PSYCHOLOGICAL AND NEUROLOGICAL IMPLICATIONS OF WALKING IN URBAN NATURE

BY

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DISSERTATION

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ABSTRACT

Exposure to urban nature is beneficial to the health and well-being of people from a variety of cultures and across the human lifespan (Hartig et al. 2014; Sullivan, Frumkin, Jackson, & Chang, 2014); Tzoulas et al. 2007). Considerable evidence demonstrates that the design of places in which we live, work and play impact the extent to which we experience mental fatigue and recover from that fatigue. We do not know, however, the precise neurological mechanism that underlies the relationship between exposure to urban settings that vary in the amount of vegetation they contain and attentional performance.

Although previous research has made it clear that looking at, being in or walking through green urban spaces reduces mental fatigue (Li et al. 2019; Li and Sullivan 2016), the neural pathways through which these impacts occur and the other associated psychological implications that underlie their reactions have been entirely unclear. The lack of this information is an important problem because it limits our ability to design urban settings that support healthy neurological functioning for a growing population of humans who live in cities.

I address this gap in our knowledge by conducting two experimental studies designed to answer the following question: “To what extent does walking in urban nature impact the neurological and psychological well-being of people?” To address these issues, this dissertation includes a review of the current literature and reports on two empirical studies: the walking study and resting-state fMRI study.

In the walking study, which focuses on the psychological implications of walking in urban nature versus walking in barren settings, I asked, “To what extent does the greenness of an urban walk impact healthcare workers attentional functioning, affect, and anxiety when they take a walk during their workday?" To answer this question, I conducted a randomized experimental design with healthcare workers. The experiment had two conditions, three, 40-minute walks in either a barren or green urban setting during a 7-day period. We found that walking in the green setting had significant impacts on measures of attention, affect and anxiety. The green setting resulted in higher total attention and affect scores and lower scores on anxiety.

The resting-state fMRI study, which focuses on the neurological implications of walking in urban settings rich in nature versus walking in urban settings that are nearly devoid of nature, I asked: To what extent does exposure to green versus barren urban settings impact brain functional connectivity – a measure of attentional capacity – when ascertained at resting state?"

In this study, 48 healthy adults were randomly assigned to walk three times for 40 minutes in either a green or barren urban setting during a one-week period. Participants in the green group maintained about the same attentional scores after the one-week treatment, but the attentional scores significantly decreased in the barren group. Findings from the fMRI portion of this study revealed that the functional network connectivity at rest was significantly higher in the green treatment compared to the barren treatment.

The studies presented here strongly suggest that walking in green settings can promote psychological and neurological well-being. This research is among the first studies using resting-state fMRI to examine the relationship between walking in different environments and attentional functioning. This results of this work are significant because they help us understand the relationship between urban green infrastructure and human well-being at psychological and neurological levels. The findings should be of interest to designers, policy makers, and public health providers and can be used to pave the way for targeting urban nature interventions to moderate the neurological and psychological outcomes of typical urban environments in support of mental health.

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CHAPTER 1: INTRODUCTION

Introduction

One hundred sixty years ago, Fredrick Law Olmsted sought to improve the health and well-being of the residents of New York City by designing and supervising the construction of Central Park (Eisenman 2013; Epstein 2003). Central Park promoted the health and wellbeing of New York City residents by adding nature a considerable amount of nature to Manhattan. The political will required to design, finance, and build Central Park grew from the argument that green urban landscapes can improve human health. Today, we have concrete evidence that green landscapes can improve health and well-being. Trees near homes help people recover from stress (Jiang, Chang, & Sullivan, 2014) and mental fatigue (Sullivan & Li, 2021), maintain stronger ties with their neighbors (Kweon, Sullivan, & Wiley, 1998), even when facing extreme poverty (Faber Taylor and Kuo 2009; Taylor, Kuo, and Sullivan 2001; Ward Thompson et al. 2012). Studies suggest that urban nature (e.g., spaces with trees and other forms of vegetation) is beneficial to the health and well-being of people from a variety of cultures and across the human lifespan (Hartig et al. 2014; Sullivan, Frumkin, Jackson, & Chang, 2014); Tzoulas et al. 2007). As urbanization increases across the world, hundreds of millions of people lack regular contact with nature. One consequence of this lack of exposure is that these individuals are deprived of the restorative qualities that nature bestows on attentionally fatigued individuals.

Attention Restoration Theory (ART)—a concept central to my dissertation – posits that contact with nature boosts our capacity to pay attention (Kaplan, 1995). ART argues that attention is a mental process whereby certain information gets highlighted in our brains to enhance our ability to focus on that information, while less important information is, at the same time, de-emphasized (Ward 2016). There is an extensive body of empirical evidence in support of ART, showing that exposure to green nature helps people more quickly recover from mental fatigue. This faster recovery improves attentional functioning. Based on ART and other psycho-evolutionary theories, the literature suggests that nature walks, nature views (being in nature), and experience with nature simulations reduce emotional and psychological stress and help restore directed attention functioning (Ward Thompson et al. 2012).

Research Gap

Although previous research has made it clear that looking at, being in or walking through green urban spaces reduces mental fatigue (Li et al. 2019; Li & Sullivan 2016), the neural pathways through which these impacts occur and the other associated psychological implications that underlie their reactions have been entirely unclear. The lack of this information is an important problem because it limits our ability to design urban settings that support healthy neurological functioning for a growing population of humans who live in cities. It also means that we have fewer science-based arguments for increasing the demand for services of landscape architects.

I address this gap in our knowledge by conducting two empirical studies designed to answer the following question: "To what extent does walking in urban nature impact the neurological and psychological well-being of people?"

Organization

This dissertation is organized in five chapters. Following this chapter, Chapter 2 reviews related literature that provides a basis for this research and provides a discussion of issues related to the specific research question. This review explores recent literature regarding attention restoration theory, which is the foundation for this research, and the mental health benefits of walking for people.

Chapter 3 presents the first experimental study (Be Careful Where You Walk), which measures the impact walking in urban nature versus walking in barren urban settings on a range of psychological outcomes. There is considerable evidence demonstrating the physical and psychological benefits of walking. Walking improves self- perception and self-esteem, cognitive functioning, memory, attention, mood, and sleep quality, reducing stress, anxiety, and fatigue (Barton, Hine, and Pretty 2009; Johansson, Hartig, and Staats 2011; Neale et al. 2019; Olafsdottir et al. 2020). The question I ask concerns the extent to which one walk is as good as any other walk of similar physical demands. That is, does a walk in an urban space with little or no vegetation provide the same benefits as a simiar walk in an urban green space? Some studies have shown that walking in greener settings is more likely to enhance a person's capacity to pay attention after the walk (Berman, Jonides, and Kaplan 2008; Faber Taylor and Kuo 2009). Those studies, however, focused on students. Do the benefits of walking in green spaces documented with students extend to other individuals such as healthcare workers, who face unrelenting cognitive demands during their work hours? Do these walks also impact other psychological domains that healthcare workers are likely to face such as affect and anxiety? In Chapter 3, I explore these questions through a randomized experimental design with healthcare workers. The experiment had two conditions, three, 40-minute walks in either a barren or green urban setting during a 7-day period. We asked, "To what extent does the greenness of an urban walk impact healthcare workers attentional functioning, affect, and anxiety when they take a walk during their workday?"

Chapter 4 presents another experimental study (fMRI Assessment of Brain Functional Connectivity at Resting State: Implications for Attention Restoration Theory), which focuses on the neurological implications of walking in urban settings rich in nature versus walking in urban settings that are nearly devoid of nature. Considerable evidence demonstrates that the design of places in which we live, work and play impact the extent to which we experience mental fatigue and recover from that fatigue. We do not know, however, the precise neurological mechanism that underlies the relationship between exposure to various environments and attentional performance. The research thus far has not been able to look inside human brains to ascertain why that relationship occurs. I address this problem in Chapter 4 where I explore this issue through a randomized experimental design that compares changes in brain functional connectivity using functional Magnetic Resonance Imaging (fMRI) and analyze the differences in participants randomly assigned to walk in green versus barren urban settings. I ask, "To what extent does exposure to green versus barren urban settings impact brain functional connectivity – a measure of attentional capacity – when ascertained at resting state?"

Chapters 3 and 4 are each complete studies by themselves, and yet together, they are complementary in that they tell a comprehensive story regarding the impacts of walking in urban environments that vary in the density of vegetation on psychological and neurological outcomes.

Chapter 5 summarizes the findings from the two studies in Chapter 3 and 4 and discusses the framework of the neurological and psychological effects of walking in urban nature. The methodological contributions and limitations are discussed, as are areas for future research. The policy implications and design responses are demonstrated using a design case study.

A note on language. This is my dissertation and thus I am responsible for what is written here. In the chapters that follow, however, I write in recognition that the data collection, analysis have been joint efforts. I relied on experts in neuroscience to assist with design and data analysis of the study presented in Chapter 4. And I had help with data collection from individuals in Professor Chun-Yen Chang’s lab at National Taiwan University for the study reported in Chapter 3. In recognition that this dissertation grows from a team effort, I use the word “we” in describing the efforts we made.

CHAPTER 2: LITERATURE REVIEW

Introduction

Understanding the relationship between humans and nature has long been an area of study. It is easy to understand why. Humans have continuously relied on nature for food, water, shelter and medicine for survival, and to support our well-being. Over the past century or so, with the growth and densification of cities, access to nature in urban areas has become increasingly limited for hundreds of millions of people. In the past century, rapid technical advances such as elevators that made high-rise buildings possible and innovations in transportation and commuting such as cars and subways have changed the way billions of people live and engage with nature. Today, it is possible, for a person to awake in an interior room, take an elevator down to the car park or walk a block to the bus stop, ride inside that vehicle until arriving at the car park of one's place of work, without spending more than a few minutes out of doors. The host of technological changes that have taken place over the past few decades help people in some ways, but also change the way in which they interact with their surrounding environment. (Marcus 1999).

By 2050 nearly 70% of the world's population will live in urban areas (United Nations, 2018). Along with the rapid growth of urbanization in the 21st century, there has been a decrease in the ease with which people can access nearby nature. Corresponding to this decrease in the experience of nature in urban areas, there has been an increase in research into the health benefits of nature. The findings from these studies have been unequivocal. Decreased access to nature, what Louv calls Nature Deficit Disorder (Louv 2008) is likely to have considerable impacts on the health and well-being of people who live in urban settings. That is because regular exposure to nature helps people recover from mental fatigue (Sullivan & Li, 2021), improve their moods (Li et al. 2018) and reduce anxiety (Telch and Lancaster 2012; Yin et al. 2020).

A variety of theoretical frameworks help us understand how contact with nature might promote health and well-being. Attention Restoration Theory, which the work in this dissertation draws from, seeks to explain why people feel restored after they are exposed to natural settings. ART predicts that being in nature or looking at scenes of nature is restorative for our capacity to pay attention which fatigues with use (Kaplan 1995).

Attention is the process of some object or some thought capturing the mind or the withdrawal from focusing on one thing to effectively deal with other things (James, 1892). Humans pay attention to various stimuli or ideas to order to learn, interact with, or act on those stimuli or ideas effectively. The capacity to pay attention is one of the most important and consequential resources that humans possess. As anyone who has ever written a funding proposal or syllabus, graded final exams, planned a budget, solved a complex social problem, or even planned a vacation can attest, one's ability to pay attention is not only limited, it is also essential to accomplishing all our goals (Sullivan & Li, 2021).

The brain's capacity to focus on a particular stimulus or activity, however, is limited because the neural mechanisms that support attention fatigue with use. Thus, for instance, after spending an extended period of time writing, editing, or reading a dissertation, a person is likely to feel that continued focus takes a greater and greater amount of effort and work (Sullivan 2015). The environment has a significant impact on our capacity to recover from this fatigue. ART suggests that softly fascinating settings restore and revive the fatigued mechanism that supports our capacity to focus our attention (Bringslimark, Hartig, and Patil 2009).

Although there is considerable empirical evidence in support of the predictions of ART, the neurological mechanisms that underlie the restoration process have not been well understood or documented until now. Through the use of tools such as functional Magnetic Resonance Imaging (fMRI), which allows scientists to observe neural activity in real time, we are gaining initial insights into the physical mechanism that supports attention and attention restoration (Jiang, 2019). In spite of these new discoveries, we still do not know exactly which regions of the brain are involved when people are in or view urban settings that vary in nature. We also do not know the extent to which exposure to urban nature impacts the neural networks associated with attention. By better understanding these issues, we will be able to have a more detailed understanding of the extent to which contact with urban nature impacts one of our most important capacities – our ability to recover from the mental fatigue that is endemic of urban life today.

This literature review consists of three parts. First, I describe Attention Restoration Theory (ART) as one of the most important theoretical frameworks in Environmental Psychology, and I review the evidence that supports ART. Next, I explain mental fatigue and inhibitory control, and review the literature that examines these concepts. In the last section, I discussed recent studies in the area of exercise and mental health.

Attention Restoration Theory

Engaging with nature, whether through watching a sunset, gazing at the mountains, walking in nature, or even just spending time staring out the window to a green space, can be a delightful and satisfying experience. It is likely that everyone has at one time experienced such a moment, especially during a busy day, in which exposure to nature revives oneself or boosts one's mood. Why does it elevate our mood and provide a sense of calm? One of the most important benefits of exposure to nature for humans is that it promotes our capability to pay attention by speeding recovery from mental fatigue. ART argues that exposure to nature, whether by being in it or simply looking at it, can be restorative (Kaplan 1995; Sullivan, 2015). Restoration – restoring one's ability to pay attention to pre-fatigued status – occurs through engaging in softly fascinating activities such as observing nature. Such engagement with soft fascination allows our attention to rest and restore. A restored attention is one that has recovered from fatigue and is able to be effectively directed again.

Top-down attention

ART recognizes we have two modes of attending to things: top-down and bottom-up. Top-down attention allows us to focus of our attention by making the object of our attention more salient while, at the same time, dampening down, or making less salient, competing distractions, stimuli, or thoughts. Top-down attention (sometimes called directed attention or paying attention) takes effort and fatigues with extended use. When we are writing a paper, for example, we must make many complex decisions and extend considerable efforts to focus on what we are writing. After a period of focused writing, we feel tired and fatigued.

Top-down attention is goal-oriented and is achieved through the determination of an individual intent on accomplishing a specific task. This mode of attention requires that an individual expend effort in managing thoughts and emotions. Top-down also involves utilizing information in the mind, multitasking and synthesizing between tasks, identifying the focus of our attention, and resisting distraction (Katsuki and Constantinidis 2014).

Top-down attention unconsciously reduces the intensity of possible distractions both from the environments and within our minds. The neural mechanisms can reduce the intensity of distractions, but it requires effort. Like our muscles, our capacity to diminish the intensity of distracting stimuli and focus our attention fatigues over time. As the mechanisms that support top-down attention fatigue, our capacity to function effectively also diminishes. For most people, we use directed attention for everything we care to accomplish – from learning, problem solving, planning and carrying out tasks, self-monitoring and self-regulation to effective social functioning.

The state of attentional fatigue is often referred to as mental fatigue (Katsuki and Constantinidis 2014). The most common costs of mental fatigue are reductions in functioning due to a reduced ability to focus, diminished capacity to monitor our behavior and inhibit impulses, and an increase in irritability (Sullivan 2015). After becoming mentally fatigued, we need to restore our directed attention to be productive again. Attention Restoration Theory posits that being in nature or looking at nature scenes can help our top-down attention regain its focus and efficacy.

Bottom-up attention

Contrary to top-down attention, bottom-up attention is guided by external stimuli and thus is not goal-driven. Because bottom-up attention (sometimes called involuntary attention) is automatic, it takes no effort and therefore does not fatigue. Daydreaming and mind wandering fall into this category.

For example, when we are sitting by a campfire, we do not deliberately decide to pay attention to the fire. Involuntarily, our eyes will be drawn to the fire without our conscious awareness of doing so (Sullivan 2015). Table 1 provides a summary of some of the critical features of top-down and bottom-up attention.

Table 1. comparison between top-down and bottom-up attention

Attention	
Top-Down	Bottom-Up
Goal oriented Effortful Fatigues	External stimuli Effortless Does not fatigue

Central idea of ART

The duality between top-down and bottom-up attention is highlighted when we experience external stimuli. Natural stimuli, moving water, wildlife, vegetation engages our bottom-up attention, allowing us to rest the brain mechanism that underlie and support top-down attention. By engaging in bottom-up attention, we restore our top-down attentional capacity and can once again perform mentally demanding tasks (Sullivan 2015).

Natural environments help in recovery from mental fatigue because they require less considerably directed attention that urban environments require. Many natural settings provide soft fascination (features of the environment that capture attention effortlessly), in which our directed attention is less triggered. Nature is more likely to provoke the bottom-up stimulation that requires little directed attention, like looking at waterfall or a field of wheat waving gently moving because of the breaze (Marc G. Berman et al. 2008).

Jonides and Irwin (1981) discussed methodologies of capturing attention. They observed that natural experiences provide opportunities for us to shift from task-oriented top-down attention to the soft fascination associated with bottom-up attention. When the mind activates the bottom-up directed attention, it allows and provides time to restore and recover top-down attention (Jonides and Irwin 1981). Therefore, while bottom-up directed attention may seem the opposite of top-down attention, it actually supports and enables it.

Empirical evidence related to ART

Studies related to ART are diverse with respect to the populations and environmental settings that have been examined. The findings, on the other hand, are strongly consistent. When people are exposed to green landscapes, their attention capacity is enhanced (Sullivan & Li, 2021; Sonntag-Öström et al. 2014). Take for instance, a within-subjects empirical study designed to measure the attention performance of adults exposed to a downtown walk on a sidewalk lined with buildings versus an arboretum walk. Findings from this study showed a significant improvement in attention performance after the participants had walked in the arboretum compared to after they walked in the downtown business district (Marc G. Berman et al. 2008).

A large body of literature demonstrates the impacts of exposure to urban nature on effective functioning of students. One study showed that university students living in dorms with more natural views from their windows scored better on tests of attention (e.g., Digit Span Forwards, Digit Span Backwards Necker Cube Pattern Control, Symbol Digit Modalities Test) and their attentional functioning was rated more effective than those with less natural views (Tennessen and Cimprich, 1995). In another study of university students' measured student's attention after they experienced indoor campus settings that varied in their views to nature during their study break. Students ranked settings with views of nature murals more restorative than settings with window views of real but boring nature with buildings (Felsten 2009). In a study of

94 students from five high schools were randomly assigned to classrooms without windows, with windows that opened on to built spaces, and with windows that opened on to green spaces. Students in the green window view condition scored significantly higher on tests of attentional functioning than their peers who were assigned to rooms without views to green spaces (Li and Sullivan 2016). Moreover, students who watched videos of natural landscapes compared to ones who watched video of urban landscapes did better on attention-orienting tasks (Laumann, Gärling, and Stormark 2003).

The positive impacts of exposure to urban nature on attention have been documented in a range of populations, from students, to children and the elderly. Children with ADHD, after a 20-minute walk in a park, had better concentration than children who walked in a downtown area. In a study of children in Chicago who had varying levels of tree cover surrounding their apartment buildings, those with higher levels of tree cover close by scored significantly higher on measures of attention and self-discipline than their counter-parts who had less nearby tree cover (Taylor et al. 2001; Taylor, Kuo, and Sullivan 2002). Merely viewing pictures that contain nature can improve attention for older adults. In this study university students and older adults were randomly assigned to watched pictures of nature settings or urban settings in a randomized experiment. Participants attention was measured before and after watching the pictures. The result showed that viewing nature, but not urban, pictures significantly improved executive attention in both older and young adults as measured by the Attention Network Test (Gamble, Howard Jr, and Howard 2014).

Contact with nature also has been shown to have positive effects on attentional functioning among people suffering from various types of illnesses; for example, a 120-minutes nature exposure per week for women who were diagnosed with breast cancer showed positive effects on their attentional functioning (Cimprich and Ronis 2003).

Inhibitory control

The propensity to eliminate distractions is generally described as inhibitory control by researchers (Logan et al. 1997). Literature from prior research has described these deficits of inhibitory control to be the sole contributors to lack of concentration and focus, inefficiency in performing tasks, and other attention-related dysfunctionalities.

Although several findings have yielded results that show that natural experience efficiently assists in inhibitory control from external distractions, there is a gap in the science in that we still do not understand what controls such internal distractions in our brain. The mechanism of this inhibitory control in encountering nature and the brain's response is unclear. While our attention is resting, the absence of external stimuli from internal emotions and thoughts may provide similar mental activity as visual or audible senses (Northoff, Qin, and Nakao 2010).

To address this research gap, Sahni & Kumar (2021) initiated a project to identify the effects of nature experience on neurocognitive processes of directed attention utilizing EEG. The research involved a cognitive task designed to identify differences in cognitive processes from the absence or presence of contradicting information and distractions. The task also involved the participants being exposed to natural experience and a control measure of open eye resting state. The objective was to evaluate the level at which nature experience would affect the inhibitory control of the contradicting and distracting information as an enhancement on directed attention. From a total of 53 participants, the research findings provided sufficient evidence of the effects of nature experience on the neurocognitive processes of directed attention. There was a significant improvement in cognition after a brief encounter with nature experience compared to the brief experience with an open eye resting state (Sahni and Kumar 2021). The findings from this research elucidate that enhanced inhibitory control may be one of the significant factors of improving directed attention using nature experience. The findings also concur with prior research findings that found that a natural environment requires lower attentional and cognitive processing as compared to an urban environment with stimuli (Sahni and Kumar 2021).

Psychological implications of exercise (walking)

Medical practitioners use psychiatric medications to treat and prevent minor and significant mental disorders; yet we know that physical activities can also be helpful in treating some forms of mental illnesses. Physical activity is essential to strengthen human bodies, maintain, and improve health and can have a positive impact on alleviating states such as anxiety and mild depression. Physical exercises are now being used to address some psychological symptoms, such as anxiety and slight mood variations, that are often treated by medications (Ashdown-Franks et al. 2020); Landers and Arent 2007; Paluska and Schwenk 2000). While medications often have unwanted side effects, the side effects of exercise are often desireable and include increased bone density, increased strength and ease of movement, loss of excess weight, and a temporary mood elevation. This shift from medication to physical activity is a result of studies documenting the positive impact of physical exercises on cognitive and mental outcomes (Biddle and Asare 2011; Paluska and Schwenk 2000; Peluso and Andrade 2005a, 2005b).

Recent research is shedding new light on the various cognitive and emotional benefits of physical exercise (Yu et al. 2021). A recent experiment conducted with military personnel found that exercise interventions enhance overall physical health and mental health (Zwilling et al. 2020) And recent reports described several types of exercises protocols that reduce the symptoms of mental illness and the need for medications (Zwilling et al. 2020). The benefits of exercise come from intense exercise but also from activities as relatively undemanding as walking (Han 2017). And indeed, the cognitive and emotional benefits of walking are supported by research (Ashdown-Franks et al. 2020; Choi et al. 2019) and by the popular media (Helpguide.org, 28 June 2021).

Advancements in technology can be wonderful, but they often come with unintended or negative consequences. Engaging friends and family throughout the world with social media helps us stay connected, but doing so is likely to keep us distracted, and is likely to increase the level of mental fatigue we experience. These modern life pressures are an inevitable aspect for humans as we face a complex world. Statistics in the United States suggest that a minimum of seven out of ten people are prone to depression and anxiety disorders in their daily lives, which can have considerable impacts on quality of life (American Psychiatric Association, 2013). In recent years, stress and anxiety levels have significantly increased in developed countries (Yatham et al. 2018).

Walking has been proposed as one method for addressing the challenges of dealing with stress, changes in mood, and anxiety. One benefit of walking, for instance, is that walking produces mood-elevating chemicals in the human body (Johansson et al. 2011; Kelly et al. 2018; Neale et al. 2019). Walking and other physical exercises produce endorphins, chemicals which play a significant role in our physical and emotional health. Endorphins act as pain relievers and result in an elevated mood (Barton et al. 2009, 2009; Franěk and Režný 2017; Johansson et al. 2011; Neale et al. 2019). Moreover, endorphins support sleep, so that people who walk enough to release endorphins have a greater likelihood of recovering from daily stress.

Gap in our knowledge

According to CDC guidelines, adults should engage in 150 minutes per week of moderate- intensity exercise to guarantee substantial health benefits (Physical Activity Guidelines for Americans, 2018). But one major gap in our knowledge about the benefits of exercise concerns the interaction between exercise and exposure to nature (Duvall and Sullivan 2016; Zwilling et al. 2020). We do not know, for instance, the extent to which physical exercise experience in a natural setting improves the cognitive and emotional benefits of exercise. While both exercise and nature confer benefits, it is possible that the significant benefits of exercise overwhelm the benefits that grow from contact with nature. It is also possible that one might experience additional benefits associated with attention, mood, and anxiety from exercising in a greener space compared to a more barren space.

To fill this gap in our knowledge, we conducted a study in which 48 healthy adults were randomly assigned to walk three times for 40 minutes in either a green or barren urban setting during a one-week period. We performed fMRI scans on participants before and after this intervention to measure changes in attentional functioning in their brains. Chapter Three of this dissertation examines the walking experiment with a focus on its impact on attention, affect, and anxiety. Chapter Four discusses the brain data and findings from the analysis of brain activity regarding the interventions.

References:

Ashdown-Franks, Garcia, Joseph Firth, Rebekah Carney, Andre F. Carvalho, Mats Hallgren, Ai Koyanagi, Simon Rosenbaum, Felipe B. Schuch, Lee Smith, and Marco Solmi. 2020. “Exercise as Medicine for Mental and Substance Use Disorders: A Meta-Review of the Benefits for Neuropsychiatric and Cognitive Outcomes.” *Sports Medicine* 50(1):151–70.

Barton, J., R. Hine, and J. Pretty. 2009. “The Health Benefits of Walking in Greenspaces of High Natural and Heritage Value.” *Journal of Integrative Environmental Sciences* 6(4):261–78. doi: 10.1080/19438150903378425.

Berman, Marc G., John Jonides, and Stephen Kaplan. 2008. “The Cognitive Benefits of Interacting With Nature.” *Psychological Science* 19(12):1207–12. doi: 10.1111/j.1467-9280.2008.02225.x.

Biddle, Stuart JH, and Mavis Asare. 2011. “Physical Activity and Mental Health in Children and Adolescents: A Review of Reviews.” *British Journal of Sports Medicine* 45(11):886–95.

Bringslimark, Tina, Terry Hartig, and Grete G. Patil. 2009. “The Psychological Benefits of Indoor Plants: A Critical Review of the Experimental Literature.” *Journal of Environmental Psychology* 29(4):422–33.

Choi, Karmel W., Chia-Yen Chen, Murray B. Stein, Yann C. Klimentidis, Min-Jung Wang, Karestan C. Koenen, and Jordan W. Smoller. 2019. “Assessment of Bidirectional Relationships between Physical Activity and Depression among Adults: A 2-Sample Mendelian Randomization Study.” *JAMA Psychiatry* 76(4):399–408.

Cimprich, Bernadine, and David L. Ronis. 2003. “An Environmental Intervention to Restore Attention in Women with Newly Diagnosed Breast Cancer.” *Cancer Nursing* 26(4):284–92.

Duvall, Jason, and William C. Sullivan. 2016. “How to Get More out of the Green Exercise Experience: Insights from Attention Restoration Theory.” Pp. 53–61 in *Green Exercise*. Routledge.

Eisenman, Theodore S. 2013. “Frederick Law Olmsted, Green Infrastructure, and the Evolving City.” *Journal of Planning History* 12(4):287–311. doi: 10.1177/1538513212474227.

Epstein, Helen. 2003. “Ghetto Miasma: Enough to Make You Sick.” *The New York Times* 12.

Faber Taylor, Andrea, and Frances E. Kuo. 2009. “Children With Attention Deficits Concentrate Better After Walk in the Park.” *Journal of Attention Disorders* 12(5):402–9. doi: 10.1177/1087054708323000.

Felsten, Gary. 2009. “Where to Take a Study Break on the College Campus: An Attention Restoration Theory Perspective.” *Journal of Environmental Psychology* 29(1):160–67. doi: 10.1016/j.jenvp.2008.11.006.

Franěk, Marek, and Lukáš Režný. 2017. “The Effect of Priming with Photographs of Environmental Settings on Walking Speed in an Outdoor Environment.” *Frontiers in Psychology* 8. doi: 10.3389/fpsyg.2017.00073.

Gamble, Katherine R., James H. Howard Jr, and Darlene V. Howard. 2014. “Not Just Scenery: Viewing Nature Pictures Improves Executive Attention in Older Adults.” *Experimental Aging Research* 40(5):513–30.

Han, Ke-Tsung. 2017. “The Effect of Nature and Physical Activity on Emotions and Attention While Engaging in Green Exercise.” *Urban Forestry & Urban Greening* 24:5–13.

Hartig, Terry, Richard Mitchell, Sjerp De Vries, and Howard Frumkin. 2014. “Nature and Health.” *Annual Review of Public Health* 35:207–28.

Jiang, Bin, Chun-Yen Chang, and William C. Sullivan. 2014. “A Dose of Nature: Tree Cover, Stress Reduction, and Gender Differences.” *Landscape and Urban Planning* 132(Supplement C):26–36. doi: 10.1016/j.landurbplan.2014.08.005.

Johansson, Marcus, Terry Hartig, and Henk Staats. 2011. “Psychological Benefits of Walking: Moderation by Company and Outdoor Environment.” *Applied Psychology: Health and Well-Being* 3(3):261–80.

Jonides, John, and David E. Irwin. 1981. “Capturing Attention.”

Jiang, X. 2019. “Green infrastructure and human health: Nature exposure, attention, and well being.” University of Illinois at Urbana-Champaign.

Kaplan, Stephen. 1995. “The Restorative Benefits of Nature: Toward an Integrative Framework.” *Journal of Environmental Psychology* 15(3):169–82. doi: 10.1016/0272-4944(95)90001-2.

Kaplan, Stephen, and Marc G. Berman. 2010. “Directed Attention as a Common Resource for Executive Functioning and Self-Regulation.” *Perspectives on Psychological Science* 5(1):43–57. doi: 10.1177/1745691609356784.

Katsuki, Fumi, and Christos Constantinidis. 2014. “Bottom-up and Top-down Attention: Different Processes and Overlapping Neural Systems.” *The Neuroscientist* 20(5):509–21.

Kelly, Paul, Chloë Williamson, Ailsa G. Niven, Ruth Hunter, Nanette Mutrie, and Justin Richards. 2018. “Walking on Sunshine: Scoping Review of the Evidence for Walking and Mental Health.” *British Journal of Sports Medicine* 52(12):800–806.

Landers, Daniel M., and Shawn M. Arent. 2007. “Physical Activity and Mental Health.”

Laumann, Karin, Tommy Gärling, and Kjell Morten Stormark. 2003. “Selective Attention and Heart Rate Responses to Natural and Urban Environments.” *Journal of Environmental Psychology* 23(2):125–34. doi: 10.1016/S0272-4944(02)00110-X.

Li, Dongying, Yen-Cheng Chiang, Huiyan Sang, and William C. Sullivan. 2019. “Beyond the School Grounds: Links between Density of Tree Cover in School Surroundings and High School Academic Performance.” *Urban Forestry & Urban Greening* 38:42–53.

Li, Dongying, Brian Deal, Xiaolu Zhou, Marcus Slavenas, and William C. Sullivan. 2018. “Moving beyond the Neighborhood: Daily Exposure to Nature and Adolescents’ Mood.” *Landscape and Urban Planning* 173:33–43.

Li, Dongying, and William C. Sullivan. 2016. “Impact of Views to School Landscapes on Recovery from Stress and Mental Fatigue.” *Landscape and Urban Planning* 148:149–58. doi: 10.1016/j.landurbplan.2015.12.015.

Logan, Gordon D., Russell J. Schachar, and Rosemary Tannock. 1997. “Impulsivity and Inhibitory Control.” *Psychological Science* 8(1):60–64.

Louv, Richard. 2008. *Last Child in the Woods: Saving Our Children from Nature-Deficit Disorder*. Algonquin books.

Marc G. Berman, John Jonides, and Stephen Kaplan. 2008. “The Cognitive Benefits of Interacting With Nature.” *Psychological Science* 19(12):1207–12. doi: 10.1111/j.1467-9280.2008.02225.x.

Marcus, Clare Cooper. 1999. *Healing Gardens: Therapeutic Benefits and Design Recommendations*. John Wiley & Sons.

Neale, Chris, Peter Aspinall, Jenny Roe, Sara Tilley, Panagiotis Mavros, Steve Cinderby, Richard Coyne, Neil Thin, and Catharine Ward Thompson. 2019. “The Impact of Walking in Different Urban Environments on Brain Activity in Older People.” *Cities & Health* 1–13. doi: 10.1080/23748834.2019.1619893.

Northoff, Georg, Pengmin Qin, and Takashi Nakao. 2010. “Rest-Stimulus Interaction in the Brain: A Review.” *Trends in Neurosciences* 33(6):277–84.

Olafsdottir, Gunnthora, Paul Cloke, André Schulz, Zoé Van Dyck, Thor Eysteinsson, Björg Thorleifsdottir, and Claus Vögele. 2020. “Health Benefits of Walking in Nature: A Randomized Controlled Study under Conditions of Real-Life Stress.” *Environment and Behavior* 52(3):248–74.

Paluska, Scott A., and Thomas L. Schwenk. 2000. “Physical Activity and Mental Health.” *Sports Medicine* 29(3):167–80.

Peluso, Marco Aurélio Monteiro, and Laura Helena Silveira Guerra de Andrade. 2005a. “Physical Activity and Mental Health: The Association between Exercise and Mood.” *Clinics* 60:61–70.

Peluso, Marco Aurélio Monteiro, and Laura Helena Silveira Guerra de Andrade. 2005b. “Physical Activity and Mental Health: The Association between Exercise and Mood.” *Clinics* 60:61–70.

Sahni, Pooja, and Jyoti Kumar. 2021. “Effect of Nature Experience on Fronto-Parietal Correlates of Neurocognitive Processes Involved in Directed Attention: An ERP Study.” *Annals of Neurosciences* 0972753121990143. doi: 10.1177/0972753121990143.

Sonntag-Öström, Elisabet, Maria Nordin, Ylva Lundell, Ann Dolling, Urban Wiklund, Marcus Karlsson, Bo Carlberg, and Lisbeth Slunga Järvholm. 2014. “Restorative Effects of Visits to Urban and Forest Environments in Patients with Exhaustion Disorder.” *Urban Forestry & Urban Greening* 13(2):344–54.

Sullivan, WC. 2015. “In Search of a Clear Head.” *Fostering Reasonableness: Supportive Environments for Bringing out Our Best* 54–69.

Sullivan, W.C., & Li, D. (2021). Nature and attention. In A.R. Schutte, J. Taurquati, & J. R. Stevens (Eds). Nature and psychology: Biological, cognitive, developmental, and social pathways to well-being. Springer Nature, Switzerland. ISBN 978-3-030-69019-9

Taylor, Andrea Faber, Frances E. Kuo, and William C. Sullivan. 2001. “Coping with Add: The Surprising Connection to Green Play Settings.” *Environment and Behavior* 33(1):54–77. doi: 10.1177/00139160121972864.

Taylor, ANDREA FABER, FRANCES E. Kuo, and WILLIAM C. Sullivan. 2002. “VIEWS OF NATURE AND SELF-DISCIPLINE: EVIDENCE FROM INNER CITY CHILDREN.” *Journal of Environmental Psychology* 22(1):49–63. doi: 10.1006/jevp.2001.0241.

Telch, Michael J., and Cynthia Luethcke Lancaster. 2012. “Is There Room for Safety Behaviors in Exposure Therapy for Anxiety Disorders?” Pp. 313–34 in *Exposure therapy*. Springer.

Tennessen, Carolyn M., and Bernadine Cimprich. 1995. “Views to Nature: Effects on Attention.” *Journal of Environmental Psychology* 15(1):77–85. doi: 10.1016/0272-4944(95)90016-0.

Tzoulas, Konstantinos, Kalevi Korpela, Stephen Venn, Vesa Yli-Pelkonen, Aleksandra Kaźmierczak, Jari Niemela, and Philip James. 2007. “Promoting Ecosystem and Human Health in Urban Areas Using Green Infrastructure: A Literature Review.” *Landscape and Urban Planning* 81(3):167–78.

Ward, Jamie. 2016. *The Student’s Guide to Social Neuroscience*. Psychology Press.

Ward Thompson, Catharine, Jenny Roe, Peter Aspinall, Richard Mitchell, Angela Clow, and David Miller. 2012. “More Green Space Is Linked to Less Stress in Deprived Communities: Evidence from Salivary Cortisol Patterns.” *Landscape and Urban Planning* 105(3):221–29. doi: 10.1016/j.landurbplan.2011.12.015.

Yatham, Swetha, Shalini Sivathasan, Rosalia Yoon, Tricia L. da Silva, and Arun V. Ravindran. 2018. “Depression, Anxiety, and Post-Traumatic Stress Disorder among Youth in Low and Middle Income Countries: A Review of Prevalence and Treatment Interventions.” *Asian Journal of Psychiatry* 38:78–91.

Yin, Jie, Jing Yuan, Nastaran Arfaei, Paul J. Catalano, Joseph G. Allen, and John D. Spengler. 2020. “Effects of Biophilic Indoor Environment on Stress and Anxiety Recovery: A between-Subjects Experiment in Virtual Reality.” *Environment International* 136:105427.

Yu, Qian, Fabian Herold, Benjamin Becker, Ben Klugah-Brown, Yanjie Zhang, Stephane Perrey, Nicola Veronese, Notger G. Müller, Arthur F. Kramer, and Liye Zou. 2021. “Cognitive Benefits of Exercise Interventions: An FMRI Activation Likelihood Estimation Meta-Analysis.” *Brain Structure and Function* 1–19.

Zwilling, Christopher E., Adam Strang, Evan Anderson, Jennifer Jurcsisn, Erica Johnson, Tapas Das, Matthew J. Kuchan, and Aron K. Barbey. 2020. “Enhanced Physical and Cognitive Performance in Active Duty Airmen: Evidence from a Randomized Multimodal Physical

Fitness and Nutritional Intervention.” *Scientific Reports* 10(1):17826. doi: 10.1038/s41598-020-74140-7.

CHAPTER 3: BE CAREFUL WHERE YOU WALK

Introduction

Healthcare workers, who are constantly under pressure to deliver high-quality care, rely continuously on their capacity to direct their attention to solve problems, remember details, and deal with challenging social situations. Because of these pressures, healthcare workers are subject to mental fatigue, mood disorders, and anxiety on a daily basis (Cimprich and Ronis 2003; Sullivan and Kaplan 2016) that negatively impact their memory and ability to problem-solve. How might healthcare workers respond to the intensity of the pressures they face given that they spend the majority of their time inside a hospital and clinic?

One possible way to enhance attentional functioning, increase affect and reduce anxiety is to get some form of exercise (Ashdown-Franks et al. 2020). Perhaps the easiest way to exercise during the work day is to go for a walk. And indeed, there is considerable evidence demonstrating the physical and psychological benefits of walking. Walking improves self-perception and self- esteem, cognitive functioning, memory, attention, mood, and sleep quality, and reduces stress, anxiety, and fatigue (Johansson, Hartig, and Staats 2011; Neale et al. 2019).

But is any walk as good as any other walk of similar physical demands? Perhaps not. Some studies have shown that walking in greener settings is more likely to enhance a person's capacity to pay attention ((Berman, Jonides, and Kaplan 2008; Faber Taylor and Kuo 2009). Those studies, however, focused on students. Do the benefits of walking in green spaces documented with students extend to healthcare workers, who face unrelenting pressure due to the demands of their work? To what extent are other reported benefits of green spaces, such as more positive moods (Jiang et al, 2021) and less anxiety (Barton et al, 2012) available to these healthcare workers?

We explore these questions through a randomized experimental study with healthcare workers as the study participants. The experiment had two conditions, a 40-minute walk in either a barren or green urban setting. Participants took three walks during a 7-day period. We asked, "To what extent does the greenness of an urban walk impact healthcare workers attentional functioning, affect, and anxiety when they take a walk during work?"

Pressure in the workplace and mental health

Considerable pressure in the work environment can lead to poor performance. Work environments are one of the primary sources of occupational anxiety (Prasad et al. 2020). Stress, up to a certain level, is known to increase productivity at work, but if the pressure becomes excessive, productivity declines, and workers experience mental distress (Gabriel and Zierath 2017).

When healthcare providers are subjected to considerable demands, they are likely to experience attentional fatigue. Attention fatigue is a naturally occurring mental state that results from deploying attentional resources until they are depleted, and not an illness cured by medication (Bhargava and Trivedi 2018). Healthcare providers are often affected by attention fatigue because of the demanding nature of their work that requires a great deal of focus (Sullivan & Kaplan, 2016). Attentional fatigue resulting from the demands of work can negatively impact cognitive performance on the job and reduce the quality of the experience that derives from one’s work (Seaward 2017).

Too many demands in the workplace can lead to negative moods, stress, and anxiety. Collectively, these states can lead to poor decision making, reduced productivity, and increased errors (Noval and Stahl 2017). In medical settings, even small of errors can have disastrous consequences.-Although it is not likely that healthcare workplaces can be designed to be stress-free, it may be possible to create interventions that allow healthcare workers to recover from the demands they face on a daily basis.

Healthcare workers, walking and mental health

Healthcare workers face considerable pressure to provide quality care: they must direct their attention to the task at hand, recall a great variety of details, procedures, and protocols, all the while dealing with sensitive social dynamics (Lin et al. 2019). Thus, healthcare providers are subjected to the effects of mental tiredness, mood disorder, and nervousness daily. Mental fatigue caused by long consecutive working hours can be reduced by taking a walk, which improves a person’s physical health and can also enhance their psychological wellbeing (Abbina et al. 2020).

Empirical research and sage advice suggest that some form of exercise will help people recover from mental fatigue, stress, and anxiety they experience from the demands they face at work (Ashdown-Franks et al. 2020, wang et al. 2020). Walking, may be the most accessible exercise activity available to people during the workday. Walking results in a number of psychological benefits such as helping people recover from the stress and anxiety they experience in daily life. Walking, especially in green environments, improves self-perception, self-esteem, mood levels, attention and reduced pressure (Neale et al. 2019; Singleton 2019, Barton et al. 2012).

Although it is clear that walking has significant benefits, the questions remains: does it matter where we walk? Does the level of vegetation to which people are exposed during their walk provide benefits above and beyond the exercise? What are the benefits of 40 minutes of walking in urban contexts that vary in the density trees and other forms of vegetation?

Gap in our knowledge

My purpose here is to understand the differences in walking to urban settings that are more or less green have on psychological well-being, especially on attention, affect, and anxiety. I address this question through a randomized experiment that included three separate walks in a green setting or a barren one, followed by three questionnaires of the attentional functioning index (AFI), Affect Grid, State-Trait of Anxiety Inventory (STAI).

Methods

Participant selection

Approval for this study was obtained from the National Taiwan University (NTU) Research Committee (REC) and then from the University of Illinois at Urbana-Champaign Institutional Review (IRB) (protocol # 18772) in 2018. Eligible participants were chosen among the doctors and nurses who were working full time at National Taiwan University Hospital. Inclusion criteria were that potential participant be healthy, with no history of mental health diagnoses or brain injury such as concussion. Written informed consent was obtained from each participant, and participants were paid 3,000 NTD which was roughly equivalent to $100.

Fifty-four individuals participated in this study (we excluded 6 participants either because they did not complete the experiment or complete the online surveys). We advertised in order to encourage participation in our experiment by hanging posters around the NTU Hospital. We also received permission from the hospital administration to send an announcement inviting participation in our study via email to employees at the NTU Hospital. We provided an online platform where people could read a brief summary of the experiment, and a description of the requirements for participation. Individuals could register as participants using email. We contacted each person who registered to assess the extent to which they met our inclusion criteria and, if they did, to schedule participating in the experiment.

Site selection

We chose two sites for the walking experiment. Both were in close proximity to the NTU Hospital and thus easily accessible, large enough to walk in for 40 minutes, and were in the urban context of Taipei City (see Figure *1*). We selected DAAN Forest Park for the urban green treatment and a commercial and residential neighborhood that contained very little vegetation for the barren urban treatment (see Figure 2 and Figure *3*). Before the experiment, members of our research team examined the physical settings and confirmed that they were both comfortable to walk in for 40 minutes.

Participants were randomly assigned to one of the two treatment groups (green or barren). Each participant walked in the assigned environment three times for 40 minutes during a one-week period for a total of 120 minutes. During the walk, participants were not allowed to use their phone or listen to music. They were required to walk during the daytime, but not on Saturday or Sunday afternoons (as the settings were more crowded during those times). During the walk, participants wore a GPS-sensor that allowed us to verify the exact path and duration of their walk.

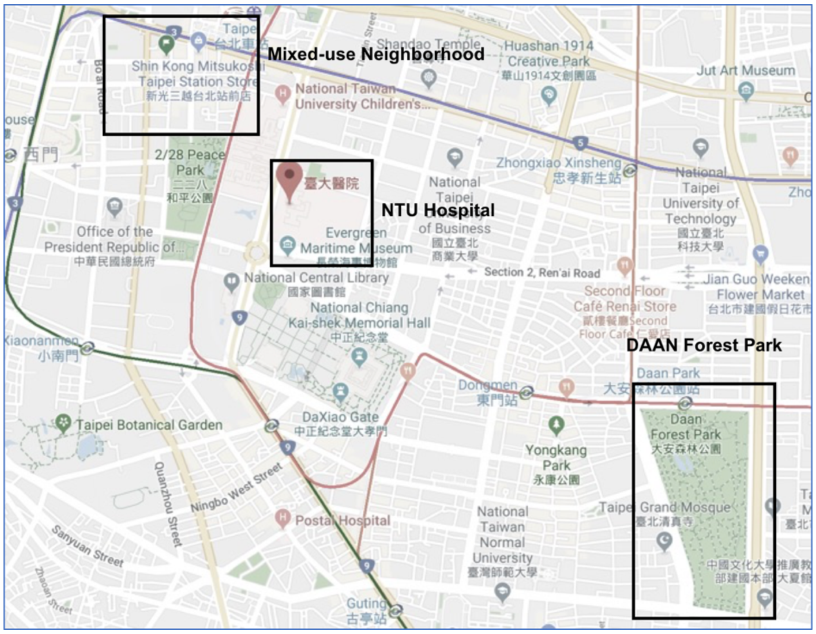


Figure 1. Relative locations of the National Taiwan University (NTU) Hospital, DAAN forest park, and the mixed-use neighborhood settings in Taipei that served as treatment sites for this study.

Figure 2. Example images from DAAN forest park in Taipei, Taiwan (Green walk).

Figure 3. Example images from the mixed-use neighborhood in Taipei, Taiwan (Barren walk).

Procedures

Each participant was randomly assigned to walk in one of the two groups (green walk and barren walk). They were required to walk three times during the week for 40 minutes each time. We chose walks of 40 minutes based on literature (Bang et al. 2017; Cimprich and Ronis 2003; Johansson, Hartig, and Staats 2011; Olafsdottir et al. 2020). Before they walked, each participant attached a GPS sensor to their chest that allowed us to track their walking route, the duration and time of their walk. Each participant also needed to have a smartphone for the walking experiment to connect the GPS to the app.

Before starting the experiment, each participant came to our lab, located at Yonglin Biomedical Engineering Hall close to NTU campus. During that initial visit, we explained the overall procedure of the experiment. We also gave each participant a small package that included the schedule for the week, the location of the setting to which they were assigned to walk, and a GPS sensor with adhesive patches used to secure the GPS sensor to their chest (Figure 4). The package also included instructions regarding using the GPS sensor, how to export GPS data online, and how to answer the online questionnaires after each walk. We trained each participant to install an app – Wahoo – on their phone so that they could transmit the GPS data to us. We trained them to use the app and made sure that it was working correctly.

We provided a map of the setting they were to walk during the week; however, we asked them not to look at the map while they walk. The purpose of the map was simply to get them familiar with the setting. Participants were not supposed to pay attention to their phone or walk with anybody else. We explained that the purpose was for them to experience the environment. All these rules were also written on the map that we provided for each person.

They were also asked to send an email each day after they walked and give us the time of the day that they walked. After each walk, they answered three online questionnaires; Attentional Functioning Index (AFI), Affect and State trait of Anxiety Inventory (STAI). Questionnaires and attention tests were administered at each time period.

Figure 4. GPS that used in the experiment to track participants walking. The GPS would be attached with patches on participants body.

Constructs and measures

Attentional Functioning Index (AFI)

Participants completed the Attentional Function Index (AFI) questionnaire so that we could assess their perceived effectiveness in conducting daily tasks and activities which require attention. AFI consists of 3 Factors. Factor 1, Effective Action, assess individual's perceived effectiveness in carrying out basic activities in daily living that requires top-down attention. Factor 2, Attentional Lapses, measures perceived difficulties in directing attention in daily tasks. Factor 3, Interpersonal Effectiveness, measures perceived ability to interact in a deliberate manner that depends on attentional or inhibitory control. In general, AFI assesses perceived effectiveness of daily activities that depend on basic cognitive processes related to attention, working memory, and higher-level executive functions. The AFI has been used in numerous previous studies as a measure general attentional functioning in a person's recent life. AFI has been tested for validity and reliability, and has sensitivity in measuring perceived changes in attention, working memory, and higher-level executive function, besides the deficits in the capacity to direct attention (Cimprich, Visovatti, and Ronis 2011) . Participants answered AFI questionnaire after each walk.

Affect

To measure participants emotional status, we employed the Affect grid (Russell, Weiss, and Mendelsohn 1989). The Affect grid assesses feelings along two dimensions of pleasure-displeasure and arousal-sleepiness (Figure 5). This grid has been used in a wide range of studies from different disciplines (Killgore 1998). Affect grid includes a 2-dimentional 9x9 grid. Participants mark their current emotional state. Each participant responded to the Affect Grid after each of the three 40-minute walks. We used this grid as a quick way to measure participant's moods after walking in environment to which they were assigned.

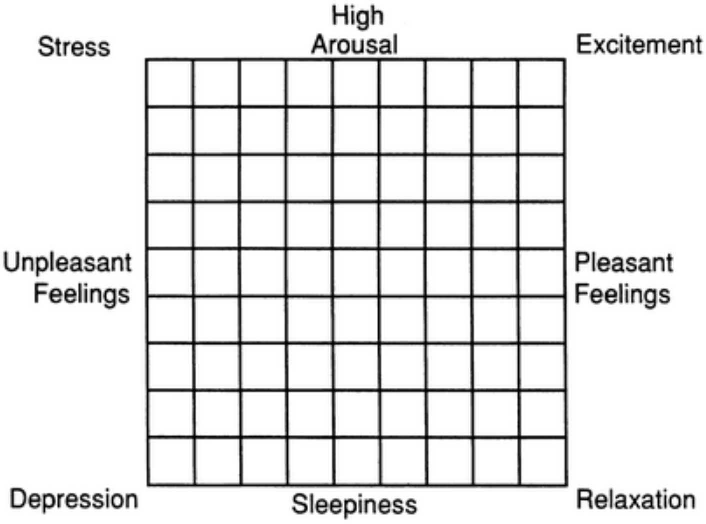


Figure 5. The Affect Grid. Participants read the general instructions [given in the Appendix] and then are given specific instructions, such as "Please rate how you are feeling right now." The participants then rate their feeling from 1 to 10.

State-Trait Anxiety Inventory

We also employed the State-Trait (STAI) to measure anxiety. We used 20-item STAI often referred to as Form Y, that includes separate measures of state and trait anxiety. State anxiety includes items such as “I am tense; I am worried” and “I feel calm; I feel secure.” The trait anxiety items include items such as “I worry too much over something that really doesn’t matter” and I am content: I am a steady person.” Items are rated on a 4-point scale from “Almost Never” to “Almost Always.” Higher scores on the STAI indicate higher levels of anxiety.

The STAI has been widely used for research and clinical practice (Sesti 2000). Numerous reliability and validity tests have been conducted on the STAI and have provided sufficient evidence that the STAI is an appropriate and adequate measure for studying anxiety in research and clinical area (Sesti 2000). The original STAI form was published in 1964 (Spielberger 1989). Participants answered AFI questionnaire after each walk.

Control variables and confounds

Even though each participant was randomly assigned to one treatment group, it is impossible to control for individual differences among participants in an experiment that that took place in real-world settings over a period of days. Thus, we asked participants to complete a background questionnaire. We collected data about participant's age, gender, recent physical and mental health, and their daily and weekly physical activities. We also collected data on a variety of potential confounding variables such as socio-economic information, automobile access, recent challenging events in participant's lives, and any chronic mental disorders they might have experienced.

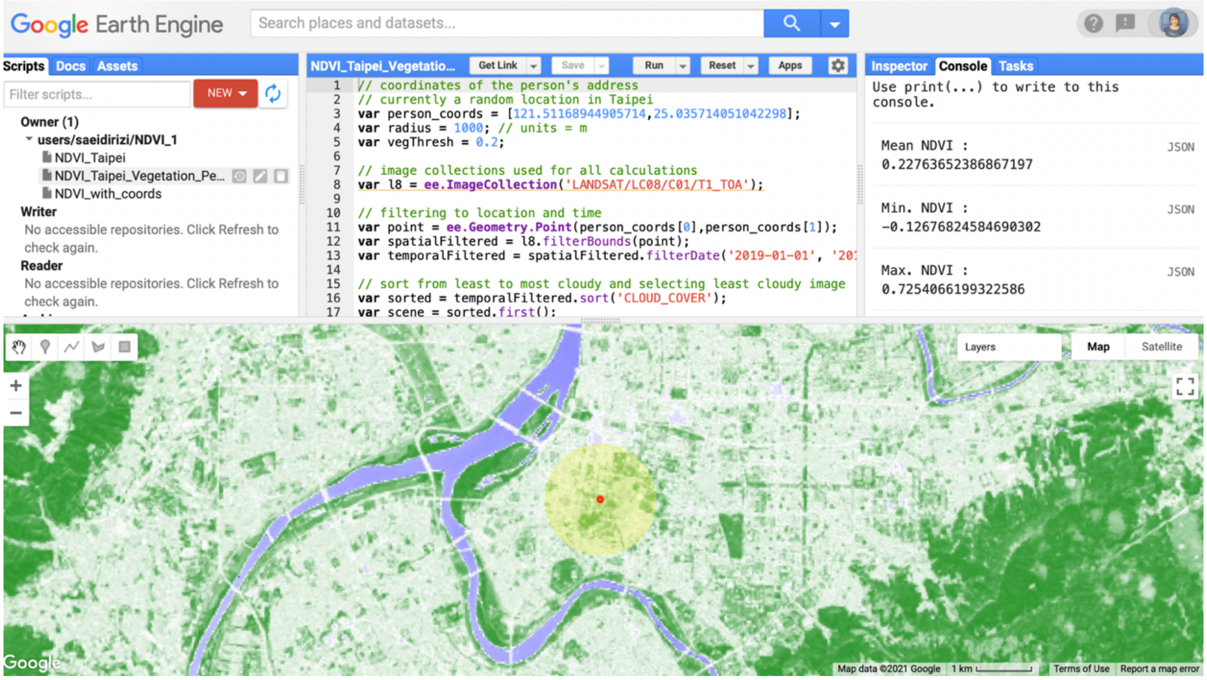
Residential greenness

We examined residential greenness as a potential confound to the walking treatments. To assess residential greenness, we used Google Earth Engine (EE) to calculate the Normalized Difference Vegetation Index (NDVI) percentage values for the area around each participant's home address (Huang et al. 2017). Our analysis involved three steps: i) locating each participant's home address using Google Earth, ii) developing a JavaScript program to compute vegetation percentage within a specific radius around the residential address, and iii) using this program to compute NDVI value for each participant.

We extracted the longitude and latitude of the locations of each participant using the standard graphical interface of EE. We generated a list of the coordinates for the subsequent steps of the analysis. The list of participants' locations was stored in an EE list object. The list contains a set of coordinates (P) for each participant held as elements of an EE list.

We developed a JavaScript program that took the coordinates of each participant's home address and computed the NDVI percentage values as follows. The program took participant's coordinates in our EE list and returned the corresponding NDVI percentage value. The function has two important internal variables: radius (R), and vegetation threshold (T). The value for R corresponds to the radius around participant's home (in meters) that will be used for data collection, and the T variable represents the minimum NDVI value that is considered as vegetation. We set the values for R and T before performing any analysis. The function pulls Google Earth imagery data from EE's *LANDSAT/LC08/C01/T1_TOA* image collection. It then filters collected image data for: i) the spatial location of the participant (using an EE's point geometry object generated), ii) a time period (using 2019-01-01 to 2019-12-31 in this study), and iii) the lowest value of cloud coverage (i.e., sorting image data based on the visibility during this period and selecting maximum visibility data). The function then computes NDVI values using near-infrared (B5 band) and red (B4 band) values for each pixel within the collection. The function then applies a threshold value of T on the computed NDVI data. In the next step, the function creates an EE point buffer object (a circular region) by taking R as the radius value. The function then uses this buffer to perform two reduction operations. The first reduction operation counts the total number of all vegetation pixels. The second reduction computes the total number of pixels in the buffer. The function then divides the summation of vegetation pixels by the total number of pixels and multiplies the outcome by 100 to compute the vegetation percentage. The vegetation percentage is then returned.

In the last step of the analysis, we mapped the JavaScript function to the list of participant home addresses to compute the list of vegetation percentages. We employed radius values of 50m, 100m, 250m, 500m, and 1,000m. NDVI values range from +1.0 to -1.0. Areas of barren rock, sand, or snow usually show very low NDVI values (for example, 0.1 or less). Sparse vegetation such as shrubs and grasslands may result in moderate NDVI values (approximately 0.2 to 0.5). High NDVI values (approximately 0.6 to 0.9) correspond to dense vegetation such as that found in tropical forests or crops at their peak growth stage. Therefore, we also varied the NDVI at 0.2 and 0.3 threshold.



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```
// coordinates of the person's address
// currently a random location in Taipei
var person_coords = [121.51168944905714,25.035714051042298];
var radius = 1000; // units = m
var vegThresh = 0.2;

// image collections used for all calculations
var l8 = ee.ImageCollection('LANDSAT/LC08/C01/T1_TOA');

// filtering to location and time
var point = ee.Geometry.Point(person_coords[0],person_coords[1]);
var spatialFiltered = l8.filterBounds(point);
var temporalFiltered = spatialFiltered.filterDate('2019-01-01', '20

// sort from least to most cloudy and selecting least cloudy image
var sorted = temporalFiltered.sort('CLOUD_COVER');
var scene = sorted.first();
```

```
Use print(...) to write to this
console.

Mean NDVI :                         JSON
0.22763652386867197

Min. NDVI :                         JSON
-0.12676824584690302

Max. NDVI :                         JSON
0.7254066199322586
```

Figure 6. We employed the Google Earth Engine platform to calculate NDVI for the areas around the residence of each participant in this study.

Results

Results are presented in four sections. First, we compare the baseline attention among all participants to ensure there are no pre-treatment group differences. Second, we explore the effect of each treatment group on participants attentional functioning after each walk (total of three walks). Third, we follow the same procedure to examine the impact of the walks on anxiety and affect. In the last section, we investigate potential confounds to see if there are any other mediating variables that impact the outcomes.

The effect of walking setting on attentional functioning

Were there differences among the baseline levels of attention for participants who were randomly assigned to the two treatment conditions? To answer this question, we conducted independent t-test examining differences in AFI scores between the two treatment groups before the experiment. We found no significant difference in the baseline attentional functioning levels between the two groups ($t(46) = -0.23$ $p = 0.82$). As you can see in Table 2, the AFI means before starting the experiment are nearly identical.

Table 2. Means for pre-AFI

Treatment	Mean	Std. Deviation	N
Green	7.5	1.29	24
Barren	7.6	1.02	24

We predicted that participants in the greener urban condition would have higher AFI scores compared to people in the barren condition. To assess if was the case, we performed t-tests examining the AFI summary variable across the three measures (3 timepoints) (Table 3). We found that participants who were randomly assigned to the green walk scored 67% higher on the summary of AFI scores compared to participants who walked in the barren setting. This finding indicates that people in the green condition were functioning significantly better on activities depending on working memory, setting goals, planning, and carrying out tasks.

Table 3. independent t-test to compare AFI scores between two conditions after the treatment

	t	**df**	**Sig (2-tailed)**	**Mean Difference**
Sum of AFI scores	11.27	145	.00	3.4

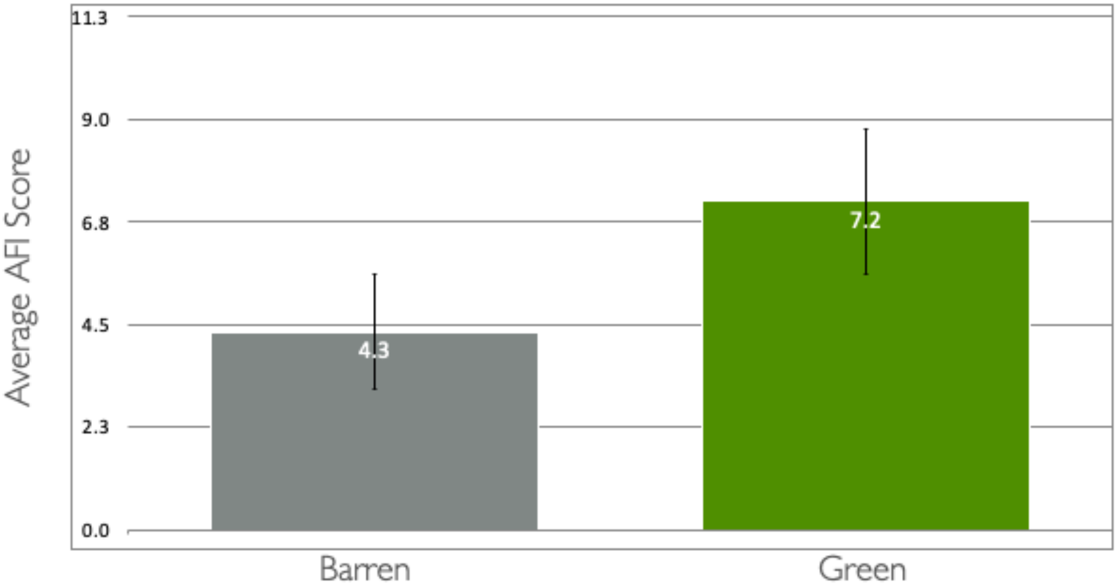


Figure 7. Differences in the average AFI scores for participants randomly assigned to the green and barren treatments.

Did this pattern hold after each of the three walks? To answer this question, we conducted a repeated-measures ANOVA with the walk condition as the between-subject factor and time as the within-subject and found that the pattern held. After each walk, the attentional functioning of participants in the green walk condition was higher than individuals who were randomly assigned to walk in the barren condition ($F(1, 46) = 115.48$, $p = 0.00$, $\eta^2 = 0.715$).

Did the difference in attentional functioning occur after each walk within each condition? To answer this question, we conducted a one way ANOVA examining the impact of treatments at the end of each walk for each condition separately. We found no differences in AFI scores among the first walk, second or third walk for either the green or barren condition.

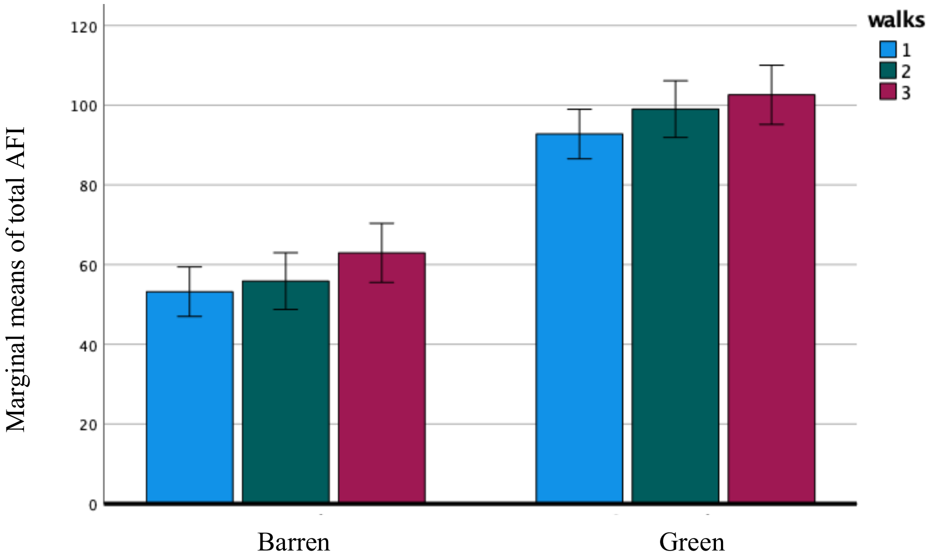


Figure 8. shows scores for both treatments at three timepoints. There are no statistically significant differences within treatments among the three walks.

The effect of walking condition on affect

We assessed the impact of the walks on changes in affect. The results mirrored those in the AFI. The pattern was identical to the impact of the walks on AFI scores. We predicted that participants in the greener walk condition would score higher on measures of affect than participants assigned to the barren walk condition. We performed a t-test examining the summary variable for Affect across the three measures (3 timepoints), and indeed, we found participants who were randomly assigned to green walk treatment scored 60% higher in affect than participants who walked in the barren-condition (See Table 4 and Figure 9). These findings indicate that healthcare workers in the green condition were experiencing more elevated feeling and emotions than their peers who walked in urban settings with low levels of vegetation.

Table 4. independent t-test to compare Affect scores between two conditions.

	t	**df**	**Sig (2-tailed)**	**Mean Difference**
Sum of Affect scores	7.64	145	.00	.64

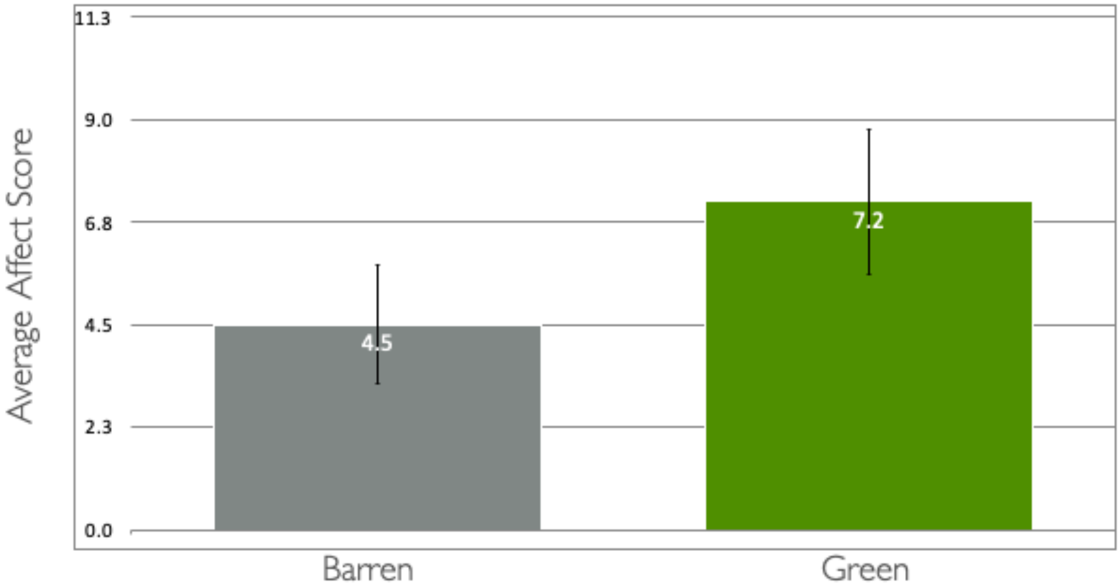


Figure 9. Summary variable of green-urban and barren-urban group.

Next, we asked, did this pattern hold after each three walks? To answer this question, we conducted a repeated-measures ANOVA with the walk condition as the between-subject factor and time as the within-subject factor. Here again, we found the pattern held. After each walk the mood of participants in the green walk condition was more elevated than individuals who were randomly assigned to walk in the barren condition ($F(1, 46) = 38.26$, $p = 0.00$, $\eta^2 = 0.45$).

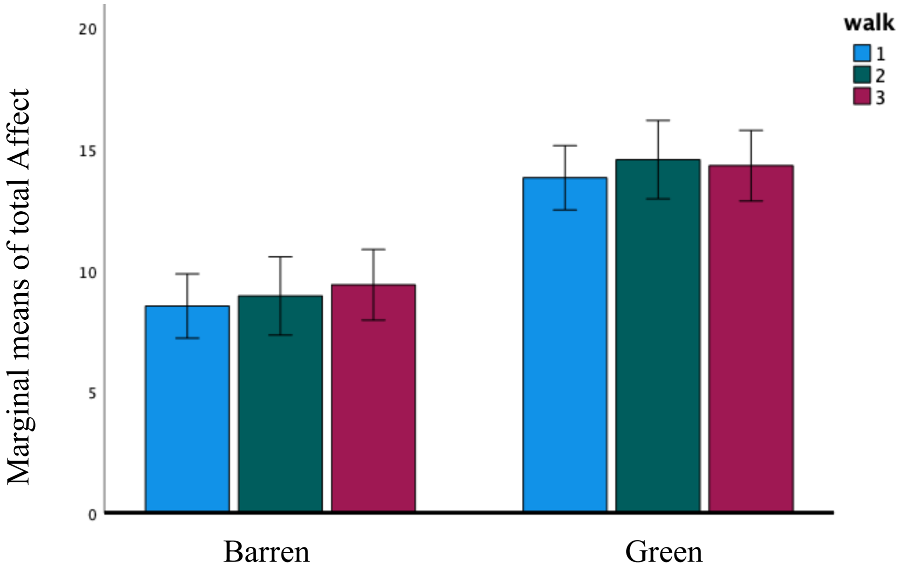


Figure 10. Shows the Affect scores for both treatments at three timepoints. There are no statistically significant differences within treatments among the three walks.

The effect of walking condition on anxiety

We also assessed the impact of the green versus barren walks on anxiety levels. We predicted that participants in the greener urban condition would have lower STAI scores – that is, lower anxiety scores -- compared to participants assigned to the barren condition. To assess this prediction, we performed t-tests examining the difference in summary STAI scores (across three timepoints) between treatment conditions. Participants who were randomly assigned to green walk treatment scored 35% lower in STAI than their peers who walked in the barren treatment setting. This relationship was strongest between time points 1 and 3 in the green walk group ($p = .07$). These findings (Table 5) indicate that immediately after their walks, participants assigned to the green condition had significantly lower anxiety levels compared to participants in the barren condition.

Table 5. independent t-test to compare STAI scores between the two conditions.

	t	**df**	**Sig (2-tailed)**	**Mean Difference**
Sum of STAI scores	-10.48	145	.00	-21.19

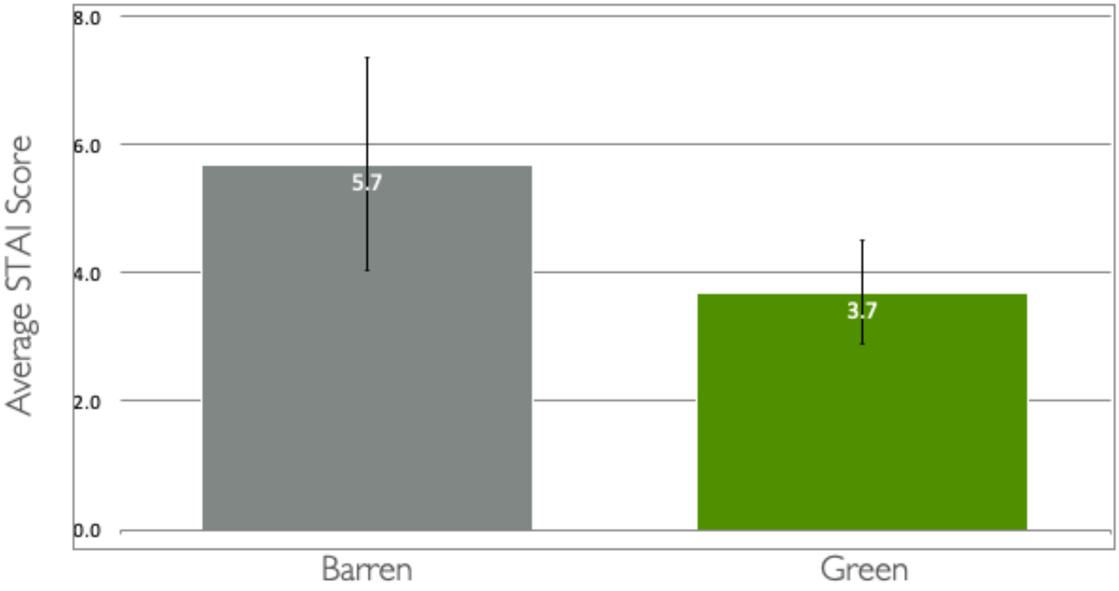


Figure 11. Summary variable of green and barren treatment.

Did this pattern of lower anxiety scores for participants who walked in the green condition hold after each three walks? To answer this question, we conducted a repeated-measures ANOVA with the walk condition as the between-subject factor and time as the within-subject factor. We found the pattern held. After each walk, the anxiety level of participants in the green walk condition was significantly lower than individuals who were randomly assigned to walk in the barren condition (F (1, 46)= 58.94, p = .00, η^2 = 0.96).

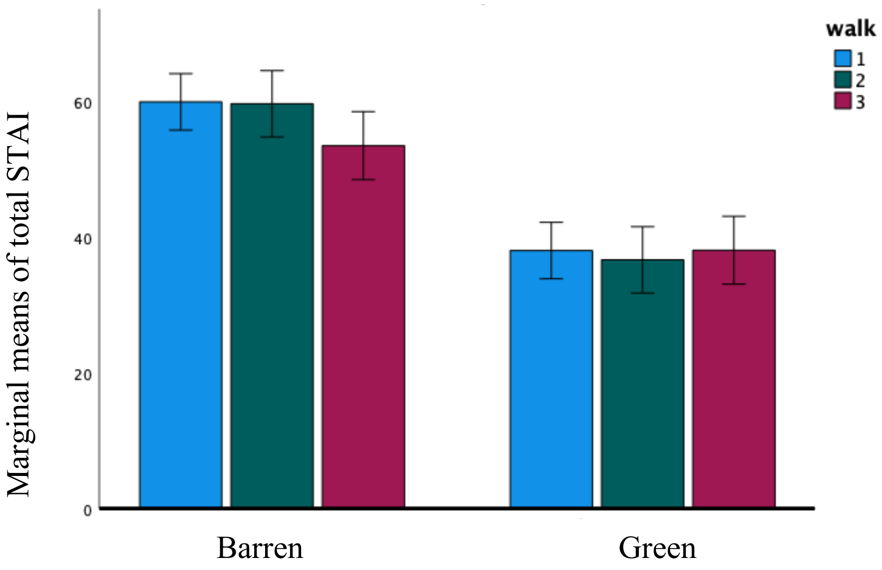


Figure 12. Shows STAI scores for both treatments at three timepoints. There are no statistically significant differences within treatments among the three walks.

Testing Potential Confounds

Controlling for percentage of residential greenness.

One of the critical variables to control in examining the impact of an experimental treatment involving urban nature is the density of vegetation that a person is exposed to outside of the experimental setting. To explore this possibility, we measured the density of vegetation around each participant's home address using NDVI. We used a circular buffer around each address in which the center of the residence was at the center of the circle. We made NDVI measurements with circle radii at 50m, 100m, 250m, 500m, and 1,000m. We then used these percent vegetation found within each of these buffers as our measure of residential greenness.

Did the greenness around participant's homes moderate the relationship reported above between walking condition and AFI scores? To address this question, we conducted a moderation analysis in which the walk condition was the independent variable, the summary AFI scores were the dependent variable, and the percentage of residential greenness was the moderator.

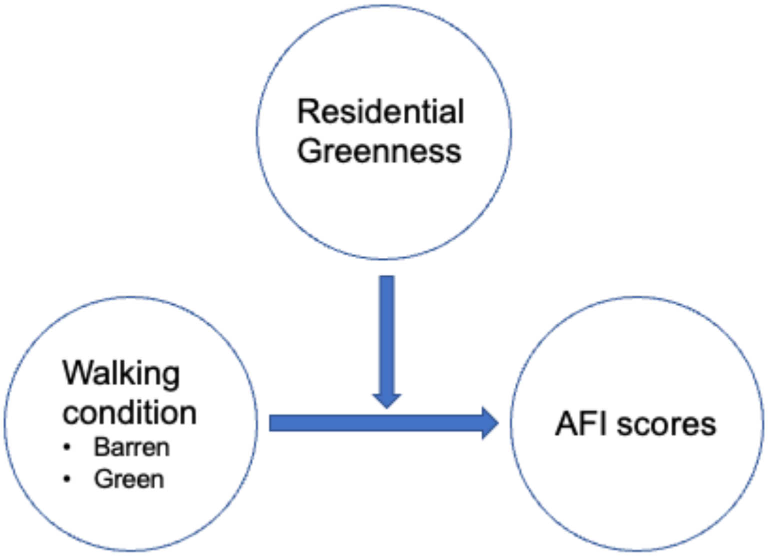


Figure 13. Conceptual model for moderation analysis; consisting of the dependent variable (attention), independent variable (green and barren walk), and a moderator (residential greenness).

We conducted a series of linear regressions examining the relationship between residential greenness at the various distances from the residence and AFI scores. If the residential greenness moderated the relationship between walking condition and the summary AFI scores, we would expect that the slope of the regression line would be positive. That is, we would expect that people living in greener settings would score higher on the summary AFI scores.

As can be seen in Figure 14, we found, for each of the five buffer sizes, that the regression was not statistically significant. That is, residential greenness did not moderate the treatment effects of walking condition on AFI scores.

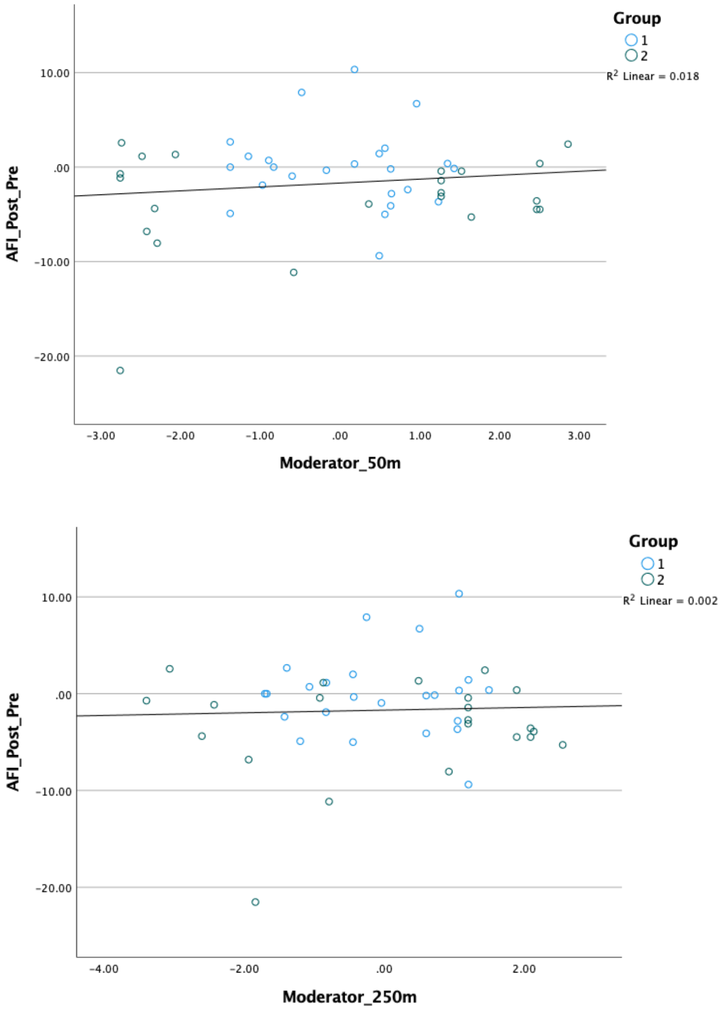


Figure 14 (cont.)

Figure 14 (cont.)

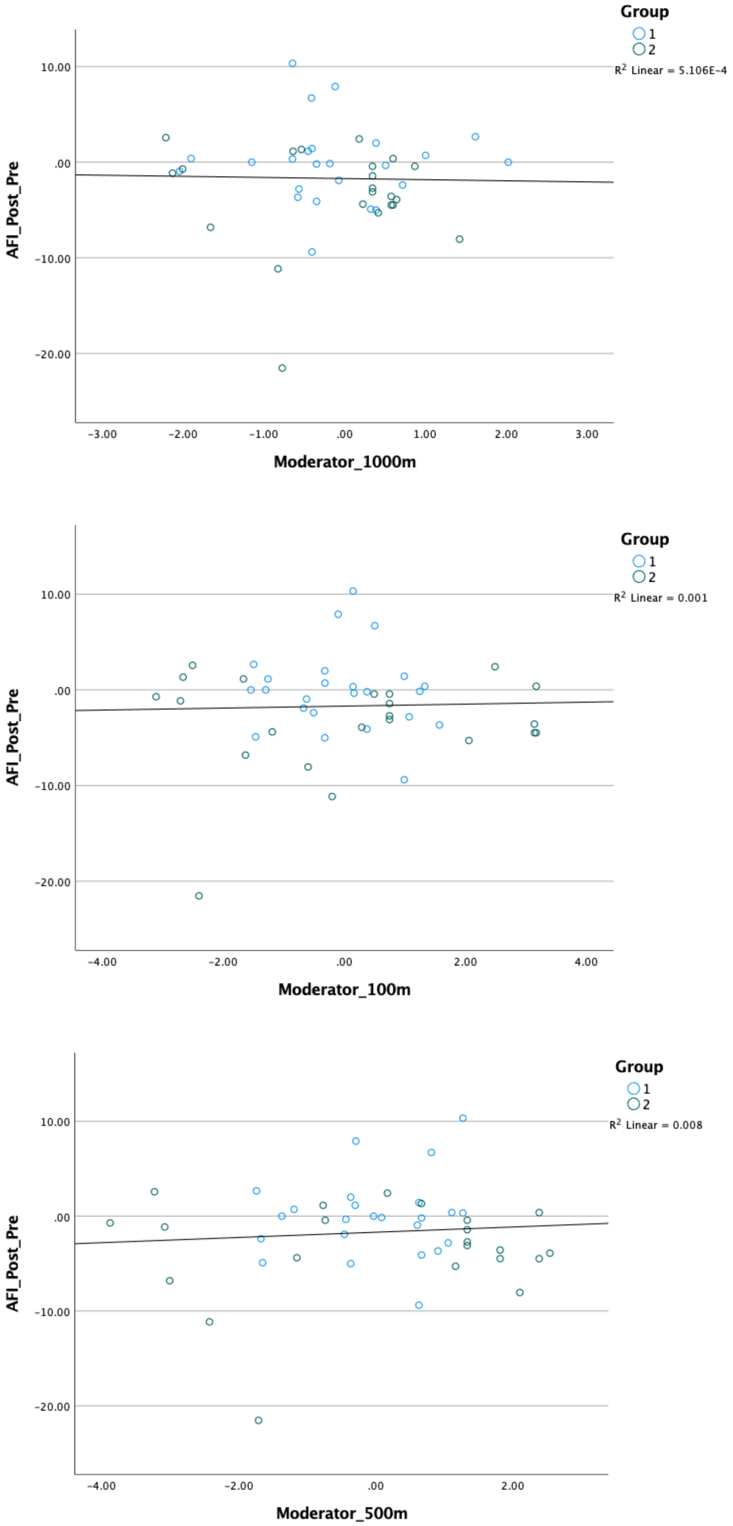


Figure 14. The linear relationship between attention scores and percentages of residential greenness at various buffer sizes calculated from the center point of each residence.

Discussion

In this study in which healthcare professionals were randomly assigned to walk three times in a green or barren landscape, we found that walking in the green setting had significant impacts on measures of attention, affect and anxiety. The green setting resulted in higher total attention and affect scores and lower scores on anxiety.

It is interesting to note that the green walk treatment had 67% higher AFI scores, 60% higher Affect scores, and 35% lower anxiety scores compared to the barren walk treatment. Although we found significant differences in scores between the two conditions, the differences within each condition among the three time points were not statistically significant. Additionally, we did not find any significant association between our measures of residential greenness and the post-walk measures of attention, affect, or anxiety. That is, the density of the vegetation around participant's homes did not predict any of the outcome measures in this study. In the paragraphs below, we consider the contributions of these findings, their implications, and several questions for future research.

Contributions

Our findings show that walking in an urban environment with vegetation is positively associated with higher levels of self-reported attentional functioning, more positive affect, and lower levels of anxiety. The findings contribute to our understanding of the extent to which walking in urban environments with varying concentrations of nearby nature is related to cognitive functioning and emotional experiences.

The first contribution of this study is to add nuance to the age-old advice to "go for a walk" to restore one's mind or improve one's mood. For many people, it has been hard to avoid such advice. Not only have we heard this counsel from trusted adults all our lives, but also from research papers (Ashdown-Franks et al. 2020; Choi et al. 2019). and from thousands of stories on the Internet with messages similar to this quote:

> “Even a short, 15-minute walk can help clear your mind, improve your mood, and boost your energy level. As you move and start to feel a little better, you'll often boost your energy enough to exercise more vigorously — by walking further, breaking into a run, or adding a bike ride” (Helpguide.org, 28 June 2021).

Although every participant in this study walked 120 minutes outdoors in an urban setting during the week of the experiment, the two treatment groups differed a great deal in the cognitive and emotional benefits gained from their exercise. Those who walked in an urban green setting gained the benefits that our grandmothers and our research colleagues told us about. Participants who walked in barren urban settings did not gain these benefits.

The second contribution of this study is to extend our understanding of the impact of walking in urban nature on the everyday experiences of people who live in cities. From previous research, we knew that walks in urban nature produced cognitive benefits for people (Berman, Jonides, and Kaplan 2008) and our findings are consistent with these studies. Our findings extend the previous work by showing that the greenness of the walks impacted the affect and anxiety that participants reported immediately after the walks.

A third contribution of this work is to have presented evidence that these previous findings extend to a critical population of people – healthcare workers. Previous studies have demonstrated links between exposure to green spaces and higher performance on attentional tasks among public housing residents (Kuo and Sullivan 2001) , AIDS caregivers (Canin 1991), cancer patients (Cimprich 1993), high school students, (Li et al. 2018; Li and Sullivan 2016) , college students (Jiang et al. 2019), prairie restoration volunteers (Miles, Sullivan, and Kuo 1998), and employees of large organizations (Kaplan 1993). The findings presented here demonstrate that the cognitive benefits associated with exposure to green settings can impact healthcare workers who are exposed to nature during their workday.

Our final contribution concerns a question from previous research that posited the beneficial effects of a nature walk may be moderated by the greenness of the walker's residential surroundings (Gascon et al. 2015). Our findings suggest that a walk in a green urban setting has immediate, positive impacts independent of residential greenness.

Implications

The findings from this study are clear: "be careful where you walk!" Most people, of course, are already careful not to walk in dangerous places. The results of this study suggest they would also be wise to be mindful of how green the settings are that they walk within. Walking in greener settings will likely produce benefits for our ability to pay attention, our experience of positive moods, and a reduced likelihood of experiencing high levels of anxiety.

The findings add to the line of research regarding the health impacts of being exposed to nearby nature, suggesting that urban greening is a suitable investment for cities that want to create a positive influence on the health and wellbeing of their residents and workers – in this case, healthcare workers.

Another implication is to call our attention to the importance of having green settings available for people to walk within close to work places. Far too many urban workers do not have access to green spaces nearby their workplaces that are both safe and easily accessible.

Planners, designers, developers, and policy makers should insist on creating green settings within and around all manner of work places.

One promising approach is to have small-scale interventions in the urban environment, such as pocket parks, parklets, rain gardens, and walking trails with vegetation that can transform an existing urban space and bring nature's benefits to places that people walk every day. A great example is Beltline in Atlanta. It works both an outdoor trail to connect people to city and also brings nature to the city.

Other small interventions such as reducing the amount of turf grass, reducing the amount of hardscape, and making sure that there are vegetated places that are green within neighborhood, schools, shopping centers, and other urban spaces.

The findings here suggest that walking in green settings may be an effective treatment for healthcare workers who experience mental fatigue, mood disturbances, and anxiety. Leaders of healthcare organizations should consider the findings here as they design the landscapes around their healthcare centers and design policies around breaks that workers can take.

Limitations and future research directions

Some limitations associated with this study should be addressed in future research. First, measures of attention, affect, and anxiety can be influenced by a number of individual, social, and environmental factors. Although we controlled a variety of potentially confounding variables, we could not control all the possible confounds such as changes in weather, air quality, traffic, number of social contacts a person engages in during the experimental treatment and a host of other variables. It should be noted that we did not observe any variables that might have systematically confounded one or the other treatment. Still, replications of this work will give us additional confidence in the findings. Such replications could also vary the environmental settings to include other types of urban landscapes,

A second limitation concerns the homogeneity of participants we sampled. Future research should include knowledge-workers who have greater variability in the kind of work they do, the pressures they experience, and the demands on their attention.

This study demonstrated the feasibility of using a GPS tracker for determining peoples' routes while walking in urban environments. Similar approaches can be used in future studies to create more realistic and ecologically valid representations of individual interactions to a host of environmental variables that are associated with various walking routes. The GPS tracker will document the exact route taken by participants. Knowing the exact walking route will allow researchers to measure a number of environmental exposures that vary by walking route.

Future work might also increase the duration of the experiment. In this study, we focused on the impact of the density of the vegetation along walking routes and the impact of this vegetation density on attention, affect, and anxiety over the course of one week. We found the same pattern of results for each outcome variable after each of the three walks: Although attention and affect scores for participants in the green walk treatment did not increase significantly from the first walk to the second or third walk, the trends in the data hint at the possibility that a fourth and fifth walk might produce greater impacts on attention, affect, and anxiety. Extending the duration of the experiment in order to be able to examine the impact of a number of repeated walks seems a promising avenue for future research.

Conclusion

This study examined the impacts of walking in urban settings that varied in the amount of vegetation they contained on attention, affect, and anxiety. The results showed that walking in green urban is associated with better attentional functioning and affect and less anxiety level compared to barren urban. The results of this study emphasize the context and location of walking and state that where we walk has a significant impact on our mental health.

References:

Abbina, Srinivas, Lily E. Takeuchi, Parambath Anilkumar, Kai Yu, Jason C. Rogalski, Rajesh A. Shenoi, Iren Constantinescu, and Jayachandran N. Kizhakkedathu. 2020. "Blood Circulation of Soft Nanomaterials Is Governed by Dynamic Remodeling of Protein Opsonins at Nano-Biointerface." *Nature Communications* 11(1):1–12.

Ashdown-Franks, Garcia, Joseph Firth, Rebekah Carney, Andre F. Carvalho, Mats Hallgren, Ai Koyanagi, Simon Rosenbaum, Felipe B. Schuch, Lee Smith, and Marco Solmi. 2020. "Exercise as Medicine for Mental and Substance Use Disorders: A Meta-Review of the Benefits for Neuropsychiatric and Cognitive Outcomes." *Sports Medicine* 50(1):151–70.

Bang, Kyung-Sook, Insook Lee, Sungjae Kim, Chun Soo Lim, Hee-Kyung Joh, Bum-Jin Park, and Min Kyung Song. 2017. "The Effects of a Campus Forest-Walking Program on Undergraduate and Graduate Students' Physical and Psychological Health." *International Journal of Environmental Research and Public Health* 14(7):728.

Berman, Marc G., John Jonides, and Stephen Kaplan. 2008. "The Cognitive Benefits of Interacting With Nature." *Psychological Science* 19(12):1207–12. doi: 10.1111/j.1467-9280.2008.02225.x.

Bhargava, Deepti, and Hemant Trivedi. 2018. "A Study of Causes of Stress and Stress Management among Youth." *IRA-International Journal of Management & Social Sciences* 11(03):108–17.

Canin, Lisa Hoffman. 1991. “Psychological Restoration among AIDS Caregivers: Maintaining Self-Care.”

Choi, Karmel W., Chia-Yen Chen, Murray B. Stein, Yann C. Klimentidis, Min-Jung Wang, Karestan C. Koenen, and Jordan W. Smoller. 2019. “Assessment of Bidirectional Relationships between Physical Activity and Depression among Adults: A 2-Sample Mendelian Randomization Study.” *JAMA Psychiatry* 76(4):399–408.

Cimprich, B. 1993. “Development of an Intervention to Restore Attention in Cancer Patients.” *Cancer Nursing* 16(2):83–92.

Cimprich, Bernadine, and David L. Ronis. 2003. “An Environmental Intervention to Restore Attention in Women with Newly Diagnosed Breast Cancer.” *Cancer Nursing* 26(4):284–92.

Faber Taylor, Andrea, and Frances E. Kuo. 2009. “Children With Attention Deficits Concentrate Better After Walk in the Park.” *Journal of Attention Disorders* 12(5):402–9. doi: 10.1177/1087054708323000.

Faber Taylor, Andrea, and Frances E. Kuo. 2011. “Could Exposure to Everyday Green Spaces Help Treat ADHD? Evidence from Children’s Play Settings.” *Applied Psychology: Health and Well-Being* 3(3):281–303.

Gabriel, Brendan M., and Juleen R. Zierath. 2017. “The Limits of Exercise Physiology: From Performance to Health.” *Cell Metabolism* 25(5):1000–1011.

Gascon, Mireia, Margarita Triguero-Mas, David Martínez, Payam Dadvand, Joan Forns, Antoni Plasència, and Mark J. Nieuwenhuijsen. 2015. “Mental Health Benefits of Long-Term Exposure to Residential Green and Blue Spaces: A Systematic Review.”

Hamdan, Mohammed Akram. 2018. “Developing a Proposed Training Program Based on Discrete Trial Training (DTT) to Improve the Non-Verbal Communication Skills in Children with Autism Spectrum Disorder (ASD).” *International Journal of Special Education* 33(3):579–91.

Helpguide.org (28 June 2021). The mental health benefits of exercise. (Faber Taylor and Kuo 2011)

Jiang, Bin, Rose Schmillen, and William C. Sullivan. 2019. “How to Waste a Break: Using Portable Electronic Devices Substantially Counteracts Attention Enhancement Effects of Green Spaces.” *Environment and Behavior* 51(9–10):1133–60.

Johansson, Marcus, Terry Hartig, and Henk Staats. 2011. “Psychological Benefits of Walking: Moderation by Company and Outdoor Environment.” *Applied Psychology: Health and Well-Being* 3(3):261–80.

Kaplan, Rachel. 1993. “The Role of Nature in the Context of the Workplace.” *Landscape and Urban Planning* 26(1–4):193–201.

Kawai, Hisashi, Shuichi Obuchi, Yutaka Watanabe, Hirohiko Hirano, Yoshinori Fujiwara, Kazushige Ihara, Hunkyung Kim, Yoshiyuki Kobayashi, Masaaki Mochimaru, and Eiki Tsushima. 2020. “Association between Daily Living Walking Speed and Walking Speed in Laboratory Settings in Healthy Older Adults.” *International Journal of Environmental Research and Public Health* 17(8):2707.

Killgore, William D. Scott. 1998. “The Affect Grid: A Moderately Valid, Nonspecific Measure of Pleasure and Arousal.” *Psychological Reports* 83(2):639–42. doi: 10.2466/pr0.1998.83.2.639.

Kling, Hannah E., Kevin J. Moore, Debi Brannan, and Alberto J. Caban-Martinez. 2021. “Walking Meeting Effects on Productivity and Mood Among White-Collar Workers: Evidence From the Walking Meeting Pilot Study.” *Journal of Occupational and Environmental Medicine* 63(2):e75–79.

Koohsari, Mohammad Javad, Hannah Badland, Suzanne Mavoa, Karen Villanueva, Jacinta Francis, Paula Hooper, Neville Owen, and Billie Giles-Corti. 2018. “Are Public Open Space Attributes Associated with Walking and Depression?” *Cities* 74:119–25.

Kuo, Frances E., and William C. Sullivan. 2001. “Environment and Crime in the Inner City: Does Vegetation Reduce Crime?” *Environment and Behavior* 33(3):343–67.

Li, Dongying, Brian Deal, Xiaolu Zhou, Marcus Slavenas, and William C. Sullivan. 2018. “Moving beyond the Neighborhood: Daily Exposure to Nature and Adolescents’ Mood.” *Landscape and Urban Planning* 173:33–43.

Li, Dongying, and William C. Sullivan. 2016. “Impact of Views to School Landscapes on Recovery from Stress and Mental Fatigue.” *Landscape and Urban Planning* 148:149–58. doi: 10.1016/j.landurbplan.2015.12.015.

Lin, Feng-Lien, Mei-Ling Yeh, Yeur-Hur Lai, Kuan-Chia Lin, Chong-Jen Yu, and Jung-San Chang. 2019. “Two-month Breathing-based Walking Improves Anxiety, Depression, Dyspnoea and Quality of Life in Chronic Obstructive Pulmonary Disease: A Randomised Controlled Study." *Journal of Clinical Nursing* 28(19–20):3632–40.

Miles, Irene, William C. Sullivan, and Frances E. Kuo. 1998. "Ecological Restoration Volunteers: The Benefits of Participation." *Urban Ecosystems* 2(1):27–41.

Nazarahari, Milad, and Hossein Rouhani. 2018. "Detection of Daily Postures and Walking Modalities Using a Single Chest-Mounted Tri-Axial Accelerometer." *Medical Engineering & Physics* 57:75–81.

Neale, Chris, Peter Aspinall, Jenny Roe, Sara Tilley, Panagiotis Mavros, Steve Cinderby, Richard Coyne, Neil Thin, and Catharine Ward Thompson. 2019. "The Impact of Walking in Different Urban Environments on Brain Activity in Older People." *Cities & Health* 1–13. doi: 10.1080/23748834.2019.1619893.

Noval, Laura J., and Günter K. Stahl. 2017. "Accounting for Proscriptive and Prescriptive Morality in the Workplace: The Double-Edged Sword Effect of Mood on Managerial Ethical Decision Making." *Journal of Business Ethics* 142(3):589–602.

Olafsdottir, Gunnthora, Paul Cloke, André Schulz, Zoé Van Dyck, Thor Eysteinsson, Björg Thorleifsdottir, and Claus Vögele. 2020. "Health Benefits of Walking in Nature: A Randomized Controlled Study under Conditions of Real-Life Stress." *Environment and Behavior* 52(3):248–74.

Prasad, Kriti, Sara Poplau, Roger Brown, Steven Yale, Ellie Grossman, Anita B. Varkey, Eric Williams, Hannah Neprash, and Mark Linzer. 2020. "Time Pressure during Primary Care Office Visits: A Prospective Evaluation of Data from the Healthy Work Place Study." *Journal of General Internal Medicine* 35(2):465–72.

Russell, James A., Anna Weiss, and Gerald A. Mendelsohn. 1989. "Affect Grid: A Single-Item Scale of Pleasure and Arousal." *Journal of Personality and Social Psychology* 57(3):493–502. doi: 10.1037/0022-3514.57.3.493.

Seaward, Brian Luke. 2017. *Managing Stress*. Jones & Bartlett Learning.

Sesti, A. M. 2000. "State Trait Anxiety Inventory (STAI) in Medication Clinical Trials." *Quality of Life Newsletter* 15–16.

Singleton, Patrick A. 2019. "Walking (and Cycling) to Well-Being: Modal and Other Determinants of Subjective Well-Being during the Commute." *Travel Behaviour and Society* 16:249–61.

Spielberger, Charles D. 1989. “State-Trait Anxiety Inventory: Bibliography . Palo Alto.”

Sullivan, William C., and Rachel Kaplan. 2016. “Nature! Small Steps That Can Make a Big Difference.” *HERD: Health Environments Research & Design Journal* 9(2):6–10. doi: 10.1177/1937586715623664.

Wang, Guangning, Menglu Zhao, Fuguo Yang, Ling Jie Cheng, and Ying Lau. 2020. “Game-Based Brain Training for Improving Cognitive Function in Community-Dwelling Older Adults: A Systematic Review and Meta-Regression.” *Archives of Gerontology and Geriatrics* 104260.

Wells, N. (2000). At home with nature: effects of ‘green- ness’ on children’s cognitive functioning. Environment & Behavior, 32, 775^795.

CHAPTER 4: FMRI ASSESSMENT OF BRAIN FUNCTIONAL CONNECTIVITY AT RESTING STATE: IMPLICATIONS FOR ATTENTION RESTORATION THEORY

Introduction

Cities impact human health and well-being in a variety of ways. On the one hand, they support economic development, innovation, and provide a wide variety of services; on the other hand, they can be sources of stress, crime, disease transmission, and, at times, a detriment to our mental health.

One aspect of the relationship between the built environment and mental health that has received considerable scrutiny concerns the impact of physical settings on our capacity to pay attention. Considerable evidence demonstrates that the design of places in which we live, work and play, impact the extent to which we experience mental fatigue and recover from that fatigue. We do not know, however, the neurological mechanism that underlies the relationship between exposure to various environments and attentional performance.

We explore this issue through a randomized experimental design that compares the changes in brain functional connectivity using functional Magnetic Resonance Imaging (fMRI) and analyzes the differences in green versus barren treatments. We ask, "To what extent does exposure to green versus barren urban settings impact brain functional connectivity – a measure of attentional capacity – when ascertained at resting state?"

Nature and Attention

There has been an increased interest to undertake research on the impacts of exposure to urban nature on human and well-being (Bin Jiang et al. 2016; Frumkin et al. 2017; Sullivan et al. 2014). One of the most influential works in this area of scholarship is Kaplan and Kaplan's

Attention Restoration Theory (ART) (Kaplan 1995). Many studies have demonstrated the attention improvement that result from spending time in nature – even urban nature (Berto 2005; Korpela et al. 2008; Taylor, Kuo, and Sullivan 2001).

One of the most important benefits of exposure to nature for humans is that it promotes our capability to pay attention by speeding recovery from mental fatigue. Attention Restoration Theory (ART) argues that exposure to nature, whether by being in it or simply looking at it, can be restorative.

ART recognizes we have two modes of attending to things: top-down and bottom-up. Top-down attention allows us to focus of our attention by making the object of our attention more salient while, at the same time, dampening down, or making less salient, competing distractions, stimuli, or thoughts. Top-down attention (sometimes called directed attention or paying attention) takes effort and fatigues with extended use. This mode of attention requires an individual's effort in managing their thoughts and emotions.

Top-down attention unconsciously reduces the intensity of possible distractions both from the environments and within our minds. The neural mechanisms that reduce the intensity of distractions takes effort. Like our muscles, our capacity to diminish the intensity of distracting stimuli and focus our attention fatigues over time. As the mechanisms that support top-down attention fatigues our capacity to function effectively also diminishes. The state of attentional fatigue is often referred to as mental fatigue (Kaplan and Berman 2010). The most common costs of mental fatigue are reductions in functioning due to a reduced ability to focus, diminished capacity to monitor our behavior and inhibit impulses, and an increase in irritability (Sullivan 2015). After becoming mentally fatigued, we need to restore our directed attention to be productive again. Attention Restoration Theory posits that being in nature or looking at nature scenes is restorative for our top-down attention.

Contrary to top-down attention, bottom-up attention is guided by external stimuli and thus is not goal-driven. Bottom-up attention (sometimes called involuntary attention) is automatic and takes no effort. Therefore, it does not fatigue. For example, when we are sitting by a campfire, we do not decide to pay attention to the fire. Involuntarily, we will be absorbed by the fire without even being aware of it (Sullivan 2015). The duality between top-down and bottom-up attention is highlighted when we experience external stimuli. Natural stimuli, moving water, wildlife, vegetation engages our bottom-up attention, allowing us to rest the brain mechanism that underlie and support top-down attention. By engaging in bottom-up attention, we restore our top-down attentional capacity and can once again perform mentally demanding tasks (Sullivan 2015).

Natural environments help in recovery from mental fatigue because they require considerably less directed attention that urban environments require. Many natural settings provide soft fascination (features of the environment that capture attention effortlessly), in which our directed attention is less triggered. Nature is more likely to provoke the bottom-up stimulation that requires little directed attention (Marc G. Berman, John Jonides, and Stephen Kaplan 2008).

Attentional functioning and brain network connectivity

While attention restoration theory has been widely supported by empirical research (Cimprich and Ronis 2003; Li and Sullivan 2016; Marc G. Berman et al. 2008) we do not have a clear understanding of the neurological pathways that support the process of attention restoration. Despite the impact that ART has had in Environmental Psychology, the neurological underpinnings of the theory remain a mystery.

One way to uncover the mechanism by which exposure to nature impacts attentional functioning is to observe the associated brain activity of individuals before and after contact with nature. Functional MRI (fMRI) is a powerful tool used to investigate neural functioning, especially changes in brain activity in response to a task or stimulus (Fox et al. 2005) . fMRI uses blood oxygenation level-dependent imaging to infer changes in neural activity from hemodynamic changes—changes related to blood flow (Hermans et al. 2014). Thousands of published studies have used fMRI to explore functional neuroanatomy in response to mental tasks.

Previous studies investigating the impact of exposure to nature on brain activation have focused on describing the location of neural activity in human brains (Bratman et al. 2015; Kim et al. 2010; Martínez-Soto et al. 2013; Tang et al. 2017). Mapping the areas of the brain that respond to nature has been a crucial first step in our understanding of the neural pathways that might underlie ART. What is missing is our understanding of the extent to which various areas of our brains connect in response to exposure to nature and how these connections relate to attention restoration.

In this study, we use resting state fMRI to identify functional connectivity among the Default Mode Network (DMN), Front-parietal Control Network (FPCN), Cingulo-Opercular Control Network (COCN), Salience Network (SN) and Visual Network (VN). We examined the fMRI results before and after participants were exposed to green and barren urban environments. This method provides a more complete picture of brain functionality regarding attentional function and the attentional network than simply looking at network connectivity while individuals are looking at images of green or barren landscapes.

To the best of our knowledge, there has been only one published study that examined the impact of exposure to nature on brain functional connectivity (Kühn et al. 2021). That study found that functional connectivity was significantly higher when participants saw photographs of natural rather than build environments. The connectivity was higher in neural circuits consisting of the dorsal attention network (DAN) and the ventral attention network (VAN). It was also higher in circuits consisting of the DAN and the default mode network (DMN) and between the DMN and Somatomotor circuits. The Kuhn study makes a significant contribution to literature and opens the door to the question that we ask here. Can we observe changes in the strength of these network ties while observing differences in self-reported attention measures to validate the findings from the Kunh et, al study?

My purpose here is to understand the differences that exposure to real urban settings that are more or less green have on whole-brain functional connectivity and especially connectivity associated with attention. I pursue two research questions:

I address these questions through a randomized experiment that included (A) baseline measures of attentional functioning and fMRI assessments of participants brains at resting-state, (B) a green or barren nature intervention, and (C), post intervention measure that were identical to the baseline measures.

1.To what extent does exposure to urban nature impact participants attentional functioning?

2.To what extent does this exposure impact brain connectivity changes as measured at resting state?

Methods

Participants selection

Because this research was carried out at National Taiwan University (NTU) by a University of Illinois Urbana-Champaign (UIUC) PhD student under the supervision of professors from NTU and UIUC, approval for the methods study was obtained from the National Taiwan University Research Committee (REC) and then the University of Illinois at Urbana-Champaign Institutional Review (IRB) (protocol # 18772) in 2018. Eligible participants were chosen among the doctors and nurses who were working full time at National Taiwan University (NTU) Hospital. Inclusion criteria were that potential participants be healthy, with no history of mental health diagnoses or brain injury such as concussion. Written informed consent was obtained from each participant, and participants were paid 3,000 NTD which was roughly equivalent to US $100.

Forty-eight individuals participated in this study. In order to encourage participation in our experiment we advertised the study by hanging posters around the NTU Hospital. We also received permission from the hospital administration to send an announcement, inviting participation in our study, via email to employees at the NTU Hospital. We provided an online platform where people could read a brief summary of the experiment, and a description of the requirements for participation. Individuals could register as participants using email. We contacted each person who registered to assess the extent to which they met our inclusion criteria and, if they did, to schedule the fMRI sessions. We scheduled each participant for two fMRI sessions exactly one week apart. For example, if a participant was scheduled for a Monday, they were also scheduled for the following Monday. We followed this procedure for all participants.

Site selection

We chose two sites for the walking experiment. Both were in close proximity to the NTU Hospital and thus easily accessible, large enough to walk in for 40 minutes, and were in the urban context of Taipei City (see Figure 15). We selected DAAN Forest Park for the urban green treatment and a commercial and residential neighborhood that contained very little vegetation for the barren treatment (see Figures 16 and 17). Before the experiment, members of our research team examined the physical settings and confirmed that they were both comfortable to walk in for 40 minutes.

Participants were randomly assigned to one of the two treatment groups (green or barren). Each participant walked in the assigned environment three times for 40 minutes during a one-week period for a total of 120 minutes. During the walk, participants were not allowed to use their phone or listen to music. They were required to walk during the daytime, but not on Saturday or Sunday afternoons (as the settings were more crowded during those times). During the walk, participants wore a GPS-sensor that allowed us to verify the exact path and duration of their walk.

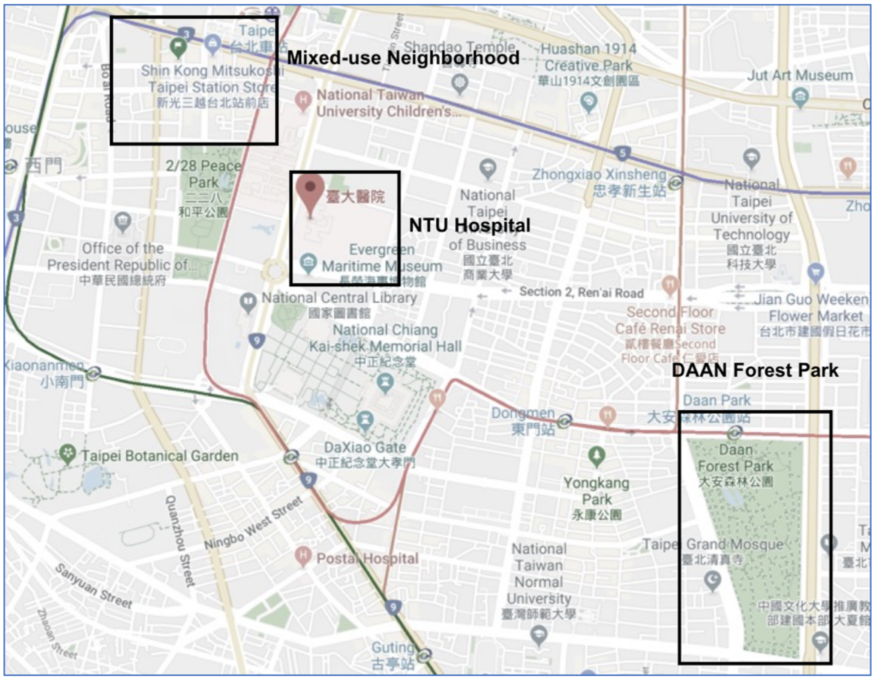


Figure 15. Relative locations of the NTU hospital, DAAN forest park, the mixed-use neighborhood settings in this study.

Figure 16. Example images from DAAN forest park in Taipei, Taiwan associated with the Green treatment.

Figure 17. Example images from the mixed-use neighborhood in Taipei, Taiwan associated with the Barren treatment.

Procedure

We conducted an experiment consisting of three phases. These three phases took place during one week. We have *pre* and *post* phases and an intervention between pre and post. Each participant was randomly assigned to walk in one of the assigned settings three times and each time 40 minutes during one week. See Figure 18 for a description of the overall procedure.

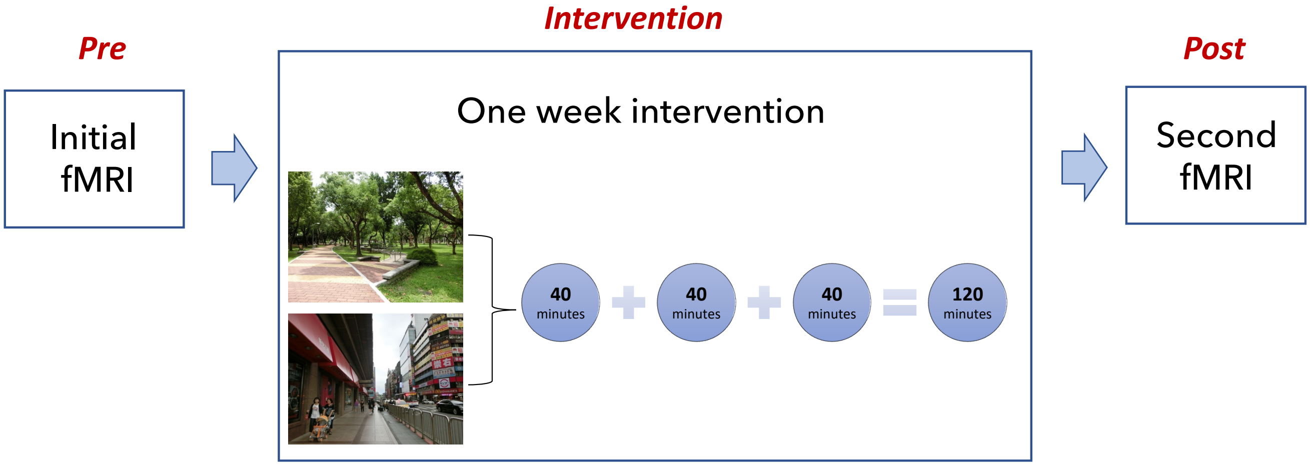


Figure 18. Experiment procedure: initial fMRI scan (pre), followed by a one week intervention that included three forty-minute walks in either a green or barren setting, followed by the second fMRI scan (post).

Initial fMRI

To conduct the fMRI scan, we used a 3 Tesla Magnetic Resonance Imaging (MRI) machine at the NTU Social Sciences Laboratory. The first time that participants came to the fMRI lab, we described the benefits and risks associated with this experiment; after addressing any questions participants had, and when they felt comfortable that they understood the procedures, risks and benefits, participants signed a consent form. We then prepared participants for the first fMRI scan. This scan included a 10-minute structural scan and a 10-minutes functional scan.

We used a head coil to stabilize participant's heads since even slight movement during the experiment could cause an error in the image scanning of the brain and result in data that were unusable. Participants wore noise-cancelling earbuds to subdue the sound created by the fMRI machine and so to be able to listen to our instructions. We also gave participants a safety ball to hold during their scan. If they had any problem or anxiety while inside the fMRI machine, they could squeeze the safety ball to stop the experiment. If a participant did squeeze the ball, we immediately stopped scanning and helped the person exit the machine. This first set of scans took about 20 minutes. After the initial scan, each participant filled out a background questionnaire and the attentional functioning index questionnaire.

After participants completed the two questionnaires, we explained the overall procedure again and handed each individual a small package that included the schedule for the week, the location of the setting to which they were assigned to walk, and a GPS-sensor. The package also included instructions regarding how to use the GPS-sensor and how to export the GPS data to our database.

We provided a map of the setting they were to walk within during the week; however, we asked them not to look at the map while they walked. The purpose of the map was simply to get them familiar with the setting. Participants were not supposed to pay attention to their phone or walk with anybody else. We explained that the purpose was for them to experience the environment. All these rules were also written on the map that we provided for each person. Each participant also needed to have a smartphone for the second phase (walking) of the experiment.

Intervention

For the second phase of the experiment, each participant walked in the urban setting – green or barren – to which they had been randomly assigned. While they walked, they wore a GPS sensor that allowed us to track their walking route, the duration, and time of their walk. Participants were required to walk three times during the week for 40 minutes each time.

Second fMRI

Each participant returned to the fMRI lab one week after their initial scan. This second fMRI procedure began with a 10-minute structural scan followed by a 10-minute functional scan. After finishing the fMRI scanning, participants completed the attention functioning index questionnaire. Finally, we asked two questions about their experience to learn about how participants felt about our experiment. The answers to these questions were transcribed for further analysis. Before participants left the building, they returned the package of materials we gave them during their first visit to the lab, and we paid them their stipend.

Measures

Attention

Participants completed the Attentional Function Index (AFI) questionnaire so that we could assess their perceived effectiveness in conducting daily tasks and activities which require attention. AFI consists of 3 Factors. Factor 1, Effective Action, assess individual's perceived effectiveness in carrying out basic activities in daily living that requires top-down attention. Factor 2, Attentional Lapses, measures perceived difficulties in directing attention in daily tasks. Factor 3, Interpersonal Effectiveness, measures perceived ability to interact in a deliberate manner that depends on attentional or inhibitory control. In general, AFI assesses perceived effectiveness of daily activities that depend on basic cognitive processes related to attention, working memory, and higher-level executive functions.

The AFI has been used in numerous previous studies as a measure general attentional functioning in a person's recent life. AFI has been tested for validity and reliability, and has sensitivity in measuring perceived changes in attention, working memory, and higher-level executive function, besides the deficits in the capacity to direct attention (Cimprich, Visovatti, and Ronis 2011). We used the AFI after the first and second fMRI scans.

Control variables

Even though each participant was randomly assigned to one treatment group, it is impossible to control for individual differences between participants in an experiment that that took place in real-world settings over a period of days. Thus, we asked participants to complete a background questionnaire. We collected data about participant's age, gender, recent physical and mental health, and their daily and weekly physical activities. We also collected data on a variety of potential confounding variables such as socio-economic information, automobile access, recent challenging events in participant's lives, and any chronic mental disorders they might have experienced.

Neuroimaging data acquisition

fMRI scanning was conducted on a 3Tesla Siemens PRISMA scanner. After the localizer, T1-weighted (TR = 2000 ms; TE = 2.3 ms; flip angle = 8°; FOV = 240 × 240 mm2 ; matrix size = 256 × 256 mm2 ; slice thickness = 0.94 mm; volume size = 192 slices; voxel size = 0.9 × 0.9 × 0.9 mm3) and T2-weighted (TR = 9530 ms; TE = 103 ms; flip angle = 150°; FOV = 192× 192 mm2 ; matrix size = 288 × 384mm2; slice thickness = 3 mm; volume size = 45 slices; voxel size = 0.50 × 0.50 × 3 mm3) anatomical images were acquired. EPI images were acquired axially for a 10-min resting state scan (TR = 3000 ms; TE = 30 ms; flip angle = 90°; FOV = 192× 192 mm2; matrix size = 64 × 64 mm2 ; slice thickness = 3 mm; volume size = 45 slices; voxel size = 3 × 3 × 3 mm3; number of volumes = 200). Dummy scans (4 TRs) were acquired for signal stabilization and were dropped at the scanner.

Neuroimaging data preparation

Images collected at both timepoints (i.e., pre- and post-intervention) were first despiked using 3dDespike in AFNI (Cox 1996), before being submitted to preprocessing in SPM12.

Longitudinal Registration toolbox (Ashburner and Ridgway 2013)was used, whereby bias-corrected, intra-subject average images were first created for each subject, which were then segmented to obtain intra-subject tissue maps. The DARTEL image registration toolbox (Ashburner 2007) was then used to generate a group template to be used for normalization.

Finally, the DARTEL transformations were applied to normalize all images to MNI space on an isotropic 3mm grid, combined with transformations estimated at previous steps in a single interpolation. Smoothing was done using a FWHM kernel of 6 mm, but unsmoothed images were used for functional connectivity analysis.

Given the research focus on the changes in the resting-state scans in the brain at rest as a result of the intervention, we employed functional connectivity analysis as our main methodical strategy.

Instead of imposing a temporal structure through trial-by-trial modeling in the case of conventional task-based fMRI analysis, we conducted resting state functional connectivity analysis. Resting-state fMRI (rsfMRI) is an application of functional magnetic resonance imaging (fMRI) that we use in brain mapping to evaluate regional interactions that occur in a resting state, when no task is being performed. This way, we measure the intrinsic functional infrastructure of the brain at rest, by examining the temporal correlations between the timeseries of blood-oxygen-level-dependent (BOLD) signals extracted from a priori “nodes”, each comprised of a group of contiguous voxels. Since the signals are assumed to reflect spontaneous fluctuations in the brain, it is thus of crucial importance in the functional connectivity analysis to make sure that the signals submitted to analysis were indeed intrinsically generated, by filtering out known elements of noise as much as possible.

Therefore, after preprocessing, further steps were taken to denoise the data, including (1) demeaning and detrending, (2) nuisance regressions, which used a combination of motion regressors (6 realignment parameters and their first-order derivatives), aCompCor (Behzadi et al. 2007) regressors (signals from top 5 principal components generated from each of the tissue maps of white matter and cortico-spinal fluids, along with their first-order derivatives), and main session effects (computed by convolving runs with a canonical hemodynamic response function to further remove simple task-related co-activation confounds and artifacts related to the ramping up of the scanner), and (3) a simultaneous bandpass filter of [0.009, 0.08] (Hallquist, Hwang, and Luna 2013). To further reduce the impact of scan-to-scan motion, framewise displacement (FD) was calculated for each session, and volumes with FD>=0.5mm were entered into the nuisance regression for censoring (Power et al. 2014). Denoising steps were implemented in the CONN toolbox (v. 18b;(Whitfield-Gabrieli and Nieto-Castanon 2012)), and subsequent visual inspections assured that the denoising procedure was effective.

Network-based functional connectivity analysis

Network-based statistics (NBS; (Zalesky, Fornito, and Bullmore 2010)) were employed to measure large-scale changes across the brain as a result of the interventions. In contrast to link-based functional connectivity analysis, in which mass-univariate hypothesis testing is performed at each pairwise connection between nodes in order to answer questions concerning *particular links*, NBS seeks to identify *connected components* (i.e., groups of interconnected nodes, or subnetworks) associated with effects or contrasts of interest. In orther words, NBS is best suited for the current study, which examines changes in the global network characteristics associated with the interventions, rather than narrowing in on a specific hypothesis concerning specific connections between particular regions of interest. NBS determines whether the strength and pattern of connections between these regions is significantly different from chance. To rephrase it, NBS tests whether the topology of the connections is significantly different, rather than the strength of the connections themselves (Zalesky et al., 2010). The pattern of the networks can then be used to classify different groups or cognitive states (Rubinov & Sporns, 2010).

Network-based statistics (NBS) were calculated for both the Green and Barren groups. First, correlation measures are calculated between each region of interest (ROI) in the atlas provided with the CONN toolbox (i.e., the Harvard-Oxford atlas provided by FSL: https://fsl.fmrib.ox.ac.uk/fsl). Network ROIs were also provided with the CONN toolbox, defined by CONN's ICA analyses of the HCP dataset (Whitfield-Gabrieli & Nieto-Castanon, 2012). These correlation values are then standardized as Z-values and entered into the NBS toolbox.

To this end, nodes of interest were first selected (radius = 5mm; total number of nodes = 146) from an established and widely used resting state functional network atlas (Brett et al. 2002; Power et al. 2011), consisting of nodes from the default mode network (DMN), the fronto-parietal task control network (FPCN), the cingulo-opercular task control network (COCN), the salience network (SN), and the visual network (VN), given the particular interest in attention and cognitive control mechanisms. Next, BOLD timeseries were extracted from unsmoothed data, averaged across all voxels within each node. Pairwise connectivity values were calculated as the Pearson correlation coefficients (r) between nodes, subsequently transformed into Fisher's Z scores. This resulted in a 146x146 connectivity matrix for each participant at each timepoint.

To identify changes in global functional connectivity patterns between groups as a result of the intervention, individual connectivity matrices were submitted to the NBS toolbox (Zalesky et al. 2010) for statistical testing in a general linear model. Time was modeled as a within-subject factor, Interaction Effect as a between-subject factor; individual within-subject means were modeled as well to account for repeated measurements.

The critical contrast of interest was the Interaction Effect [Green (Post-Pre) - Barren (Post-Pre)], tested for each tail. In the NBS procedure, a primary threshold of $p<0.005$ (corresponding to $t>2.687$), was first applied to each connection in the 146x146 network in the mass-univariate test. This process yielded a sparse matrix of supra-threshold connections that provided a basis for the extent-based testing to identify significant components (a component is a set of supra-threshold connections for which a path can be found between any two nodes) that survived an extent threshold of $p<0.05$ empirically determined by permutation testing (number of permutations = 5000). This procedure has been shown to ensure sufficient control over family-wise error rate while providing gains in statistical power (Zalesky et al. 2010). The identified network components were visualized with the BrainNet Viewer (Xia, Wang, and He 2013) and the NeuroMArVL (Dawyer et al. 2015). With the exception of AFNI, the rest of the analyses were performed in MATLAB 2019a.

Results

The results of the experiment is presented in two sections. First, we examine the impact the walking interventions – walking in either barren or green spaces – had on attentional functioning (AFI). Second, we examine the extent to which the walking interventions are related to functional connectivity between brain regions involved in cognitive control and visual processing.

Behavioral test results

Were there differences among the pre-intervention and post-intervention of attention scores for participants who were randomly assigned to the two treatments? To answer this question, we conducted an independent t-test examining differences in AFI scores between the two treatments before and after the intervention. We found no significant differences in the before-intervention AFI scores between the two treatments ($t(46) = -0.23$ $p = 0.82$). We found significant differences in the after-intervention AFI scores between the two treatments ($t(46) = 2.25$ $p = 0.03$). The bar graph in Figure 19 shows the comparison between pre and post AFI scores for the two treatments.

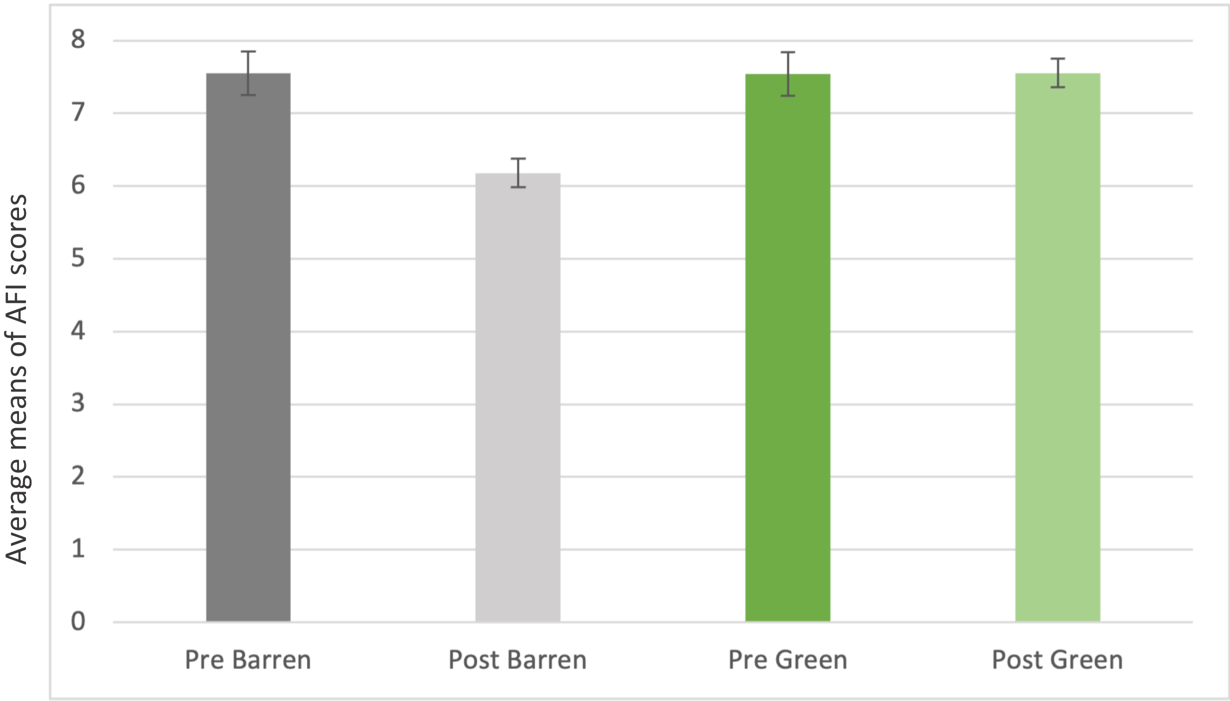


Figure 19. Comparing pre and post AFI scores in two treatments (Means and SE).

To what extent did the treatments impact participants attentional functioning? To answer this question, we conducted a repeated-measures ANOVA with the treatments as the between-subject factor and time (pre and post) as the within-subject factor and found significant interaction effect. The two treatment conditions differed in terms of their impact on participants attentional functioning ($F(1, 46) = 7.37$, $p = 0.009$, $\eta^2 = 0.138$). The attentional functioning improvement of walking intervention differed based on the treatment ($F(1, 46) = 6.70$, $p = 0.01$, $\eta^2 = 0.127$).

In summary, there is no decrease in attentional functioning of the green treatment. In contrast, there was a significant decrease in attentional functioning for participants randomly assigned to walk with the barren setting.

Functional Connectivity

To what extent did the treatments impact changes in brain connectivity as measured at resting state? To address this question, we calculated differences in functional connectivity between measures (paired t-test) made from participants assigned to the green and barren treatment using the NBS statistical toolbox. Differences in functional connectivity were observed in a set of connections calculated from the functional parcellation derived from the Harvard-Oxford atlas (FSL, 31 July 2021) (see Figure 20A, 20B, 21D, and 21E) (threshold = 2.6, $p<.05$). We found greater between-network connectivity among the set of five networks associated with the green treatment and less between-network connectivity associated with the barren treatment.

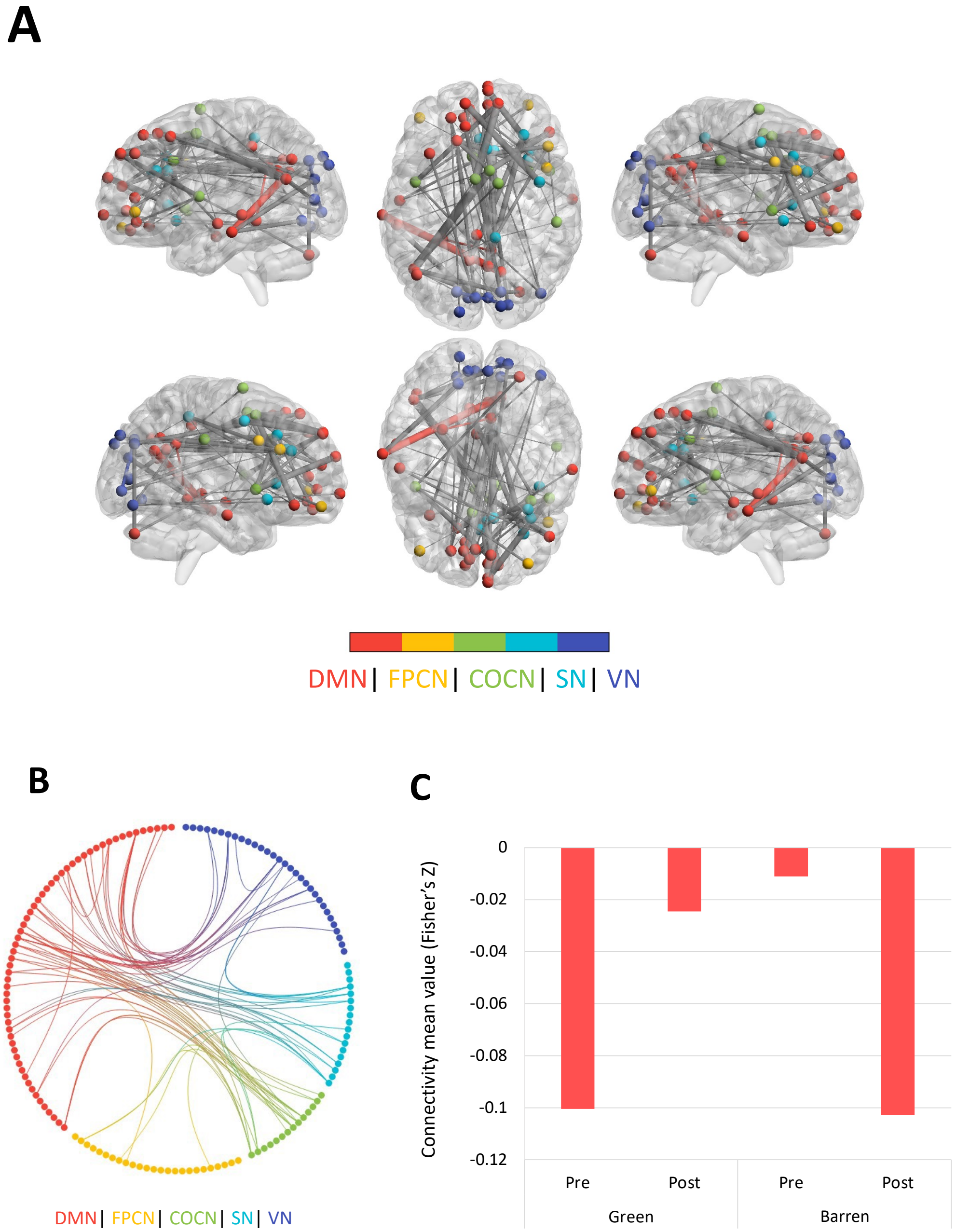


Figure 20. A: The network components and connections identified that show higher connectivity after the green treatment. B: Connectogram derived from network-based statistical (NBS) analysis of participants in the green treatment showing functional connections within and between the network components shown identified in Figure 20A. The important thing to note here is the large number of connections between nodes for the green treatment compared to the relatively few connections between nodes for the barren treatment (Figure 21E). C: Comparison of pre and post connectivity values as measured by Z-transformed Pearson correlation coefficients, in the network components identified in Figure 20A. Notice the increase in the mean connectivity value from the initial scan (Pre) to the scan following the green treatment (Post). Notice too, the opposite pattern that resulted from the barren treatment.

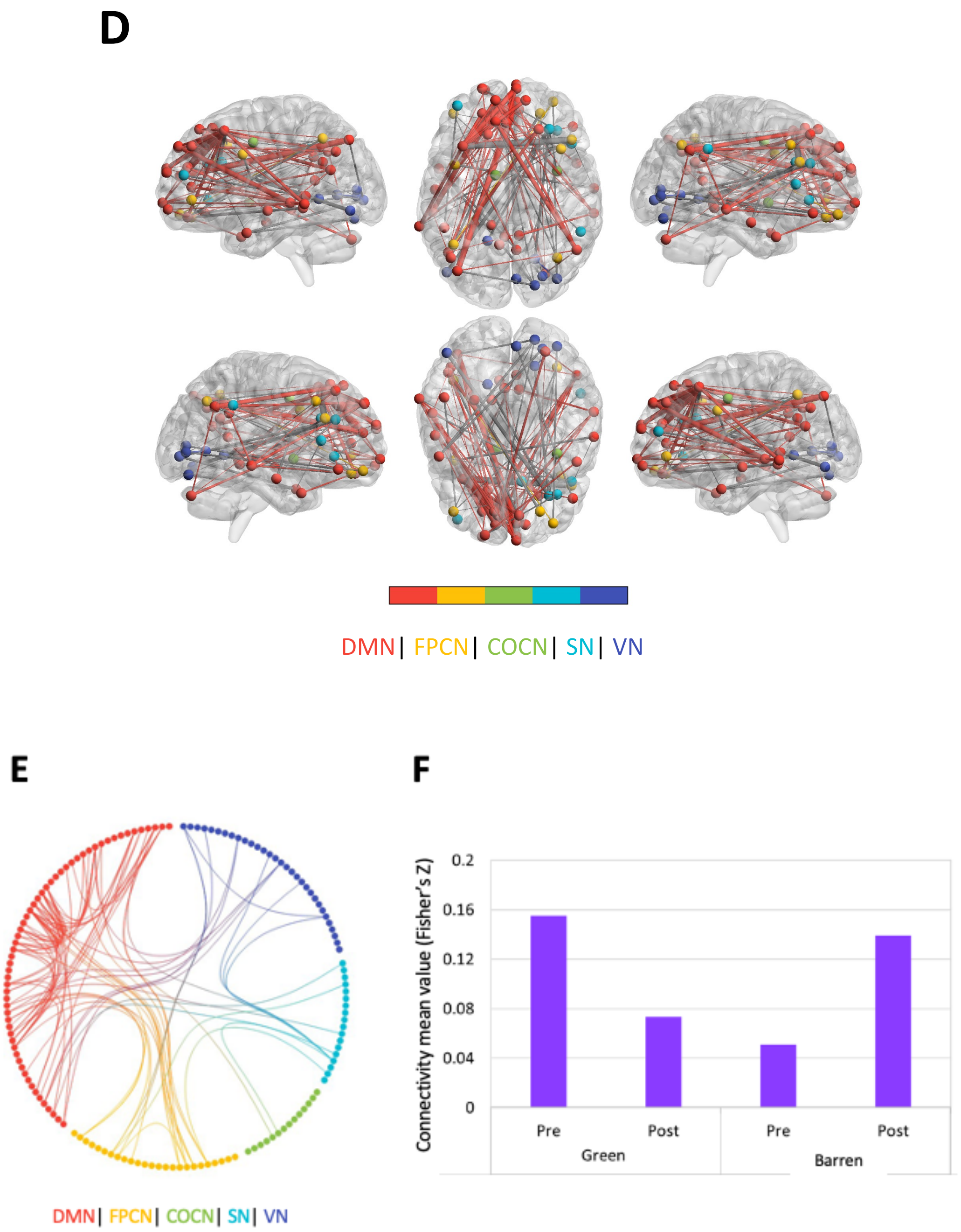


Figure 21. D: The network components and connections identified that show higher connectivity after the barren treatment. E: Connectogram derived from network-based statistical (NBS) analysis of participants in the barren treatment showing functional connections. F: Comparison of pre and post connectivity values as measured by Z-transformed Pearson correlation coefficients, in the network components identified in Figure 21D. Notice the decrease in the mean connectivity value from the initial scan (Pre) to the scan following the green treatment (Post). Notice too, the opposite pattern that resulted from the barren treatment. In A and D, the visualization was created using Brain Data viewer (https://immersive.erc.monash.edu/neuromarvl/). The lines connecting two nodes represent the connections between the corresponding nodes within the two brain networks. The width of the lines correspond to the strength of connectivity between nodes. Different networks are denoted by different colors. Within-network lines are depicted in the color of the network, whereas between-network lines are grayed out (here only DMN showed an increase of within-network changes).

Discussion

In this study, 48 healthy adults were randomly assigned to walk three times for 40 minutes in either a green or barren urban setting during a one-week period. Participants in the green group maintained about the same attentional functioning scores after the one-week treatment, but these scores significantly decreased for participants in the barren group. Findings from the fMRI portion of this study revealed that the functional network connectivity at rest was significantly higher for participants in the green treatment group compared to the barren group. These findings are consistent with and supportive, the proposals made in Attention Restoration Theory (Kaplan 1995).

The findings establish a causal relationship: walking in urban nature produced better attentional functioning and greater functional connectivity measured at resting state than did comparable walks in urban settings that had little vegetation. In the paragraphs that follow, I describe the major contributions of this research, discuss their implications, and propose future research opportunities.

Contributions

This study presents the results of a ground-breaking experiment using resting-state fMRI to analyze the impact of walking in green or barren urban settings on the neural activity in participant's brains. The first contribution here is that walking in settings that differ in terms of the density of vegetation has implications for the functional connectivity of our brains at rest – and thus for our capacity to pay attention. We found that functional network connectivity at rest was significantly higher after participants who walked in green urban settings than those who walked in barren urban settings.

These results support our hypothesis that network connectivity among brain regions increase as a result of the green treatment compared to the barren treatment while network connectivity decreased in the barren group after the treatment. A contrast of the networks between the green and barren groups showed higher connectivity within the DMN for the Green group, and especially between the frontal and temporal-occipital regions (Figure 20A).

The findings were consistent across the Default Mode Network (DMN), Front-parietal Control Network (FPCN), Cingulo-Opercular Control Network (COCN), Salience Network (SN) and Visual Network (VN) connections. It is worth noting that all of these were positively correlated. That is, each of these networks responded in a similar fashion when participants walked in green or barren urban settings.

The results are furthermore consistent with other work demonstrating increased connectivity between the DMN and Somatomotor networks in response to natural as opposed to simulated environments (Kühn et al. 2021)

The fMRI results were consistent with the scores obtained through the Attentional Functioning Index (AFI). The AFI results validate the resting-state findings by providing empirical evidence that attentional performance was significantly better after the green treatment compared to the barren treatment The combined fMRI and AFI results demonstrate that attentional functioning was maintained for participants in the green treatment but that it decreased for participants in barren treatment. These findings contribute to our understanding because they are the first to suggest that exposure to urban nature improves attentional functioning by triggering functional connectivity.

By demonstrating the impact of green and barren treatments on neural functional connectivity rather than simply the amount of neural activity observed, the findings here build on and extend our understanding from previous studies that compared only brain activation in response to urban environments with and without vegetation (Kühn et al. 2021; Tang et al. 2017).

The second contribution of this study is to link changes in cognitive performance to changes in resting state functional connectivity as a result of exposure to settings that vary in the density of vegetation. In making this link between cognitive performance and neural connectivity, the findings enhance our understanding by showing that what might contribute to better attentional functioning may not be the increased neural activity associated with exposure to green spaces but the increased neural connectivity that such exposure causes.

Previous studies have primarily employed comparisons between task-related brain activity among participants randomly assigned to different treatments (e.g., Kuhn et al, 2021). In this study, however, we employed components of with and between subject designs to make comparisons between the treatment groups. We investigated changes in resting-state neural connectivity pre and post treatment – that is, before and after the walking treatments.

Although previous studies have investigated brain regions that are activated when participants are exposed to nature, no previous studies have examined attentional functioning as it relates to neural activity as an outgrowth of exposures to urban settings that vary in their concentration of nature.

A final contribution of the replication of previous work demonstrating that exposure to urban nature restores attentional functioning (Hartig et al. 2003; Marc G. Berman et al. 2008; Tennessen and Cimprich 1995). The AFI results provide contribute to a growing body of evidence in support for Attention Restoration Theory and especially the theory's predictions that exposure to urban forests and urban parks speed recovery from mental fatigue.

Implications

This research stands at the intersection of landscape architecture, neuroscience, urban design, and health, and it has the potential to contribute substantively to each of those disciplinary fields. The evidence presented here points to environmental factors that designers, planners, and policy makers can manipulate in order to enhance healthcare workers' mental health and well-being with a focus on improving their attentional functioning.

And while our study focused on healthcare workers, it is logical to assume that similar benefits would accrue to anyone – including patients, visitors, and staff – seeking to rest the brain. Therefore, one implication of the results reported above is that city planners, landscape architects, and hospital administrators should create nature rich settings adjacent to or immediately proximate to hospitals. Given the mounting evidence about the health and wellness benefits of urban nature, we should make every effort to create cities with 30% tree canopy (Jiang, Chang, and Sullivan 2014). Such efforts will likely have considerable benefits for knowledge workers of all sorts.

Second, although the availability of green settings near work places is important, it is not enough. The findings here suggest that knowledge workers should actively seek (and be encouraged to seek) opportunities to walk in nature three or more times per week. Employers might create programs that enable and perhaps reward people for walking in nearby green spaces. Or they might partner with parks departments to design walking breaks and circuits during the workday. Such activities are likely to reduce the levels of mental fatigue that many knowledge workers experience on a daily basis.

Finally, the results of this study suggest that community members might join together to add green trees and plants to urban settings that would otherwise lack such environmental amenities. Community members can support the mental well-being of local residents by uniting to create a more urban nature (Kaplan, 1995). For instance, a community might mobilize to develop street trees, gardens, parks and green landscapes within neighborhood, on school properties, and along roadsides. Such actions will extend the benefits of urban nature more broadly and evenly across our cities. I hope the evidence presented in this dissertation will persuade policy makers and planners to insist that trees be planted in every new development, in every renovation, and at every doorstep.

Limitations and Future Research

To assess the effect of exposure to urban nature on attentional functioning and functional connectivity, we carefully controlled a number of factors in the design of this research. We limited the demographic variability of the participants in this study to individuals who were professional healthcare workers. Thus, the external validity or generalizability, of the findings is limited to professionals who have time to walk during the work day (at lunch, for instance), and who are likely to have considerable demands on their attention during the workday. It is not clear the extent to which these findings generalize to people who have fewer demands on their attention (e.g., security guards in a safe setting) and yet one can imagine that office workers and teachers might similarly benefit from exposure to nature. Future research could confirm this hypothesis.

The ecological validity of this work is worth considering. On the one hand, we exposed participants to real physical environments and all the complexity and richness that comes with being in real places. Conducting this research in real places, rather than laboratory or simulated settings, is a strength of this study and increased the external validity of this work.

On the other hand, although we controlled some environmental conditions associated with the research design (e.g., access to the setting, proximity to work, amount of vegetation) the fact that this experiment took place in the field – rather than in a typically tightly controlled fMRI laboratory – means that some extraneous variables *may* have impacted the findings. We could not, for instance, measure participants' social interactions during their walks, their physical activities in addition to the experimental walks, the extent to which they had immersive experiences during the week, or their exposure to green space outside the context of this experiment. Thus, this week-long field experiment has limitations related to internal validity. Consequently, it is important that we see this work as a first step from which more research will follow. Future research should attempt to replicate and extend this study – doing so will help address any concerns about internal validity.

Future research might collect more physiological and behavioral data during exposure to different environments in order to aid interpretation of the observed functional connectivity differences, and to link potential changes in behavioral and other cognitive changes.

We wonder about the duration of this experiment. Participants in this study engaged in three walks of about 40 minutes each over the course of one week. Would a longer treatment phase of one or two months produce findings similar to what we reported here? A longer the treatment time might allow us to document even greater changes in resting state brain connectivity. Future work might include both a longer treatment phase and additional fMRI resting state measurements.

Finally, we were not able to measure the length of time that it takes for the brain function to be restored. Is a 40-minute walk sufficient? Would a shorter walk have the same effect? To our knowledge, no research has established the time-course of attention recovery associated with urban nature. This is a promising area for future research.

Conclusion

This study examined the impacts of walking three times for 40-minutes each time on participants who were randomly assigned to walk in urban settings that varied in the amount of vegetation they contained. We found that participants in the green group maintained about the same attentional functioning scores after the one-week treatment, but that these scores significantly decreased for participants in the barren group. Findings from the fMRI portion of this study revealed that functional network connectivity at rest was significantly higher for participants in the green treatment group compared to the barren group.

These results support our hypothesis that network connectivity among brain regions increase as a result of the green treatment compared to the barren treatment while network connectivity decreased in the barren group after the treatment.

By demonstrating the impact of green and barren treatments on neural functional connectivity rather than simply the amount of neural activity observed, the findings here build on and extend our understanding from previous studies that compared only brain activation in response to urban environments with and without vegetation (Kühn et al. 2021; Tang et al. 2017). The findings enhance our understanding by showing that what might contribute to better attentional functioning may not be the increased neural activity associated with exposure to green spaces but the increased neural connectivity that such exposure causes.

The findings from this study take a fundamental steps forward in our efforts to understand the mechanisms through which, and the extent to which, urban urban settings that vary in their density of vegetation affects human brain functionality. This is no trivial matter given that 55% of world population now reside in cities. Thus, the findings here could contribute to the development of healthier, more supportive cities.

This study is an important step forward for the growing number of landscape researchers, environmental psychologists, neuroscientists, policy makers, and others concerned with understanding the effects of landscape on human mental health and well-being. It opens the way for greater collaboration among them.

References

Ashburner, John. 2007. "A Fast Diffeomorphic Image Registration Algorithm." *Neuroimage* 38(1):95–113. Ashburner, John, and Gerard R. Ridgway. 2013. "Symmetric Diffeomorphic Modeling of Longitudinal Structural MRI." *Frontiers in Neuroscience* 6:197.

Behzadi, Yashar, Khaled Restom, Joy Liau, and Thomas T. Liu. 2007. "A Component Based Noise Correction Method (CompCor) for BOLD and Perfusion Based FMRI." *Neuroimage* 37(1):90–101.

Berto, Rita. 2005. "Exposure to Restorative Environments Helps Restore Attentional Capacity." *Journal of Environmental Psychology* 25(3):249–59. doi: 10.1016/j.jenvp.2005.07.001.

Bin Jiang, Dongying Li, Linda Larsen, and William C. Sullivan. 2016. "A Dose-Response Curve Describing the Relationship Between Urban Tree Cover Density and Self-Reported Stress Recovery." *Environment and Behavior* 48(4):607–29. doi: 10.1177/0013916514552321.

Bratman, Gregory N., J. Paul Hamilton, Kevin S. Hahn, Gretchen C. Daily, and James J. Gross. 2015. "Nature Experience Reduces Rumination and Subgenual Prefrontal Cortex Activation." *Proceedings of the National Academy of Sciences* 112(28):8567–72. doi: 10.1073/pnas.1510459112.

Brett, Matthew, Jean-Luc Anton, Romain Valabregue, and Jean-Baptiste Poline. 2002. “Region of Interest Analysis Using an SPM Toolbox.” P. 497 in Vol. 16. Sendai, Japan.

Cimprich, Bernadine, and David L. Ronis. 2003. “An Environmental Intervention to Restore Attention in Women with Newly Diagnosed Breast Cancer.” *Cancer Nursing* 26(4):284–92.

Cimprich, Bernadine, Moira Visovatti, and David L. Ronis. 2011. “The Attentional Function Index—a Self-Report Cognitive Measure.” *Psycho-Oncology* 20(2):194–202. doi: 10.1002/pon.1729.

Cox, Robert W. 1996. “AFNI: Software for Analysis and Visualization of Functional Magnetic Resonance Neuroimages.” *Computers and Biomedical Research* 29(3):162–73.

Fox, Michael D., Abraham Z. Snyder, Justin L. Vincent, Maurizio Corbetta, David C. Van Essen, and Marcus E. Raichle. 2005. “The Human Brain Is Intrinsically Organized into Dynamic, Anticorrelated Functional Networks.” *Proceedings of the National Academy of Sciences* 102(27):9673–78.

Frumkin, Howard, Gregory N. Bratman, Sara Jo Breslow, Bobby Cochran, Peter H. Kahn Jr, Joshua J. Lawler, Phillip S. Levin, Pooja S. Tandon, Usha Varanasi, Kathleen L. Wolf, and Spencer A. Wood. 2017. “Nature Contact and Human Health: A Research Agenda.” *Environmental Health Perspectives* 125(7). doi: 10.1289/EHP1663.

FSL. (2021, July 31). FMRIB Software Library v6.0. https://fsl.fmrib.ox.ac.uk/fsl/fslwiki

Hallquist, Michael N., Kai Hwang, and Beatriz Luna. 2013. “The Nuisance of Nuisance Regression: Spectral Misspecification in a Common Approach to Resting-State FMRI Preprocessing Reintroduces Noise and Obscures Functional Connectivity.” *Neuroimage* 82:208–25.

Hartig, Terry, Gary W. Evans, Larry D. Jamner, Deborah S. Davis, and Tommy Gärling. 2003. “Tracking Restoration in Natural and Urban Field Settings.” *Journal of Environmental Psychology* 23(2):109–23. doi: 10.1016/S0272-4944(02)00109-3.

Hermans, Erno J., Marloes JAG Henckens, Marian Joëls, and Guillén Fernández. 2014. “Dynamic Adaptation of Large-Scale Brain Networks in Response to Acute Stressors.” *Trends in Neurosciences* 37(6):304–14.

Jiang, Bin, Chun-Yen Chang, and William C. Sullivan. 2014. "A Dose of Nature: Tree Cover, Stress Reduction, and Gender Differences." *Landscape and Urban Planning* 132(Supplement C):26–36. doi: 10.1016/j.landurbplan.2014.08.005.

Kaplan, Stephen. 1995. "The Restorative Benefits of Nature: Toward an Integrative Framework." *Journal of Environmental Psychology* 15(3):169–82. doi: 10.1016/0272-4944(95)90001-2.

Kaplan, Stephen, and Marc G. Berman. 2010. "Directed Attention as a Common Resource for Executive Functioning and Self-Regulation." *Perspectives on Psychological Science* 5(1):43–57. doi: 10.1177/1745691609356784.

Kim, Tae-Hoon, Gwang-Woo Jeong, Han-Su Baek, Gwang-Won Kim, Thirunavukkarasu Sundaram, Heoung-Keun Kang, Seung-Won Lee, Hyung-Joong Kim, and Jin-Kyu Song. 2010. "Human Brain Activation in Response to Visual Stimulation with Rural and Urban Scenery Pictures: A Functional Magnetic Resonance Imaging Study." *The Science of the Total Environment* 408(12):2600–2607. doi: 10.1016/j.scitotenv.2010.02.025.

Korpela, Kalevi M., Matti Ylén, Liisa Tyrväinen, and Harri Silvennoinen. 2008. "Determinants of Restorative Experiences in Everyday Favorite Places." *Health & Place* 14(4):636–52.

Kriegeskorte, Nikolaus, W. Kyle Simmons, Patrick SF Bellgowan, and Chris I. Baker. 2009. "Circular Analysis in Systems Neuroscience: The Dangers of Double Dipping." *Nature Neuroscience* 12(5):535–40.

Kühn, Simone, Caroline Garcia Forlim, Anja Lender, Janina Wirtz, and Jürgen Gallinat. 2021. "Brain Functional Connectivity Differs When Viewing Pictures from Natural and Built Environments Using FMRI Resting State Analysis." *Scientific Reports* 11(1):1–10.

Li, Dongying, and William C. Sullivan. 2016. "Impact of Views to School Landscapes on Recovery from Stress and Mental Fatigue." *Landscape and Urban Planning* 148:149–58. doi: 10.1016/j.landurbplan.2015.12.015.

Marc G. Berman, John Jonides, and Stephen Kaplan. 2008. "The Cognitive Benefits of Interacting With Nature." *Psychological Science* 19(12):1207–12. doi: 10.1111/j.1467-9280.2008.02225.x.

Martínez-Soto, Joel, Leopoldo Gonzales-Santos, Erick Pasaye, and Fernando A. Barrios. 2013. "Exploration of Neural Correlates of Restorative Environment Exposure through

Functional Magnetic Resonance." *Intelligent Buildings International* 5(sup1):10–28. doi: 10.1080/17508975.2013.807765.

Power, Jonathan D., Alexander L. Cohen, Steven M. Nelson, Gagan S. Wig, Kelly Anne Barnes, Jessica A. Church, Alecia C. Vogel, Timothy O. Laumann, Fran M. Miezin, and Bradley L. Schlaggar. 2011. "Functional Network Organization of the Human Brain." *Neuron* 72(4):665–78.

Power, Jonathan D., Anish Mitra, Timothy O. Laumann, Abraham Z. Snyder, and Bradley L. Schlaggar. 2014. "Steven E. 1224 Petersen." *Methods to Detect, Characterize, and Remove Motion Artifact in Resting State Fmri. NeuroImage* 84:320–41.

Sullivan, WC. 2015. "In Search of a Clear Head." *Fostering Reasonableness: Supportive Environments for Bringing out Our Best* 54–69.

Sullivan, William C., Howard Frumkin, Richard J. Jackson, and Chun-Yen Chang. 2014. "Gaia Meets Asclepius: Creating Healthy Places." *Landscape and Urban Planning* 127:182–84. doi: 10.1016/j.landurbplan.2014.03.005.

Tang, I.-Chun, Yu-Ping Tsai, Ying-Ju Lin, Jyh-Horng Chen, Chao-Hsien Hsieh, Shih-Han Hung, William C. Sullivan, Hsing-Fen Tang, and Chun-Yen Chang. 2017. "Using Functional Magnetic Resonance Imaging (FMRI) to Analyze Brain Region Activity When Viewing Landscapes." *Landscape and Urban Planning* 162:137–44. doi: 10.1016/j.landurbplan.2017.02.007.

Taylor, Andrea Faber, Frances E. Kuo, and William C. Sullivan. 2001. "Coping with Add: The Surprising Connection to Green Play Settings." *Environment and Behavior* 33(1):54–77. doi: 10.1177/00139160121972864.

Tennessen, Carolyn M., and Bernadine Cimprich. 1995. "Views to Nature: Effects on Attention." *Journal of Environmental Psychology* 15(1):77–85. doi: 10.1016/0272-4944(95)90016-0.

Whitfield-Gabrieli, Susan, and Alfonso Nieto-Castanon. 2012. "Conn: A Functional Connectivity Toolbox for Correlated and Anticorrelated Brain Networks." *Brain Connectivity* 2(3):125–41.

Xia, Mingrui, Jinhui Wang, and Yong He. 2013. "BrainNet Viewer: A Network Visualization Tool for Human Brain Connectomics." *PloS One* 8(7):e68910.

Zalesky, Andrew, Alex Fornito, and Edward T. Bullmore. 2010. "Network-Based Statistic: Identifying Differences in Brain Networks." *Neuroimage* 53(4):1197–1207.

CHAPTER 5: CONCLUSION

Summary

The purpose of this dissertation research was to examine the impact of exposure to green and barren urban settings on the psychological and neurological well-being of people in experimental and observational settings. Exposure to nature has been proposed as a technique for restoring attentional capacities, promoting positive affect and reducing anxiety.

Although previous research has made it clear that looking at, being in or walking through green urban spaces reduces mental fatigue (Li & Sullivan 2016; Sullivan & I, 2021), the neural pathways through which these impacts occur and the other associated psychological implications that underlie their reactions have been entirely unclear. The lack of this information has been an important problem because it limits our ability to design urban settings that support healthy neurological functioning for a growing population of humans who live in cities. It also means that we have fewer science-based arguments for increasing the demand for services of landscape architects.

To fill this gap in our understanding, I first conducted an experiment – the Walking study – designed to assess the impact of walking in green and barren environments on human attention, affect and anxiety. The most important finding from this experiment was that walking in green urban places was consistently associated with improved psychological well-being. One of the strengths of this experiments was its ecologically valid. Participants, who were employees at the National Taiwan University Hospital in Taipei, walked in either green or barren settings close to the hospital. That is, this was a field experiment in which the complexities of the real world were encountered by the participants in the study.

My second step in filling the gap in our knowledge was to conduct an experiment designed to document the impact of walking in urban settings that vary in the density of nature on neurological changes in the brains of participants. The resting-state fMRI study employed a randomized controlled experiment and demonstrated that exposure to green urban settings caused significant changes in brain network connectivity that support recovery from attentional fatigue. The strength of this connectivity was significantly reduced in participants who were randomly assigned to the barren treatment.

In this concluding chapter, I summarize the major findings of the walking study and the resting-state fMRI study (Chapter 3 and 4) and discuss the contributions of each study to theory, as well as the methodological significance of this work. I conclude with a discussion of future research directions in creating healthy places for people.

Main Findings

Through two studies, this work investigated the extent to which walking in green and barren urban environments impacts people's psychological and neurological well-being. In the walking study, I examined the extent to which the greenness of an urban walk impacted participant’s attentional functioning, affect, and anxiety as a result of taking a walk during their workday.” In findings that are consistent with the results from Chapter 4, (the resting-state fMRI study), this work revealed a positive, causal relationship between the greenness of the walk and psychological well-being.

In the resting-state fMRI study, I asked: To what extent does exposure to green versus barren urban settings impact brain functional connectivity – a measure of attentional capacity – when ascertained at resting state?” To answer this question, I recruited 48 healthy adults and then randomly assigned them to walk three times for 40 minutes in either a green or barren urban setting during a one-week period. After walking in either green or barren environments, participants in the green group maintained about the same attentional scores, while the attentional scores for the barren group significantly decreased. Findings from this resting-state fMRI study revealed that the functional network connectivity at rest was significantly higher for participants in the green treatment group compared to the barren-urban group.

These findings are consistent with, and supportive of, the proposals made in ART (Kaplan 1995). The findings establish a causal relationship: Walking in urban nature produced greater functional connectivity measured at resting state, and better attentional functioning than did comparable walks in an urban setting that had little vegetation.

Contributions

The most important contribution of this dissertation is to understand the effects of walking in different urban settings on humans’ neurological and psychological well-being. By combining a randomized experimental study utilizing functional MRI in a controlled setting where the cause and effect was isolated from other background factors with an intervention that took place in real urban settings, the results of this dissertation broadened our understanding of the relationships between environmental settings and human health.

The primary contribution of the resting-state fMRI study is to have established a causal relationship between walking in green or barren urban settings and participant’s observed neural activity that underlies our capacity to pay attention. This study is the first to demonstrate that walking in greener settings causes higher levels of neural functional connectivity when measured at rest. This is direct evidence that walking in green settings improves the neural pathways that support our capacity to pay attention.

The Walking study (Chapter 3) found a significant association between walking in varying levels of nature and health outcomes. The findings demonstrate that walking in areas with higher concentrations of vegetation induces significant psychological benefits. The Walking study presented evidence that extends or understanding of the benefits that grow from exposure to urban nature to a critical population – healthcare workers. The findings demonstrate that the cognitive and emotional benefits associated with exposure to green settings can impact healthcare workers exposed to nature during their workday.

The resting-state fMRI study (chapter 4) observed neural correlates of attention restoration, which provides evidence to explain the proposed mechanism of ART. Walking in a green urban setting increases the functional connectivity across the Default Mode Network (DMN), Front-parietal Control Network (FPCN), Cingulo-Opercular Control Network (COCN), Salience Network (SN), and Visual Network (VN) connections. To the best of my knowledge, only one previous study has examined the impact of exposure to nature on the neural foundations of attention (Jiang, 2020); my work builds on Jiang's findings by demonstrating the rich set of underlying neural connections that support attention.

The functional connectivity results are consistent with previous findings demonstrating, in a range of settings and through a wide variety of participants, that exposure to urban nature has positive impacts on attentional test scores. The attention test results I report in Chapter 3 provide additional empirical evidence to support Attention Restoration Theory, while the functional connectivity observed in real-time validates the mechanism through which neural activity supports attention.

Practical implications

Several policies and design implications can be derived from this dissertation. Here, I briefly discuss the implications for urban nature design and planning strategies in cities and programmatic interventions to promote public health.

Green spaces close to healthcare facilities and work places

One of the most important implications of this research is to call our attention to the importance of having green settings available for people to walk with easy access to work places. Still, easy access might not be enough. Although the findings suggest that knowledge workers can obtain measurable benefits from walking in nature three or more times per week, these benefits will not accrue to workers who are not permitted a break long enough to be able to seek out green spaces. Based on the findings here, employers should create programs that encourage people to walk in nearby green spaces. Alternatively, they might partner with parks departments to design walking breaks during the workday. Such activities are likely to reduce the levels of mental fatigue that many knowledge workers experience on a daily basis.

Small interventions to green barren landscape

The findings I have presented here suggest that designers and planners should pay special attention to barren landscapes. Adding even a small amount of vegetation to a barren landscape will yield significant health benefits. One promising approach is to introduce small-scale interventions in the urban environment, such as pocket parks and walking trails with vegetation that can transform an existing urban space and bring nature's benefits to places where people walk every day. Many people do not have access to green spaces near their workplaces that are safe and easily accessible. Planners, designers, developers, and policy makers should insist on creating green settings within and around all manner of work places.

Recommendations for the location of walking

While much research needs to be conducted regarding the impact of urban nature on mental health and well-being, we found that walking in greener settings will likely produce benefits for our ability to pay attention, our experience of positive affect, and a reduced likelihood of experiencing high levels of anxiety. The findings presented here suggest that people should be proactive in seeking green settings in which to walk.

Recommendations for policy makers

Taken together, the findings reported here demonstrate the versatile role of urban nature in supporting people's mental health. Urban nature can promote attentional functioning in addition to contributing to a variety of ecological benefits. With increasing empirical evidence regarding the effectiveness of greenness in urban settings, leaders of healthcare organizations should consider the findings here as they design the landscapes around their healthcare centers and design policies around breaks that workers can take during the workday. I hope the evidence presented in this dissertation will persuade policy makers and planners to insist that trees be planted in every new development, in every renovation, and at every doorstep.

Future research

Future research can build upon this study in multiple ways. Questions regarding the duration and frequency of exposure to nature is a critical gap in our knowledge. How long do people need to be exposed to nature to gain cognitive and emotional benefits? And at what frequency should these exposures occur?

Future studies might explore questions regarding duration and frequency in part by replicating this work. We relied on the published literature to determine the duration of the walks that we asked participants to take. After reviewing a variety of studies (Cimprich and Ronis 2003; Johansson, Hartig, and Staats 2011; Olafsdottir et al. 2020), we designed our walking interventions to last about 40 minutes, and we asked participants to walk three times during a one-week period. Would a more extended treatment phase of one or two months produce findings similar to what we reported here? A longer treatment time might allow us to document even more significant changes in resting-state brain connectivity or it might reveal that as the brain becomes accustomed to nature, the "nature effect" wears off. However, that is unlikely. In addition to a longer treatment time, adding or subtracting the frequency of exposure time within a week or within a month might also shed new light on the amount of time necessary to produce and maintain the benefits of exposure to nature. Future work might include both a more extended treatment phase, greater frequency of walking (or other exposure to nature), and additional fMRI resting-state measurements – perhaps at the midpoint of longer studies.

To our knowledge, no research has established the time-course of attention recovery associated with exposure to urban nature. This is a promising area for future research.

Future research might also take advantage of emerging technologies such as Google Earth Engine and perhaps machine learning to develop modeling techniques for the health benefits of landscapes. Currently, we are able to model a range of landscape impacts on water purification and flood protection. Future research should explore the extent to which we can produce reliable models the mental health benefits of various landscape.

In this study, we focused on the impact of the density of the vegetation along walking routes and the impact of this vegetation density on attention, affect, and anxiety over the course of one week. We found the same pattern of results for each outcome variable after each of the three walks. Although attention and affect scores for participants in the green walk treatment did not increase significantly from the first walk to the second or third walk, the trends in the data hint at the possibility that a fourth and fifth walk might produce more significant impacts on attention, affect, and anxiety. Extending the duration of the experiment in order to be able to examine the impact of a number of repeated walks seems a promising avenue for future research.

Conclusion

This research is among the first studies using resting-state fMRI to examine the relationship between walking in different environments and attentional functioning. This study is significant because it helps us understand the relationship between urban green nature and human well- being at a neurological level. I have found significant differences in recovery from mental fatigue and brain connectivity between the two treatment groups that illuminate the way that Attention Restoration Theory works and provides a broader field for future research.

The studies presented here strongly suggest that walking in green settings can promote psychological well-being. These findings add to our theoretical understanding and highlight the vast potential of using planning and design measures to enhance people’s environments.

Finally, I hope that the knowledge provided in this dissertation can help bring more awareness to the human health benefits of being exposed to nature, particularly for those people living in urban environments. The results reinforce previous findings that barren settings and green settings have systematically different impacts on humans with greener settings, on the whole, providing supporting health and more barren settings undermining health. The findings of this dissertation can be used to pave the way for targeting urban nature interventions to moderate the neurological and psychological outcomes of typical urban environments in support of mental health.

Still, there is much to learn and indeed it seems we have just opened the door to our understanding of the extent to which varying levels of vegetation in urban settings can impact human neurological functionality in ways that promote health and well-being. To this end, this dissertation took a small but important step forward. For a growing number of landscape researchers, environmental psychologists, neuroscientists, policy makers, and others concerned with understanding the effects of landscape on human mental health and well-being, we need to learn a great deal more. My guess is that the gaps in our knowledge will best be filled by collaboration among these various disciplines. I am hopeful that this environmental neuroscience approach will lead to fruitful discoveries and improvements in the design of the built environment. I am excited to play a role in this effort.

References

Cimprich, Bernadine, and David L. Ronis. 2003. "An Environmental Intervention to Restore Attention in Women with Newly Diagnosed Breast Cancer." *Cancer Nursing* 26(4):284–92.

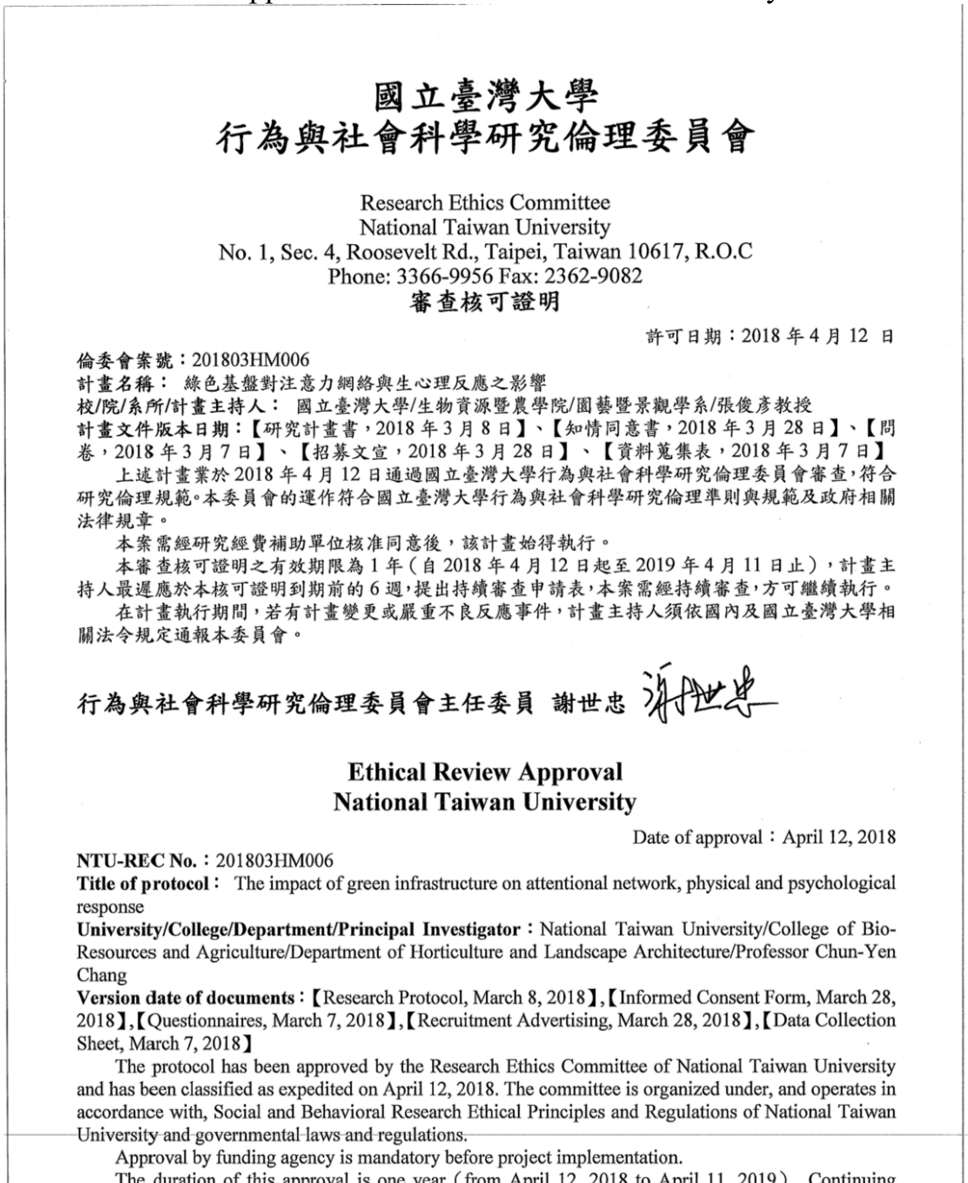
Johansson, Marcus, Terry Hartig, and Henk Staats. 2011. “Psychological Benefits of Walking: Moderation by Company and Outdoor Environment.” *Applied Psychology: Health and Well-Being* 3(3):261–80.

Kaplan, Stephen. 1995. “The Restorative Benefits of Nature: Toward an Integrative Framework.” *Journal of Environmental Psychology* 15(3):169–82. doi: 10.1016/0272-4944(95)90001-2.

Olafsdottir, Gunnthora, Paul Cloke, André Schulz, Zoé Van Dyck, Thor Eysteinsson, Björg Thorleifsdottir, and Claus Vögele. 2020. “Health Benefits of Walking in Nature: A Randomized Controlled Study under Conditions of Real-Life Stress.” *Environment and Behavior* 52(3):248–74.

APPENDIX A: INSTRUMENT OF THE SURVEY AND EXPERIMENT

Research Ethics Committee Approval from National Taiwan University



國立臺灣大學
行為與社會科學研究倫理委員會

Research Ethics Committee
National Taiwan University
No. 1, Sec. 4, Roosevelt Rd., Taipei, Taiwan 10617, R.O.C
Phone: 3366-9956 Fax: 2362-9082

審查核可證明

許可日期：2018 年 4 月 12 日

倫委會案號：201803HM006
計畫名稱： 綠色基盤對注意力網絡與生心理反應之影響
校/院/系所/計畫主持人： 國立臺灣大學/生物資源暨農學院/園藝暨景觀學系/張俊彥教授
計畫文件版本日期：【研究計畫書，2018 年 3 月 8 日】、【知情同意書，2018 年 3 月 28 日】、【問卷，2018 年 3 月 7 日】、【招募文宣，2018 年 3 月 28 日】、【資料蒐集表，2018 年 3 月 7 日】

上述計畫業於 2018 年 4 月 12 日通過國立臺灣大學行為與社會科學研究倫理委員會審查，符合研究倫理規範。本委員會的運作符合國立臺灣大學行為與社會科學研究倫理準則與規範及政府相關法律規章。

本案需經研究經費補助單位核准同意後，該計畫始得執行。

本審查核可證明之有效期限為 1 年（自 2018 年 4 月 12 日起至 2019 年 4 月 11 日止），計畫主持人最遲應於本核可證明到期前的 6 週，提出持續審查申請表，本案需經持續審查，方可繼續執行。

在計畫執行期間，若有計畫變更或嚴重不良反應事件，計畫主持人須依國內及國立臺灣大學相關法令規定通報本委員會。

行為與社會科學研究倫理委員會主任委員 謝世忠

Ethical Review Approval
National Taiwan University

Date of approval：April 12, 2018

NTU-REC No.：201803HM006
Title of protocol： The impact of green infrastructure on attentional network, physical and psychological response
University/College/Department/Principal Investigator：National Taiwan University/College of Bio-Resources and Agriculture/Department of Horticulture and Landscape Architecture/Professor Chun-Yen Chang
Version date of documents：【Research Protocol, March 8, 2018】,【Informed Consent Form, March 28, 2018】,【Questionnaires, March 7, 2018】,【Recruitment Advertising, March 28, 2018】,【Data Collection Sheet, March 7, 2018】

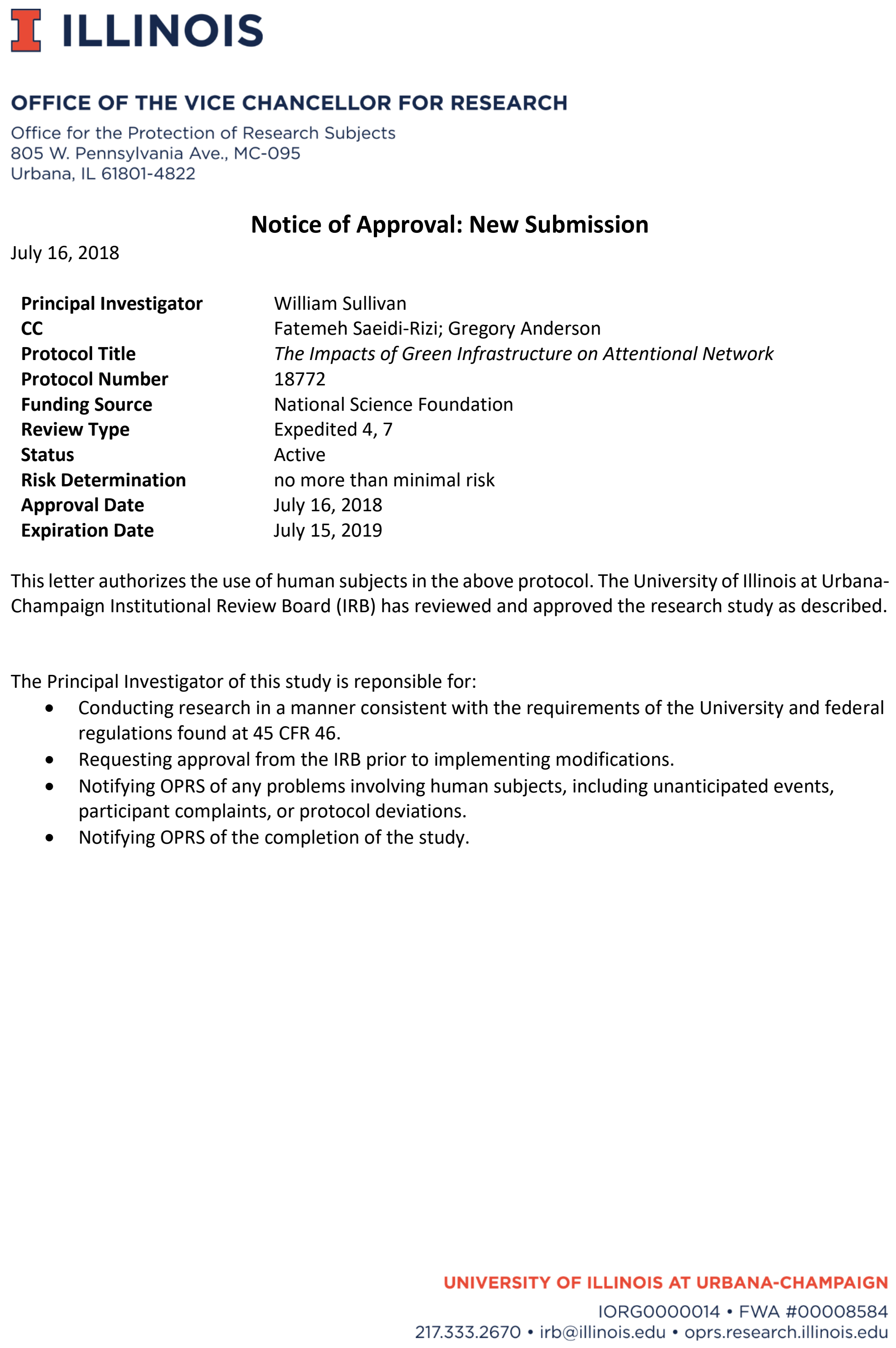
The protocol has been approved by the Research Ethics Committee of National Taiwan University and has been classified as expedited on April 12, 2018. The committee is organized under, and operates in accordance with, Social and Behavioral Research Ethical Principles and Regulations of National Taiwan University and governmental laws and regulations.

Approval by funding agency is mandatory before project implementation.

The duration of this approval is one year（from April 12, 2018 to April 11, 2019）. Continuing Review Application should be submitted to Research Ethics Committee no later than six weeks before current approval expired. The investigator is required to report protocol amendment and Serious Adverse Events in accordance with the National Taiwan University and governmental laws and regulations.

Chairperson Shih-chung Hsieh
Research Ethics Committee

Institutional Review Board Approval from UIUC



ILLINOIS

OFFICE OF THE VICE CHANCELLOR FOR RESEARCH

Office for the Protection of Research Subjects
805 W. Pennsylvania Ave., MC-095
Urbana, IL 61801-4822

Notice of Approval: New Submission

July 16, 2018

Principal Investigator	William Sullivan
CC	Fatemeh Saeidi-Rizi; Gregory Anderson
Protocol Title	*The Impacts of Green Infrastructure on Attentional Network*
Protocol Number	18772
Funding Source	National Science Foundation
Review Type	Expedited 4, 7
Status	Active
Risk Determination	no more than minimal risk
Approval Date	July 16, 2018
Expiration Date	July 15, 2019

This letter authorizes the use of human subjects in the above protocol. The University of Illinois at Urbana-Champaign Institutional Review Board (IRB) has reviewed and approved the research study as described.

The Principal Investigator of this study is reponsible for:

- Conducting research in a manner consistent with the requirements of the University and federal regulations found at 45 CFR 46.
- Requesting approval from the IRB prior to implementing modifications.
- Notifying OPRS of any problems involving human subjects, including unanticipated events, participant complaints, or protocol deviations.
- Notifying OPRS of the completion of the study.

UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
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The Attentional Functioning Index (AFI)

I. At this time, how well do you feel you are functioning in each of the areas below?
(Place a mark through the line at whatever point best describes how you are doing in each area at present.)

1. Getting started on activities (tasks, jobs) you intend to do.
   Not at all ____Extremely well
2. Following through on your plans
   Not at all ____Extremely well
3. Doing things that take time and effort.
   Not at all ____Extremely well
4. Making your mind up about things.
   Not at all ____Extremely well
5. Keeping your mind on what you are doing.
   Not at all ____Extremely well
6. Remembering to do all the things you started out to do.
   Not at all ____Extremely well
7. Keeping your mind on what others are saying.
   Not at all ____Extremely well
8. Keeping yourself from saying or doing things you did not want to say or do
   Not at all ____Extremely well
9. Being patient with others.
   Not at all ____Extremely well

II. At this time, how would you rate yourself on:

1. How hard you find it to concentrate on details.
   Not at all ____A great deal
2. How often you make mistakes on what you are doing.
   Not at all ____A great deal
3. Forgetting to do important things.
   Not at all ____A great deal
4. Getting easily annoyed or irritated.
   Not at all ____A great deal

State Trait Anxiety Inventory

Read each statement and select the appropriate response to indicate how you feel right now, that is, at this very moment. There are no right or wrong answers. Do notspend too much time on any one statement but give the answer which seems to describe your present feelings best.

1	**2**	**3**	**4**
Not at all	**A little**	**Somewhat**	**Very Much So**

1. I feel calm	1	2	3	4
2. I feel secure	1	2	3	4
3. I feel tense	1	2	3	4
4. I feel strained	1	2	3	4
5. I feel at ease	1	2	3	4
6. I feel upset	1	2	3	4
7. I am presently worrying over possible misfortunes	1	2	3	4
8. I feel satisfied	1	2	3	4
9. I feel frightened	1	2	3	4
10. I feel uncomfortable	1	2	3	4
11. I feel self confident	1	2	3	4
12. I feel nervous	1	2	3	4
13. I feel jittery	1	2	3	4
14. I feel indecisive	1	2	3	4
15. I am relaxed	1	2	3	4
16. I feel content	1	2	3	4
17. I am worried	1	2	3	4
18. I feel confused	1	2	3	4
19. I feel steady	1	2	3	4
20. I feel pleasant	1	2	3	4