THE TRANSITION TO A HOME WORKFORCE:

AN ANALYSIS OF DISASTER RECOVERY, SEDENTARY BEHAVIOR, AND AIR QUALITY

A Dissertation

by

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ABSTRACT

Across business sectors and industries, modern technology has allowed for the shift of employees from the traditional, commercial building office space to a workforce that can support business continuity from virtually anywhere. Employees are increasingly choosing to work from home, foregoing the traditional office space in exchange for less traffic, more flexibility, and autonomy. Less overhead cost for real estate is a strong business case for companies, however, the health implications of this shift is largely unknown. This research aimed to assess the potential public health implications of remote working to help companies form remote working policies that are the best fit for the health and productivity of their employees.

The ability to remote work helps business continuity following disasters. Computer use metrics collected by an ergonomic software were used as a measurement of productivity in employees displaced after Hurricane Harvey. An interrupted time series analysis was conducted to determine if there was a significant impact on computer use while the employees were displaced. This study found that while there was a significant impact on computer use metrics immediately following the disaster, employees were able to return to their baseline productivity within 45 working days despite not having access to a traditional meeting space.

Remote working changes the environment that the employee spends most of their time in. Office work has previously been associated with sedentary behavior. Accelerometers were used to assess the differences in behaviors between individuals in a traditional office and those that work from home. Despite the difference in built environment between the two spaces, this study found that there was not a statistically significant difference in sedentary behaviors between the two cohorts.

The General Duty Clause requires employers to provide a work environment free of hazards, therefore, they regularly maintain their air conditioning systems and often attain certificate programs to optimize their air quality. This study assessed the differences in pollutant levels of total volatile organic compounds, carbon dioxide, and particulate matter in home office spaces and in traditional office buildings. All pollutant levels were significantly higher in the home than in the traditional office space. This suggests that home office employees could be exposed to more pollutants while working from home than they would in a traditional office space.

Our research suggests that remote working policies can support company resiliency in the event of a disaster. However, health implications of sedentary behavior and increased pollutants should be kept in mind while designing policies.

DEDICATION

This dissertation is dedicated to my parents. They have supported every crazy idea I decided to pursue. My mother, Bridget Sarnosky, taught me to dance through life, despite any circumstance. My father, John Sarnosky (Sgt Ski), taught me that there is nothing more valuable than an education. I hope that I make you proud and that my life is a reflection of how hard you worked to get me here.

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"But those who wait upon the LORD will renew their strength; they will mount up with wings like eagles, they shall run and not grow weary, they will walk and not faint" Isaiah 40:31

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CHAPTER I INTRODUCTION

REMOTE WORKING

The evolution of the workforce from manual labor to technology driven has allowed the shift of employees from working in a traditional office space to working wherever there is internet connection. As a result, the composition of the workforce is changing dramatically. Across business sectors and industries, opportunities for employees to work from home are now being provided alongside other options, such as flexible hours and compressed work schedules. Some companies may offer the ability to work from home on an ad hoc basis, or telework, whereas, others may hire employees to work virtually full-time.

The idea of “telework” is not a new concept. In 1976, Jack Nilles published *The Telecommunications-Transportation Tradeoff: Options for Tomorrow*, a book that attempted to address heavy congestion and transportation issues in the midst of a national energy crisis. Though this was prior to the dawn of easily accessible internet and personal computers, Nilles suggested that there is little reason to gather in the same building every day and instead individuals should gather in smaller groups closer to their homes (Nilles, 1976). Over the past several decades, the concept of bringing the work to the worker rather than commuting to a traditional office space has become increasingly common. Some companies, such AT&T have drastically invested in remote work and remote worker policies as they have found a dispersed workforce is beneficial to their business. However, other companies are beginning to question if remote working is actually a benefit. IBM, an international information technology company based in the United States, had heavily invested in virtual employment for over 30 years before the company requested half of its remote workers return to the office (Goman, 2017).

Reviewing the scientific literature on individuals who work outside the traditional office space is challenging due to the terminology that varies between companies. Different terms are used to describe deviations from traditional working arrangements- that is, employees work in a dedicated space that is funded by the company. Furthermore, an employee who is “teleworking” or “remote working” may be working from any place other than a standard office, such as a coffee shop or library. For consistency, throughout this proposal “remote work” will be defined as employees who work 100% offsite, with ≥ 51% of their work time during prime work hours (8 am- 5pm). Telecommuting will be used to describe workers who typically work in a traditional office space, but sometimes have the ability to work away from the office. Furthermore, it is important to distinguish between a virtual office and a home office. A virtual office is the ability of the employee to work from anywhere, whereas, a home office is specifically when the home is the primary work venue.

As of 2015, the Bureau of Labor & Statistics reported that 24% of American workers completed some or all of their work from home, including over one-third of individuals in management or financial operations positions (Bureau of Labor Statistics, U.S. Department of Labor, 2016). Companies are experiencing that remote work opportunities benefit both the employer and the employee. Employees are reporting being positively impacted by the ability to remote work. They are now able to take on more roles in their personal lives as well as their careers; they are able to have children at home, walk their pets, and maintain a household while being “on the clock”.

Allowing employees to work from home has a strong case from the business standpoint as well, as the fixed cost per employee is lower for remote workers. First, companies are not geographically-restricted in their talent search. They are able to hire qualified employees from all around the globe without the cost and burden of relocation. Additionally, the cost of business space, utilities, and in some cases, office furniture shifts from the employer to the employee (de Menezesm & Kelliher, 2011; Schmidt & Duenas, 2002). Furthermore, employers experience less absenteeism from employees who work from home (Schmidt & Duenas, 2002). In addition to the reduced cost of retail space and decreased absenteeism, employees are being rated as more productive by their supervisors when they are working remotely (Gajendran & Harrison, 2007). However, true increases in productivity are difficult to determine due to the variation in objective measurements of “productivity” across industries and between employees. For example, one employee may consider the ability to concentrate or the need to repeat a job as an indicator of productivity (Goetzel, et al., 2004). However, another individual may consider productivity to be the ability to collaborate and form ideas face-to-face.

Several studies have assessed the impact of employee satisfaction and productivity while remote working. However, very few studies have assessed the short- and long-term human health implications of transitioning employees from a traditional office to a remote work space. In a cross-sectional study by Henke et al. (2016), health risks, such as obesity, physical inactivity, and poor nutrition, were higher in non-telecommuters than those who telecommuted at least 8 hours per month (Henke, et al., 2016). Lundberg and Lidfors (2002) found that teleworking was associated with lower blood pressure than when working in a traditional office (Lundberg & Lindfors, 2002).

Other literature suggests potential negative impacts on health. While lower blood pressure may suggest that remote working could reduce stress, Hartig et al (2007) found that teleworkers experienced less restoration at home (Hartig, Kylin, & Johansson, 2007; Judice, Hamilton, Sardinha, Zderic, & Silva, 2016).

This suggests that employees have trouble switching off their work day and transitioning into family life. In fact, Druxbury et. al (1992) found that employees who have merged their work and home life tend to work more hours than employees who work in a traditional office setting (Duxbury, Higgins, & Mills, 1992). While this work is rather dated in regards to scientific literature, the improvement of technology and the ease of access to email communications makes it likely that individuals are working more in addition to their normal work hours.

DISASTER RECOVERY

Among the many benefits of remote working is the ability for companies to build resilience against disasters. A year after Hurricane Katrina, AT&T published an article explaining how the company was able to provide almost un-interrupted service to the costumers in the Gulf Region due to its abundance of virtual employees who would not be able to provide their services had they been working in a traditional office area (Roitz & Jackson, 2006). AT&T employees' ability to work away from the office has benefitted their organization in other natural disasters as well, such as the SARS epidemic in Hong Kong, China, where individuals were able to avoid crowded public places by working from home (Roitz & Jackson, 2006).

Due to the unexpected and fast nature of disasters, epidemiologic studies on resilience of employees to return to a traditional office job after a catastrophic event is scarce. However, some work has been published on the psychiatric effects of disaster events that have resulted in employee death and survivor displacement. Psychiatric distress and displacement impact employee productivity through increased absenteeism and/or decreased presenteeism (Goetzel, et al., 2004). For example, Following the bombing of the Alfred P. Murrah Federal Building in Oklahoma City in 1995, almost half of the surviving primary victims of the attack were diagnosed with a psychiatric disorder post-disaster (North, et al., 1999). Additionally, many employees impacted by the terrorist attacks of 9/11 were diagnosed with psychiatric disorders two years following the incident and self-reported a significant decrease in job performance (Osinubi, et al., 2008). While no two disasters are comparable, these studies quantify the effect of catastrophic events on employee well-being and serve as the evidence that there is room for companies to improve disaster-recovery plans.

While past disasters have required the use of temporary work spaces in order to enable business continuity, the advancement of technology in recent years has alleviated this necessity. Employees are now able to continue responsibilities largely uninterrupted by working from a safe location during and after a potential disaster. While relatively recent technology makes it possible for employees to continue working, we do not know if other factors affect the individuals' productivity. To enable companies to create viable disaster-recovery plans for their employees, it is critical that we understand the impact of disasters on productivity.

SEDENTARY BEHAVIOR

The direct and indirect benefits of being physically active are well studied and well documented. The World Health Organization (WHO) recommends adults up to age 64 should engage in a minimum of 150 minutes of moderate to vigorous physical activity every week (World Health Organizaton, 2018). However, a growing body of literature suggests that being physically active is not equivalent to the absence of sedentary behavior. Sedentary behavior is characterized by energy expenditure ≤1.5 metabolic equivalent of task (METs) while in a sitting or reclining position (Mansoubi M. , et al., 2015). Therefore, an individual who sets aside a block of time to exercise in order to meet the WHO recommendations is not necessarily mitigating the risks of acute and chronic health impacts associated with low energy expenditure throughout the remaining hours of day (Bergouignan, et al., 2016). In addition to a recommended decrease in total sedentary time, the most recent research suggests that intermittently breaking up sedentary bouts can significantly reduce the risk of adverse health outcomes (Healy, et al., 2008; Bergouignan, et al., 2016). To address this, the American Medical Association has recommended that adults should achieve 150-300 minutes of moderate to vigorous physical activity as well as "move more and sit less" during the day (Piercy, et al., 2018).

Sedentary behavior is associated with a variety of adverse chronic health consequences, such as such as obesity, type 2 diabetes mellitus, cardiovascular disease and all-cause mortality (Katzmarzyk, Church, Craig, & Bouchard, 2009; Chau, et al., 2013; Healy, Matthews, Dunstan, Winkler, & Owen, 2011; Wilmont, et al., 2012). In 2016, the American Heart Association published a science advisory that warns that sedentary behavior may be associated with obesity and type 2 diabetes, each of which are risk factors for cardiovascular disease (Young, et al., 2016). Cardiovascular disease is the leading cause of death in the US (Centers for Disease Control and Prevention, 2017). Human studies suggest that, in periods of uninterrupted sedentary behavior, insulin sensitivity is decreased- a risk factor for type 2 diabetes mellitus (Stephens, Granados, Zderic, Hamilton, & Braun, 2011; Ford, et al., 2010). Long periods low energy expenditure are also associated with many acute, subclinical events such as fatigue and musculoskeletal discomfort (Kar, et al., 2017; Thorp A. , Kingwell, Owen, & Dunstan, 2014).

Office workers are particularly at risk for sedentary behavior, often spending between two-thirds and three-quarters of their working hours sitting (Perry & Straker, 2013; Clemes, O'Connell, & Edwardson, 2014; Ryan, Dall, Granat, & Grant, 2011). Computer-based tasks, such as typing and screen work, average about 1.45 METS (Mansoubi M. , et al., 2015). Completing the same tasks while standing requires higher energy expenditure (Judice, Hamilton, Sardinha, Zderic, & Silva, 2016). Furthermore, the act of transitioning from a sitting to a standing position has been shown to expend significantly higher energy than sitting or standing alone (Judice, Hamilton, Sardinha, Zderic, & Silva, 2016). While the research is conclusive that sedentary behavior during the work day is attributable to a variety of adverse health effects, studies suggest that the most sedentary office employees do not compensate by increasing their physical activity outside of working hours (Clemes, O'Connell, & Edwardson, 2014).Given the copious amount of adverse health events attributable to sedentary behavior in the work place that impacts employee health, productivity, and presenteeism (Puig-Ribera, et al., 2015; Brown, 2013), excessive workplace sitting is a clear workplace health and safety issue that is attracting many companies' attention.

Employers have shown increasing interest in the modifiable behaviors to increase employee physical activity and reduce their sedentary behavior. For example, the Centers for Disease Control and Prevention (CDC) found ways to improve their built environment to encourage employees to take the stairs, such as painting the walls and adding artwork (Kerr, Yore, Ham, & Dietz, 2004). Additionally, some companies have invested in specially-designed workstations that allow the employee to change positions and decrease sedentary behavior throughout their workday. A meta-analysis by Neuhaus et al. found that activity-permissive workstations, such as fixed standing desks or treadmill desks, are an effective at reducing employee sedentary time without inhibiting the employee from completing their tasks (Neuhaus, et al., 2014). Additionally, the use of software and gamification is being explored for use in reminding employees to reduce their sedentary behavior by changing postures (Sharma P. P., Mehta, Pickens, Han, & Benden, 2018). This technology can be useful in combination with a stand-capable desk or other equipment that allows the employee to move without committing significant time or distracting them from their task.

Although there is increasing interest in built environment, ergonomically-designed office furniture, and software to enable employees to increase energy expenditure and change postures throughout the traditional workspace (Neuhaus, et al., 2014; Sharma P. P., Mehta, Pickens, Han, & Benden, 2018; Prince, Saunders, Gresty, & Reid, 2014), the same interventions may not be feasible in the home work space. Individuals who work from home may not have the resources or space for the equipment that is being implemented in a traditional office space. Additionally, there is an absence of research determining the impact of a home-work environment on sedentary behavior. Previous studies have shown that excessive sitting is common in the home during leisure activities such as watching television, driving, or browsing on the internet (Chau, van der Ploeg, Mero, Chey, & Bauman, 2012; Hadgraft, et al., 2015). However, we do not know the behaviors of individuals who are now spending both working hours and leisure hours in their homes.

MUSCULOSKELETAL DISCOMFORT AND ERGONOMICS

Musculoskeletal disorders (MSDs) are the leading cause of work-related discomfort and disability in the United States (United States Department of Labor, 2018). MSDs are conditions that involve the nerves, tendons, muscles, and supporting structures of the body that are commonly injured while an individual is working. While MSDs have been recognized as work-related since the 18th century, it was not until the 1970s that scientific literature examined occupational ergonomic hazards using epidemiologic methods (Center for Disease Control and Prevention, 2014). Employers are responsible for mitigating known risks under the Occupational Safety and Health Administration (OSHA) General Duty Clause (United States Department of Labor, date accessed 2018; United States Department of Labor, date accessed 2018; United States Department of Labor, date accessed 2018), and therefore must do their part to understand and address hazards that could result in an MSD. Nonetheless, new cases of MSDs continue to occur. In 2007, an estimated 335 thousand individuals were diagnosed with the condition from work- related repetitive movements (Bhattacharya, 2014). In an attempt to reduce the occupational epidemic of MSDs, ergonomic interventions are designed to understand the interactions of the workplace and human factors to optimize wellbeing and performance. The end goal of these interventions is to reduce ergonomic hazards, or physical stressors, and conditions that pose a risk for injury or illness.

Musculoskeletal disorders are multifactorial and may be attributable to a combination of occupational exposures, personal stress, and non-work-related activities (Sanders, 2004). Many conditions are classified as an MSD, including arthritis, ganglion cysts, carpal tunnel syndrome, myofascial pain syndrome, and many others (Sanders, 2004). The repetitive body motions experienced during the work day can lead to discomfort and pain, eventually leading the employee to visit a physician for diagnosis with one of the many conditions that are considered MSDs. Because there are a variety of conditions that are considered

MSDs, it is likely that many conditions are misdiagnosed or underreported by the variety of self-reported evaluations of overall body discomfort. Nonetheless, several studies have shown that the majority of office employees experience some sort of discomfort that can lead to a diagnosed MSD. For example, Akrouf et al. (2012) found that 80% of computer-based workers in a banking company suffered at least one episode of musculoskeletal discomfort and over 40% had suffered through at least one disabling episode of discomfort in the past year. Additionally, Soares et al. (2012) found that 70% of employees in a telecommunications company had reported symptoms of musculoskeletal discomfort in the past year. While there have been studies on MSDs in a variety of computer-based occupations, the literature suggests that all occupational groups working in a computer-based environment are similarly exposed to ergonomic hazards (Griffiths, Mackey, Adamson, & Pepper, Prevalence and risk factors for musculoskeletal symptoms with computer based work across occupations, 2012).

Computer-based employees are particularly vulnerable to prolonged, uninterrupted bouts of sedentary behavior while using only a few specific muscles in their upper extremities repetitively to operate a keyboard and mouse (Pickens, et al., Stand-capable desk use in a call center: a six-month follow-up pilot study, 2016; Kaliniene, Ustinavieciene, Skemiene, Vaiculis, & Vasilavicius, 2016). Several studies have shown that duration of computer use per day is associated with musculoskeletal pains for all body areas (Griffiths, Mackey, & Adamson, Behavioral and psychophysiological responses to job demands and association with musculoskeletal symptoms in computer work, 2011; Kaliniene, Ustinavieciene, Skemiene, Vaiculis, & Vasilavicius, 2016; Alvai, Makarem, Abbasi, Rahimi, & Mehrdad, 2016). This is consistent with the generally accepted pathogenesis that MSDs are attributable to the accumulation of microinjuries (Sanders, 2004). While individual sessions of repetitive movement may not cause any inflammatory responses or pain, if adequate recovery time is not allowed, microinjuries can accumulate and produce stress on the body (Sanders, 2004).These microinjuries can cause individuals pain and discomfort, ultimately leading to the diagnosis of a condition that is considered an MSD.

There have been educational tools and specially designed equipment created to minimize ergonomic hazards and reduce MSDs in the workplace. Awkward postures are generally the target of workplace ergonomic interventions. Awkward postures place strain on soft tissues that are not conditioned to perform for long periods of time (Sanders, 2004; Kroemer, 2009). From an engineering standpoint, office furniture has been designed to allow the user to change postures regularly during the day. Regular changes in posture throughout the workday has been associated with decreased upper and lower body discomfort and can be encouraged by offering stand-capable or stand-biased desks (Kar & Hedge, Effects of sitting and standing work postures on short-term typing performance and discomfort, 2016; Thorp A. A., Kingwell, Owen, & Dunstan, 2014; Husemann, Von Mach, & Borsotto, 2009). Furthermore, a variety of software programs can be used to remind employees to routinely change their posture or take a break (Sharma P. P., Mehta, Pickens, Han, & Benden, 2018). Educational interventions have also been shown to reduce musculoskeletal risk if the employee is offered the proper equipment (Robertson, et al., 2009; Amick, et al., 2003). Software companies, such as Wellnomics or Enviance, offer assessment tools that guide managers to existing ergonomic risk and high-risk individuals as well as provide educational tools to address them (Wellnomics, date accessed 2018; CARDINUS Risk Management, date accessed 2018; CARDINUS Risk Management, date accessed 2018; CARDINUS Risk Management, date accessed 2018).

However, many workplace ergonomic interventions do not address the multifactorial nature of MSDs as they do not target the psychosocial wellness of the employee. It is becoming increasingly accepted in the literature that there is an association between psychological health and MSDs (Cho, Hwang, & Cherng, 2012; Alvai, Makarem, Abbasi, Rahimi, & Mehrdad, 2016; Choobineh, Motamedzade, Kazemi, Moghimbeigi, & Pahlavian, 2011; Lima & Coelho, 2018; Kroemer, 2009). Alvi et al. 2016 found that office workers upper extremity MSDs were more likely to be experiencing mental distress. Furthermore, they suggest that as many as one in five employees were at risk of mental distress and therefore at higher risk for developing an MSD (Alvai, Makarem, Abbasi, Rahimi, & Mehrdad, 2016).

As the workforce spends more time on computer-based tasks and the percentage of employees opting to work from home grows, the factors influencing MSDs will change. As of February 2000, OSHA instructions mandate that employers are not required to inspect home offices and cannot be held liable for employee’s home offices (Occupational Safety and Health Administration, date accessed 2018). Some companies, such as Trello, a software company comprised of 65% full-time remote workers, prefer to give virtual employees autonomy over their office space, believing that giving the employee management over their space will increase productivity (Webb, 2018). Other companies provide employees with educational interventions that have shown to improve the ergonomic outcomes of employees in a traditional workspace. However, there is limited evidence to suggest that interventions used in the commercial office would have the same impact on health outcomes in a remote work space.

In 2004, Harrington & Walker created an ergonomic training program for teleworkers and reported that computer-based training techniques for teleworkers were effective at influencing employees to make recommended changes to their workstations. Workers in this study self-reported reductions of body discomfort as a result of the training. However, participants were asked to self-report if they had “experienced discomfort, soreness or pain while teleworking”. This method of analysis does not consider temporality or use a validated measurement. The ergonomic implications of allowing the employee to design their workspace remain largely unknown.

While there are software packages to help make recommendations to the employee based on self-reported variables, we anticipate the workspace of remote workers to be widely heterogeneous with regard to furniture and work equipment. This variability will make it challenging to use the same interventions used in a traditional office setting to protect virtual employees. CARDINUS risk assessment software, for example, offers self-reported assessments to assess fire safety, electrical safety, and the placement of the employee’s computer. However, employees who are responsible for purchasing their own office equipment may not know how to properly and safely adjust the equipment to the recommendations made by the software. Additionally, the software cannot measure that the employee is implementing the recommendations correctly. Some companies are currently using a variety of methods to address these issues, such as recommending certain equipment or using digital pictures or web cameras to assess the employee’s workspace. Each of these methods has limitations that are not faced in a traditional office ergonomics intervention. Digital pictures, for example, are a snap shot of the employee and are not representative of the individual’s overall working experience. Additionally, it is unknown if the employee spends the entire work day at a designated workstation or if they move around throughout the day. Web cameras are typically attached to a computer and are unable to capture the complete office space, therefore allowing many of the ergonomic risks to go largely unseen.

Home office spaces are often not dedicated to only the office worker. As multi-use rooms, they typically consist of different décor and aesthetic considerations combined with price limits and low quantity buying power as single purchase customers. The home is also subject to use and interaction by pets and children that most offices do not need to consider when specifying office building space. Furthermore, there is a gap in scientific literature exploring the ergonomic conditions of home offices. Because of the unique characteristics of each workspace and variability between home offices, it is difficult to make a generalizable conclusion about the ergonomic challenges for remote employees.

While OSHA mandates that employers maintain an office that mitigates the risk of MSDs, the same regulations do not apply in the home. The transition of employees from traditional office spaces to the home office transfers the responsibility if designing, assembling, and maintaining safe work spaces from the employer to the worker. This creates a new challenge for ergonomists and employers to develop interventions to reduce these often-disabling conditions and exposures in the absence of academic literature addressing the baseline ergonomic issues of the home worker and the consequences of shifting the responsibility of safety from the employer to the employee.

INDOOR AIR QUALITY

The Environmental Protection Agency (EPA) has identified indoor air quality (IAQ) as one of the top five most urgent environmental risks to public health (Occupational Safety and Health Administration, 2011). Climate change mitigation and high energy costs have influenced home and business owners to rethink their property's design. Weatherization, or steps taken to limit indoor/outdoor air exchange, increases energy efficiency and conservation. However, reduced ventilation of homes with outdoor air is also associated with increased indoor pollutant levels (Offerman, 2010). Overall, indoor air pollution has been associated with exacerbation of pre-existing conditions, such as asthma, and is attributable to several other chronic and acute health conditions (Dales, Liu, Wheeler, & Gilbert, 2008). Because American adults spend ~90% of their day indoors (Dales, Liu, Wheeler, & Gilbert, 2008; Bernstein, et al., 2008), the population is continuously exposed to complex mixtures of chemicals and contaminants in indoor air for the majority of their life.

Many employees spend the majority of their time in their home or in a commercial office setting. It is therefore important to understand the human health and wellness ramifications of modifications to improve energy efficiency such as reduced ventilation. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), an organization that develops and publishes the technical standards for best practices in heating, ventilation, and air conditioning (HVAC), is the most common resource for setting the minimum standard for new buildings (Persily, 2015). These standards have been modified over time to address Sick Building Syndrome (SBS) or Building Related Illness (BRI) in the working population. The terms SBS and BRI are used to describe a variety of illnesses experienced by occupants that are attributable to the building environment and indoor air contaminants. These conditions have typically been associated with symptoms such as eye irritation, fatigue, and decreased work performance (Tsai, Lin, & Chan, 2012; Satish, et al., 2012; Allen, et al., 2016). Companies have been attempting to address these issues in recent decades to improve employee health and productivity. However, adverse health consequences continue to be reported in environments that meet the minimum ASHRAE standards (Allen, et al., 2016; Tsai, Lin, & Chan, 2012; Pickett & Bell, 2011). Furthermore, while the ASHRAE standards exist for both commercial and residential environments, home settings are not likely to be maintained to these standards.

States are mandated by the government to ensure that their regions are meeting the National Air Quality Standards (NAAQS) by monitoring six criteria air pollutants determined by the Environmental Protection Agency (EPA). These pollutants are carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter and sulfur dioxide. The ambient air monitoring tends to take place in areas of high population, potentially due to the likelihood of high pollution in the area. For example, in Texas the majority of the air monitors are in the largest cities (Texas Commission on Environmental Quality, date accessed 2019). While the state is responsible for making sure criteria air pollutants are below a certain level outdoors, the same attention is not paid to the indoor environment. Some of the criteria pollutants, such as nitric oxide, can be double the concentration in a home than in the ambient air due to lack of ventilation (U.S. Environmental Protection Agency, 2017). While all air pollutants are of concern, the focus of this proposal will be volatile organic compounds, particulate matter, and carbon dioxide.

Volatile Organic Compounds

Volatile organic compounds (VOCs) are gaseous organic pollutants found in both outdoor and indoor air (United States Environmental Protection Agency, 2017). Several VOCs have been classified as human carcinogens by the International Agency for Research on Cancer (American Cancer Society 2014). The EPA has listed several examples of carcinogenic compounds commonly found in indoor environments, such as formaldehyde, toluene, and chemicals used in fire retardants (United States Environmental Protection Agency, 2017). VOCs have been the focus of many sick building syndrome (SBS) studies (Lu, Lin, Chen, & Chen, 2015; Allen, et al., 2016) due to their association with irritation with the respiratory tract, skin, and central nervous system.

Formaldehyde, one of the most common VOCs found in homes, can be produced by several indoor sources such as wood-based furniture, paints, and combustion processes (e.g. cooking) (Salthammer, Mentese, & Marutzky, 2010; United States Environmental Protection Agency, 2017). Formaldehyde inhalation has been associated with eye irritation, increased risk of asthma, decreased lung function, and neurological effects (Agency for Toxic Substances & Disease Registry, 2015).

Other VOCs, such as polybrominated diphenyl ethers (PBDEs) and those in pesticides (organochlorines, organophosphates, and pyrethroids), are associated with endocrine disruption (Institute of Medicine of The National Academies, 2011). For example, Harley et al. (2010) found that exposure to PBDEs was associated with decreased fertility in women.

Volatile organic compounds are slowly released from many common products used in homes and offices; therefore, individuals may be exposed to low levels of VOCs for long periods of time (Salthammer, Mentese, & Marutzky, 2010). To reduce formaldehyde levels in indoor spaces, the EPA has mandated that certain composite wood products produced as of June 1, 2018 must comply with emission standards identical to those set by the state of California several years ago (United States Environmental Protection Agency, 2019). Unfortunately, products made before that time may remain in homes and continue to emit toxic substances.

Particulate Matter

Particulate matter (PM) is a mixture of solid or liquid particles suspended in the air that are classified by their diameter. PM is often classified as PM_{10}, or inhalable particles with diameters less than 10 micrometers, or $PM_{2.5}$, or particles with diameters 2.5 micrometers or less. In general, the smaller the PM, the more dangerous it is to human health (United States Environmental Protection Agency, 2018). Indoor PM can be created from within the building by anthropogenic activities (e.g. cooking and washing), or be brought in from outdoor environments with poor air quality or pollutant-emitting activities such as construction.

PM is considered a criteria pollutant by the EPA, meaning it is included as one of the six regulated air pollutants (United States Environmental Protection Agency, 2015). A plethora of studies have linked exposure to PM to severe health effects such as cardiovascular issues, aggravated asthma, and decreased lung function (United States Environmental Protection Agency, 2018; Ackermann-Liebrich, et al., 1997; Sekine, Shima, Nitta, & Adachi, 2004).

Because PM is considered a criteria pollutant by the EPA, ambient air is monitored by states to attain National Ambient Air Quality Standards (NAAQS). While the ambient air is routinely assessed by the states, residential homes are not routinely monitored for the presence of PM (United States Environmental Protection Agency, 2018). Particulate matter may be removed from indoor air by heating, ventilation, and air conditioning (HVAC) filters. However, the filters must be continually maintained and be of higher quality than those commonly used in homes to be able to reach maximum efficiency. Although HVAC systems are designed to reduce particulate matter and NAAQS standards are met by most areas, outdoor air is still a major source of PM in homes and offices (Offerman, 2010; Abt, Suh, Catalano, & Koutrakis, 2000). Outdoor PM may enter an indoor environment through open doors, open windows, or cracks and fissures in the structure. Therefore, it is possible that homes in areas with less PM ambient air have less indoor PM than those in areas with higher pollutant levels.

Carbon Dioxide

Occupied indoor areas have higher levels of carbon dioxide (CO_2) than ambient air due to human exhalation. As ventilation rates decrease, as is the case with many energy-efficient homes and offices, the concentration of CO_2 increases. Carbon dioxide, even at levels below the recommended limits of ASHRAE, has commonly been associated with SBS, such as upper respiratory irritations, fatigue and decreased work performance (Tsai, Lin, & Chan, 2012; Satish, et al., 2012; Allen, et al., 2016). The concentration of CO_2 is commonly used to assess ventilation rate, and serves as an overall indicator of air quality (Satish, et al., 2012).

OCCUPATIONAL SETTINGS

The importance of indoor air quality in occupational settings has been recognized by the Occupational Safety and Health Administration (OSHA), which requires employers to provide acceptable air quality through the general clause that a work environment must be free from recognized hazards (United States Department of Labor, date accessed 2018). Additionally, OSHA has specific standards for employers for ventilation requirements in their commercial buildings (United States Department of Labor, date accessed 2018). Along with the requirements from OSHA, the states of California and New Jersey have mandated more stringent guidelines and procedures to address IAQ in the workplace (United States Department of Labor, date accessed 2018).

There are also several private initiatives that have the goal of increasing energy efficiency while maintaining optimum IAQ in commercial buildings. Perhaps the most recognized, the Leadership in Energy and Environmental Design (LEED) certification, is a voluntary energy efficiency standard that has become commonly recognized in the U.S. Research has supported the benefits of complying with the recommendations to qualify for these certifications. Allen et al. (2016) conducted a laboratory simulation of the conditions of the minimum requirements of ASHRAE and those necessary for the LEED certification, analyzing the correlation of environmental conditions with the cognitive function of employees. The results suggested that the presence of VOCs and higher CO_2 were associated with lower cognitive scores (Allen, et al., 2016). Improved air quality in the workplace has also been associated with increased productivity in a variety of office-related tasks (Wargocki, Wyon, Baik, Clausen, & Fanger, 1999; Fisk & Rosenfeld, 1997; Seppanen & Fisk, 2006) as well as decreased prevalence of SBS among employees (Lu, Lin, Chen, & Chen, 2015). Companies have been motivated to obtain the certifications because evidence from the literature clearly shows that compliance with environmental certifications improves employee health and productivity, while simultaneously achieving energy savings and sustainability.

Companies have improved indoor air quality not only by striving for LEED certifications, but also by striving to use low VOC materials (i.e. furniture, rugs, paint) in the commercial office space. There are multiple organizations that provide advice and certification of indoor materials. For example, the GREENGUARD Environmental Institute was established in 2001 to certify the building materials and furnishings that meet emission standards for VOCs, respirable particles (PM), and organic acids (GREENGUARD certification, date accessed 2018). Businesses have widely accepted GREENGUARD certified products, such as office furnishings and building supplies (e.g. carpet), as standard throughout their companies.

Companies have made great strides in improving indoor air quality in commercial office buildings, but there has been less consideration given to IAQ in work locations outside company office buildings.

RESIDENTIAL SPACES

According to the Bureau of Labor and Statistics, over a third of individuals in professional and management, business, or financial operations performed some or all of their main job in their residence (Bureau of Labor Statistics, U.S. Department of Labor, 2015). Although there are IAQ standards for commercial office buildings, residential indoor air is unregulated. The home environment has many potential sources of pollution that commercial office spaces may not need to address, such as close proximity to cooking fumes or a wood-burning fireplace. While commercial office buildings are more likely to increase their energy efficiency to improve employee wellness and lower energy cost, residential settings are likely to be more complex and there are likely to be unique barriers due to individual decision-making. For example, an individual that is renting a property may not have the ability to make renovations to meet the evolving ASHRAE standards. Additionally, an individual may not be able to afford to replace their home’s air filters on a regular basis or maintain an HVAC system, whereas, a commercial building is required to maintain their equipment due to the OSHA regulations. Pickett et al. conducted a study in middle class family homes and found levels of PM, CO_2, and TVOCs were above the suggested air quality guidelines that were developed by the authors using a combination of ASHRAE, U.S. EPA, and WHO recommendations (Pickett & Bell, 2011). This suggests that individuals in the U.S. may be exposed to less pollutants in the traditional office space than in the home. The understanding of potential impacts of IAQ on human health is far from complete, and the effects of residential IAQ on home office workers remains poorly understood.

The transition of the workforce from commercial office buildings to their residence shifts the responsibility of attaining acceptable IAQ from the employer to the employee. With fewer regulations targeting home offices, and most certification programs focused on traditional office furnishings and supplies, individuals are potentially exposed to higher levels of pollutants for longer periods of time in a home office than they would be in a traditional office. There is an absence of quantitative research to show how these environments differ and the potential consequences of shifting the responsibility of environmental safety from the employer to the employee.

CHAPTER II COMPUTER PERFORMANCE DURING DISASTER RECOVERY

INTRODUCTION

Advances of technology have allowed businesses to become less reliant on their physical office space for business continuity. The ability to remote work can be useful in a variety of situations- including recovery from natural disasters.

Prior to the ease of employees being able to connect remotely following natural disasters, companies impacted by natural disasters would have to quickly provide an alternative meeting space while their offices were being repaired. While quantitative studies are scarce, some studies have shown decreased employee presenteeism in the wake of catastrophic events. A study of employees who worked near the World Trade Center during the terrorist attacks of September 11, 2001 reported that, even two years after the disaster, employees felt they had a significant decrease in job performance (Osinubi, et al., 2008). While subjective data has associated psychiatric distress and employee performance through increased absenteeism and/or decreased presenteeism (Goetzel, et al., 2004), no quantitative data exists to suggest that being displaced after a catastrophic event influences the work output of employees.

There is a paucity of research concerning the impact of natural disasters and worker displacement on the employee to help companies create emergency management and employee displacement policies in light of the ability to work offsite. When Hurricane Harvey devastated Houston in August 2017, the Westlake campus of BP oil and gas company was closed for about seven months, displacing hundreds of employees. Unfortunately, the flooding also impacted many of the employees' homes and they were displaced into hotels or the homes of friends and family. Fortunately, the company had systems in place that allowed employees to continue working from wherever they were living during the disaster recovery.

Prior to the natural disaster, BP America, Inc. contracted with Enviance, a software company that specializes in health and safety. RSIGuard software is installed on employees' computers and collects over 100 objective data points on computer performance (e.g. hours of use, words typed per day, number of mouse clicks, etc.). Traditionally, this information is used by companies to estimate how much time the users spend in between scheduled and natural breaks in order to help employees reduce patterns that lead to high incidences of injuries. Here, we use these same metrics to understand the computer usage of employees before the hurricane and after the disaster while employees were still unable to work in their regular commercial office space.

Employees are now able to continue computer-based responsibilities largely uninterrupted by working from a safe location during and after a potential disaster. While the technology makes it possible to continue working, we have yet to objectively measure how efficiently employees work while displaced. To enable companies to create viable disaster-recovery plans for their employees, it is critical that we understand the impact of disasters on productivity. The aim of this study was to gain an understanding of computer performance among displaced employees to help guide company policies on disaster recovery plans for the workplace. The objective was to use de-identified, time-stamped computer performance data to observe the impact of a natural disaster on workplace computer use.

METHODS

The retrospective RSIGuard data included employee performance data from the Houston campus of BP America, Inc. from January 3, 2017 – December 29, 2018 was provided by the company. De-identified data for 792 individuals with RSIGuard software installed was provided. The RSIGuard data included 15 continuously collected metrics of computer-usage (Table 1). No social or demographic data was provided for the dataset. However, the company provided a list of job titles that were included in the RSIGuard software during the time of data collection. The participants were from a variety of computer-based jobs within the company, including engineers and accountants. We can also assume that the population consisted of working-age adults who lived in the Houston area during Hurricane Harvey (August 24, 2017). This study was approved by the Texas A&M University Institutional Review Board (IRB2018-1623M).

Table 1 RSIGuard metrics and definitions

RSIGuard Metric	Definition
Total Hours	Indicates how much time a user spends working at the computer- includes when the user is actively using the keyboard, mouse, or both
Mouse Hours	Indicates how much time a user spends using the mouse
Keyboard Hours	Indicates how much time a user spends using the keyboard
Words Typed	Indicates the total word count per day; words are measured as any sequence of letters followed by a space
Words Typed AM	Indicates total words typed in the morning
Words Typed PM	Indicates total words typed in the afternoon
Typos	Indicates how many errors the user is making at the keyboard
Typos AM	Indicates how many errors made in the morning
Typos PM	Indicates how many errors are made in the afternoon
Mouse Clicks	Indicates the total amount of clicks the user performed
Mouse Distance	Indicates a relative value that indicates how much the user moves the mouse cursor
Double Clicks	Indicates how many times the user performed a double click
Left Clicks	Indicates how many times the user performed a left click
Right Clicks	Indicates how many times the user performed a right click
Mouse Scrolls	Number of pointer scroll clicks
Typos Per Hour*	Rate of typos per hour of active keyboard use
Words Typed Per Hour*	Rate of words typed per hour of active keyboard use
Mouse Clicks Per Total Mouse Use*	Rate of words typed per hour of active keyboard use
Mouse Scrolls Per Mouse House*	Rate of mouse scroll clicks per hour of active mouse use

(= variables defined by research group)*

ANALYSIS

DESCRIPTIVE ANALYTICS

Initial descriptive analyses were used to describe productivity measures prior to, during, and following Hurricane Harvey. Variable means, medians, and ranges were calculated for three time periods: before the hurricane (January 1, 2017- August 23, 2017), during Hurricane Harvey (August 24, 2017 – September 24, 2017), and post-hurricane (September 25, 2017- December 28, 2018). A repeated measures ANOVA was used to compare mean values between the three time periods. Variables that were not normally distributed were log transformed prior to analysis. Results were considered significant at $\alpha = 0.05$.

We performed an interrupted time series (ITS) analysis to investigate the immediate effects of the natural disaster on employee computer use. An ITS analysis is a quasi-experimental statistical approach that has historically been used to evaluate the impact of public health interventions (Lopez Bernal, Soumerai, & Gasparrini, 2018; Lopez Bernal, Cummins, & Gasparrini, 2018; Shao, Zhang, & Zhen, 2017).   However, recently the technique has been used to evaluate the impact of policy change (Brett, Schaffer, Dobbins, Buckley, & Pearson, 2018). In order to perform and ITS, there must be a clear differentiation of the pre-intervention time period and the post-intervention time period. Additionally, an ITS model works best with interventions that have an acute outcome (Lopez Bernal, Cummins, & Gasparrini, 2018).

Here, segmented regression modeling was used to estimate changes in daily computer use metrics before and after Hurricane Harvey. While the ITS has not traditionally been used to analyze disaster impacts, this situation presents a well-defined pre- and post- disaster time period and an anticipated acute outcome. Here, we defined the interruption date as the day Hurricane Harvey forced the Westlake Campus to close down (August 24, 2017). Variables in the model were metrics that represent the employee's computer usage. Typing accuracy and mouse tasks have been used as an indicator of work performance and computer use in previous studies (Torbeyns, et al., 2016; Koren, Pisot, & Simunic, 2016; Russel, et al., 2016; Straker, Levine, & Campbell, 2010). An ITS analysis was performed for each variable. The dataset was restricted to individuals who were located at the West Lake campus and had RSIGuard installed on their work computer from May 22, 2017 and after November 22, 2017 (n=184) to ensure that the individual was employed at BP pre- and post-Hurricane Harvey. The medians of each variable were generated for 42 work days prior to the disaster and 42 work days following August 24, 2019. The medians were used in the ITS analysis to control for extreme outliers. We accounted for a one-day lag in the model, as the hurricane impact caused the West Lake campus to close on the day of the disaster. Individual ITS analyses were conducted for the following variables: total active computer hours, clicks per active computer use hours, words typed per active keyboard use hours, typos per active keyboard use, and mouse scroll distance per active computer use. All analyses were performed on STATA/IC 15.1 for Mac (College Station, TX). The significance level was set at α= 0.05.

RESULTS

The means of each variable and the results from the repeated-measures ANOVA are presented in Table 2. The repeated-measures ANOVA suggested that all metrics were statistically significant before, during, and after Hurricane Harvey. At baseline (pre- Hurricane Harvey), the total active hours averaged at 3.29 hours per day. Immediately following the hurricane, the average total active hours fell to 2.88 hours and returned to an average of 3.20 hours after the hurricane.

Table 2 Means and ranges of RSIGuard Metrics for pre-disaster, during Hurricane Harvey, and post-disaster for the full dataset

	Pre-Hurricane	Hurricane Harvey & Month following	Post-Displacement	P-value
	Jan 1, 2017 – Aug 23, 2017	Aug 24, 2017-Sep 24, 2017	Sep 25, 2017 – December 28	
Total active hours				
Data points	55739	4911	80197	
Min	0.06	0.06	0.06	
Max	17.63	14	16.69	
Mean (SD)	3.29 (1.87)	2.88 (2.01)	3.20 (1.91)	<0.001
Clicks per active computer use hour				
Data points	55739	4911	80196	
Min	0	0	0	
Max	4855.56	3946.51	9230.70	
Mean (SD)	834.9 (334.16)	796.65 (315.19)	766.72 (288.23)	<0.001
Mouse scroll clicks per active computer use hour				
Data points	55739	4911	80196	
Min	0	0	0	
Max	48388.89	15190	56344.45	
Mean (SD)	817.88 (959.09)	737.25 (920.16)	919.73 (1378.18)	<0.001
Words typed per active keyboard use hour				
Data points	55583	4877	80002	
Min	0	0	0	
Max	3950	2260.71	3750	
Mean (SD)	615.52 (364.00)	701.63 (393.62)	654.25 (368.90)	<0.001
Typos per active keyboard use hour				
Data points	55583	4877	80002	
Min	0	0	0	
Max	3333.33	2500.00	6666.66	
Mean SD	176.1 (104.37)	193.78 (112.25)	191.41 (109.35)	<0.001

The ITS suggested that total active computer use hours significantly decreased immediately following the event (Hurricane Harvey) (p<0.001). After the initial shift in total computer use, the median active computer use returns to baseline within four weeks (Figure 1). Computer metrics of mouse use (mouse scrolls per hour of active mouse use and mouse clicks per hour of active mouse use) significantly declined immediately following the interruption ($p< 0.001$ and $p< 0.001$, respectively). In both cases, the trend gradually increases back to baseline (Figure 2 and Figure 3, respectively). Words typed per hour of active keyboard use significantly increased following the event ($p=0.011$) (Figure 4). Typos per hour of active keyboard use also significantly increased following the hurricane ($p=0.002$) (Figure 5). Based on segmented regression models, all computer performance metrics returned to pre-Harvey levels within 4 weeks.

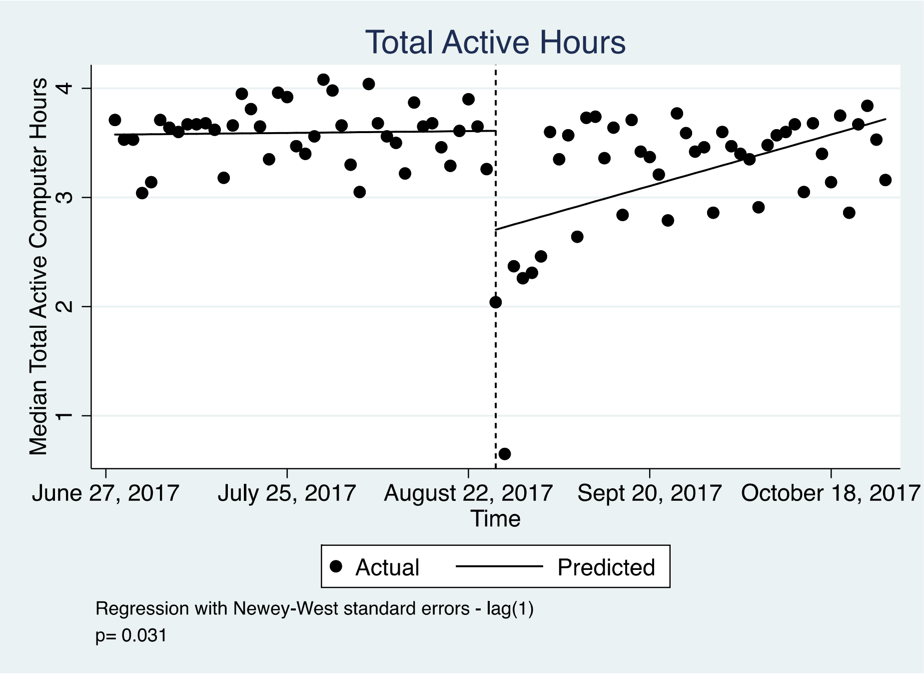

Figure 1 Level shift of active hours of computer use by BP America, Inc. employees. Data points represent the median of total active hours.

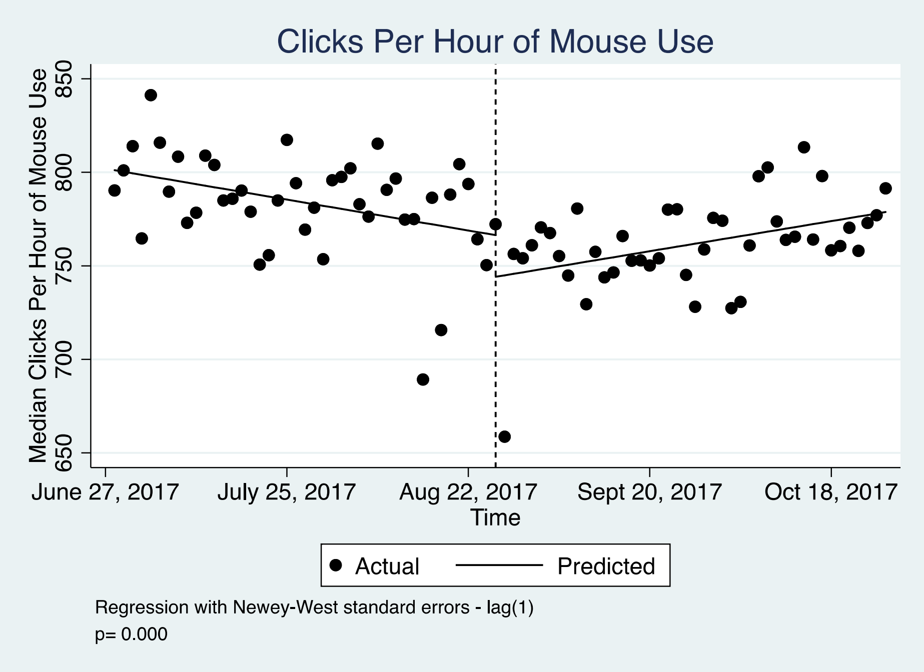

Figure 2 Level shift of clicks per hour of mouse use by BP America, Inc. employees. Data points represent the median of clicks per hour

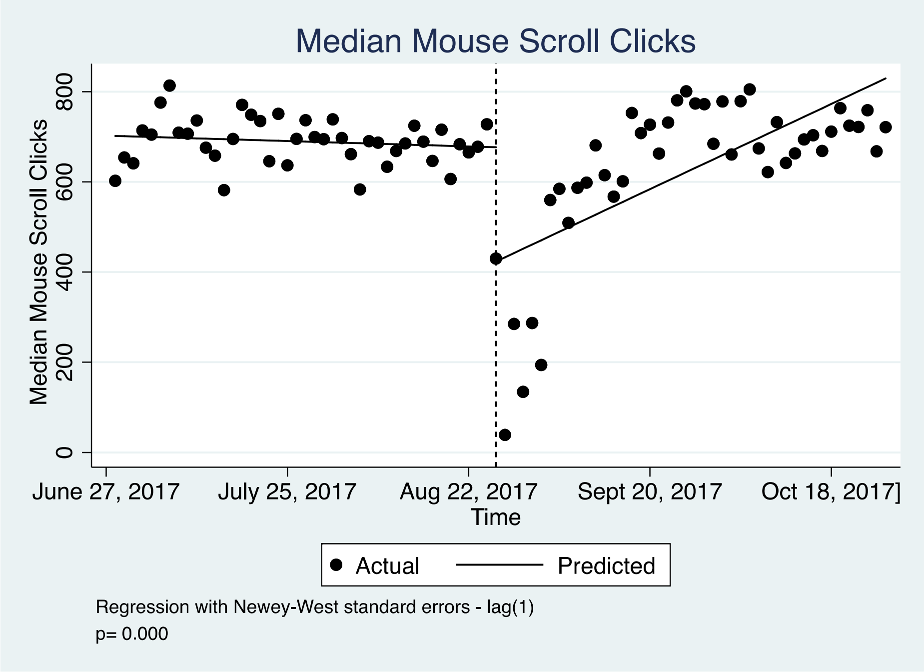

Figure 3 Level shift of mouse scroll clicks per hour by BP America, Inc. employees. Data points represent the median of mouse scroll clicks per hour

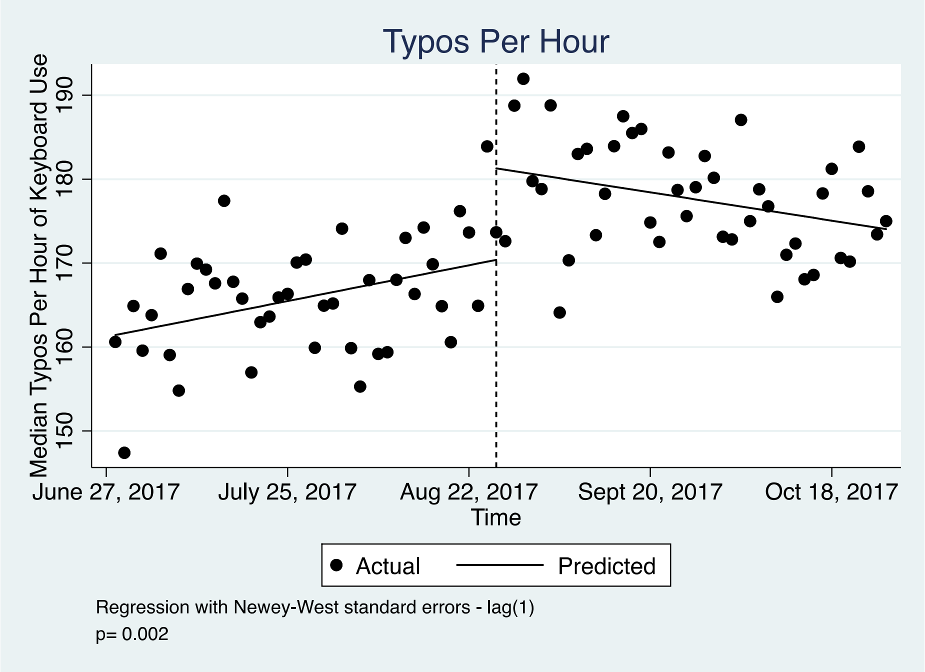

Figure 4 Level change of typos per hour of keyboard use by BP America, Inc. employees. Data points represent the median of typos per hour

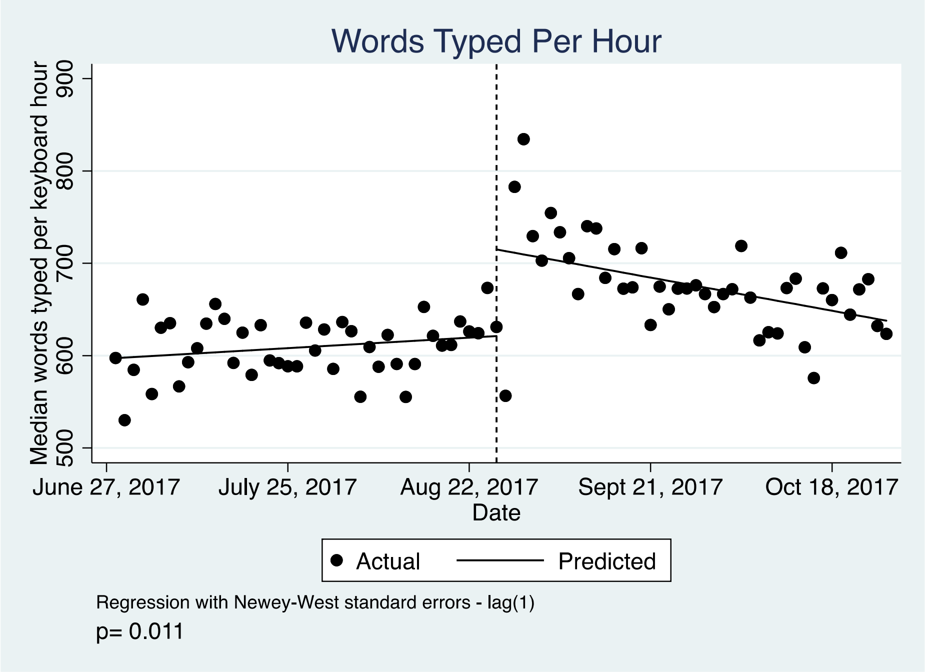

Figure 5 Level change of words typed per hour by BP America, Inc. employees. Data points represent the median of words typed per hour

DISCUSSION

Based on results from a novel statistical approach to evaluate worker computer-usage as an estimate of employee productivity, we found that Hurricane Harvey significantly influenced the computer usage of employees at the Westlake campus of BP America, Inc. in Houston, TX. The total active computer use hours were significantly decreased immediately following the natural disaster. Likewise, computer mouse metrics (clicks per hours and mouse scroll clicks) and keyboard metrics (words typed per hour and typos per hour) also significantly decreased after the hurricane. This aligns with what was expected, as employees were no longer able to access their normal work environment and were likely juggling family affairs and disaster recovery plans while working.

Our study is, to our knowledge, the first to quantify the disruption of the computer usage by employees during a natural disaster and their subsequent return to a renovated and restored office. Additionally, the ITS analysis has not been used for analysis of natural disaster impact. Here, we define the hurricane as the ‘interruption’ of the normal daily computer use of the employees. We used the computer-usage metrics as the variables in the model to show the impact the hurricane had on each variable. The five metrics used in our ITS analysis were selected due to the likelihood that they represent the employee’s work day computer productivity. While there are no previous studies using these metrics for measuring disaster recovery, typing speed and typing error rate have been used to describe computer performance in studies evaluating the impact of workstations on productivity (Russel, et al., 2016; Koren, Pisot, & Simunic, 2016; Torbeyns, et al., 2016). We included mouse use metrics as the tasks performed by the employees in this study likely included both keyboard and mouse use.

Total active computer use, which represents the median of daily total hours using a computer while using the keyboard or mouse, was consistent before the hurricane and showed a statistically significant change after the disaster. This is consistent with the assumption that many individuals were impacted by the hurricane and may have had to work reduced hours to address disaster remediation and relocation, yet were able to return to their baseline computer use without having a physical meeting space. Interestingly, it appears that the population returned to their baseline total active computer use within three weeks of the disaster. This suggests that the ability to remote work may influence the resiliency of employees to return to baseline computer use after a devastating natural disaster- even without the ability to return to their traditional meeting space. A statistically significant decrease in keyboard and mouse metrics immediately following the hurricane was also observed. It is not surprising that we observed a significant change in these metrics as well, as these measures tie directly to active computer use time. These variables, however, showed larger variability prior to the hurricane and it is less clear what impact was made by the loss of a physical meeting location. Nonetheless, the metrics appear to return to baseline within the 45 workdays following the hurricane that were included in our ITS analysis.

This study presents several strengths and a variety of limitations. The quasi-experimental nature of the ITS analysis allows us to infer causality of the decrease of employee computer usage. For example, we can attribute the decrease in computer use metrics and increase in typing errors to the change of workstyle and the inability to work from the normal workstation. However, the data provided was from a single, large oil and gas company with thousands of employees. The demographics of the sample are unknown. Additionally, the RSIGuard data can currently only provide information on work done on the computer, which is not necessarily representative of the employee's entire work day. Thus, we cannot make direct correlations of the total amount of time spent working and the natural disaster. Other tasks completed during the work day, such as meetings and phone calls are not necessarily a computer-based task and are likely not captured in our dataset. From this dataset we are unable to determine the type of computer-based tasks the individuals were doing. While it appears that the individuals included in our analysis were able to return to baseline within a month post-disaster, it is possible that the content of their "normal" work day may have shifted to create more computer-based tasks. Future studies should consider using validated, objective questionnaires to supplement measures of employee productivity during disaster recovery.

We selected the variables in our analysis as a rough indicator of overall productivity. However, true measures of productivity are difficult to determine due to the variation in objective measurements of “productivity” across industries and between employees. For example, one employee may consider the ability to concentrate or the need to repeat a job as an indicator of productivity (Goetzel, et al., 2004). However, another individual may consider productivity to be the ability to collaborate and form ideas face-to-face. In this case, we consider the computer-use metrics of productivity under the assumption that, with no physical meeting place, the majority of our sample was completing business tasks by using their computer. Additionally, this data was collected from a Fortune 100 company in Houston, Texas. The results may not be generalizable for other companies or other industries that may require face-to-face interactions for business continuity.

This study presents a business case for remote working policies to be established and understood by employees prior to the occurrence of a natural disaster. In addition to the obvious safety benefits of keeping employees off of the roads during Category 4 Hurricanes, allowing for virtual presence may also allow for individuals to evacuate their homes and secure their belongings without the stressor of being away at work. Here, we show that, with the ability to remote work, employees were able to return to their baseline computer-use within a month of the hurricane. Some buildings on the BP West Lake Campus did not reopen until March of 2018. While it is likely that the company would have been able to find an alternative group meeting space for the company earlier than seven months later, this need was mitigated due to the ability to connect remotely. Many individuals in Houston lost their homes due to Hurricane Harvey and had to rebuild completely. While we cannot assume that this was the case for any individuals in our dataset, it is likely that this situation would have prohibited some individuals from returning to work had they not had the ability to log in virtually.

CONCLUSION

The ITS analysis is traditionally used to explore the effectiveness of public health interventions. Here, we use ITS to quantify the disruption of computer usage in employees affected by Hurricane Harvey. As expected, the total amount of hours worked on the computer was significantly impacted by the Hurricane. However, the short amount of time to return to baseline computer use suggests that the ability to work remotely may positively impact the company's resiliency to natural disasters. This information may help guide workplace policies that improve disaster recovery plans.

CHAPTER III EXPLORATORY STUDY OF SEDENTARY BEHAVIOR IN TRADITIONAL EMPLOYEES AND REMOTE WORKERS

INTRODUCTION

Across business sectors and industries, the innovation in technology has increased opportunities for employees to work from home. However, the long-term effects of transitioning the workforce from maintained and regulated offices to a home environment are unknown. One of those effects may be on the amount of movement required to operate in each environment. Therefore, there may be differences in the sedentary behaviors of remote, modern office workers and the traditional office worker.

Office workers are particularly at risk for sedentary behavior, often spending between two-thirds and three-quarters of their working hours sitting (Perry & Straker, 2013; Clemes, O'Connell, & Edwardson, 2014; Ryan, Dall, Granat, & Grant, 2011). Sedentary behavior is characterized by energy expenditure ≤1.5 metabolic equivalent of task (METs) while in a sitting or reclining position (Mansoubi M. , et al., 2015). Computer-based tasks, such as typing and screen work performed during traditional office duties, average about 1.45 METS (Mansoubi, et al., 2015).

Sedentary behavior is associated with a variety of adverse chronic health consequences, such as obesity, type 2 diabetes mellitus, cardiovascular disease and all-cause mortality (Katzmarzyk, Church, Craig, & Bouchard, 2009; Chau, et al., 2013; Healy, Matthews, Dunstan, Winkler, & Owen, 2011; Wilmont, et al., 2012). In 2016, the American Heart Association advises that sedentary behavior may be associated with obesity and type 2 diabetes, each of which are risk factors for cardiovascular disease (Young, et al., 2016). Human studies suggest that, in periods of uninterrupted sedentary behavior, insulin sensitivity is decreased- which is a risk factor for type 2 diabetes mellitus (Stephens, Granados, Zderic, Hamilton, & Braun, 2011; Ford, et al., 2010). Long periods of low energy expenditure are also associated with many acute, subclinical events such as fatigue and musculoskeletal discomfort (Kar, et al., 2017; Thorp A. , Kingwell, Owen, & Dunstan, 2014).

With the transition of individuals from traditional office environments to home office environments, the impact this will have on the long-term health of the workforce is currently unknown. This aim of this exploratory study was to assess the baseline differences in sedentary behaviors in home office workers and those in a traditional office. This research will be valuable for developing recommendations for the virtual workforce as the home office continues to increase in popularity.

METHODS

This longitudinal cohort study was conducted with fulltime employees using activPAL™ technology to assess the differences in sedentary behavior by measuring postural changes, number of steps taken, and estimating energy expenditure for five consecutive workdays. The target sample size for each cohort was 20 participants.

RECRUITMENT

This cohort study investigated differences in sedentary behavior in traditional office spaces compared to home office environments. All participants were full-time employees that worked in occupations that would require the majority of their time to be dedicated to computer-based tasks. Recruitment emails were sent from March 2019 through May 2019 to enroll individuals for the two cohorts of this study. The original recruitment email was sent to all employees of the Texas A&M Health Science Center and members of the Bryan-College Station Chamber of Commerce (APPENDIX A). In an attempt to reach the target sample size for the home worker cohort, recruitment emails were also sent to individuals who were referred by other participants and alumni of the Texas A&M Health Science Center (HSC).

Participants for the traditional office space cohort were recruited from the Texas A&M HSC (n=21). Traditional office cohort participants were eligible to participate if they worked in their office space at the HSC for the majority (>50%) of their work week. No other exclusion criteria were applied. The HSC employees (n=21) were considered traditional office space employees. Each traditional office employee had a designated work space in a building of Texas A&M University or a university-affiliated medical care facility in College Station, TX, Round Rock, TX, or Lake Jackson, TX. Each office included a traditional seated desk, a computer, and a computer task chair. All HSC employees had access to traditional meeting rooms, a kitchen-area, and community-style restrooms on the floor of their office.

The home office cohort consisted of local workers from the community who were recruited by email. All home office cohort participants lived in Central Texas (n=9) and were eligible to participate if they worked in their office space for the majority (>50%) of their work week.

Participants were asked to sign an informed consent (APPENDIX B, APPENDIX C) and compensated $100 for participating. This study was approved by the Texas A&M University Institutional Review Board (IRB2018-0617D).

DATA COLLECTION

All participants were asked to wear an activPAL3TM micro or activPAL4TM micro (PAL Technologies Ltd., Glasgow, UK) for five consecutive days during a selected work week between April 15, 2019 – July 5, 2019. Participants were asked to complete a questionnaire (APPENDIX B), home worker participants were asked additional questions to describe some features of their home office space. Participants were compensated $100 for participating. This study was approved by the Texas A&M Institutional Review Board (IRB2018-1623M).

EQUIPMENT

Upon the start of the study, the activPAL™ activity monitor was placed on the anterior portion of the participant’s thigh and adhered with a Tegaderm film dressing. The activPAL™ activity monitor is a small device (23.5mm x 43mm x 5mm) that uses an accelerometer to sense body position. The activPAL™ device has been shown by several studies to be a valid and reliable measure of postural changes, sedentary behavior, and physical activity (Grant, Ryan, Tigbe,

& Granat, 2006; Godfrey, Culhane, & Lyons, 2007; Kim, Barry, & Kang, 2015; Oliver, Schofield, Badland, & Shepherd, 2010). The default sampling frequency was used (20 Hz) and the minimum hold posture was set at 10 seconds. This means that the participant would have to hold a new posture (from sitting/lying to standing, vice versa) for a minimum of ten seconds for the device to capture the transition. The step count and posture status was recorded by a microprocessor. Data were originally processed by a proprietary software (activPAL™ v7.2.38, PAL Technologies Ltd., Glasgow, UK). The software stratified data points into sitting/ lying, standing, and stepping and used an algorithm to calculate an estimate of energy expenditure during the activity. Each participant was asked to wear an activPAL™ activity monitor (models activPAL3TM micro or activPAL4TM micro) during a regular Monday-Friday work week and to not remove the device except during activities that would require the device to be submerged in water, such as bathing or swimming.

ANALYSIS

Statistical analysis was performed with STATA/IC 15.1 for Mac (College Station, TX). Mondays and Fridays were cut from the dataset to create a midweek snapshot of each participant’s activity. Restricting the dataset to a midweek snapshot allowed for the exclusion of days that equipment distribution took place and mitigate aberrant behaviors. An initial analysis was performed using 24-hour data. An additional analysis was performed that restricted the dataset to the traditional work day (9:00 am – 5:00 pm). The 24-hour comparison was performed to account for the full day of activity. This would determine if employees practice sedentary behavior during the traditional work day but compensate for those behaviors off-the-clock. The activPAL™ data were excluded if the accelerometer recorded 0 movement for a twelve hour or greater block of time, as it is likely the equipment may have been removed or malfunctioning.

Daily Totals

Means, medians, and ranges were reported for all variables collected by the activPAL™ (total step count, number of sit to stand transitions, total time sitting/lying, standing, stepping) for 24-hour days. A repeated measures ANOVA was performed to compare the home office cohort to the traditional office cohort for each daily total variable. Data transformation was performed on nonparametric data to meet the assumptions of a repeated measures ANOVA.

Traditional Work Day

Hourly data was used to restrict the data to 9:00 am – 5:00 pm to reflect the traditional work day. While we are unable to confirm that the home office cohort followed the standard work day, this blocking helps us understand normal work hours even for those at home who are expected to be available and/or interacting with distant colleagues. Means, medians, and ranges were reported for hourly step count, number of sit to stand movements, number of stand to sit movements, as well as minutes of the hour sitting/lying, standing, stepping during the 9:00 am – 5:00 pm timeframe. A repeated measures ANOVA was performed for each variable to compare the traditional work day sedentary behaviors in home workers and traditional office workers.

Power and Significance

Given the sample size, this study had 80% power to detect a 2.53-hour difference in daily total time standing, a 2.00 hour difference in daily time stepping, a 4775.03 step difference in total step count, a 15.52 difference in total transitions, and a 1.98 difference in daily average energy expenditure. Additionally, the sample size for traditional work hours allowed for 80% power to detect a 17.29-minute difference in time sitting/lying, a 13.05-minute difference in time stepping, a 3.04 difference in sit to stand transitions, a 3.03 difference in stand to sit transitions, a 480.28 difference in step count and a 0.21 difference in average energy expenditure per hour.

Results were considered significant at $\alpha = 0.05$.

RESULTS

The questionnaire captured the demographics and jobs of participants (Table 3). The traditional office cohort composed of individuals who worked as administrators/coordinators (n=13), a nurse (n=1), professors/educators (n=3), research associates (n=2) and an accountant (n=1). The home office cohort composed of business owners (n=2), a virtual assistants (n=1), a salesman (n=1), a director of operations (n=1), a relator (n=1), and an insurance agent (n=1). The home office workers were homogenous in terms of race/ethnicity (100% white) and a smaller age range (31-60 years). However, the home worker cohort had greater gender representation (44% male, 56% female). The office worker demographics were majority female (90.48%) and had more heterogenicity in age (20- >60 years) and race. The majority of home and traditional office workers reported spending between six and seven hours at their primary workstation (55.56% and 85.71%, respectively). All participants had traditional workstations- without the ability to transition to a standing position, walk on a treadmill or stand during computer-based tasks.

Table 3 Participant Demographics of Home and Office Workers

	Home n=9 n(%)	Office n=21 n(%)
Gender		
Male	4 (44.44)	2 (9.52)
Female	5 (55.56)	19 (90.48)
Age		
Mean (Range)	43.89 (35-52)	42 (24-65)
Race		
White	9 (100)	15 (71.43)
Black	0	2 (9.52)
Asian	0	1 (4.76)
Hispanic	0	2 (9.52)
Hawaiian	0	1 (4.76)
Multicultural	0	0
Education		
High school degree	1 (11.11)	5 (23.81)
Undergraduate	5 (55.56)	9 (42.86)
Postgraduate	3 (33.33)	6 (28.57)
Unanswered	0	1 (4.76)
Household Income		
$20,000- $50,000	0	4 (19.05)
$50,000- $75,000	2 (22.22)	9 (42.86)
$100,000- $150,000	1 (11.11)	6 (28.57)
$150,000- $200,000	1 (11.11)	2 (9.25)
>$200,000	4 (44.44)	2 (18.18)
Unanswered	1 (11.11)	0
Hours a Day at Workstation		
</= 5	2 (22.22)	3 (14.29)

Table 3 (continued)

6-7	5 (55.56)	18 (85.71)
>8	2 (22.22)	0

We asked additional questions to the homeworkers to attain some understanding of the environment in which they work (Table 4). At least 81% of the participants had other individuals in the home during working hours. Over half of the home office participants reported having children who lived in the home (63.64%). All home office participants lived in a single-family detached dwelling in Central or South Texas.

Table 4 Home Office Questionnaire (n=9)

Number of individuals in the home	
Mean (Range)	4.14 (3-5)
Number of individuals in the home during the work day	
Mean (Range)	2.57 (1-4)
Number of children in the home	
Mean (Range)	21.85 (0-3)
Average hours a week worked from home	
20-30	2 (18.18)
30-40	3 (27.27)
>40	3 (27.27)
Unanswered	3 (27.27)

The daily totals of time sitting/lying, standing, and stepping in the traditional office environment and the home office were not significantly different (p= 0.1938, p=0.1618 and p=0.8134, respectively) (Table 5, Figure 4). Additionally, total daily step count (Figure 5) and number of transitions (Figure 6) were not statistically significant between home office workers and traditional office workers (p=0.6023 and p=0.1246, respectively). Energy expenditure, measured in metabolic equivalents, of traditional office employees and individuals working from home was not statistically significant in this study (p= 0.4367).

Table 5 Daily Total Mean, Median, Range of all daily measures collected in home and office workers. Statistical Significance results of Repeated Measures ANOVA (p-value)

	Traditional Office n=21	Home Office n=9	p-Value
Time Sitting/ Lying (h)			
Mean (SD)	18.12 (2.26)	19.82 (2.18)	p= 0.1838
Median	18.96	20.19	
Min	11.20	12.63	
Max	22.18	23.60	
Time Standing (h)			
Mean (SD)	3.87 (2.14)	2.93 (1.73)	p=0.1618
Median	3.44	2.40	
Min	0.87	0.38	
Max	11.66	9.07	
Time Stepping (h)			
Mean (SD)	1.30 (0.49)	1.25 (0.83)	p=0.8134
Median	1.24	1.27	
Min	0.35	0.02	
Max	2.68	3.57	
Step Count			
Mean (SD)	6497.59 (2574.65)	5927.77 (4128.48)	p=0.6023
Median	6300	5910	
Min	1640	66	
Max	13886	19794	
Sit to Stand Transitions			
Mean (SD)	61.83 (20.56)	52.23 (13.42)	p=0.1246
Median	61	51	
Min	13	22	
Max	106	83	
Energy Expenditure*			
Mean	33.12 (1.08)	32.77 (1.71)	p=0.4367
Median	33.08	32.88	
Min	31.43	30.08	
Max	36.16	37.71	

* Average METs per day over 24-hour period

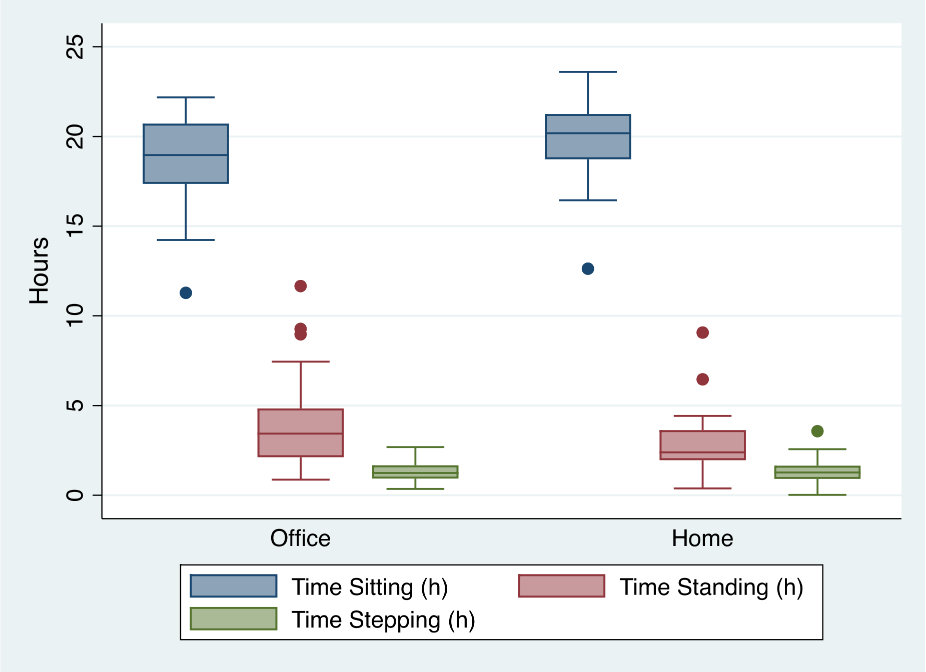

Figure 6 Median and range of daily time sitting (h), time standing (h) and time stepping (h) in traditional office and home office employees

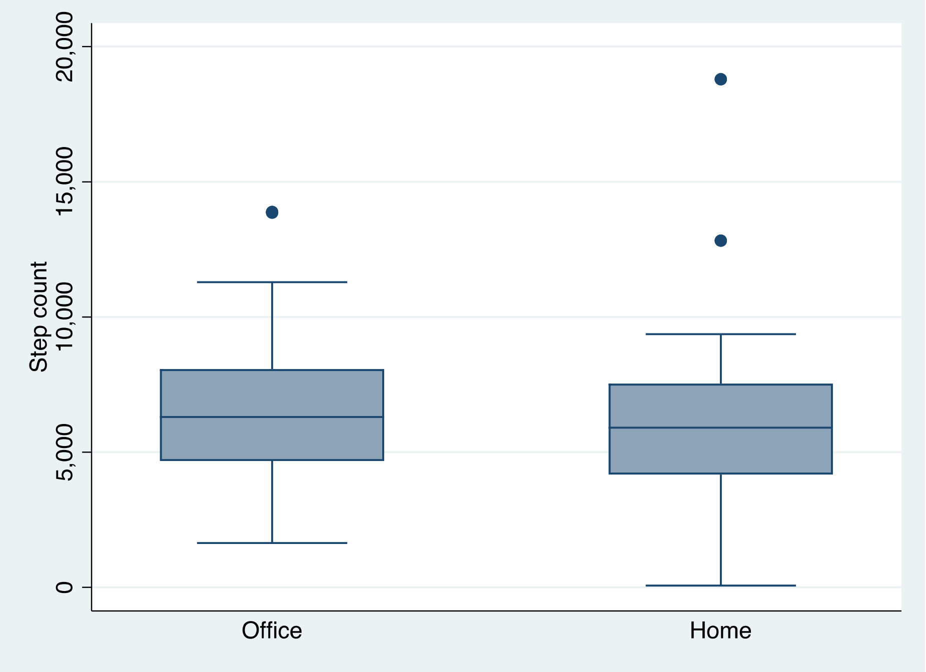

Figure 7 Median and range of daily step count in traditional office and home office employees

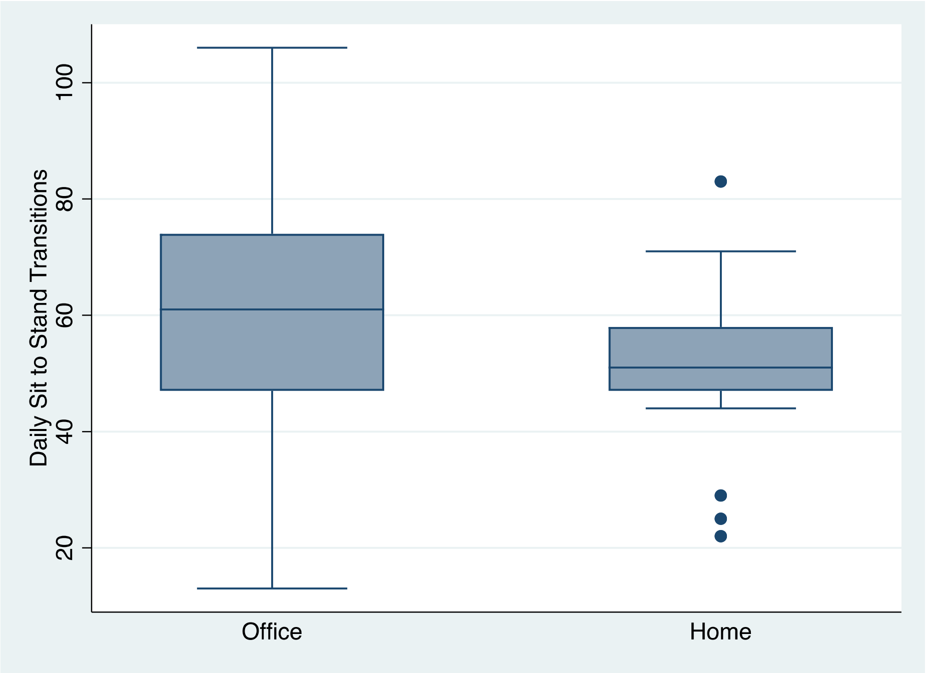

Figure 8 Median and range of daily transitions from sitting to standing in traditional office and home office employees

The traditional working hours (9:00 am – 5:00 pm) totals of time sitting/lying, standing, and stepping in the traditional office environment and the home office did not significantly differ between traditional office workers and home office employees (p= 0.6004, p=0.4299 and p=0.4857, respectively) (Table 6, Figure 7). Furthermore, total daily step count and amount of transitions were not statistically significant between home office workers and traditional office workers (p=0.6023 and p=0.1246, respectively) (Figure 8, Figure 9, respectively). Energy expenditure of traditional office employees and individuals working from home was not statistically significant between the hours of 9:00 am and 5:00 pm (p= 0.4367).

Table 6 Traditional Work Hours (9:00 am- 5:00 pm) Total Mean, Median, Range, Statistical Significance Results of Repeated Measures ANOVA

	Traditional Office n=21	Home Office n=9	p-Value
Time Sitting/ Lying (m)			
Mean (SD)	41.89 (14.82)	43.94 (14.95)	p= 0.6004
Median	49.70	49.70	
Min	3	3	
Max	24.60	60	
Time Standing (m)			
Mean (SD)	13.73 (13.01)	11.28 (11.51)	p=0.4299
Median	9.95	7.25	
Min	0	0	
Max	58.80	46.60	
Time Stepping (m)			
Mean (SD)	14.37 (4.41)	4.77 (5.43)	p=0.4857
Median	3.10	3.20	
Min	0	0	
Max	18.90	23.10	
Sit to Stand Movements			
Mean (SD)	4.25 (2.92)	3.29 (2.63)	p=0.0676
Median	4	3	
Min	0	0	
Max	13	13	
Stand to Sit Transitions			
Mean (SD)	3.65 (2.87)	2.72 (2.62)	p=0.0696
Median	3	2	
Min	0	0	
Max	12	12	
Step Count			
Mean	375.62 (378.04)	363.07 (415.25)	p=0.5210
Median	272	254	
Min	0	0	
Max	1782	1864	
Energy Expenditure*			
Mean	1.43 (0.16)	1.42 (0.18)	p=0.9678
Median	1.40	1.37	
Min	0	0	
Max	2.01	2.03	

* Average METs per day over 24-hour period

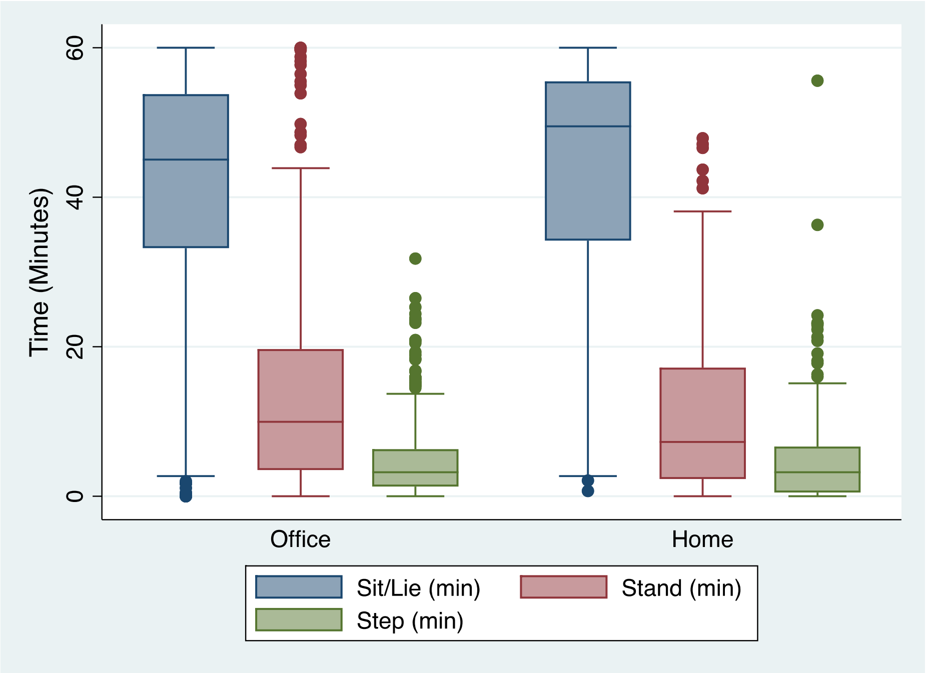

Figure 9 Median and range of minutes per hour sitting, standing, and stepping during the traditional work day (9:00 am- 5:00 pm) for traditional office and home office employees

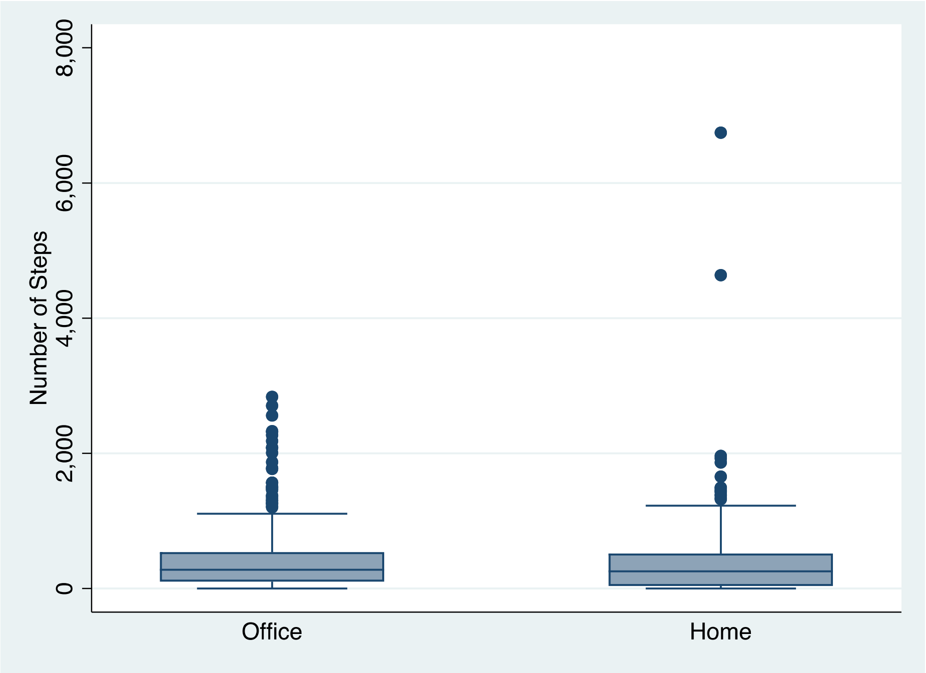

Figure 10 Median and range of hourly step count during the traditional work day (9:00 am- 5:00 pm) for traditional office and home office employees

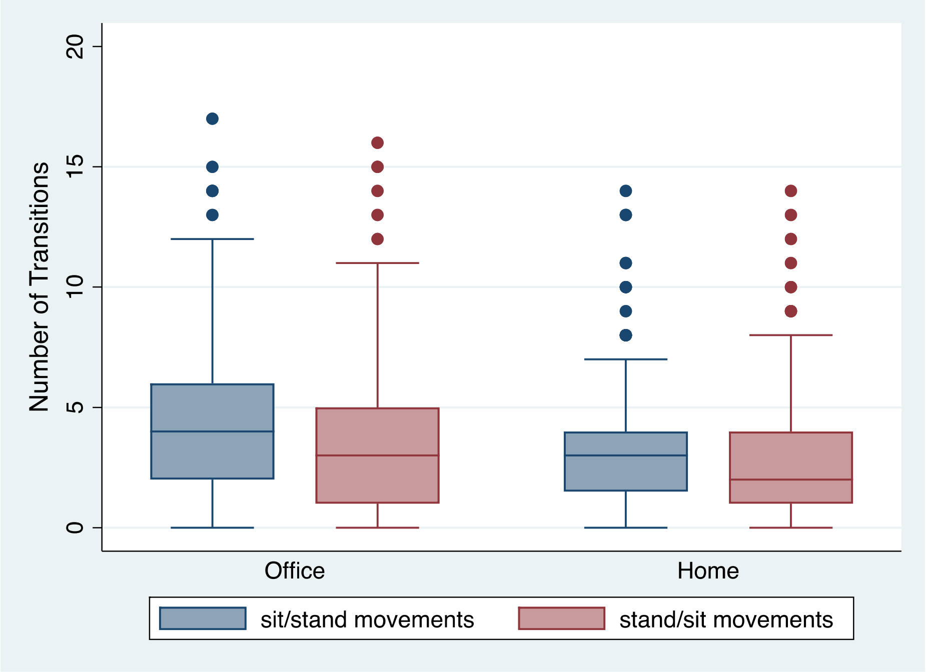

Figure 11 Median and range of sit to stand movements and stand to sit movements during the traditional work day (9:00 am- 5:00 pm) for office and home workers of sit to stand movements and stand to sit movements in traditional office and home office employees

DISCUSSION

We anticipated there to be a difference in sedentary behaviors in home office workers and traditional office employees due to differences in built environment. However, the results of this study suggest that there is little difference in the total time stepping, standing, transitions, and energy expenditure in the two environments during the

This exploratory study investigates the difference in sedentary behavior patterns between remote workers and those in the traditional office environment. The nature of working in a traditional office building creates the need to move more frequently during day-to-day business. For example, utilizing meeting rooms, community dining areas, or restrooms requires the individual to walk further than the equivalent activity would require in a private residence where the employee has a virtual presence. Additionally, many companies invest in creating a built environment that encourages employees to move throughout the day by creating gyms and supplying desks that allow the worker to change positions during working hours. The same conveniences are not likely to be available for remote employees. However, home workers may feel their schedule is more flexible and, as a result, move about their community more than those at traditional offices.

Between the home worker cohort and the traditional workplace cohort, the amount of time spent in different postures (sitting, lying, or standing) was not significantly different. Our study was consistent with other studies in suggesting that workers spend about 2/3 of their day in a sitting or lying position (Hadgraft, et al., 2016; Chau, et al., 2013; Young, et al., 2016; Miller & Brown, 2004). This suggests that office employees are practicing sedentary behaviors the majority of their day independent of location.

One common measurement of sedentary behavior is to estimate the total energy expenditure. Here, there was not a statistically significant difference in the total energy expenditure during the traditional work day (p=0.96) or in the daily total (p=0.43). Previous studies have determined that sedentary time, measured by energy expenditure, was higher during the traditional work week than on the non-work days (Parry & Straker, 2013). Here, we differentiated between two time blocks to account for compensation for workplace sedentary behaviors by exercising outside of the traditional working hours. Our study suggests that there is not a statistically significant difference in the total amount of energy expenditure during traditional working times or in daily totals.

Some research suggests that one way to break up a worker's sedentary behaviors is to encourage postural transitions throughout their workday. Research is conflicting on the relation between the amount of transition movements and the effects on impact of public health, specifically energy expenditure and obesity. A study out of Texas A&M University associated the ability to transition from a sitting to a standing position throughout the work day results in increased productivity (Garrett, et al., 2016). However, researchers at the Exercise and Health Laboratory in Cruz-Quebrada, Portugal and the Texas Obesity Research Center warn that interrupting sitting frequently only has modest impact on energetic cost (Judice, Hamilton, Sardinha, Zderic, & Silva, 2016). Regardless of the potential for body transitions to have negligible metabolic impacts, other studies have associated changes in body position with lower self-reported discomfort (Pickens, et al., Stand-capable desk use in a call cennter: a six-month follow-up pilot study, 2016) and lower risk of musculoskeletal discomfort (Thorp A. , Kingwell, Owen, & Dunstan, 2014; Danquah, Kloster, Holtermann, Aadahl, & Tolstrup, 2017). All participants in this study had traditional desks. This means that they did not have the ability to change postures from sitting to standing while working on computer-based tasks. Previous studies have suggested that employees who have the ability to transition from seated position to a standing position throughout their workday have decreased total sitting time and increased self-reported comfort (Pickens, et al., Stand-capable desk use in a call cennter: a six-month follow-up pilot study, 2016). Here, the amount of transitions from sitting to standing and standing to sitting were not significantly different between home office workers and traditional office employees in this study. Future studies should investigate the difference in transitions in the two cohorts without the restriction of traditional workstations, as this likely limited the generalizability of our study.

We anticipated that there would be a difference in the daily steps taken between the two cohorts due to the differences in built environment and flexibility of work schedules. A study by Miller & Brown (2004) suggested that professionals, managers, and administrative workers recorded the lowest number of steps on weekdays when compared to technicians and blue-collar workers (Miller & Brown, 2004). They compared the number of steps per day to the commonly quoted 10,000 steps per day. While it is unclear where this arbitrary goal originated, 10,000 steps per day is commonly used by consumer-activity trackers as a realistic goal to increase physical activity and has been shown to encourage individuals to walk for >30 minutes per day (Welk, et al., 2000). Our study found the mean steps per day were ~6500 for workers in the traditional office environment and about ~5930 for those in the home office environment. These values are not significantly different in this study, suggesting that the majority of individuals did not reach 10,000 steps in neither the home nor office environment. In addition to the total steps taken throughout the day, our study also included the total time stepping in traditional office employees and home office workers. While the total time stepping was not significantly different between the two cohorts, it is noteworthy that the mean hours of time stepping were 1.27 hours for the home worker cohort and some of those individuals did not reach 30 minutes of total walking time during our data collection period.

Our study presents a variety of limitations. Due to our small sample size, we cannot exclude the possibility that our study was insufficiently powered to detect a smaller effect size. We are unable to confirm that the home office employees were working during traditional work times. Over half of the home office participants in this study reported having at least one child living in the home. This study took place in the late spring/early summer time, we anticipated that school-age children would be on summer vacation and therefore be present in the home during the participant's working hours. We did not ask the age-range of the children living in the residence. However, future studies should consider the effects of childcare duties of parents who work from home for younger children during work hours. Also, it is likely that the HSC employees worked from home on projects outside of the 9-5 work day. Furthermore, all participants in this study had computer-based jobs, such as administrators, insurance agents, and professors. A previous study has suggested that there are significant differences in sedentary behaviors of those in computer-based work and physically-demanding work, such as farming (Pontt, Rowlands, & Dollman, 2015). Therefore, this study may not be generalizable to positions that require the individual to travel or complete physically demanding tasks. Future research should include ergonomic software that will enable the researcher to verify when the employee is completing computer-based tasks to determine if differences in physical activity during the two cohorts are due to the flexibility of the work environment, such as the ability to walk pets or play with children throughout the day.

Although there is increasing interest in built environment, ergonomically-designed office furniture, and software to enable employees to increase energy expenditure and change postures throughout the traditional workspace (Neuhaus, et al., 2014; Sharma P. P., Mehta, Pickens, Han, & Benden, 2018; Prince, Saunders, Gresty, & Reid, 2014), the same interventions may not be feasible in the home work space. Individuals who work from home may not have the resources or space for the equipment that is being implemented in a traditional office space. While we know that sedentary behaviors in the traditional office space have been associated with obesity (Hadgraft, et al., 2016; Mummery, Schofield, Steele, Eakin, & Brown, 2005), the results of this study suggest that sedentary behavior interventions should be modified to include remote workers as well as traditional office employee. Future research should consider using ergonomic software and validated musculoskeletal discomfort measurement tools to assess the burden of computer-based work on home office employees.

CONCLUSION

Sedentary behavior is one of the most important public health issues of the century. This study suggests that with the transition of the work environment from commercial office buildings to private residences, it is important to continue to encourage physical activity for computer-based workers regardless of their physical location. Ergonomists and employers should be sure to design for movement and ergonomics. Additionally, it would be mutually beneficial for companies to educate their workers on the benefits of reducing sedentary behaviors and providing resources and equipment to encourage this throughout the work day.

CHAPTER IV EXPLORATORY ANALYSIS OF INDOOR AIR QUALITY OF COMMERCIAL OFFICE BUILDINGS AND THE HOME OFFICE

INTRODUCTION

The Environmental Protection Agency (EPA) has identified indoor air quality (IAQ) as one of the top five most urgent environmental risks to public health (Occupational Safety and Health Administration, 2011). Climate change mitigation and high energy costs have influenced home and business owners to rethink their property's design (U.S. Department of Energy, 2008). Weatherization, or steps taken to limit indoor/outdoor air exchange, increases energy efficiency and conservation. However, reduced ventilation of homes with outdoor air is also associated with increased indoor pollutant levels (Offerman, 2010). Indoor air pollution has been associated with exacerbating pre-existing conditions, such as asthma, and is attributable to several other chronic and acute health conditions (Dales, Liu, Wheeler, & Gilbert, 2008). Poor indoor air quality has also been associated with sick building syndrome (SBS) (Tsai, Lin, & Chan, 2012; Satish, et al., 2012; Allen, et al., 2016; Lu, Lin, Chen, & Chen, 2015). SBS describes any illness or discomfort experienced by occupants that are attributable to the building environment and indoor air contaminants. SBS often manifests as a variety of symptoms such as eye irritation, fatigue, and decreased work performance (Tsai, Lin, & Chan, 2012; Satish, et al., 2012; Allen, et al., 2016).

In addition to the pollutants associated to SBS, the EPA considers several common indoor air pollutants to be carcinogenic- such as, formaldehyde, toluene, and chemicals used in fire retardants (United States Environmental Protection Agency, 2017). International Agency for Research on Cancer (IARC) has also listed common indoor air pollutants as human carcinogens (International Agency for Research on Cancer, 2018). For example, benzene is considered a Group 1 carcinogen, described as being carcinogenic to humans (International Agency for Research on Cancer, 2018) and is commonly found in residential spaces (Chatzis, Alexopoulos, & Linos, 2005; Delgado-Saborit, Aquilina, Meddings, Baker, & Harrison, 2011). Other common and potentially harmful indoor air pollutants are regulated and monitored in outdoor air but not in the residential space. For example, Particulate matter (PM) is one of the six criteria pollutants monitored by the EPA in outdoor air (Clean Air Act of 1963). However, it is not monitored or regulated in the home environment. Previous studies have linked exposure to PM to severe health effects such as cardiovascular issues, aggravated asthma, and decreased lung function (United States Environmental Protection Agency, 2018; Ackermann-Liebrich, et al., 1997; Sekine, Shima, Nitta, & Adachi, 2004). Furthermore, carbon dioxide, even at levels below the recommended limits of ASHRAE, has commonly been associated with SBS, such as upper respiratory irritations, fatigue and decreased work performance (Tsai, Lin, & Chan, 2012; Satish, et al., 2012;

Allen, et al., 2016). Despite the potential adverse health impacts due to long-term exposure to indoor air, the majority of Americans' are spending increasing amounts of time in indoor environments (Dales, Liu, Wheeler, & Gilbert, 2008; Bernstein, et al., 2008).

American adults spend ~90% of their day indoors (Dales, Liu, Wheeler, & Gilbert, 2008; Bernstein, et al., 2008), most likely because they spend the majority of their time in indoor work and home environments. The population is therefore continuously exposed to complex mixtures of chemicals and contaminants in indoor air for the majority of their life. Across business sectors and industries, employees are increasingly being given the opportunity to work from home. According to the Bureau of Labor and Statistics, over a third of individuals in professional and management, business, or financial operations performed some or all of their main job in their residence (Bureau of Labor Statistics, U.S. Department of Labor, 2015). While traditionally an adult worker would spend some of their day in an office building and some of their day in their home, the shift to a remote workforce keeps employees in the same microenvironment for more time. This would increase the individuals' exposure to pollutants in that microenvironment. Although there are IAQ regulations and standards for commercial office buildings, residential indoor air is unregulated and largely unmonitored. Researchers Pickett & Bell (2011) conducted a study in middle class family homes and found levels of particulate matter (PM), carbon dioxide (CO_2), and total volatile organic compounds (TVOCs) were above the suggested air quality guidelines that were developed by the authors using a combination of American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), U.S. EPA, and WHO recommendations (Pickett & Bell, 2011). Therefore, it is likely that there will be pollutants in the offices of those who work from home.

Companies who own commercial office space are required to keep the working space free from all known hazards, including air quality issues, due to the Occupational Safety and Health Administration (OSHA) General Duty Clause (OSH Act of 1970 General Duty Clause). Increasingly, companies have attempted to address indoor air quality issues while maintaining energy efficiency by making improvements to their buildings following the recommendations of the ASHRAE (ASHRAE, 2018) or obtaining certifications for sustainable buildings such as the Leadership in Energy and Environmental Design (LEED) certification (U.S. Green Building Council, 2018; U.S. Green Building Council, 2019). However, residential settings are likely to be more complex and untouched by the company. The home environment has many potential sources of pollution that commercial office spaces may not need to address, such as close proximity to cooking fumes or a wood-burning fireplace. There are likely to be unique barriers due to individual decision-making for maintaining air quality in the home. For example, an individual that is renting a property may not have the ability to make renovations to meet the evolving ASHRAE standards. Furthermore, many of the standards used in commercial office buildings must be purchased, such as the WELL Building Standard (International WELL Building Institute, 2019). The WELL building standard is a green building standard that companies can follow to become WELL Certified. However, the standards are not accessible to the public and the certification includes an onsite assessment and a performance test (International WELL Building Institute, 2019). This process may not be feasible for a residential space. Additionally, an individual may not be able to afford to replace their home's air filters on a regular basis or maintain an HVAC system, whereas, a commercial building is required to maintain their equipment due to OSHA General Duty Clause (OSH Act of 1970 General Duty Clause).

While the exact composition of indoor air is complex and expensive to measure, this study aims to assess four pollutants that have been associated with SBS and other adverse health effects in both the home office space and commercial work environment: particulate matter, CO_2, and TVOCs. We measured particulate matter 10 (PM_{10}), or inhalable particles with diameters less than 10 micrometers, and particulate matter 2.5 ($PM_{2.5}$), or particles with diameters 2.5 micrometers or less (United States Environmental Protection Agency, 2018) due to their clinical relevance (United States Environmental Protection Agency, 2018; Ackermann-Liebrich, et al., 1997; Sekine, Shima, Nitta, & Adachi, 2004) and presence in residential spaces (Offerman, 2010; Abt, Suh, Catalano, & Koutrakis, 2000). With the increasing popularity of remote working, specifically in a home office, it is important to understand the potential environmental differences between the two spaces. The objective of this study was to: (1) determine if there was a significant difference in air composition between the office workspace provided by employers, and the home office, (2) identify existing health-based standards for key indoor air contaminants, (3) assess the concentrations of these contaminants compared to current health-based standard(s), and (4) identify areas for future research. Due to the differences in maintenance responsibilities and available guidelines in commercial office buildings and residential homes, we hypothesized that individuals in the U.S. may be exposed to higher concentrations of pollutants in the home than in a traditional office environment, where there are initiatives to keep indoor air pollutants as low as possible.

METHODS

RECRUITMENT

This cohort study consisted of a sample of traditional office employees and a sample of individuals who work primarily from a space within their residence. The traditional office cohort, or work space that is managed by an employer, was recruited from the Texas A&M Health Science Center in College Station, TX (HSC) (n=11). Recruitment emails were sent from March 2019 through May

2019 to enroll individuals for the two cohorts of this study. A recruitment email was sent to all employees of the Texas A&M Health Science Center and members of the Bryan-College Station Chamber of Commerce (APPENDIX A). To reach the target sample size for the home worker cohort, recruitment emails were also sent to individuals who were referred by other participants and alumni of the Texas A&M Health Science Center (HSC). A convenience sample of local workers from the community and national companies who work primarily from their residence in South Texas were recruited via email to represent the home worker cohort (n=11). Participants were asked to complete a survey and allow an air quality monitor to run in their home from Monday through Friday of a work week. Participants were asked to sign an informed consent (APPENDIX B, APPENDIX C) and compensated $100 for participating. This study took place over an eight-week period from April 15, 2019 – June 14, 2019. This study was approved by the Texas A&M University Institutional Review Board (IRB2018-0617D).

INDOOR AIR QUALITY MONITORING

Indoor air monitoring was conducted for CO_2, $PM_{2.5}$, PM_{10}, TVOCs, temperature, and relative humidity. A ParticlesPlus 7302 Air Quality and Environmental Monitor (ParticlesPlus, Stoughton, MA, USA) was used to collect measurements. The ParticlesPlus 7302 Environmental Monitor measures particles between 0.3- 25 µm. Additionally, the monitor contains a nondispersive infrared (DNIR) CO_2 sensor that allows for a reading of up to 5000 ppm. The monitor also contains photo ionization sensor (PID) that will respond to volatile organic compounds between 0-50 ppm.

The monitor was placed in a representative location of the area that the participant reported spending the majority of their time working. Care was taken not to place the monitor in direct sunlight or near open flames. Typically, the monitor was placed on a side table or on top of a shelf near a desk or primary workspace. The monitor was set to take a one-minute sample every fifteen minutes continuously from Monday to Friday of the participants' work week. The air sampling flow rate was 0.1 cubic feet per minute (CFM). Monitors were calibrated according to the manufacturer's instructions between every other sampling period.

The office workers recruited from this study were all employed by the Texas A&M University Health Science Center. The Texas A&M Health Science Center consists of several office buildings in Texas- this study was performed at the HSC buildings in College Station, TX. The buildings are maintained by a facilities services team, who ensure that the building has new minimum efficiency reporting value- 11 (MREV-11) air filters monthly. The conditioning and maintenance of indoor air of the home offices were unknown prior to this study.

ANALYSIS

Statistical analysis was performed using STATA/IC 15.1 (College Station, TX). Survey data was used to describe participant demographics and select consumer products or other known sources of pollutants that may be found in the residential space. Mondays and Fridays were cut from the dataset to create a midweek snapshot of the participant's work environment. Midweek data was used to allow for equipment pick up/ drop off time. Means, medians, and ranges were calculated for each parameter and each cohort. A repeated measures ANOVA was performed for each parameter ($\alpha=0.05$). Non-parametric data ($PM_{2.5}$, PM_{10}, CO_2 & TVOCs) were log transformed prior to performing the ANOVA.

RESULTS

PARTICIPANTS

The demographics of the home and office workers included in this study are presented in Table 7. The home worker cohort consisted of white individuals (n=11), the average age was 45.9 years and ranged from 35-61 years. The office cohort was less homogenous, with more diversity in race and the average age was 35.9 years and ranged from 23-55 years (Table 7). All study participants were employed in computer-based jobs, such as university faculty positions and administrative assistants. The home worker cohort was employed in jobs including business owner, sales representative and ergonomists. All offices were located in Central or South Texas.

Table 7 Participant Demographics for Home and Office Workers

	Home N=11 n(%)	Office N=11 n(%)
Gender		
Male	6 (54.5)	3 (27.27)
Female	5(45.5)	8 (72.73)
Age		
Mean (Range)	45.9 (35-61)	35.9 (23-55)
Race		
White	11(100)	7 (63.64)
Black	0	0
Asian	0	1 (9.09)
Hispanic	0	2 (18.18)
Hawaiian	0	1 (9.09)
Multicultural	0	1 (9.09)
Highest Level of Educational Attainment		
High school degree	1 (9)	1 (9.09)
Undergraduate	5 (45.5)	6 (54.55)
Postgraduate	5 (45.5)	4 (36.36)
Household Income		
$20,000- $50,000	0	3 (27.27)
$50,000- $75,000	2 (18.18)	3 (27.27)
$100,000- $150,000	1 (9)	3 (27.27)
$150,000- $200,000	7 (63.50)	2 (18.18)

Table 7 (continued)

Unanswered	1 (9)	0
Hours a Day at Workstation		
≤ 5	4 (36.36)	2 (18.18)
6-7	5 (45.45)	8 (72.73)
>8	2 (18.18)	1 (9.09)

Primary Working Areas

A survey was administered to the home worker cohort to create a snapshot of their primary working area (Table 7). All participants in the study were residents in a single-family, detached dwelling with at least one other individual living in the home. All participants had either electric or gas heating sources and central air conditioning.

The home workers in our study were asked additional questions to describe their work environment (Table 8). All participants who fully completed the survey lived in single-family, detached dwellings with central air conditioning (81.82%). Over half of the home worker population reported children living in the home (63.64%).

Table 8 Home Worker Questionnaire

Home Office Space Description	Mean/n(%)
Number of individuals living in home	
Mean (Range)	4.11 (3-5)
Number of individuals home during working hours	
Mean (Range)	2.88 (1-5)
Number of children in the home	
Mean (Range)	1.67 (0-3)
Average hours a week worked from home	
Mean (Range)	4 (3-9)
Type of home	
Single-family detached dwelling	9 (81.82)
No answer	2 (18.18)
Office claimed as tax deduction	
Yes	5 (45.45)
No	4 (36.36)
No answer	2 (18.18)
Year home was built	
1900-1949	1 (9.09)
1950-2000	1 (9.09)
>2000	7 (63.64)
No answer	2 (18.18)
Home size (square feet)	
<2000 sq ft	2 (18.18)
2000-3000 sq ft	3 (27.27)
3000-4000 sq ft	2 (18.18)
4000- 4500 sq ft	4 (36.36)
Heat source	
Gas	4 (36.36)
Electric	2 (18.18)
Gas & Electric	3 (27.27)
Unsure/ Unanswered	2 (18.18)
Home air conditioning	
Central Air	9 (81.82)
How often air filter is changed	
Every month	0
Every other month	1 (9.09)
Quarterly	6 (54.55)
Twice a year	2 (18.18)
Annually	0
Unanswered	2 (18.18)
Smoker in home	
No	9 (81.82)
No answer	2 (18.18)

Table 8 (continued)

Fireplace in home (used)	
Yes	6 (54.55)
No	3 (27.27)
No answer	2 (18.18)
Office remodeled	
Yes	2 (18.18)
No	7 (63.64)
No answer	2 (18.18)
Home remodeled	
Yes	4 (36.36)
No	5 (45.45)
No answer	2 (18.18)
New furniture in home office space in the past 5 years	
Yes	6 (54.55)
No	3 (27.27)
No answer	2 (18.18)
Wall paint in home office space	
Yes	4 (36.36)
No	5 (45.45)
No answer	2 (18.18)
Presence of rug in primary office space	
Yes	4 (36.36)
No	5 (45.45)
No answer	2 (18.18)
Presence of cats in home	
Yes	5 (45.45)
No	4 (36.36)
No answer	2 (18.18)
Presences of dogs in home	
Yes	5 (45.45)
No	4 (36.36)
No answer	2 (18.18)
Presence of room deodorizer in primary office	
Yes	2 (18.18)
No	7 (63.64)
No answer	2 (18.18)
Presence of candles in primary office	
Yes	1 (14.29)
No	9 (81.82)
No answer	1 (9.09)
Presence of space heater in primary office	
Yes	3 (27.27)

No	6 (54.55)

Table 8 (continued)

No answer	2 (18.18)

Indoor Air Monitoring

The mean, median, range and ANOVA results are presented in Table 8. $PM_{2.5}$ and PM_{10} levels were significantly higher in private residential spaces than in the traditional commercial office buildings ($p<0.0001$ and $p<0.0001$, respectively). The average $PM_{2.5}$ level in the traditional office space was 1.93 $\mu g/m_3$ and the average level in the home office space was more than triple that amount (5.97 $\mu g/m_3$) (Figures 12 & 13). The average PM_{10} level in the traditional office space was 16.37 $\mu g/m_3$ and the average level in the home office space was more than triple that amount (7.47 $\mu g/m_3$) (Figures 14 & 15). Furthermore, the levels of TVOCs, CO_2, temperature, and RH differed significantly between home offices and traditional office spaces ($p<0.000$; Figures 16-23). There were consistently wider variabilities of pollutant levels in the home offices. For example, while the mean CO_2 levels were higher in the traditional office space than the home, the maximum level measured in the home was triple than that in the traditional office environment (<0.0001; Figure 18 & Figure 19). The average home office temperature ranged from 64.22 ºF – 87.44ºF, while the traditional office ranged from 70.34 ºF – 84.92ºF (Table 5). The difference in temperature in the home and office building were statistically significant ($p<0.000$).

Table 9 Mean, median, range and statistical significance of air quality monitoring results in traditional office spaces and home offices

	Traditional Office	Home Office	p-value
PM$_{2.5}$ (µg/m$_3$)			
Mean	1.93	5.97	p<0.0001
Median	1.24	2.68	
Min	0.15	0.38	
Max	119.90	307.74	
PM$_{10}$ (µg/m$_3$)			
Mean	7.47	16.37	p<0.0001
Median	3.27	8.15	
Min	0.17	0.48	
Max	345.07	830.57	
TVOCs (ppb)			
Mean	53.04	213.00	p<0.0001
Median	1	154.00	
Min	0	0	
Max	2395	620	
CO$_2$ (ppm)			
Mean	432.07	370	p<0.0001
Median	415	696	
Min	330	370	
Max	763	2309	
Temperature (F)			
Mean	77.61	76.06	p<0.0001
Median	77.54	76.28	
Min	70.34	64.22	
Max	84.92	87.44	
Relative Humidity (%)			
Mean	43.93	50.83	p<0.0001
Median	45.00	50.00	
Min	34	37	
Max	53	66	

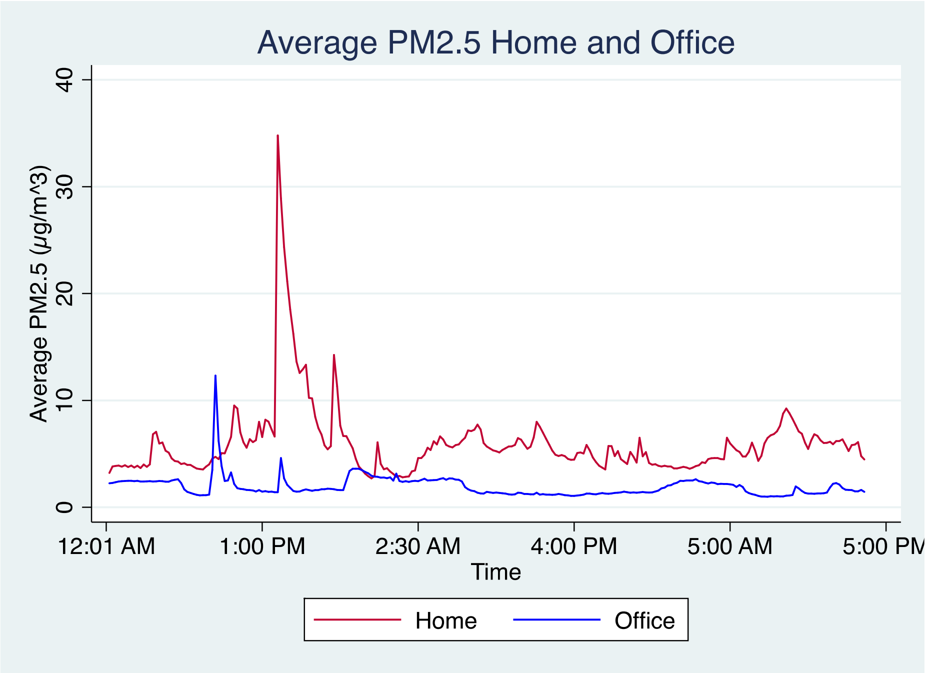

Figure 12 Average PM$_{2.5}$ (µg/m$_3$) levels over three-day time period in home office spaces (Home) and traditional office spaces (Office) in mg/m$_3$

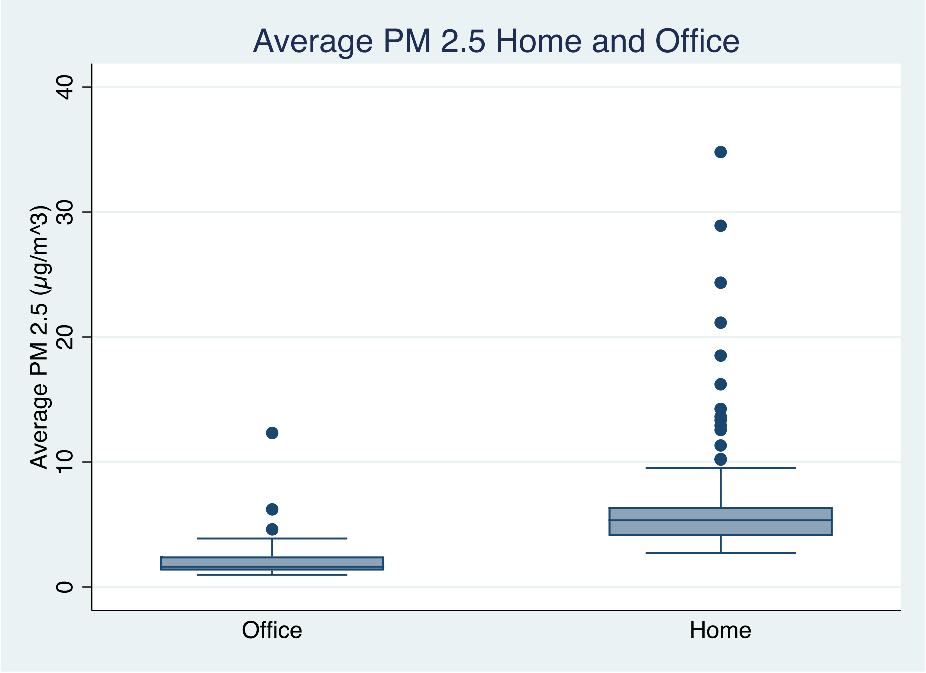

Figure 13 Variability of PM$_{2.5}$ (µg/m$_3$) in traditional offices and home offices ($p<0.0001$)

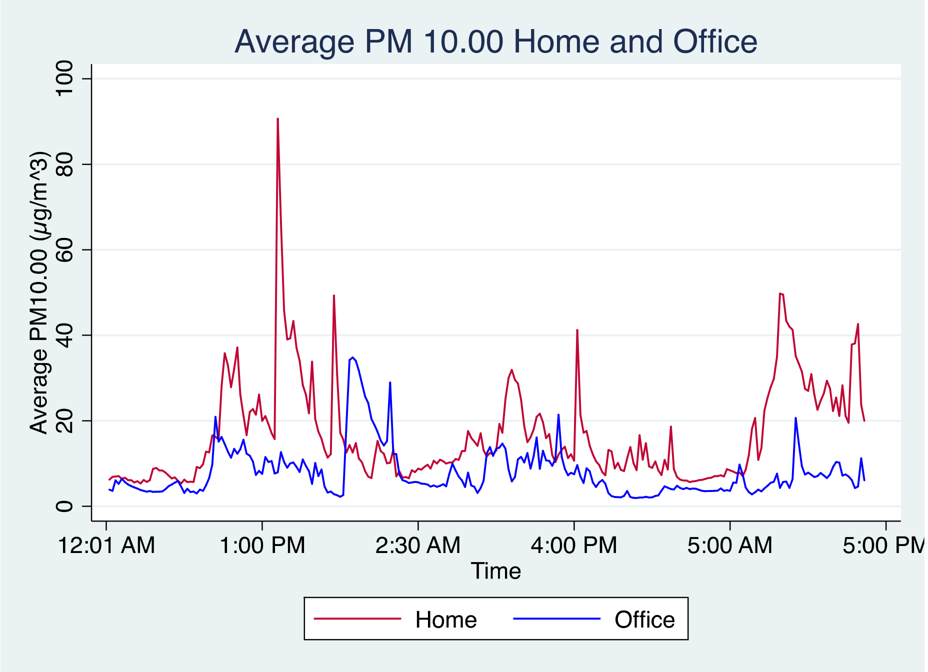

Figure 14 Average PM10 (µg/m3) over three-day time period in home office spaces (Home) and traditional office spaces (Office)

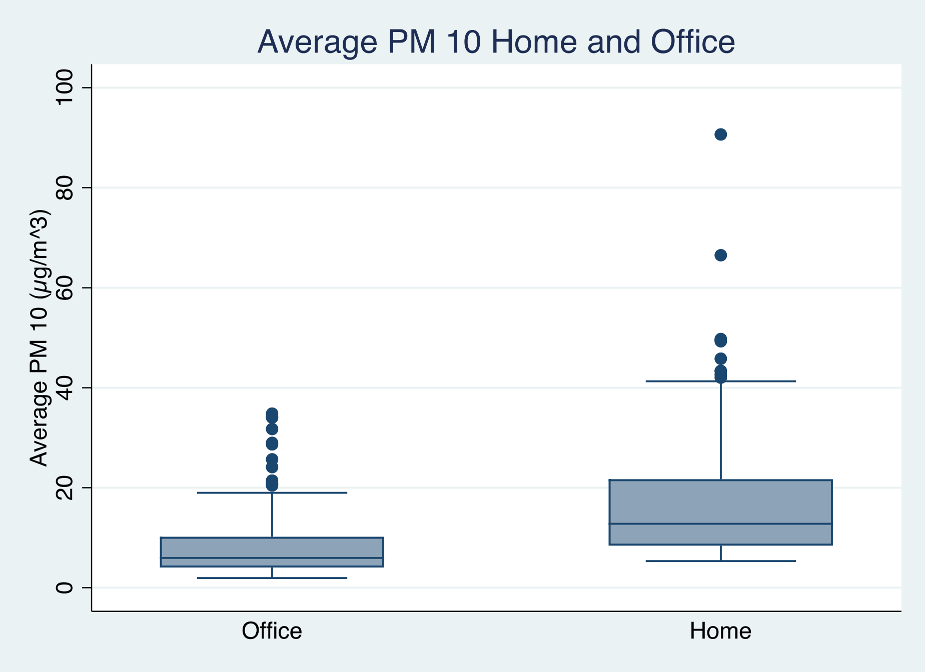

Figure 15 Variability of PM10 (µg/m3) in traditional offices and home offices (p<0.0001)

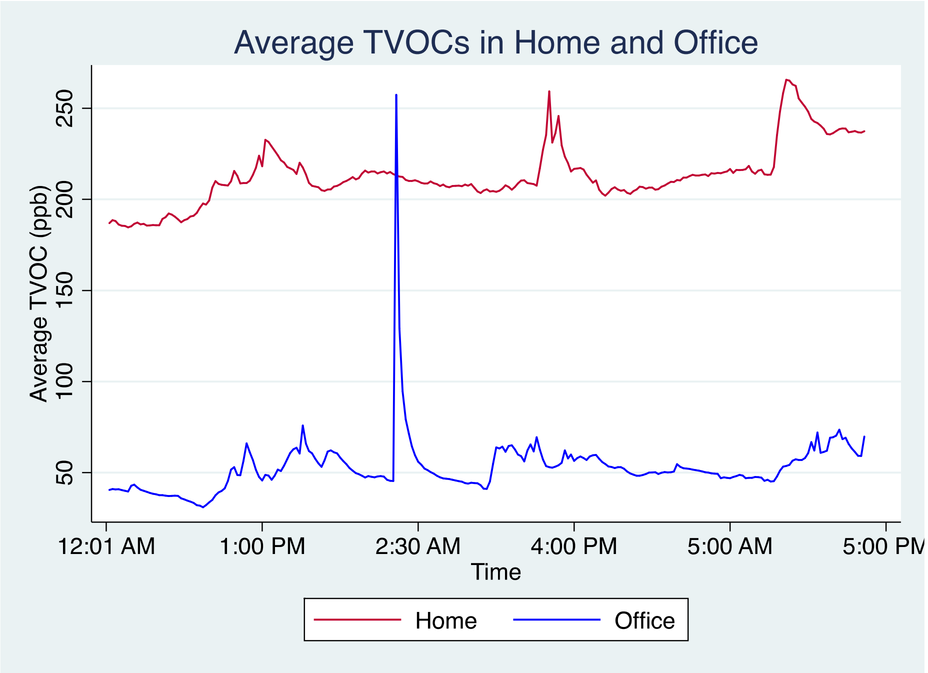

Figure 16 Average TVOCs (ppb) over three-day time period in home office spaces (Home) and traditional office spaces (Office)

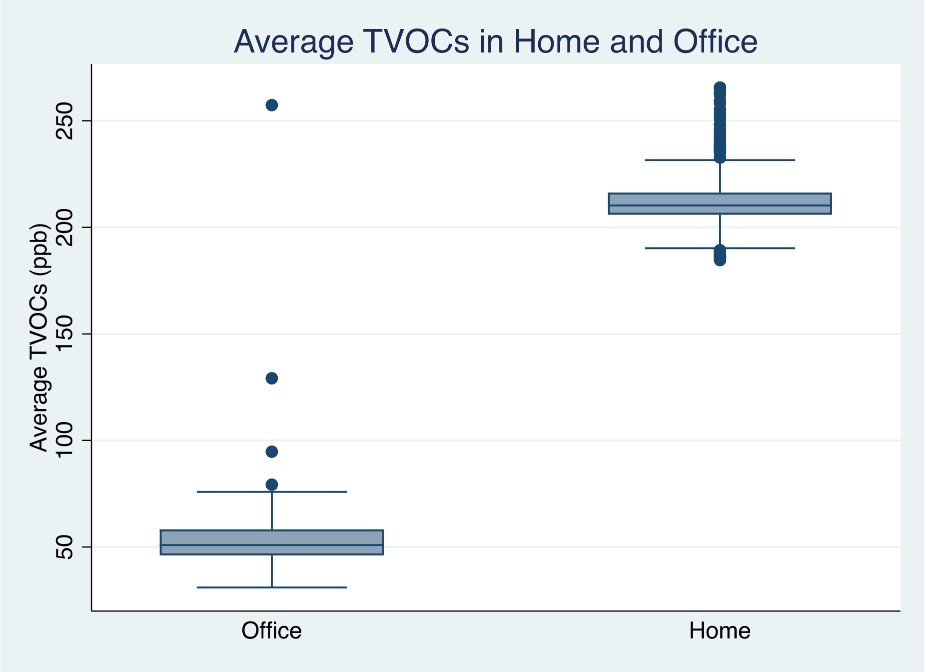

Figure 17 Variability of TVOCs (ppb) in traditional offices and home offices (p<0.0001)

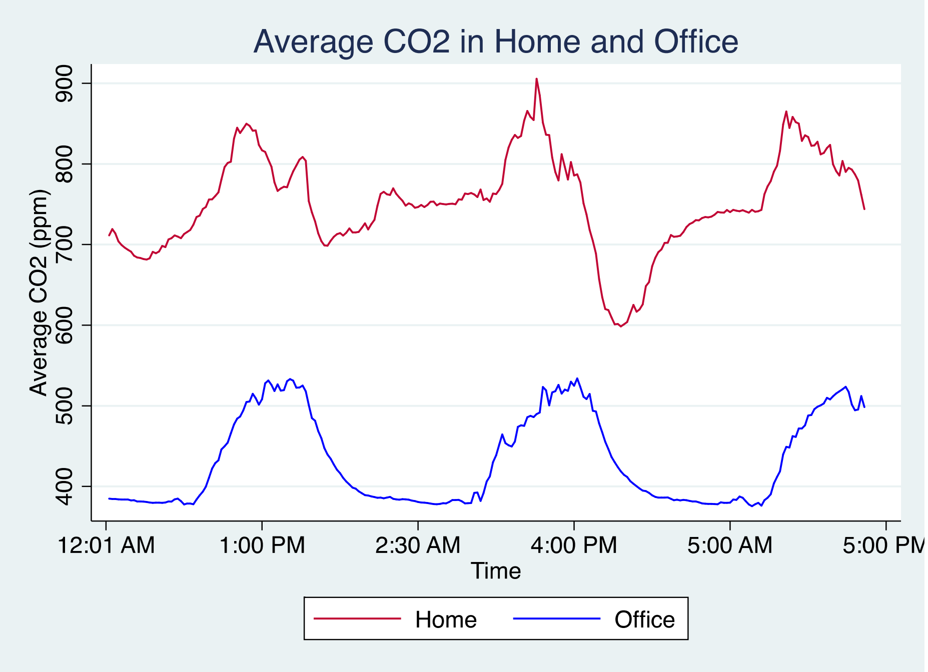

Figure 18 Average CO2 (ppm) over three-day time period in home office spaces (Home) and traditional office spaces (Office)

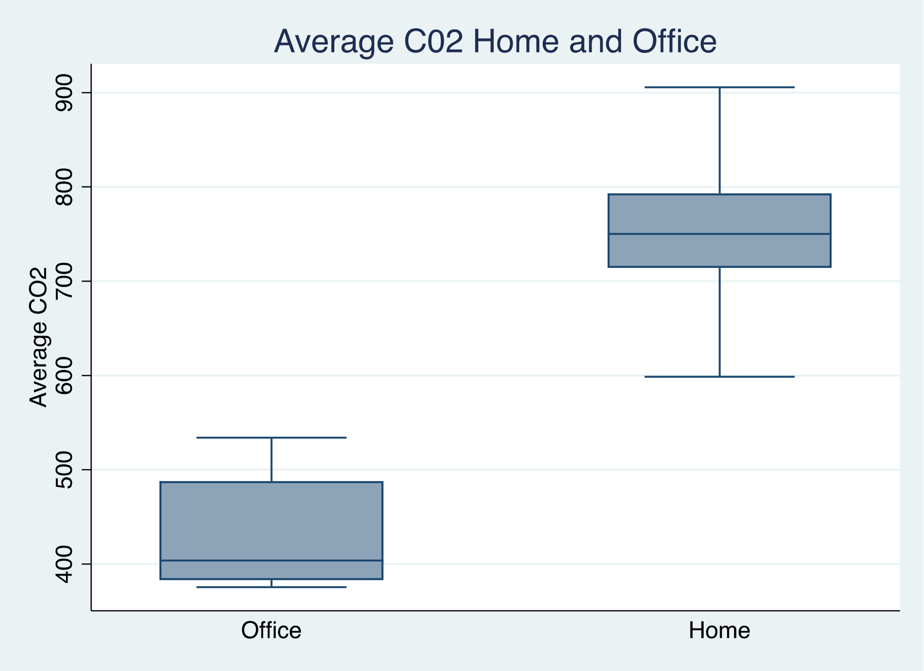

Figure 19 Variability of CO2 (ppm) in traditional offices and home offices ($p<0.0001$)

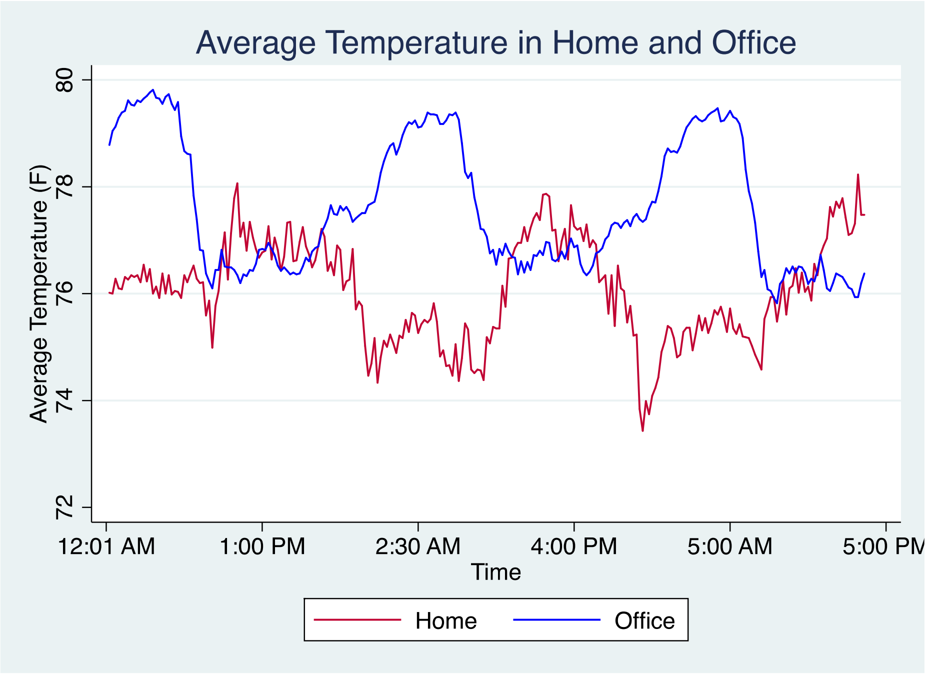

Figure 20 Average temperature (F) over three-day time period in home office spaces (Home) and traditional office spaces (Office)

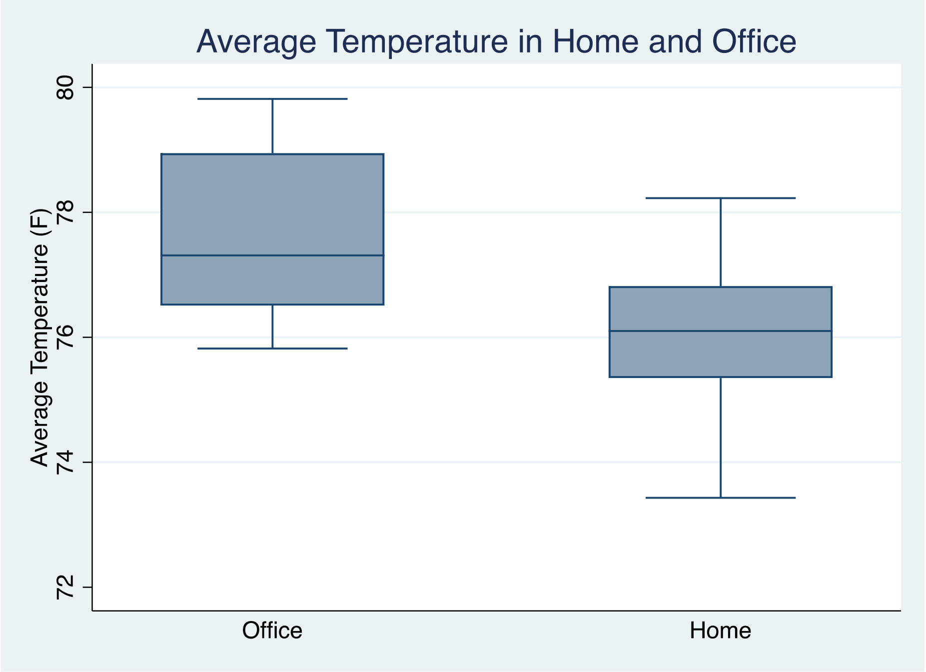

Figure 21 Variability of temperature (F) in traditional offices and home offices (p<0.0001)

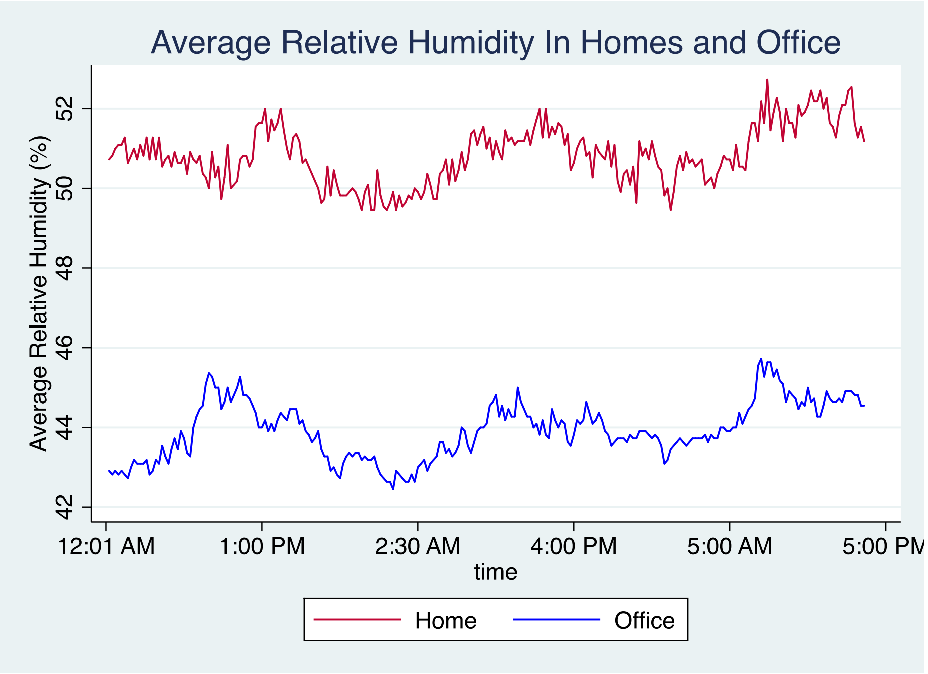

Figure 22 Average relative humidity (%) over three-day time period in home office spaces (Home) and traditional office spaces (Office)

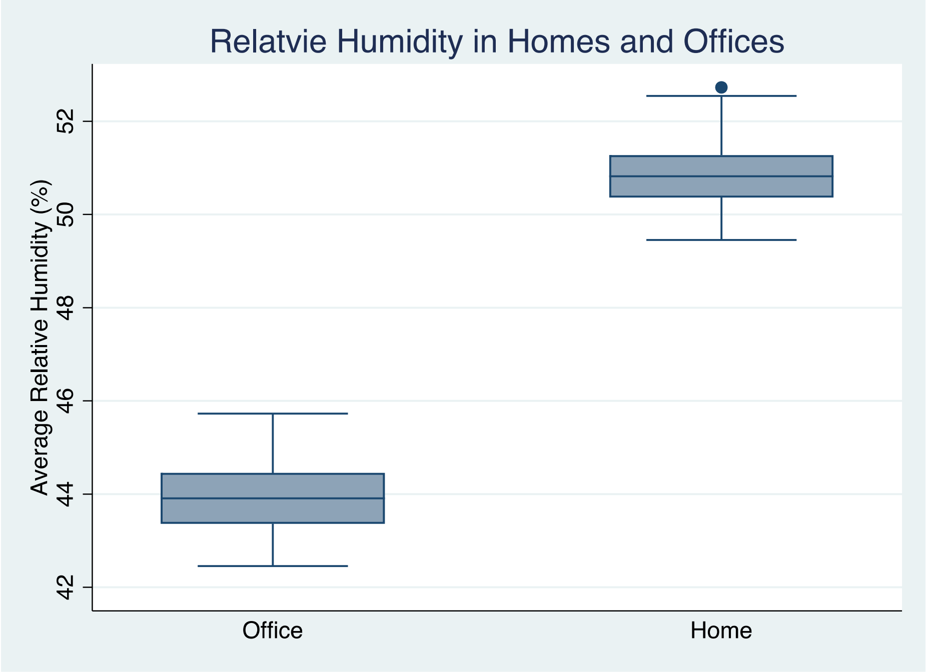

Figure 23 Variability of relative humidity (%) in traditional offices and home offices ($p<0.0001$)

DISCUSSION

This pilot study found a statistically significant difference in the indoor air quality in home offices and traditional office spaces for all monitored variables. The levels of the parameters measured (TVOCs, PM_{10}, $PM_{2.5}$, RH, Temp, CO_2) are c conclusively higher in the home offices included in this study. The importance of living and working within a home conductive to leading a healthy lifestyle is underscored by the fact that many of the participants were living within an environment that was in excess of several standards.

The Agency for Toxic Substance and Disease Registry (ATSDR) has published a list of minimal risk levels (MRLs) for many VOCs (Agency for Toxic Substances & Disease Registry, 2019). ATSDR defines MRLS as the amount of a chemical that a person can be exposed to without a detectable risk to health (Agency for Toxic Substances & Disease Registry, 2019). This list includes MRLs for individual VOCs, such as benzene, formaldehyde, and toluene. An MRL is defined as ‘an estimate of daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse non-cancer effects’ (Agency for Toxic Substances & Disease Registry, 2019). While our study monitored TVOCs, the MRLs for some individual VOCs are well below the levels recorded in both traditional office and home office spaces. For example, the median level of TVOCs in the home office and traditional office space was 1 ppb and 154 ppb, respectively. The MLR reported by ATSDR for inhalation of benzene is 0.003 ppm (Agency for Toxic Substances & Disease Registry, 2019). However, we cannot conclude what the composition of TVOCs were in the home. It is likely that the TVOC measurements recorded were a mixture of many gases. Additionally, this study did not measure the route of exposure to individuals in the home. The WELL building standards require TVOC concentrations to be lower than 500 $\mu g/m_3$ to comply with WELL certification standards (International WELL Building Institute, 2019). However, we measured TVOCs in ppb, and therefore cannot compare our levels to this standard. None-the-less, this study found a statistically significant difference between TVOCs in the home and in the office settings. Our results are consistent with a previous study that suggested VOC levels were higher in the home environment than the office environment (Delgado-Saborit, Aquilina, Meddings, Baker, & Harrison, 2011). This indicates future studies should explore specific VOCs that are present in home office air at levels that represent a health concern.

OSHA has no regulations concerning temperature or relative humidity, as they are matters of human comfort. However, OSHA offers recommendations to alleviate indoor air quality issues in Section III, Chapter 2, Subsection V of the technical manual “*Recommendations for the Employer,*” where they recommend maintaining a temperature between 68ºF - 76ºF and humidity control in the range of 20%-60% (United States Department of Labor, 2003; United States

Department of Labor, n.d.). In our study, the average home office temperature ranged from 64.22 ºF – 87.44ºF, while the traditional office ranged from 70.34 ºF – 84.92ºF. The temperature between 5 pm – 5 am tended to be cooler in the home and warmer in the office. However, during traditional working hours (8 am – 5 pm) were cooler in the office and warmer in the home. This is potentially due to the commercial building conserving energy at night when employees are not in the office. While thermal environment preferences differ by individual, some studies have shown that employees reported greater productivity in warmer temperatures (Richardson, Li, Gohlke, & Allison, 2018). Furthermore, another study found that thermal discomfort is associated with decreased task speed and accuracy (Lan, Wargocki, & Lian, 2014). Here, we are comparing 24-hour snapshots of both environments as we do not know what times the home office workers were "on the clock." Future studies comparing work environments should consider comparing temperatures during the time that the individual is actually working. Relative humidity in home offices was significantly higher than in traditional office spaces. Additionally, five homes had at least one data point at or above the OSHA recommendation of 60% RH (United States Department of Labor, 2003; United States Department of Labor, n.d.).

This study presents a variety of limitations. The population sample was homogenous, with all participants above the poverty line and, at minimum, a high school education. All air quality samples were taken in south Texas during the spring and may not be generalizable to other regions. The air quality results presented here are three-day snapshots of the chemical make-up of indoor air in a small sample of homes and office spaces. The office spaces included in this study are located in buildings at a major university and may not be consistent with other commercial building spaces. Future studies should consider the fluctuation of pollutants seasonally throughout the year. Further, it is important to make the distinction that the presence of a pollutant is not synonymous with individual exposure. The determination of an individuals' air pollution exposure is dependent on the time spent in microenvironments throughout the day (Harrison , et al., 2002).

We found consistently higher levels of pollutants in the home environment than the office environment. Due to the complexity of the makeup of air, it is difficult to determine if any of the pollutants are clinically significant. However, some of the pollutants monitored in this study exceeded health-based standards and recommendations. While this study did not investigate the sources of the pollutants or the outdoor air exchange rate within the homes, future studies should consider these factors in order to help remote employees reduce the risk of potential adverse health effects of poor indoor air quality. Some pollutants were not comparable to certain standards due to differences in measurement units. This makes determining action levels for pollutants difficult. If recommendations of pollutant levels in residential spaces are created, care should be taken to harmonize reporting units.

CONCLUSION

Traditionally, working-adults would split their time between a home and office microenvironment. However, the transition of the workforce from a commercial office building to a home-based office results in more time in the residential microenvironment. This potentially increases the long-term exposure to pollutants found in the homes. This exploratory study showed a statistically significant difference in the chemical make-up of air in residential and office space with the more favorable results appearing in the commercial office spaces. Guidance for acceptable levels of pollutants in homes should be established to enable home office employees to minimize their long-term exposure to pollutants.

CHAPTER V PUBLIC HEALTH SIGNIFICANCE

FINDINGS FROM DISSERTATION STUDIES

This dissertation work explored considerations for the transition to the remote workforce. This research aimed to assess the potential public health implications of remote working to help companies form remote working policies that are the best fit for the health and productivity of their employees.

We started with the use of ergonomic software metrics to estimate productivity after a natural disaster. We conducted an interrupted time series analysis (ITS) to determine if there was a significant difference in the computer use metrics before and after the hurricane. The graphs that were produced by the ITS analysis suggested that employees returned to their baseline computer metrics within a month following the disaster. While there were a variety of limitations to this study, this exploratory work suggests that given the opportunity to remote work could promote business continuity while their physical location is not available due to a disaster. Additionally, it is likely that many of the employees in the Houston area also suffered losses of their homes, childcare facilities, and schools. These losses would be very taxing to any individual, especially those who would be expected to return to a physical office location promptly following the disaster. The option to remote work allowed these employees to be in a physically safe location and allow them to take care of family duties while working.

Our next study investigated the potential differences in sedentary behaviors between those in a traditional office and a home office environment. While it is well established that computer-related tasks in a traditional office space are associated with obesity and sedentary behavior (Perry & Straker, 2013; Clemes, O'Connell, & Edwardson, 2014; Ryan, Dall, Granat, & Grant, 2011), this is the first study, to our knowledge, to address if these behaviors would be the same in a remote working environment. We considered a home “office” to be wherever the employee spent the majority of their week working. Therefore, it is important to note that this may not necessarily be a designated room with a desk. It is possible that individuals who work from home do not have the ergonomic equipment that those who work in a traditional office have access to. However, workers who work from home may have the schedule flexibility and the opportunity to be more active throughout the day. For example, walking pets, playing with children, and doing household chores gives the home worker the opportunity to have posture transitions and increase their total step count and walking time. Although we anticipated to see a difference in the amount of transitions, total steps, and walking time between these two populations, we did not find a significant difference in any of the metrics we collected during this study. Therefore, to address the increasing trend of computer-based work and obesity, interventions to increase physical activity and decrease sedentary behaviors should be targeted at both home workers and traditional office employees.

Finally, we investigated the pollutant levels in eleven homes and eleven traditional offices. While it is difficult to determine the clinical relevance of the individual pollutants measured here, the pollutants were consistently present in higher levels in the residential environment. Historically, traditional office employees would split their time between their commercial office space and their residence. With the transition to a remote workforce, employees are likely to spend more of their time in the residential space where we have found there to be higher levels of pollutants. This could potentially increase the lifetime exposure to common household pollutants, such as particulate matter, volatile organic compounds, and carbon dioxide. It is possible that longer exposure to even low levels of these pollutants can lead to increased levels of adverse health effects. Additionally, previous studies have shown that higher levels of pollutants are associated with decreased productivity (Wargocki, Wyon, Baik, Clausen, & Fanger, 1999; Allen, et al., 2016). From a business perspective, it may be beneficial for companies to educate their employees on the best practices for maintaining low levels of pollutants in their homes and potentially help employees pay for and install higher-level filtration systems to increase their productivity and decrease potential adverse health effects.

From a business perspective, there is much to gain from incorporating remote working programs without expecting a decrease in productivity from employees. While we know that businesses can save money on real estate cost and maintenance, our research has suggested that employees may be able to continue at their baseline productivity without a physical communal meeting location after a natural disaster. However, this transition largely shifts the responsibility of worker wellbeing and safety from the employer to the employee. Here, we have shown that it is possible that employees who work from home will perform the same amount of sedentary behavior as those in the traditional workspace. Therefore, it is critical to encourage employees to decrease the amount of sedentary behaviors throughout the day. This could be done by encouraging employees to take more frequent walks around the neighborhood or moving to different rooms of the house periodically throughout the day. Finally, our research suggested that there are higher levels of pollutants in the home than in the office. Employers should consider the potential health and productivity implications of remote work and strengthen their policies to promote employee wellbeing. Employers can educate their remote employees on the importance of indoor air quality and provide means to minimize pollutant exposure. For example, employers could potentially provide employees with high efficiency air filters that automatically ship to the employees' home on a monthly basis to minimize particulate matter exposure. Additionally, while OSHA does not provide requirements for working in a remote work space, the agency could provide recommendations to companies that would allow them to make the traditional office environment and home office environment as similar as possible. While we do not know the long-term health implications of the transition to a virtual workforce, employers should remain vigilant of the potential impact of remote working on public health.

FUTURE RESEARCH

There is a paucity of objective studies on the impact of remote working on public health. This dissertation included three exploratory studies that may serve as a baseline for future research on this topic.

We introduced the idea that the capacity to remote work may have influenced the ability of employees who worked at the Westlake campus of BP America, Inc. to return to baseline computer usage during a natural disaster. This study used ergonomic software metrics as a rough estimate of productivity. Future research should verify the use of computer-usage metrics measured by ergonomic software, such as number of typos and amount of time worked, as a valid measure of productivity. Companies should consider implementing a continuously monitoring ergonomic software, such as RSIGuard, in order to evaluate their company resiliency in the event of a disaster. Additionally, an analysis of the financial impact of the company would allow the researcher to quantitatively measure employee productivity metrics.

This dissertation work presented a variety of limitations in our primary data studies.

Our studies observed the differences in employees that were either fully a traditional office employee or fully a remote worker. Many companies offer flexible work options, allowing employees to work from home ‘as needed’ or on certain days of the week. A previous study by Henke & colleagues supported the “sweet spot” hypothesis- reporting that employees who telecommuted occasionally but did not work from home most of the time had the least overall health risks (Henke, et al., 2016). Therefore, future research should include employees who work in both environments.

The sample size in both the sedentary behavior and indoor air quality was limited. Therefore, to increase generalizability, future studies should increase the sample size. Additionally, the use of ergonomic software, such as RSIGuard, could potentially be useful in determining the work-related sedentary behaviors practices by home and traditional office workers by allowing the researcher to time stamp work activities and sedentary behaviors.

Our study on indoor air quality found that there were significant differences in the levels of select pollutants in home environments and traditional office spaces. However, our data did not allow us to determine the source of the pollutants found in the home. Future research should investigate the potential sources of pollutants within the residential space in order to minimize lifetime exposure to the pollutant. Research on this topic should also include more aspects of overall environmental quality that are associated with sick building syndrome and are likely to be different in a residential environment, such as lighting and noise levels (Mak & Yui, 2012). Furthermore, we do not know the long-term health effects of the increased time spent in the residential space. A longitudinal cohort study that follows home workers and office workers over time would help us determine if there is an impact on public health.

FINAL CONCLUSIONS

The workforce is transitioning from a traditional office setting to the ability to work wherever there is an opportunity for internet connection. There is much to gain from a business perspective as the cost of real estate is lowered and business continuity is no longer dependent on the existence of a communal meeting place. However, this transition shifts the responsibility of worker wellbeing and safety from the employer to the employee, while the employer maintains the expectation of productivity. This dissertation work considered the potential public health implications of the transition on natural disaster recovery, sedentary behavior, and indoor environmental quality. Future research is needed to build on these exploratory studies to allow for companies to create remote working policies that minimize disaster recovery time, encourage healthy behaviors, and mitigate pollutant exposure to their employees.

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APPENDIX A

RECRUITMENT EMAIL

Howdy,

The department of Environmental and Occupational Health at Texas A&M University is interested in understanding work behaviors and environmental quality in traditional office spaces and home offices. This one-week study involves a software that will help understand computer use and an air monitor to identify differences in common office pollutants. The participant will also have the opportunity to wear a physical activity monitor for one work week.

We are looking for individuals that currently work from home for the majority of their work week.

Thank you for considering participating in this important research, please take a few minutes to review the attached information sheet. If you are interested in participating, please send an email indicating your availability. This study has been reviewed and approved by the Texas A&M University Institutional Review Board.

I look forward to working with you.

Kamrie Sarnosky
DrPH Student
Department of Environmental & Occupational Health Texas A&M School of Public
Health sarnosky@sph.tamhsc.edu
931-551-5023

APPENDIX B

HOME WORKER INFORMED CONSENT

Texas A&M University School of Public Health Study

CONSENT FORM

Workstation Study

The purpose of this form is to give you information that will help you decide if you want to participate in a workstation study. If you decide to participate in this study, this form will be used to document your consent.

The purpose of the study is to compare traditional office settings to home office settings. The study will evaluate computer usage, reductions in sitting time, and environmental quality. This study is being sponsored/funded by Texas A&M University.

Definitions:

Traditional workstation: a fixed height workstation set up for seated work and a normal chair.
Stand-biased workstation: a raised desk and a tall chair that allows both sitting and standing without changing the desk height.
Traditional office: an assigned office in a commercial building that is regularly maintained by the owner
Home office: a designated space to work within a primary residence

What will I be asked to do?

Day 1: Once you schedule a meeting with the research team, a researcher will visit your workplace to explain the study and answer your questions. Once you give consent, the team will make sure that the data collection software is installed on your computer. The team will provide you with a unique identification number so that all of your data will remain confidential. This visit should take between 30-40 minutes.

The software will begin to collect productivity data on day 1 and continue through the end of your study period. This will include time using the keyboard, time using the mouse, typos, words per minute, and total computer time. You will not be required to do anything special for this part of the data collection. Software will be removed at the conclusion of the study (five days total).

You will be asked to answer a questionnaire including questions on your height, weight, gender, race, physical work environment, non-work environment, and discomfort. You will also estimate the amount of time that you spend at your workstation. You will be asked to estimate how long it took to get used to working at your desk. You will also answer questions on amount of time participating in sports, walking and watching TV. You will also be asked about the presence of certain items in your work space, such as dehumidifiers and candles. The questionnaire should take approximately 15-20 minutes to complete.

A sub-sample of participants will be asked if air quality samples can be collected from the office space. If you agree to participate, the air quality monitor will be set up in a representative location that is not in the way of your daily tasks. The monitor will run continuously throughout the week and is not expected to distract or displace you in any way.

Researchers will visit **(visit #2)** your work area to place the activPal 3 sensor on your leg on the afternoon of day 1. The ActivPAL sensor will be used to collect data including time sitting, time standing, steps and time stepping, number of sit to stand transfers and energy expenditures measured in METs. The sensor will have a latex free waterproof covering and be secured to the leg with 3M^{TM} Tegaderm^{TM} transparent film dressing (commonly used to cover IVs). To protect your privacy, you should be prepared to wear or change into shorts to allow the researchers to place the sensor on your leg. The sensor will be in place for 5 days. You will be

able to complete normal activities including exercising, doing yard work and showering while wearing the sensor. We ask that you refrain from taking baths and swimming or aggressively rubbing the dressing area. You will be able to wear any clothing as long it is not restrictive on the leg area. The covering can pull hair and you may want to shave the area first. This should take approximately 5 minutes.

Additionally, if selected to participate in office air monitoring, the researcher will set up the air monitor in a non-intrusive location. He or she will explain how the monitor works and who to contact if anything should happen to the machine. For example, if the machine is accidentally knocked off of a surface, the participant can contact the researcher to address the issue.

Day 5: Researchers will return **(visit #3)** to your work area to remove the sensor and air monitoring equipment. We ask that you wear or change into shorts to allow for sensor removal. This will take approximately 3-5 minutes.

What are the risks involved in this study?

The risks linked with this study are minimal. The research team has made plans to use latex free products to minimize any risk due to a latex allergy. There is a possibility that the covering may pull hair when removed and as a result we suggest that you shave the area prior to sensor placement to minimize this. Please understand that participation in this study is not a substitute for consultation with a physician for any medical issues you may have.

What are the possible benefits of this study?

Information collected will help guide workstation changes to help reduce sedentary time and improve health. Additionally, air quality results will be shared with the participant and the Environmental Protection Agency's recommendations on protecting your home's indoor air will be shared.

Do I have to participate?

No, you do not have to participate in this study. Your participation is voluntary and is not a condition of your employment at Texas A&M. There is no penalty for choosing not to participate, and you can withdraw from any part of the study at any time.

Is there compensation for participation?

If you choose to participate in the study, you will receive a $100 gift card when the researchers pick up the workstation questionnaire. You will receive this compensation in person.

Who will know about my participation in this research study?

The data collected in this study will be kept confidential to the extent allowed by law. No personal information linking you to this study will be used in any published documents. Data will be stored securely and only Texas A&M Researchers and members of the Human Research Protection Program will have access to the information.

Who do I contact with questions about the research?

If you have questions about this study, you may contact the Principle Investigator, Dr. Mark Benden at mbenden@sph.tamhsc.edu or Ms. Kamrie Sarnosky at sarnosky@sph.tamhsc.edu

Who do I contact about my rights as a research participant?

This study has been reviewed by the Human Research Protection Program and the Institutional Review Board at Texas A&M University. For problems or questions regarding your rights as a participant, you can contact the offices at (979) 458-4067 or irb@tamu.edu.

Signature

Be sure you have read the information above and have received answers to all your questions. By signing below, you consent to participate in this study for the 1 week collection period. You will be given a copy of the signed consent form for your records.

Signature:
____ **Date:**
______________ **Printed Name:**
____
_____

Type of workstation you will be using:

☐Traditional ☐Stand-biased ☐Sit-stand ☐Unsure

Location of your primary work place: ☐Office Building ☐Home Office

Future Studies:

The researcher may contact me in the future to see if I am interested in participating in other research studies by the principle investigator of this study

I agree ______________ **I disagree** ________________

Signature of Person Obtaining Consent:
_________________________________ **Printed Name of Person:**
____

Date: ________

IRB NUMBER: IRB2018-0617D IRB APPROVAL DATE: 05/15/2019

APPENDIX C

TRADITIONAL OFFICE WORKER INFORMED CONSENT

Texas A&M University School of Public Health Study

CONSENT FORM

Workstation Study

The purpose of this form is to give you information that will help you decide if you want to participate in a workstation study. If you decide to participate in this study, this form will be used to document your consent.

The purpose of the study is to compare traditional office settings to home office settings. The study will evaluate computer usage, reductions in sitting time, and environmental quality. This study is being sponsored/funded by Texas A&M University.

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The software will begin to collect productivity data on day 1 and continue through the end of your study period. This will include time using the keyboard, time using the mouse, typos, words per minute, and total computer time. You will not be required to do anything special for this part of the data collection. Software will be removed at the conclusion of the study (five days total).

You will be asked to answer a questionnaire including questions on your height, weight, gender, race, physical work environment, non-work environment, and discomfort. You will also estimate the amount of time that you spend at your workstation. You will be asked to estimate how long it took to get used to working at your desk. You will also answer questions on amount of time participating in sports, walking and watching TV. You will also be asked about the presence of certain items in your work space, such as dehumidifiers and candles. The questionnaire should take approximately 15-20 minutes to complete.

A sub-sample of participants will be asked if air quality samples can be collected from the office space. If you agree to participate, the air quality monitor will be set up in a representative location that is not in the way of your daily tasks. The monitor will run continuously throughout the week and is not expected to distract or displace you in any way.

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able to complete normal activities including exercising, doing yard work and showering while wearing the sensor. We ask that you refrain from taking baths and swimming or aggressively rubbing the dressing area. You will be able to wear any clothing as long it is not restrictive on the leg area. The covering can pull hair and you may want to shave the area first. This should take approximately 5 minutes.

Additionally, if selected to participate in office air monitoring, the researcher will set up the air monitor in a non-intrusive location. He or she will explain how the monitor works and who to contact if anything should happen to the machine. For example, if the machine is accidentally knocked off of a surface, the participant can contact the researcher to address the issue.

Day 5: Researchers will return **(visit #3)** to your work area to remove the sensor and air monitoring equipment. We ask that you wear or change into shorts to allow for sensor removal. This will take approximately 3-5 minutes.

What are the risks involved in this study?

The risks linked with this study are minimal. The research team has made plans to use latex free products to minimize any risk due to a latex allergy. There is a possibility that the covering may pull hair when removed and as a result we suggest that you shave the area prior to sensor placement to minimize this. Please understand that participation in this study is not a substitute for consultation with a physician for any medical issues you may have.

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Is there compensation for participation?

If you choose to participate in the study, you will receive a $100 gift card when the researchers pick up the workstation questionnaire. You will receive this compensation in person.

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Signature

Be sure you have read the information above and have received answers to all your questions. By signing below, you consent to participate in this study for the 1 week collection period. You will be given a copy of the signed consent form for your records.

Signature: ____ **Date:** ______________ **Printed Name:** ____

Type of workstation you will be using:

☐Traditional ☐Stand-biased ☐Sit-stand ☐Unsure

Location of your primary work place: ☐Office Building ☐Home Office

Future Studies:

The researcher may contact me in the future to see if I am interested in participating in other research studies by the principle investigator of this study

I agree ______________ **I disagree** ________________

Signature of Person Obtaining Consent: _________________________________ **Printed Name of Person:** ____

Date: ________

IRB NUMBER: IRB2018-0617D IRB APPROVAL DATE: 05/15/2019

APPENDIX D

QUESTIONNAIRE

Home Worker interview / Questionnaire

Participant ID: ______________ **Section 1: Demographics** (optional)

1. How tall are you? ________________
2. How much do you weigh? ______________
3. What is your age? ______________
4. Do you identify yourself as Hispanic or Latino? __________
5. What is your race?
    1. American Indian or Alaskan Native
    2. Asian
    3. Black or African American
    4. Native Hawaiian or Pacific Islander
    5. White or Caucasian
    6. Multiracial or more than one race
6. What is your gender? ________________
7. What is the highest education you have completed? a. Less than high school
   b. High school degree
   c. Undergraduate degree d. Postgraduate degree e. Prefer not to answer
8. What is your current occupation? _________________
9. What is your annual household income?
   a. $10,000-20,000
   b. $20,000-50,000
   c. $50,000-75,000
   d. $100,000-150,000 e. $150,000-200,000 f. >$200,000
   g. Prefer not to answer

Section 2: Work Environment

10. How many hours a day do you estimate that you are at your primary workstation during a typical 8 hour work day?

11. Of those hours- how many hours do you believe are spent in the following postures:
a. seated
b. standing

12. Do you possess any of the following items at your workstation?

1. Footrest
2. Monitor arm
3. Adjustable keyboard tray
4. Standing pad/anti-fatigue mat
5. None of the above
6. Other (please specify):_______________________________________

13. Do you spend time standing at your primary workstation throughout a traditional work day? a. Yes
b. No
14. Have you ever used a sit-stand workstation?
a. Yes
b. No
15. Do you currently have a standing biased workstation?
a. No (please skip to Section 3)
b. Yes
16. How many individuals live in your home?
a. 1
b. 2
c. 3
d. 4
e. 5
f. ≥6
17. How many people, other than yourself, will be in your home during your working hours this week?
a. 1
b. 2
c. 3
d. 4
e. 5
f. ≥6
18. How many children (younger than 18 years old) live in the home?
a. 0
b. 1
c. 2
d. 3
e. 4
f. 5
g. ≥6
19. On average, how many hours a week do you work in your home?
a. 0
b. 1-10
c. 10-20
d. 20-30
e. 30-40
f. >40
20. On which days will you work from home this week? (select all that apply)
a. M
b. T
c. W
d. Th
e. F
21. Where is your home office located?
a. Single-family detached dwelling

b. Townhouse or duplex
c. Multiple story apartment building
d. Other, please specify: _________
22. Do you claim your home office as a tax deduction?
a. Yes
b. No
c. Unsure
23. What year was your home built?
a. <1900
b. 1900-1949
c. 1950-2000
d. >2000
e. Unsure
24. What is the square footage of your home? ________ 25. Heating source (check all that apply)
a. Oil
b. Gas
c. Electric d. Wood e. Unsure
26. Does the home have air conditioning? a. Yes
b. No
c. Unsure
27. What type of air conditioning system is in the home? a. Central Air
b. Window Units c. Unsure
28. How often do you typically change your air filter?
a. Annually
b. Twice a year
c. Quarterly
d. Every other month
e. Every month
29. Stove Type
a. Electric
b. Gas
c. Propane
d. Unsure
30. Presence in Home (check all that apply)
☐Smoker living in home
☐Smoking inside the home
☐Fireplace (used)
31. Have you remodeled your home office at any point?
a. Yes
b. No
c. Unsure
32. Have you remodeled any other part of the home?
a. Yes
b. No
c. Unsure
33. Have you purchased new furniture for your office space in the past 5 years?
a. Yes

  - b. No
  - c. Unsure
34. Have you painted the walls of your home office space?
  - a. Yes
  - b. No
  - c. Unsure
35. Have you painted any furniture in your home office space?
  - a. Yes
  - b. No
  - c. Unsure
36. Have you painted the floor or the trim of your home office space?
  - a. Yes
  - b. No
  - c. Unsure
37. If yes, did you use low Volatile Organic Compound paint?
  - a. Yes
  - b. No
  - c. I used multiple types of paint in the space d. Unsure
38. Is there wallpaper in your home office space?
  - a. Yes
  - b. No
39. Is there an area rug in your home office space?
  - a. Yes
  - b. No
    - i. Is the rug greater than 1 year old?
      - a. Yes
      - b. No
40. Is there carpet in your home office space?
  - a. Yes
  - b. No
41. Do you have one or more cats living in the home?
  - a. Yes
  - b. No
42. Do you have a dog or multiple dogs living in the home?
  - a. Yes
  - b. No
43. Do you have live plants in your home?
  - a. Yes
  - b. No
44. Are there room deodorizers (such as a wall plug-in, essential oil diffusers) in the area(s) in which you work?
  - a. Yes

b. No
c. Unsure
i. Have you used these items in the past week? a. Yes
b. No
c. Unsure
45. Are there air purifiers in the area(s) in which you work?

a. Yes
b. No
c. Unsure
i. Have you used these items in the past week? a. Yes
b. No
c. Unsure
46. Do you use aromatic candles in the area(s) in which you work?
a. Yes
b. No
c. Unsure
i. Have you used these items in the past week?
a.Yes
b.No
c. Unsure

47. Do you use a space heater in your office space?
    a. Yes
    b. No
    c. Unsure
48. Is there an area rug in your office space?
    a. Yes
    b. No
49. Is there carpet in your office space?
    a. Yes
    b. No

Section 3: Non-work Environment (The following questions will cover your physical activity and habits outside of the work environment).

50. In a typical week, on how many days do you participate in vigorous-intensity sports, fitness or recreational activities that cause large increases in heart rate or breathing (may include activities like football, aerobics or running)
51. How much time do you spend doing vigorous-intensity activities on a typical day?
52. In a typical week, on how many days do you participate in moderate-intensity sports, fitness or recreational activities that cause small increases in heart rate or breathing (may include activities like brisk walking, cycling, swimming or volleyball)
53. How much time do you spend doing moderate-intensity activities on a typical day?
54. In a typical week, on how many days do you walk for at least 10 minutes at a time? This includes walking at work, walking at home, walking for travel from place to place and any other walking that you do completely for recreation or leisure.
55. How much time do you spend walking for recreation or leisure on a typical day?
56. How much time do you typically spend sitting or reclining on a typical day? (this includes all sitting time to include time spent at a desk, sitting with friends, travelling by bus, car or train, reading, playing cards or watching television but not including time spent sleeping)?