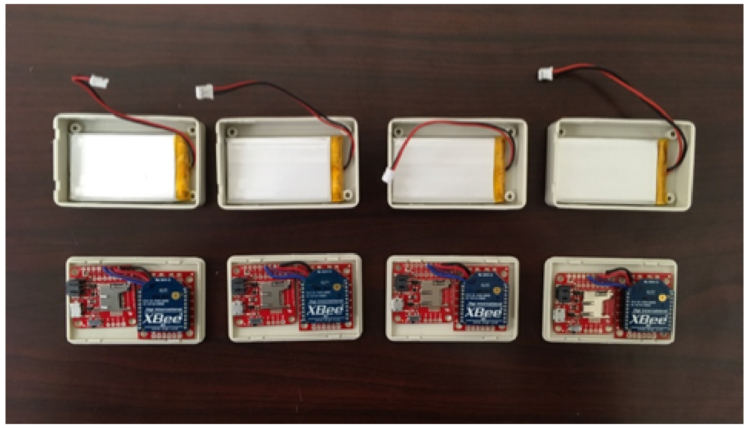

Figure 6.3. The inertial-based measurement system made up of four small inertial measurement units

The IMU is integrated with a low-power microcontroller (SMART SAM D21, Atmel Co., San Jose, CA, USA) and an inertial sensor IC (MPU 9250, InvenSense Inc., San Jose, CA, USA) comprised with a triple-axis accelerometer ($\pm$16 g), triple-axis gyroscope ($\pm$ 2000 dps), and triple-axis magnetometer ($\pm$ 4800 μT). The sensors were placed on the sacrum, thigh, shank, and shoe secured with cloth tape and Velcro straps (Figure 6.4).

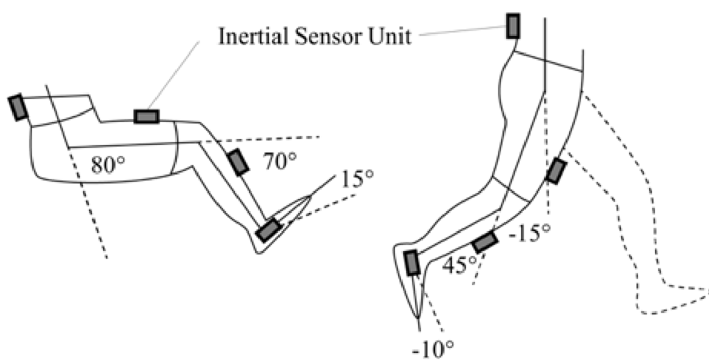

Figure 6.4. The attachment location of the inertial sensors for joint angle and range of motion measurements in the sagittal plane

The accelerometers and gyroscopes were calibrated to minimize offset drift. The tilt, hard-iron, and soft-iron effects of the magnetometers were calibrated to obtain proper heading (Konvalin, 2009). The fusion of the data from the accelerometer, gyroscope, and magnetometer was done using a Direction Cosine Matrix (DCM) algorithm and were recorded at a sampling rate of 16 Hz (Phuong et al., 2009; Premerlani and Bizard, 2009). The inertial-based measurement system was a modified version of the Razor Attitude and Heading Reference System (AHRS) by Bartz (2016).

All calibration was performed in the lab, where the data were collected, prior to each testing and validated (error of less than 5 degrees) by comparison with a goniometer (Baseline®Goniometer 12-1041, Fabrication Enterprises Inc., White Plains, NY).

6.3.5 Procedure

This study was done in conjunction with the study in the previous chapter. An introduction to the study was provided and participants provided informed consent. Age was self-reported, and height and weight was measured to the nearest 0.1 m and 0.1 kg.

The participants were first introduced to the exercise machines, the workstation, and the writing task. The writing task was adopted from the previous chapter that required participants write about a particular topic such as "Describe a city you have lived in the past." or "Describe what you want to do in the future." Participants were requested to adjust the seat and desk to their preference for the seated condition and practice the writing task. This step was repeated for the standing condition (the chair was removed by the facilitators). For the under desk cycling (DeskCycle) and under desk elliptical training (Cubii) conditions, participants were first instructed on how to properly use these exercise machines. Then they were requested to adjust the seat and desk for pedaling and stepping, and practice the exercise (at 15 and 35 W) along with the typing task. They were also informed of the speed alert notification. This step was repeated for the treadmill desk walking condition (at 2.5 and 3.2 km/h; the chair and speed alert notification was removed by the facilitators).

The second part involved attaching the measurement instrument. Surface EMG electrodes were attached to the right lower extremity of the participant and maximal voluntary contractions (MVC) of each muscle group was measured. MVC was measured as the best of two 5-second isometric contractions at different postures (Hislop, Avers, and Brown, 2013). The MVC values of each muscle group were then used to normalize subsequent EMG. EMG data during exercise motions did not exceed the MVC achieved during isometric contractions. The IMUs were attached to the sacrum and the right thigh, shank, and shoe. A goniometer was used to ensure that the joint angle values from the IMUs were equivalent to the participants' actual joint angles.

Last, the participants were guided through the experimental protocol that consisted of writing on the computer while sitting and standing at the desk, and at six different exercise conditions, i.e., under desk cycling at 15 and 35 W, under desk elliptical training at 15 and 35 W, and treadmill desk walking at 2.5 and 3.2 km/h (Figure 6.5). The intensities for the walking was chosen to be comparable with the cycling and elliptical training, but were not individually determined. Data were collected for 5 minutes at all conditions. However, the exercise conditions consisted of six minutes with an extra minute given at the beginning for the participants to steadily increase to the assigned intensity and reach steady state. A 5-minute break was given between conditions. After completing all eight conditions, participants were asked questions relating to their experiences on the active workstations. Lastly, participants were debriefed, paid, and released. Each study session was approximately 2 hours.

Figure 6.5. A participant using the DeskCycle, Cubii, and Treadmill

6.3.6 Data Analysis

Repeated measures ANOVAs were performed, using SPSS software version 22 (SPSS Inc., Chicago, IL, USA), to test for significant differences in the effect of sit, stand, and the six exercise conditions on muscle demand and kinematic data. In all analyses, *p*-values less than 0.05 were considered statistically significant. The muscle demand and kinematic data obtained were generally normally distributed, but did not have homogenous variance, as tested by Mauchly's test of sphericity. In cases where sphericity could not be assumed, the Greenhouse-Geisser correction was used to determine if significant differences existed between conditions.

6.4 Results

Repeated measures ANOVAs showed that the 8 different conditions (sit, stand, and the six exercise conditions) had significant effect on the mean and peak EMG activity (%MVC) on all 8 lower extremity muscles (Tables 6.1 and 6.2). Post hoc analysis with Bonferroni correction determined which groups differed significantly from one another.

Table 6.1. Mean EMG activity of the eight lower extremity muscles (%MVC). All repeated measures ANOVAs showed significant difference ($p < .05$). Bonferroni correction was conducted for multiple comparisons. *sphericity could not be assumed and the Greenhouse-Geisser correction was used.

	Sit	Stand	DeskCycle 15 W	DeskCycle 35 W	Cubii 15 W	Cubii 35 W	Treadmill 2.5 km/h	Treadmill 3.2 km/h
RF	1.4 (0.6)	0.8 (0.4)	3.8 (1.8)	6.6 (1.6)	7.2 (1.9)	11.2 (2.5)	2.0 (0.7)	3.8 (2.0)
*$F(2.5, 25) = 72.3$	A, B	A	C	D	D	E	B, C	B, C, D
VL	1.0 (0.8)	0.7 (0.3)	2.7 (1.6)	6.6 (2.7)	5.6 (2.2)	10.5 (3.4)	3.0 (1.8)	3.9 (1.8)
*$F(1.8, 17.9) = 35.9$	A	A	A	B	B	C	A, B	B
VM	0.7 (0.5)	0.6 (0.3)	3.3 (1.8)	8.1 (3.0)	6.5 (1.7)	11.8 (3.2)	2.5 (1.4)	3.8 (1.8)
*$F(2.6, 25.6) = 62.8$	A	A	B	C, D	D	E	A, B	B, C
BF	0.7 (0.3)	2.3 (1.4)	1.7 (0.9)	2.3 (0.6)	2.6 (1.1)	3.7 (1.3)	3.0 (1.3)	4.5 (2.6)
*$F(1.7, 17) = 10.2$	A	A, B, C	A, B	B	B	C	B, C	B, C
GL	0.6 (0.4)	2.8 (1.2)	7.3 (2.3)	9.1 (1.9)	7.2 (2.3)	10.6 (2.8)	5.7 (2.2)	6.4 (2.6)
*$F(3.5, 35.4) = 33.1$	A	B	C, D	C, D	C	D	C	C, D
GM	0.7 (0.5)	2.9 (1.4)	3.4 (1.6)	3.8 (1.5)	4.4 (2.2)	6.5 (2.8)	10.2 (3.6)	10.5 (3.6)
*$F(2.1, 21.3) = 38.4$	A	B, C	B	B, C	B	C, D	D	D
S	0.7 (0.3)	7.0 (3.2)	4.5 (2.0)	5.3 (1.6)	6.4 (2.3)	9.6 (2.4)	10.2 (2.3)	11.5 (2.0)
*$F(3.3, 32.6) = 41.1$	A	B, C	B	B	B	C, D	C	D
TA	1.0 (0.7)	0.6 (0.3)	2.0 (1.4)	3.5 (1.5)	4.7 (2.1)	6.3 (2.6)	6.2 (1.4)	6.9 (1.5)
*$F(2.4, 23.7) = 45.6$	A	A	A, B	C, D	B, C, E	D, F	E, F	F

Table 6.2. Peak EMG activity of the eight lower extremity muscles (%MVC). All repeated measures ANOVAs showed significant difference ($p < .05$). Bonferroni correction was conducted for multiple comparisons. *sphericity could not be assumed and the Greenhouse-Geisser correction was used.

	Sit	Stand	DeskCycle 15 W	DeskCycle 35 W	Cubii 15 W	Cubii 35 W	Treadmill 2.5 km/h	Treadmill 3.2 km/h
RF	2.0 (1.3)	1.5 (1.6)	11.5 (6.3)	19.0 (9.2)	19.5 (8.8)	29.7 (10.0)	4.8 (2.1)	9.3 (5.0)
$*F(2.1, 20.8) = 35$	A	A, B	C, D	C, E	E	F	B, D	C, D, E
VL	1.7 (1.0)	1.0 (0.7)	7.0 (4.1)	17.5 (7.4)	14.0 (6.9)	28.0 (11.9)	11.3 (5.2)	14.8 (5.5)
$*F(1.5, 14.7) = 26$	A	A	B	C	C	D	B, C, D	B, C, D
VM	0.9 (0.5)	1.4 (2.0)	8.4 (3.0)	20.3 (6.8)	16.3 (4.6)	32.0 (9.7)	8.4 (4.0)	12.6 (4.8)
$*F(2, 19.5) = 65.5$	A	A	B	C	C	D	B	B, C
BF	0.9 (0.3)	3.5 (2.1)	3.6 (2.5)	5.3 (3.2)	5.0 (2.7)	7.8 (3.0)	11.1 (5.1)	14.7 (8.2)
$*F(1.5, 14.7) = 14.5$	A	B, C	A, B, D	B, C, D, E	B	C, E	D, E	D, E
GL	0.8 (0.4)	3.8 (1.8)	16.8 (5.0)	23.1 (6.3)	19.6 (7.1)	27.2 (9.5)	17.2 (8.0)	17.0 (6.6)
$*F(2.1, 20.9) = 26.8$	A	B	C	C, D	C	D	C, D	C, D
GM	1.2 (0.9)	4.5 (2.0)	6.9 (2.8)	9.3 (4.7)	10.6 (4.6)	16.5 (7.3)	38.2 (13.3)	33.6 (11.0)
$*F(1.6, 15.8) = 56.1$	A	B	C	B, C	C	D	E	F
S	1.2 (0.9)	10.0 (4.8)	10.9 (4.5)	15.7 (3.8)	17.9 (5.6)	33.0 (11.6)	33.0 (10.7)	33.8 (7.6)
$*F(3, 29.5) = 52.8$	A	B	B	B	B	C	C	C
TA	1.7 (1.6)	0.8 (0.5)	3.7 (1.9)	9.4 (3.7)	9.7 (4.9)	18.5 (10.4)	15.7 (4.2)	17.6 (5.1)
$*F(2.3, 22.9) = 26.2$	A	A	B	C, D	B, C	D, E	D, E	E

Repeated measures ANOVAs showed that the 8 different conditions (sit, stand, and the six exercise conditions) had significant effect on the maximum flexion/extension and range of motions of the hip, knee and ankle angles (Table 6.3). Post hoc analysis with Bonferroni correction determined which groups differed significantly from one another. The inertial sensors attached to the ankle was unstable during the swing phase of the Treadmill conditions. Therefore, ankle joint measurements of the Treadmill conditions were discarded. However, previous reports have shown that the ankle range of motion for treadmill walking was 27.5 (5.6; Lee and Hidler, 2008). The knee and hip range of motion results from this study were also in line with Lee and Hidler (2008). Data from one participant was discarded due to signal loss.

Table 6.3. Sagittal plane kinematic measures of the hip, knee, and ankle joints (degrees). All repeated measures ANOVAs showed significant difference ($p < .05$). Bonferroni correction was conducted for multiple comparisons. *sphericity could not be assumed and the Greenhouse-Geisser correction was used.

	Sit	Stand	DeskCycle 15 W	DeskCycle 35 W	Cubii 15 W	Cubii 35 W	Treadmill 2.5 km/h	Treadmill 3.2 km/h
Max hip flexion	68.7 (9.7)	-4.8 (7.4)	93.8 (7.1)	91.3 (7.9)	79.1 (9.7)	81.7 (13.9)	21 (5.3)	25.3 (4.7)
*$F(2.6, 23) = 233.8$	A	B	C	C, D	A, D	A, C, D	E	E
Max hip extension	68.4 (9.7)	-5.2 (7.3)	67.2 (6.7)	65.3 (7.1)	68.5 (9.1)	71.2 (9.5)	-14.9 (3.3)	-17.9 (4.1)
*$F(3.2, 29) = 515.6$	A	B	A	A	A	A	B	C
Hip range of motion	0.3 (0.1)	0.4 (0.1)	26.6 (3.4)	26.1 (5.4)	10.6 (5.6)	15.4 (8.8)	35.9 (3.3)	43.2 (2.1)
*$F(2.9, 25.7) = 138.9$	A	B	C	C, D, E	F	D, F	E	G
Max knee flexion	86.2 (14.6)	3.1 (2)	92 (6.8)	91.1 (6)	89.1 (9.1)	90 (8.3)	49.9 (3.2)	60.2 (3.1)
*$F(2.2, 19.6) = 241.8$	A	B	A	A	A	A	C	D
Max knee extension	85.9 (14.6)	2.8 (2)	65.7 (6.2)	62.7 (6.1)	63.6 (11.4)	61.3 (8.8)	1.5 (2.8)	1.7 (3.3)
*$F(2.2, 20.1) = 287$	A	B	C	C	C	C	B	B
Knee range of motion	0.3 (0)	0.3 (0)	26.3 (3.6)	28.4 (2.4)	25.5 (5.4)	28.7 (4.1)	48.4 (3.3)	58.5 (2.6)
*$F(2.7, 24.1) = 433.6$	A	B	C	C	C	C	D	E
Max ankle flexion	3.4 (9.7)	4.7 (3.6)	15.6 (9.6)	15.7 (9.0)	21.2 (11.6)	15.6 (14.3)	-	-
$F(5, 45) = 57.5$	A	A	B	B	B	B	-	-
Max ankle extension	3.0 (9.7)	4.4 (3.6)	-4.8 (12.7)	-11.1 (10.6)	-20.4 (19)	-27.8 (24.2)	-	-
$F(5, 45) = 61$	A	A	A	B	C	D	-	-
Ankle range of motion	0.3 (0.1)	0.3 (0)	20.5 (8.6)	26.9 (10.4)	41.6 (10.9)	43.4 (11.6)	-	-
*$F(2.6, 23.1) = 112.8$	A	A	B	C	D	D	-	-

6.5 Discussion

Walking and remaining physically active often are the main goals for people with physical disabilities. However, many have difficulty pursuing these objectives after discharge from physical therapy due to reasons such as the unavailability of exercise equipment, prolonged working hours in sedentary jobs, or just the lack of time due to other life challenges. With approximately 17.6 million adults in the U.S. experiencing difficulty with walking, the need for an effective exercise interventions after discharge form therapy has never been more demanding (Schiller, Lucas, and Peregoy, 2012). Recently, cost efficient exercise machines that can be used at the desk, i.e., active workstations, have been burgeoning, and could augment the lower extremity rehabilitation of those with injuries. The results of this study provide normative values regarding the muscle demands of eight lower extremity muscles and sagittal plane kinematic measures of the hip, knee, and ankle joints during eight different working conditions at the desk: sitting, standing, under desk cycling (15 and 35 W), under desk elliptical training (15 and 35 W), and treadmill desk walking (2.5 and 3.2 km/h). To our knowledge, this is the first study to investigate the muscle demands and joint kinematics of under desk cycling, under desk elliptical training, and treadmill desk walking. The evidence-based data can be used to help guide clinical decision making related to the use of active workstations in lower extremity training and rehabilitation.

The treadmill desk walking condition showed similar muscle demands compared to regular treadmill walking, which have been proven to be safe and as effective as overground walking (Riley et al., 2007; Lee and Hidler, 2008; Wank, Frick, and Schmidtbleicher, 1998). This could indicate that the treadmill desk walking condition could be a potential gait training method that can be accomplished in the workplace. The muscle demands for the DeskCycle and Cubii showed opposing effects. The DeskCycle showed more similarity to the upper leg muscle demands of treadmill desk walking, while the Cubii showed more similarity to the lower leg muscle demands of treadmill desk walking. However, participant feedback indicated that the Cubii required a greater effort on the lower leg muscles to move the ankles, especially at the 35 W intensity level. Most participants also reported that it would be difficult to pedal at the 35 W for both the DeskCycle and the Cubii for longer periods. This could indicate that the DeskCycle at the lower intensity 15 W might be more appropriate in terms of muscle demands if the treadmill desk was not a feasible option (Cho, Freivalds, and Rovniak, 2017).

Kinematic analysis revealed many similarities as well as distinct differences between the use of the three different active workstations each at two different intensity levels. First, the hip range of motion was significantly higher for the Treadmill conditions and were similar to overground walking based on previous research (Lee and Hidler, 2008). This allows the users to strengthen the muscles and joints that are required for walking. However, the hip range of motion for the DeskCycle should also be notable because there was some similarity to that of the Treadmill condition. Knee range of motions were not significantly different between the DeskCycle and Cubii conditions. However, the two conditions showed significant differences in the hip and ankle range of motions. The hip, knee, and ankle range of motions for the DeskCycle were fairly balanced with 26.4, 27.4, and 23.7 degrees, while the Cubii showed minimal hip motion and greater ankle motion with 13, 27.1, and 42.5 degrees. The differences in these could be due to the nature of different motions required for cycling and elliptical training, which is in line with a study that compared the kinematics and muscle activations of isokinetic cycling and elliptical stepping (Hamzaid, Smith, and Davis, 2013). Another reason for this could be the manufacturers' different approach towards solving the desk clearance problem. Because leg motions were limited to perform underneath the desk (unlike treadmill desk walking), the kinematic motions have to be distributed towards the three joints in the lower extremity. The joint range of motions were balanced for the DeskCycle while the Cubii focused more of the kinematic motion towards the ankle joint and minimized on the hip joint. Although this was not identified in this study, these results could indicate that the Cubii has an advantage when used at standard desks due to the lower max hip flexion, which would require less desk clearance. Based on participant feedback, the DeskCycle (N=7) or Treadmill (N=4) was selected as the preferred active workstation primarily because the motion was more smooth and natural. However, the majority of participants (N=9) chose the DeskCycle considering workplace feasibility.

Several limitations of this study should be noted. The muscle demands and joint kinematics were investigated on eleven young male participants with similar anthropometric characteristics and no gait pathologies. The results might explain the effect of active workstations on this type of population and can be used as foundation work. However, further investigation is required to obtain widely applicable results, especially to those that experience difficulty with walking. Although all participants reported some experience in using exercise machines (e.g., treadmills, stationary bikes, and elliptical machines), none have had experience using active workstations. Therefore, participants were instructed on how to properly use the machines and a practice session was also given for familiarization. However, even with guidelines being provided participants sat in slightly different postures based on their preference, which would affect the muscle activity and joint kinematics. Therefore, further testing may conduct a longitudinal study and include more diverse populations to capture the variability between participants and minimize any possible carry over effects, e.g., changing their posture or acquiring muscle memory after certain amount of use. Only sagittal-plane kinematics during the use of active workstations have been discussed in this study. However, meaningful variations may exist in the frontal and transverse planes. Future studies could investigate the variations in non sagittal-plane kinematics for practice.

Chapter 7
Conclusion

Prevalence of overweight and obesity has definitely become one of the most significant epidemics in many countries around the world. Many factors are involved in the pathogenesis of this disease, but due to the etiology of obesity being complex the exact causes are still unknown. Studies have shown that one of the largest contributors to the weight gain epidemic has been the trend for work environments to require less physical activity in industrialized populations.

Recent experimental studies have found that replacing excessive sedentary behavior with light physical activity may be beneficial to one's health. However, further investigation is needed to validate and better understand the use of active workstations. This study investigates the physiological, biomechanical, and cognitive effects of using active workstations and discusses ways to improve the usability through four different studies: (1) Utilizing anthropometric data to improve the usability of desk bikes, and influence of desk bikes on reading and typing performance; (2) Effects of an under desk bike on office related tasks; (3) Energy expenditure of sitting, standing, and using three active workstations; and (4) Lower extremity muscle demands and joint kinematics of under desk cycling, under desk elliptical training, and treadmill desk walking.

The first study investigated the ergonomics features of using the DeskCycle in an office workstation. Recommended adjustable ranges of workstation settings for the general U.S. population and a preferred cycling intensity was determined. This study also extended prior research by measuring reading and typing tasks when using the DeskCycle. The results determined that cycling did not have significant effect on reading comprehension, but had significant impact on typing performance. Lastly, this study determined preferred cycling intensity when performing reading comprehension and typing tasks.

The second study investigated the feasibility of increasing physical activity by using the DeskCycle while working on office related tasks on a broader demographic. Performance of reading, logical reasoning, and phone call answering were not significantly different between the cycling conditions. Typing performance was significantly different compared to the traditional seated posture, but only a modest deterioration was shown.

The third study determined the physiological effects of sitting and standing at the desk and using three different active workstations while writing on the computer and, in addition, to determined the validity and reliability of low-cost consumer-oriented active workstations. Results showed that active workstations could increase energy expenditure by 67.5 (DeskCycle 15 W) or up to 122.5 (treadmill 3.2 km/h) more kilocalories than they would expend per hour of sedentary sitting and writing on the computer.

The fourth study compared the lower extremity muscle demands and joint kinematics while sitting at the desk, standing at the desk, under desk cycling, under desk elliptical training, and treadmill desk walking to provide evidence-based data and guide clinical decision making in lower extremity training and rehabilitation.

This study presents a range of topics on the physiological, biomechanical, and cognitive effects of using active workstations in a controlled lab setting to support the research on promoting light physical activity in the workplace. Future studies may conduct a longitudinal field study and include diverse populations to obtain widely applicable results.

Appendix A

Directory List for Phone Call Task

Administration			Finance & Accounting			Human Resources		
Last Name	**First Name**	**Ext. #**	**Last Name**	**First Name**	**Ext. #**	**Last Name**	**First Name**	**Ext. #**
Ball	May	003	Allison	Derek	861	Allen	Chelsea	888
Banks	Jorge	771	Alvarado	Naomi	825	Andrews	Perry	780
Bell	Aubrey	435	Bennett	Corey	885	Bradley	Bill	087
Cook	Felicia	627	Craig	Donald	477	Carpenter	Pam	390
Cox	Phillip	876	Cross	Allan	408	Christensen	Francis	975
Douglas	Monique	546	Douglas	Terrance	837	Day	Kara	720
Fox	Shaun	015	Edwards	Virgil	189	Doyle	Luis	468
Gomez	Leon	579	Fowler	Phillip	213	Dunn	Genevieve	948
Greene	Natalie	822	Frank	Mabel	681	Edwards	Stuart	660
Hansen	Lloyd	261	Green	Sue	063	Erickson	Shelia	081
Hayes	Kelli	033	Greene	Ella	642	Ford	Dominic	168
Hoffman	Larry	309	Gregory	Jackie	252	Garrett	Juan	009
Johnston	Bonnie	444	Guzman	Timothy	606	Glover	Alexander	141
Kennedy	Sonja	429	Hansen	Omar	012	Harrington	Marilyn	303
Kim	Shelia	453	Jackson	Judy	675	Harrison	Kirk	603
Klein	Sergio	543	Kelly	Cecilia	972	Lamb	Frank	897
Lane	Francis	129	Manning	Steven	555	Long	Tamara	558
Lawson	Gregory	717	Martinez	Tricia	147	Maldonado	Simon	495
Leonard	Jeffrey	156	Mcdonald	Amy	396	Martin	Ray	234
Lucas	Tammy	711	Mcguire	Margarita	090	Mccormick	Scott	645
Mcguire	Randall	759	Mckenzie	Frankie	939	Mckinney	Pat	084
Morton	Irma	105	Moreno	Anthony	150	Mills	Shannon	702
Newton	Cindy	732	Pittman	Malcolm	072	Moody	Leticia	471
Norton	Milton	666	Pittman	Jodi	276	Moore	Johnnie	708
Page	Susie	099	Poole	Morris	279	Morales	Estelle	450
Paul	Eugene	093	Reed	Ramiro	417	Parks	Allison	762
Pena	Tasha	561	Rose	Lynne	201	Reeves	Lucia	474
Perry	Arnold	207	Saunders	Alberto	060	Riley	Earnest	765
Quinn	Maurice	123	Sharp	Wilfred	651	Rios	Stephanie	312
Ray	Clark	960	Simmons	Carlos	777	Rivera	Judith	483
Rice	Ginger	696	Stokes	Faye	792	Robertson	Silvia	957
Roberts	Brad	903	Sutton	Ethel	231	Santos	Beverly	069
Robertson	Courtney	447	Todd	Opal	351	Sharp	Willis	051
Rowe	Ben	414	Todd	Kirk	321	Strickland	Elmer	738
Sandoval	Kristi	573	Wagner	Herman	492	Watkins	Saul	510
Simmons	Carlton	819	Walker	Muriel	597	Williams	Maurice	291
Ward	Antoinette	654	Zimmerman	Gerald	690	Zimmerman	Alex	945

Information Technology			Operations			Production & Manufacturing		
Last Name	First Name	Ext. #	Last Name	First Name	Ext. #	Last Name	First Name	Ext. #
Banks	Edmund	426	Adams	Bradley	117	Allen	Vivian	393
Bates	Harvey	921	Ball	Kate	198	Alvarez	Don	513
Buchanan	Marco	678	Becker	Francisco	909	Alvarez	Tony	411
Cannon	Doug	114	Blair	Tracy	981	Baldwin	Jodi	504
Casey	Angela	747	Brady	Javier	768	Benson	Antoinette	399
Coleman	Camille	588	Brown	Henrietta	912	Boyd	Eunice	216
Estrada	Kathleen	075	Bryant	Doris	300	Clayton	Mamie	789
Fowler	Troy	441	Cooper	Elizabeth	174	Dean	Chad	915
Garner	Billy	006	Davis	Sean	246	Fox	Benjamin	621
Gibbs	Dustin	324	Ferguson	Marcos	192	Greer	Gerard	552
Gill	Barbara	753	Foster	Orlando	774	Gregory	Lorene	984
Gutierrez	Heidi	108	Griffith	Lillian	537	Hale	Martin	057
Hines	Herman	804	Jacobs	Susie	330	Hart	Alfonso	540
Houston	Damon	894	Jacobs	Arlene	906	Haynes	Earl	249
Hughes	Geraldine	564	Jordan	Brandon	519	Horton	Julian	285
Knight	Joseph	165	Joseph	Lila	501	Houston	Salvador	381
Lamb	Mamie	870	Kelley	Myron	795	Hudson	Eugene	963
Love	Keith	927	Klein	Phil	363	Jefferson	Jessie	990
Maldonado	Eloise	699	Lane	Rudolph	171	Jensen	Vincent	369
Malone	Rachel	786	Logan	Lee	669	Jimenez	Felicia	798
Marsh	Marvin	705	Lynch	Percy	576	Johnson	Erma	657
Morris	Ricardo	489	Matthews	Essie	042	Kennedy	Ian	366
Mullins	Shelley	258	Moore	Chris	102	Kim	Shaun	387
Nelson	Brandon	801	Morris	Nick	873	Lawrence	Jared	159
Parsons	Amy	486	Neal	Allison	756	Lucas	Antonia	120
Pearson	Carla	018	Paul	Vickie	162	Mann	Julius	345
Potter	Rick	840	Potter	Clyde	456	Massey	Jo	618
Reynolds	Maxine	924	Reyes	Caroline	264	Moreno	Erik	333
Roberson	Frankie	531	Rhodes	Noel	183	Newton	Clifford	624
Romero	Jeremy	744	Sanchez	Elizabeth	900	Ramsey	Dixie	996
Salazar	Ian	375	Sandoval	Hazel	465	Ray	Rosalie	954
Silva	Jimmy	153	Soto	Casey	528	Roberts	Shannon	372
Stanley	Steve	132	Stevenson	Sophie	336	Rodriguez	Ellis	222
Stone	Loren	570	Sullivan	Terri	339	Singleton	Trevor	240
Underwood	Dora	438	Thomas	Brandon	357	Thornton	Victor	225
White	Rita	126	Wade	Fernando	633	Wheeler	Shannon	270
Wilson	Salvador	480	West	Loretta	918	Wise	Sabrina	630

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Hall	Dexter	195	Harris	Arturo	855	Hansen	Jaime	600
Hardy	Annie	726	Henderson	Jim	891	Hill	Danielle	663
Harmon	Francisco	879	Hicks	Laura	030	Howard	Cedric	615
Haynes	Margarita	021	Huff	Vicky	378	Leonard	Marion	966
Hicks	Julius	228	Maldonado	Kristine	282	Mann	Dianna	639
Hogan	Rosemarie	096	May	Marlene	066	Martinez	Orville	978
Howell	Louis	045	Morgan	Devin	267	Mathis	Wilson	507
Jennings	Justin	243	Mullins	Jody	294	Medina	Ramiro	672
King	Enrique	834	Murphy	Willis	186	Mendoza	Brian	459
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Mcbride	Marshall	522	Oliver	Alfonso	525	Norton	Muriel	288
Mendez	Veronica	882	Parks	Roger	843	Perez	Eva	828
Mendoza	Nicole	951	Patterson	Ramon	813	Peters	Yvonne	219
Nguyen	Ella	420	Perez	Dennis	741	Peterson	Percy	648
Norton	Cynthia	969	Peterson	Carrie	027	Reyes	Noel	384
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Sharp	Katherine	111	Summers	Diana	723	Snyder	Neal	549
Tran	Ora	327	Tyler	Angel	204	Spencer	Carla	423
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References

Alderman BL, Olson RL, Mattina DM. Cognitive function during low-intensity walking: a test of the treadmill workstation. Journal of physical activity and health. 2014 May;11(4):752-8.

Alkhajah, T. A., Reeves, M. M., Eakin, E. G., Winkler, E. A., Owen, N., & Healy, G. N. (2012). Sit–Stand workstations: a pilot intervention to reduce office sitting time. American journal of preventive medicine, 43(3), 298-303.

American National Standards Institute/Human Factors and Ergonomics Society. (2007). Human factors engineering of computer workstations (ANSI/HFES 100-2007). Santa Monica, CA: Human Factors and Ergonomics Society.

Aronne, L. J., Nelinson, D. S., & Lillo, J. L. (2009). Obesity as a disease state: a new paradigm for diagnosis and treatment. Clinical cornerstone, 9(4), 9-29.

Artinian NT, Fletcher GF, Mozaffarian D, et al. Interventions to promote physical activity and dietary lifestyle changes for cardiovascular risk factor reduction in adults. A scientific statement from the American Heart Association. Circulation. 2010 Jul 12.

Baddeley, A. D. (1968). A 3 min reasoning test based on grammatical transformation. Psychonomic Science, 10(10), 341-342.

Barness, L. A., Opitz, J. M., & Gilbert-Barness, E. (2007). Obesity: genetic, molecular, and environmental aspects. American Journal of Medical Genetics Part A, 143(24), 3016-3034.

Bartz, P. (2016). Razor Attitude and Heading Reference System (AHRS). Retrieved March 1, 2017, from https://github.com/Razor-AHRS/razor-9dof-ahrs

Beers, E. A., Roemmich, J. N., Epstein, L. H., & Horvath, P. J. (2008). Increasing passive energy expenditure during clerical work. European journal of applied physiology, 103(3), 353-360.

Beurskens, R., & Bock, O. (2012). Age-related deficits of dual-task walking: a review. Neural plasticity, 2012.

Biswas, A., Oh, P. I., Faulkner, G. E., Bajaj, R. R., Silver, M. A., Mitchell, M. S., & Alter, D. A. (2015). Sedentary time and its association with risk for disease incidence, mortality, and hospitalization in adults: a systematic review and meta-analysis. Annals of Internal Medicine, 162(2), 123-132.

Blair SN. Physical inactivity: the biggest public health problem of the 21st century. British journal of sports medicine. 2009 Jan 1;43(1):1-2.

Blair, S. N. & Brodney, S. (1999). Effects of physical inactivity and obesity on morbidity and mortality: current evidence and research issues. Medicine and science in sports and exercise, 31, S646-S662.

Borg, G. A. V. (1982). Psychophysical bases of perceived exertion. Med sci sports exerc, 14(5), 377-381.

Botter, J., Ellegast, R. P., Burford, E. M., Weber, B., Könemann, R., & Commissaris, D. A. (2016). Comparison of the postural and physiological effects of two dynamic workstations to conventional sitting and standing workstations. Ergonomics, 59(3), 449-463.

Buchner, D. M., Cress, M. E., De Lateur, B. J., Esselman, P. C., Margherita, A. J., Price, R., & Wagner, E. H. (1997). The effect of strength and endurance training on gait, balance, fall risk, and health services use in community-living older adults. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 52(4), M218-M224.

Bureau of Labor Statistics, U.S. Department of Labor, Occupational Outlook Handbook, 2014-15 Edition, General Office Clerks. Retrieved from http://www.bls.gov/ooh/office-and-administrative-support/general-office-clerks.htm#tab-2

Burnfield, J. M., Shu, Y., Buster, T., & Taylor, A. (2010). Similarity of joint kinematics and muscle demands between elliptical training and walking: implications for practice. Physical therapy, 90(2), 289.

Carnethon, M., Whitsel, L. P., Franklin, B. A., Kris-Etherton, P., Milani, R., Pratt, C. A., & Wagner, G. R. (2009). Worksite wellness programs for cardiovascular disease prevention a policy statement from the American Heart Association. Circulation, 120(17), 1725-1741.

Carnevale, A. P. (1990). Workplace Basics: The Essential Skills Employers Want. ASTD Best Practices Series: Training for a Changing Work Force. Jossey-Bass Inc., Publishers, 350 Sansome Street, San Francisco, CA 94104.

Carr, L. J., Karvinen, K., Peavler, M., Smith, R., & Cangelosi, K. (2013). Multicomponent intervention to reduce daily sedentary time: a randomised controlled trial. BMJ open, 3(10), e003261.

Carr, L. J., Maeda, H., Luther, B., Rider, P., Tucker, S. J., & Leonhard, C. (2014). Acceptability and effects of a seated active workstation during sedentary work: A proof of concept study. International Journal of Workplace Health Management, 7(1), 2-15.

Cattell, R. B. (1971). Abilities: their structure, growth, and action.

Centers for Disease Control and Prevention (2014). National Health and Nutrition Examination Survey. Retrieved from http://www.cdc.gov/nchs/nhanes.htm

Centers for Disease Control and Prevention (2014). Overweight and Obesity. Retrieved from http://www.cdc.gov/obesity/index.html

Centers for Disease Control and Prevention (2014). Wellness at Work. Retrieved from http://www.cdc.gov/features/workingwellness/

Chang, J., Jung, K., Hwang, J., Kang, Y., Lee, S., & Freivalds, A. (2010). Determination of Bicycle Handle Diameters considering Hand Anthropometric Data and User Satisfaction. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting (Vol. 54, No. 20, pp. 1790-1793). SAGE Publications.

Cho, J., Freivalds, A., & Rovniak, L. S. (2017). Utilizing anthropometric data to improve the usability of desk bikes, and influence of desk bikes on reading and typing performance. Applied Ergonomics, 60, 128-135.

Cho, J., Freivalds, A., Rovniak, L., Sung, K., & Hatzell, J. (2014). Using a Desk-Compatible Recumbent Bike in an Office Workstation. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting (Vol. 58, No. 1, pp. 1662-1666). SAGE Publications.

Commissaris, D. A., Könemann, R., Hiemstra-van Mastrigt, S., Burford, E. M., Botter, J., Douwes, M., & Ellegast, R. P. (2014). Effects of a standing and three dynamic workstations on computer task performance and cognitive function tests. Applied ergonomics, 45(6), 1570-1578.

Damiano, D. L., Norman, T., Stanley, C. J., & Park, H. S. (2011). Comparison of elliptical training, stationary cycling, treadmill walking and overground walking. Gait & posture, 34(2), 260-264.

Das, B., & Sengupta, A. K. (1996). Industrial workstation design: a systematic ergonomics approach. Applied Ergonomics, 27(3), 157-163.

de Rezende LF, Lopes MR, Rey-López JP, Matsudo VK, do Carmo Luiz O. Sedentary behavior and health outcomes: an overview of systematic reviews. PloS one. 2014 Aug 21;9(8):e105620.

Dempster, W. T. (1955). Space requirements of the seated operator: geometrical, kinematic, and mechanical aspects of the body, with special reference to the limbs.

Does an Exercise Ball Chair Actually Give You Any Health Benefits? (2013). Retrieved from http://www.livestrong.com/blog/does-an-exercise-ball-chair-actually-give-you-any-health-benefits/

Drewnowski, A. (2004). Obesity and the food environment: dietary energy density and diet costs. American journal of preventive medicine, 27(3), 154-162.

Drewnowski, A., & Specter, S. E. (2004). Poverty and obesity: the role of energy density and energy costs. The American journal of clinical nutrition, 79(1), 6-16.

Dunstan, D. W., Kingwell, B. A., Larsen, R., Healy, G. N., Cerin, E., Hamilton, M. T., ... & Owen, N. (2012). Breaking up prolonged sitting reduces postprandial glucose and insulin responses. Diabetes care, 35(5), 976-983.

Eknoyan, G. (2008). Adolphe Quetelet (1796 -1874) – the average man and indices of obesity. Nephrology Dialysis Transplantation, 23(1), 47-51.

Elmer, S.J. & Martin, J.C. (2014). A cycling workstation to facilitate physical activity in office settings. Appl. Ergon. 45, 1240-1246.

Evans, G. W., & Johnson, D. (2000). Stress and open-office noise. Journal of Applied Psychology, 85(5), 779.

Ezzati, M., Lopez, A. D., Rodgers, A., Vander Hoorn, S., & Murray, C. J. (2002). Selected major risk factors and global and regional burden of disease. The Lancet, 360(9343), 1347-1360.

Faghri, P. D., Omokaro, C., Parker, C., Nichols, E., Gustavesen, S., & Blozie, E. (2008). E-technology and pedometer walking program to increase physical activity at work. The journal of primary prevention, 29(1), 73-91.

Finkelstein, E. A., Khavjou, O. A., Thompson, H., Trogdon, J. G., Pan, L., Sherry, B., & Dietz, W. (2012). Obesity and severe obesity forecasts through 2030. American journal of preventive medicine, 42(6), 563-570.

Finkelstein, E. A., Ruhm, C. J., & Kosa, K. M. (2005). Economic causes and consequences of obesity. Annu. Rev. Public Health, 26, 239-257.

Finkelstein, E. A., Trogdon, J. G., Cohen, J. W., & Dietz, W. (2009). Annual medical spending attributable to obesity: payer-and service-specific estimates. Health affairs, 28(5), w822-w831.

Finucane, M. M., Stevens, G. A., Cowan, M. J., Danaei, G., Lin, J. K., Paciorek, C. J., Singh, G. M., Gutierrez, H.R., Lu, Y., Bahalim, A. N., Farzadfar, F., Riley, L. M., & Ezzati, M. (2011). National, regional, and global trends in body-mass index since 1980: systematic analysis of health examination surveys and epidemiological studies with 960 country-years and 9.1 million participants. The Lancet, 377(9765), 557-567.

Flegal, K. M., Carroll, M. D., Ogden, C. L., & Curtin, L. R. (2010). Prevalence and trends in obesity among US adults. JAMA, 303(3), 235-241.

Flegal, K. M., Kit, B. K., Orpana, H., & Graubard, B. I. (2013). Association of all-cause mortality with overweight and obesity using standard body mass index categories: a systematic review and meta-analysis. Jama, 309(1), 71-82.

Flower, L., & Hayes, J. R. (1981). A cognitive process theory of writing. College composition and communication, 32(4), 365-387.

Freedman, D. S. & Centers for Disease Control and Prevention (CDC). (2011). Obesity – United States, 1988 – 2008. MMWR Surveill Summ, 60(01), 73-7.

Fryar, C. D., Gu, Q., & Ogden, C. L. (2012). Anthropometric reference data for children and adults: United States, 2007–2010. National Center for Health Statistics Vital and Health Statistics, 11, 1-40.

Fryar, C.D., Carroll, M.D., & Ogden, C.L. (2014). Prevalence of Overweight, Obesity, and Extreme Obesity Among Adults: United States, 1960 – 1962 Through 2011 – 2012. Division of Health and Nutrition Examination Surveys

Furnham, A. (2010). Proofreading as an index of crystallised intelligence. Educational Psychology, 30(6), 735-754.

Furnham, A., & McClelland, A. (2010). Word frequency effects and intelligence testing. Personality and Individual Differences, 48(5), 544-546.

Galinsky, T., Swanson, N., Sauter, S., Dunkin, R., Hurrell, J., & Schleifer, L. (2007). Supplementary breaks and stretching exercises for data entry operators: A follow-up field study. American journal of industrial medicine, 50(7), 519-527.

Garneau, C. J., & Parkinson, M. B. (2009). Including preference in anthropometry-driven models for design. Journal of Mechanical Design, 131(10), 101006.

Garneau, C. J., & Parkinson, M. B. (2011). A comparison of methodologies for designing for human variability. Journal of Engineering Design, 22(7), 505-521.

Gordon, C. C., Churchill, T., Clauser, C. E., Bradtmiller, B., & McConville, J. T. (1989). Anthropometric survey of US army personnel: methods and summary statistics 1988. Anthropology Research Project Inc. Yellow Springs OH.

Hägg, G. M. (1991). Static work loads and occupational myalgia-a new explanation model. Electromyographical kinesiology, 949, 141-144.

Hagley, F. (1987). Suffolk Reading Scale. NFER-NELSON: Windsor.

Haines, M. M., Stansfeld, S. A., Job, R. S., Berglund, B., & Head, J. (2001). Chronic aircraft noise exposure, stress responses, mental health and cognitive performance in school children. Psychological medicine, 31(02), 265-277.

Hallal, P. C., Andersen, L. B., Bull, F. C., Guthold, R., Haskell, W., Ekelund, U., & Lancet Physical Activity Series Working Group. (2012). Global physical activity levels: surveillance progress, pitfalls, and prospects. The lancet, 380(9838), 247-257.

Hamilton, M. T., Hamilton, D. G., & Zderic, T. W. (2007). Role of low energy expenditure and sitting in obesity, metabolic syndrome, type 2 diabetes, and cardiovascular disease. Diabetes, 56(11), 2655-2667.

Hamzaid, N. A., Smith, R. M., & Davis, G. M. (2013). Isokinetic cycling and elliptical stepping: a kinematic and muscle activation analysis. Clinical Research on Foot & Ankle, 1-7.

Haskell WL, Lee IM, Pate RR, et al. Physical activity and public health. Updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. Circulation. 2007 Aug 1.

Healy GN, Matthews CE, Dunstan DW, Winkler EA, Owen N. Sedentary time and cardiometabolic biomarkers in US adults: NHANES 2003–06. European heart journal. 2011 Jan 11: 32(5):590-7.

Henning, R. A., Jacques, P., Kissel, G. V., Sullivan, A. B., & Alteras-Webb, S. M. (1997). Frequent short rest breaks from computer work: effects on productivity and well-being at two field sites. Ergonomics, 40(1), 78-91.

Hermens, H. J., Freriks, B., Merletti, R., Stegeman, D., Blok, J., Rau, G., ... & Hägg, G. (1999). European recommendations for surface electromyography. Roessingh research and development, 8(2), 13-54.

Hesse, S., Bertelt, C., Jahnke, M. T., Schaffrin, A., Baake, P., Malezic, M., & Mauritz, K. H. (1995). Treadmill training with partial body weight support compared with physiotherapy in nonambulatory hemiparetic patients. Stroke, 26(6), 976-981.

HFES 300 Committee (Ed.). (2004). Guidelines for using anthropometric data in product design. Human Factors and Ergonomics Society.

Hislop, H., Avers, D., & Brown, M. (2013). Daniels and Worthingham's muscle testing: Techniques of manual examination and performance testing. Elsevier Health Sciences.

Hjortskov N, Rissén D, Blangsted AK, Fallentin N, Lundberg U, Søgaard K. The effect of mental stress on heart rate variability and blood pressure during computer work. European journal of applied physiology. 2004 Jun 1;92(1-2):84-9.

Hrdlička, A. (1920). Anthropometry. American Journal of Physical Anthropology, 3(1), 147-173.

John, D., Bassett, D., Thompson, D., Fairbrother, J., & Baldwin, D. (2009). Effect of using a treadmill workstation on performance of simulated office work tasks. Journal of physical activity and health, 6(5), 617-624.

Joslin, R. E. (2014, September). Examination of Anthropometric Databases for Aircraft Design. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting (Vol. 58, No. 1, pp. 1-5). SAGE Publications.

Kasman, G. S., & Wolf, S. L. (2002). Surface EMG made easy: a beginner's guide for rehabilitation clinicians. Scottsdale: Noraxon USA.

Katzmarzyk, P. T., Church, T. S., Craig, C. L., & Bouchard, C. (2009). Sitting time and mortality from all causes, cardiovascular disease, and cancer. Med Sci Sports Exerc, 41(5), 998-1005.

Kellogg, R. T. (1988). Attentional overload and writing performance: Effects of rough draft and outline strategies. Journal of Experimental Psychology: Learning, Memory, and Cognition, 14(2), 355.

Keytel LR, Goedecke JH, Noakes TD, et al. Prediction of energy expenditure from heart rate monitoring during submaximal exercise. Journal of sports sciences. 2005 Mar 1;23(3):289-97.

Kirsch, I. S. (1993). Adult Literacy in America: A First Look at the Results of the National Adult Literacy Survey. US Government Printing Office, Superintendent of Documents, Washington, DC 20402 (Stock No. 065-000-00588-3).

Konvalin, C. (2009). Compensating for tilt, hard-iron and soft-iron effects. Sens. Mag, 1-11.

Kruger, J., Ham, S. A., & Kohl III, H. W. (2005). Trends in leisure-time physical inactivity by age, sex, and race/ethnicity-United States, 1994-2004. Morbidity and Mortality Weekly Report, 54(39), 991-994.

Kruger, J., Kohl III, H. W., & Miles, I. J. (2007). Prevalence of regular physical activity among adults-United States, 2001 and 2005. Morbidity and Mortality Weekly Report, 56(46), 1209-1212.

Kuczmarski, R. J., Ogden, C. L., Guo, S. S., Grummer-Strawn, L. M., Flegal, K. M., Mei, Z., Wei, R., Curtin, L.R., Roche, A.F., & Johnson, C. L. (2002). 2000 CDC Growth Charts for the United States: methods and development. Vital and health statistics. Series 11, Data from the national health survey, (246), 1-190.

Lee IM, Shiroma EJ, Lobelo F, et al. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. The lancet. 2012 Jul 27;380(9838):219-29.

Lee, D. C., Pate, R. R., Lavie, C. J., Sui, X., Church, T. S., & Blair, S. N. (2014). Leisure-time running reduces all-cause and cardiovascular mortality risk. Journal of the American College of Cardiology, 64(5), 472-481.

Lee, S. J., & Hidler, J. (2008). Biomechanics of overground vs. treadmill walking in healthy individuals. Journal of applied physiology, 104(3), 747-755.

Levine, J. A., & Miller, J. M. (2007). The energy expenditure of using a ‘walk-and-work’ desk for office workers with obesity. British journal of sports medicine, 41(9), 558-561.

Liu, Y. C., & Wen, M. H. (2004). Comparison of head-up display (HUD) vs. head-down display (HDD): driving performance of commercial vehicle operators in Taiwan. International Journal of Human-Computer Studies, 61(5), 679-697.

Lose Weight While You Work (2008). Retrieved from http://howto.wired.com/wiki/Lose_Weight_While_You_Work

Ma, J., Xiao, L., & Stafford, R. S. (2009). Adult Obesity and Office-based Quality of Care in the United States. Obesity, 17(5), 1077-1085.

MacKenzie, I. S., & Tanaka-Ishii, K. (2010). Text entry systems: Mobility, accessibility, universality. Morgan Kaufmann.

Macko, R. F., Ivey, F. M., Forrester, L. W., Hanley, D., Sorkin, J. D., Katzel, L. I., ... & Goldberg, A. P. (2005). Treadmill exercise rehabilitation improves ambulatory function and cardiovascular fitness in patients with chronic stroke. Stroke, 36(10), 2206-2211.

Mahoney, J. M., Kurczewski, N. A., & Froede, E. W. (2015). Design method for multi-user workstations utilizing anthropometry and preference data. Applied ergonomics, 46, 60-66.

Malina, R. M., Bouchard, C., & Bar-Or, O. (2004). Growth, maturation, and physical activity. Human Kinetics.

Marsh AP, Martin PE. Effect of cycling experience, aerobic power, and power output on preferred and most economical cycling cadences. Medicine and Science in Sports and Exercise. 1997 Sep;29(9):1225-32.

Matthews, C. E., Chen, K. Y., Freedson, P. S., Buchowski, M. S., Beech, B. M., Pate, R. R., & Troiano, R. P. (2008). Amount of time spent in sedentary behaviors in the United States, 2003–2004. American journal of epidemiology, 167(7), 875-881.

Miyai, I., Fujimoto, Y., Ueda, Y., Yamamoto, H., Nozaki, S., Saito, T., & Kang, J. (2000). Treadmill training with body weight support: its effect on Parkinson’s disease. Archives of physical medicine and rehabilitation, 81(7), 849-852.

Nelson ME, Rejeski WJ, Blair SN, et al. Physical activity and public health in older adults. Recommendation from the American College of Sports Medicine and the American Heart Association. Circulation. 2007 Aug 1;116(9), 1094.

Neuhaus, M., Eakin, E. G., Straker, L., Owen, N., Dunstan, D. W., Reid, N., & Healy, G. N. (2014). Reducing occupational sedentary time: a systematic review and meta-analysis of evidence on activity-permissive workstations. Obesity Reviews, 15(10), 822-838.

Ng, M., Fleming, T., Robinson, M., Thomson, B., Graetz, N., Margono, C., ... & Abraham, J. P. (2014). Global, regional, and national prevalence of overweight and obesity in children and adults during 1980?2013: a systematic analysis for the Global Burden of Disease Study 2013. The lancet, 384(9945), 766-781.

Ogden, C. L., Fryar C.D., Carroll M.D., & Flegal K.M. (2004). Mean body weight, height, and body mass index, United States 1960–2002 (pp. 1-17). Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Health Statistics.

Ogden, C. L., Yanovski, S. Z., Carroll, M. D., & Flegal, K. M. (2007). The epidemiology of obesity. Gastroenterology, 132(6), 2087-2102.

Ogden, C. L., Carroll, M. D., Kit, B. K., & Flegal, K. M. (2014). Prevalence of childhood and adult obesity in the United States, 2011-2012. Jama, 311(8), 806-814.

Oh, S., & Radwin, R. G. (1993). Pistol grip power tool handle and trigger size effects on grip exertions and operator preference. Human Factors: The Journal of the Human Factors and Ergonomics Society, 35(3), 551-569.

Ohlinger, C. M., Horn, T. S., Berg, W. P., & Cox, R. H. (2011). The effect of active workstation use on measures of cognition, attention, and motor skill. Journal of physical activity and health, 8(1), 119-125.

Osilla, K. C., Van Busum, K., Schnyer, C., Larkin, J. W., Eibner, C., & Mattke, S. (2012). Systematic review of the impact of worksite wellness programs. The American journal of managed care, 18(2), e68-81.

Owen N, Healy GN, Matthews CE, Dunstan DW. Too much sitting: the population-health science of sedentary behavior. Exercise and sport sciences reviews. 2010 Jul;38(3):105.

Parkinson, M. B., & Reed, M. P. (2010). Creating virtual user populations by analysis of anthropometric data. International Journal of Industrial Ergonomics, 40(1), 106-111.

Parry, S., & Straker, L. (2013). The contribution of office work to sedentary behaviour associated risk. BMC public health, 13(1), 1.

Perotto, A., Delagi, E. F., Iazzetti, J., & Morrison, D. (2011). Anatomical guide for the electromyographer: the limbs and trunk (5th ed.). Charles C Thomas Publisher.

Pheasant, S., & Haslegrave, C. M. (2005). Bodyspace: Anthropometry, ergonomics and the design of work. CRC Press.

Phuong, N. H. Q., Kang, H. J., Suh, Y. S., & Ro, Y. S. (2009). A DCM based orientation estimation algorithm with an inertial measurement unit and a magnetic compass. Journal of Universal Computer Science, 15(4), 859-876.

Popkin, B. M., Adair, L. S., & Ng, S. W. (2012). Global nutrition transition and the pandemic of obesity in developing countries. Nutrition reviews, 70(1), 3-21.

Premerlani, W., & Bizard, P. (2009). Direction cosine matrix imu: Theory. Diy Drone: Usa, 13-15.

Prentice, A. M. (2006). The emerging epidemic of obesity in developing countries. International Journal of epidemiology, 35(1), 93-99.

Prosser, L. A., Stanley, C. J., Norman, T. L., Park, H. S., & Damiano, D. L. (2011). Comparison of elliptical training, stationary cycling, treadmill walking and overground walking. Electromyographic patterns. Gait & posture, 33(2), 244-250.

Reed, M. P., & Flannagan, C. A. (2000). Anthropometric and postural variability: limitations of the boundary manikin approach (No. 2000-01-2172). SAE Technical Paper.

Reiff, C., Marlatt, K., & Dengel, D. R. (2012). Difference in caloric expenditure in sitting versus standing desks. Journal of Physical Activity and Health, 9(7), 1009.

Riley, P. O., Paolini, G., Della Croce, U., Paylo, K. W., & Kerrigan, D. C. (2007). A kinematic and kinetic comparison of overground and treadmill walking in healthy subjects. Gait & posture, 26(1), 17-24.

Robinette, K. M., Blackwell, S., Daanen, H., Boehmer, M., & Fleming, S. (2002). Civilian American and European Surface Anthropometry Resource (CAESAR), Final Report. Volume 1. Summary. SYTRONICS INC DAYTON OH.

Robroek, S. J., Van Lenthe, F. J., Van Empelen, P., & Burdorf, A. (2009). Determinants of participation in worksite health promotion programmes: a systematic review. International Journal of Behavioral Nutrition and Physical Activity, 6(1), 26.

Rothman, K. J. (2008). BMI-related errors in the measurement of obesity. International journal of obesity, 32, S56-S59.

Rovniak, L. S., Denlinger, L., Duveneck, E., Sciamanna, C. N., Kong, L., Freivalds, A., & Ray, C. A. (2014). Feasibility of using a compact elliptical device to increase energy expenditure during sedentary activities. Journal of Science and Medicine in Sport, 17(4), 376-380.

Salthouse, T. A. (1984). Effects of age and skill in typing. Journal of Experimental Psychology: General, 113(3), 345.

Samani, A., Holtermann, A., Søgaard, K., & Madeleine, P. (2009). Active pauses induce more variable electromyographic pattern of the trapezius muscle activity during computer work. Journal of Electromyography and Kinesiology, 19(6), e430-e437.

Schiller, J. S., Lucas, J. W., & Peregoy, J. A. (2012). Summary health statistics for US adults: national health interview survey, 2011.

Schuna JM, Tudor-Locke C, Proença M, et al. Validation of an integrated pedal desk and electronic behavior tracking platform. BMC research notes. 2016 Feb 9;9(1):74.

Schuna, J. M., Tudor-Locke, C., Proença, M., Barreira, T. V., Hsia, D. S., Pitta, F., ... & Martin, C. K. (2016). Validation of an integrated pedal desk and electronic behavior tracking platform. BMC research notes, 9(1), 74.

Sheehy, J. B., Kamon, E., & Kiser, D. (1982). Effects of carbon dioxide inhalation on psychomotor and mental performance during exercise and recovery. Human Factors: The Journal of the Human Factors and Ergonomics Society, 24(5), 581-588.

Shu, Y., Buster, T. W., Taylor, A., Keenan, S., Nelson, C. A., & Burnfield, J. M. (2010). Ergonomic redesign of elliptical trainer to promote greater safety, comfort and usability. In Online Proceedings, Rehabilitation Engineering and Assistive Technology Society of North America's 2010 Annual Conference

Soler, R. E., Leeks, K. D., Buchanan, L. R., Brownson, R. C., Heath, G. W., & Hopkins, D. H. (2010). Point-of-decision prompts to increase stair use: a systematic review update. American journal of preventive medicine, 38(2), S292-S300.

Speck, R. M., & Schmitz, K. H. (2011). Energy expenditure comparison: a pilot study of standing instead of sitting at work for obesity prevention. Preventive medicine, 52(3), 283-284.

Spurr GB, Prentice AM, Murgatroyd PR, Goldberg GR, Reina JC, Christman NT. Energy expenditure from minute-by-minute heart-rate recording: comparison with indirect calorimetry. The American journal of clinical nutrition. 1988 Sep 1;48(3):552-9.

Stach T, Graham TC, Yim J, Rhodes RE. Heart rate control of exercise video games. In: Proceedings of the 35th Graphics interface; 2009 May 25-27: Kelowna, British Columbia, Canada; 2009. p. 125-32.

Stahl SE, An HS, Dinkel DM, Noble JM, Lee JM. How accurate are the wrist-based heart rate monitors during walking and running activities? Are they accurate enough?. BMJ Open Sport & Exercise Medicine. 2016 Apr 1;2(1):e000106.

Stevens, J., McClain, J. E., & Truesdale, K. P. (2008). Selection of measures in epidemiologic studies of the consequences of obesity. International Journal of Obesity, 32, S60-S66.

Straker, L., Levine, J., & Campbell, A. (2009). The effects of walking and cycling computer workstations on keyboard and mouse performance. Human Factors: The Journal of the Human Factors and Ergonomics Society, 51(6), 831-844.

Swartz, A. M., Squires, L., & Strath, S. J. (2011). Energy expenditure of interruptions to sedentary behavior. Int J Behav Nutr Phys Act, 8(69), 10-1186.

Swinburn, B. A., Sacks, G., Hall, K. D., McPherson, K., Finegood, D. T., Moodie, M. L., & Gortmaker, S. L. (2011). The global obesity pandemic: shaped by global drivers and local environments. The Lancet, 378(9793), 804-814.

Swinburn, B., Sacks, G., & Ravussin, E. (2009). Increased food energy supply is more than sufficient to explain the US epidemic of obesity. The American journal of clinical nutrition, 90(6), 1453-1456.

Teh, K. C., & Aziz, A. R. (2002). Heart rate, oxygen uptake, and energy cost of ascending and descending the stairs. Medicine and science in sports and exercise, 34(4), 695-699.

Thomas, S., Reading, J., & Shephard, R. J. (1992). Revision of the Physical Activity Readiness Questionnaire (PAR-Q). Canadian journal of sport sciences.

Thompson, W.G., & Levine, J.A. (2011). Productivity of transcriptions using a treadmill desk. Work 40 (4), 473-477.

To, Q. G., Chen, T. T., Magnussen, C. G., & To, K. G. (2013). Workplace physical activity interventions: a systematic review. Health Promotion, 27(6), e113-e123.

Torbeyns, T., Bailey, S., de Geus, B., & Meeusen, R. (2015). The use of cycling workstations in public places–an observational study. Public health, 129(11), 1439-1443.

Tudor-Locke, C., Leonardi, C., Johnson, W. D., & Katzmarzyk, P. T. (2011). Time spent in physical activity and sedentary behaviors on the working day: the American time use survey. Journal of Occupational and Environmental Medicine, 53(12), 1382-1387.

Tudor-Locke, C., Schuna, J. M., Frensham, L. J., & Proenca, M. (2014). Changing the way we work: elevating energy expenditure with workstation alternatives. International journal of obesity, 38(6), 755-765.

U.S. Department of Health and Human Services, Washington, DC. (2000). Healthy people 2010: understanding and improving health. ERIC Clearinghouse.

U.S. Department of Labor, Bureau of Labor Statistics. (2015). General Office Clerks. Occupational Outlook Handbook, 2016-17. Retrieved from http://www.bls.gov/ooh/office-and-administrative-support/general-office-clerks.htm (visited May 17, 2017).

Untaroiu, C., Shin, J., Ivarsson, J., Crandall, J., Takahashi, Y., Akiyama, A., & Kikuchi, Y. (2007). Pedestrian kinematics investigation with finite element dummy model based on anthropometry scaling method. In Proc. 20th Int. Technical Conf. Enhanced Safety of Vehicle.

Van Uffelen, J. G., Wong, J., Chau, J. Y., van der Ploeg, H. P., Riphagen, I., Gilson, N. D., ... & Brown, W. J. (2010). Occupational sitting and health risks: a systematic review. American journal of preventive medicine, 39(4), 379-388.

Vercruyssen, M., Kamon, E., & Hancock, P. A. (2007). Effects of carbon dioxide inhalation on psychomotor and mental performance during exercise and recovery. International Journal of Occupational Safety and Ergonomics, 13(1), 15.

Wang, N., & Boubekri, M. (2010). Investigation of declared seating preference and measured cognitive performance in a sunlit room. Journal of Environmental Psychology, 30(2), 226-238.

Wang, Y. C., McPherson, K., Marsh, T., Gortmaker, S. L., & Brown, M. (2011). Health and economic burden of the projected obesity trends in the USA and the UK. The Lancet, 378(9793), 815-825.

Wang, Y., & Lobstein, T. I. M. (2006). Worldwide trends in childhood overweight and obesity. International Journal of Pediatric Obesity, 1(1), 11-25.

Wang, Y., Beydoun, M. A., Liang, L., Caballero, B., & Kumanyika, S. K. (2008). Will all Americans become overweight or obese? Estimating the progression and cost of the US obesity epidemic. Obesity, 16(10), 2323-2330.

Wank, V., Frick, U., & Schmidtbleicher, D. (1998). Kinematics and electromyography of lower limb muscles in overground and treadmill running. International journal of sports medicine, 19(07), 455-461.

Warburton, D. E., Nicol, C. W., & Bredin, S. S. (2006). Health benefits of physical activity: the evidence. Canadian medical association journal, 174(6), 801-809.

Wardle, J., & Cooke, L. (2005). The impact of obesity on psychological well-being. Best Practice & Research Clinical Endocrinology & Metabolism, 19(3), 421-440.

Waters RL, Mulroy S. The energy expenditure of normal and pathologic gait. Gait & posture. 1999 Jul 31;9(3):207-31.

Weinsier, R. L., Hunter, G. R., Heini, A. F., Goran, M. I., & Sell, S. M. (1998). The etiology of obesity: relative contribution of metabolic factors, diet, and physical activity. The American journal of medicine, 105(2), 145-150.

Winter, D. A. (1995). Human balance and posture control during standing and walking. Gait & posture, 3(4), 193-214.

World Health Organization (2000). Obesity: preventing and managing the global epidemic (No. 894). World Health Organization.

World Health Organization (2014). Obesity and Overweight Fact Sheet. Retrieved from http://www.who.int/mediacentre/factsheets/fs311/en/

World Health Organization. Global Health Observatory Data: Prevalence of insufficient physical activity [Internet]. World Health Organization; 2011 [cited 2017 May 16]. Available from: http://www.who.int/gho/ncd/risk_factors/physical_activity/en/

World Health Organization. Global health risks: mortality and burden of disease attributable to selected major risks. Geneva : World Health Organization; 2009. 9-12 p.

Wright, S. M., & Aronne, L. J. (2012). Causes of obesity. Abdominal imaging, 37(5), 730-732.

Yusuf, S., Hawken, S., Ôunpuu, S., Bautista, L., Franzosi, M. G., Commerford, P., Lang, C. C., Rumboldt, Z., Onen, C. L., Lisheng, L., Tanomsup, S., Wangai Jr, P., Razak, F., Sharma, A. M., & Anand, S. S. (2005). Obesity and the risk of myocardial infarction in 27 000 participants from 52 countries: a case-control study. The Lancet, 366(9497), 1640-1649.

Vita

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