

ACCESS TO NATURE AND ADOLESCENTS' PSYCHOLOGICAL WELL-BEING

BY

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DISSERTATION

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## Abstract

Previous research has demonstrated positive associations between the greenness of high school landscapes and school-wide academic performance. We do not know, however, if green landscapes cause better performance or if the association between the two is a product of self-selection. If there is a causal relationship, the pathways through which green school landscapes affect student performance remain unclear.

Furthermore, evidence regarding exposure to nature and adolescents' everyday stress in ecologically valid settings is lacking. We do not know, for example, whether adolescents who hang out in greener places – compared to their peers who hang out in less green places – during their daily activities experience less stress or better moods. Lack of this knowledge prevents landscape architects from making informed design and management decisions that help create places where children thrive. In addition, methods that can capture adolescents' travel patterns and actual interactions with their environments are needed in health research.

To address these issues, this dissertation includes a review of the current literature and two empirical studies: the Window View study and the Nature Tracking study. In the Window View study, I hypothesize that views to green landscapes help students recover from mental fatigue and stress. To test these hypotheses, I conducted an experiment with 94 high school students at five high schools. Participants were randomly assigned to three kinds of classrooms: 1) without windows, 2) with windows that opened onto a built space, 3) with windows that opened on to a green space. Participants engaged in typical classroom activities followed by a break in the classroom to which they were assigned. I measured participants attentional functioning using a standard battery of test and their physiological stress using a Biofeedback device. Results demonstrate that classroom views to green landscapes cause significantly better performance on tests of attention and increase student's recovery from stressful experiences. A lack of mediation effect demonstrates that attention restoration and stress recovery are two distinct processes. Implications for school site selection, design and renovation are discussed.

In the Nature Tracking study, I hypothesize that the density of daily exposure of green landscapes is positively associated with adolescents' moods. I proposed an approach that combines GPS tracking and Google Street View image processing to capture the concentration of nature in adolescents' everyday environments and examined its relationship with their mood. A total of 155 participants wore a GPS device for four days and completed an online survey every evening in which they recorded their activities and moods. Results suggest that higher concentrations of nature are associated with less mood disturbance on a daily basis, even after controlling for intra- and inter-individual characteristics. This relationship did not vary by population group. Implications for designing the urban space to promote adolescent health are discussed.

These studies are among the first to describe the cause relationship between nature, attention and stress for adolescents in educational settings, as well as the association between varying concentrations of nature and moods in everyday settings. There are multiple important methodological contributions regarding the use of physiological measures of stress, GPS tracking and Google Street View image processing.

The findings of the study should be of interest to designers, policy makers, and public health providers. Building on the study methods and findings, I propose a design workflow. Instead of focusing on the physical characteristics of the urban setting, I start with a site reading of people's movement through and interactions with the urban space. The design framework with specific small scaled urban insertions can be responsive to user's affective states and thus facilitate the bottom-up design process.

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# Chapter 1

## Introduction

Of all life stages, adolescence is one in which many rapid and challenging transitions occur. Navigating puberty, developing independent living skills, and undertaking increasingly intense academic loads prove to be serious challenges for adolescents, and for many young people, these challenges are associated with declines in physical and psychological well-being (Newcomb, Huba, & Bentler, 1981; Suldo, Shaunessy, Thalji, Michalowski, & Shaffer, 2009). The consequences of the demands experienced by many adolescents include higher levels of stress, chronic attentional fatigue, emotional distress, depression, and increased behavioral disorders (Torsheim & Wold, 2001; Watson & Pennebaker, 1989).

According to CDC surveys conducted between 2005-2010, nearly 2 million adolescents in the United States reported that they were mentally unhealthy during at least half of their days (more than 14 days within the previous month) (Centers for Disease Control and Prevention, 2011). Depression, stress and anxiety not only cause acute health problems in young people; they also are systematically associated with increased risks for chronic conditions that will manifest later in life (Miller, Chen, & Parker, 2011). Environmental stressors also affect dynamic brain maturation, which determines behavior and psychopathology in adulthood (Kuh & Shlomo, 2004; Romeo & McEwen, 2006).

Fortunately, there may be an inexpensive and easy-to-administer way to address the symptoms faced by many adolescents. A plethora of recent studies has found that exposure to natural places enhances attentional capacity, provides a buffer from stressful events and reduces psychological and physiological stress (Beil & Hanes, 2013; Roe et al., 2013; Thompson et al., 2012; Tsunetsugu et al., 2013; Van den Berg, Maas, Verheij, & Groenewegen, 2010).

Two theories set the stage for investigating the psychological benefits of access to nature: attention restoration theory (ART) (Kaplan, Kaplan, & Ryan, 1998; Kaplan, 1995) and stress reduction theory (SRT) (Ulrich et al., 1991). ART proposes that people use voluntary control to inhibit distraction and

remain focused, and this capacity to control one's attention fatigues over with use. After a short exposure to green space, however, the cognitive capacity to focus attention is renewed, because contact with nature allows the inhibitory mechanism, on which directed attention depends, to rest (Kaplan et al., 1998; Kaplan, 1995). Exposure to nature has been found to restore the cognitive resources supporting both executive functioning and self-regulation (Kaplan & Berman, 2010), which are also critical to learning.

SRT proposes that exposure to nature supports psychophysiological stress recovery, resulting in reduced blood pressure and lower levels of stress hormones (Ulrich et al., 1991). Recent studies also show positive physiological responses to nature, including better neuroendocrine functioning (Van Den Berg & Custers, 2011), immune system functioning (Li, 2010), meditative brain wave activities (Aspinall, Mavros, Coyne, & Roe, 2013), and recovery from stressful experiences (Jiang, Chang, & Sullivan, 2014; Jiang, Li, Larsen, & Sullivan, 2014).

For children and adolescents, nature has been found to provide a retreat from daily hassles, enhance coping capacity, and reduce emotional and behavioral disorders (Corraliza, Collado, & Bethelmy, 2012; Kelz, Evans, & Röderer, 2013; Kuh, Ponte, & Chau, 2013; Li & Sullivan, 2016; Markevych et al., 2014; Van den Berg et al., 2010; Wells & Evans, 2003). For example, Chawla et al. (2014) found that for individuals in the childhood and adolescent phases of development, green school grounds were places where they found refuge and developed independence and social capacities. For adolescents, nature exposure offers an approach to building positive emotions and self-esteem (Feda et al., 2015; Norton, Wisner, Krugh, & Penn, 2014). Other studies examining the physiological benefits of access to nature also show a significant association between access to nature and lower levels of systolic and diastolic blood pressure, heart rate variability and skin conductance in middle and high school students (Kelz et al., 2013; Li & Sullivan, 2016). In addition to these benefits, physical activities in green space have been shown to predict positive feelings (Reed et al., 2013).

Although evidence has pointed at the positive relationships between exposure to natural settings and adolescents' psychological health, a number of critical gaps remain that cloud our understanding of the

magnitude and conditions of this relationship. Our lack of understanding also hinders us in developing practical planning and design interventions that might create healthier places. In this dissertation, I seek to reduce this cloud and shine a light on the benefits that adolescents gain from having regular exposure to natural places and natural elements.

## **Nature exposure, adolescent attention and stress recovery – Correlation or causation?**

Is there a causal link between exposure to nature and stress recovery and attentional performance in educational settings? Two recent studies shed light on this question. One examined the relationship between the vegetation condition surrounding schools and school-based student performance on math and English as measured by the Massachusetts Comprehensive Assessment System, and found a positive association between vegetation cover and academic performance (Wu et al., 2014). Another study measured high school environments including the amount of vegetation visible from classroom and cafeteria windows, the size of the windows, and the density of vegetation in each part of the campus, to predict student performance (i.e., standardized test scores, graduate rates, the percentage of students planning to attend college). The findings demonstrated a positive correlation between exposure to nearby nature and school-wide academic performance (Matsuoka, 2010).

Although previous studies reveal a promising association between green campus landscapes and student academic performance, they are cross-sectional, correlational studies -from which one cannot draw conclusions regarding the causal impact of greener campuses on student performance. It is possible, for instance, that these findings occur in part from self-selection. Perhaps wealthier communities with more affluent families have schools that reflect the affluence, compared to the inner city neighborhoods that are largely concrete. Or more attentive parents seek out greener settings and thus self-select into neighborhoods and school districts that have more trees. If these were the case, the association between exposure to green landscapes and students' attentional performance would be spurious.

If there is a causal relationship between access to nature in educational settings and better attentional



performance and lower levels of stress, as predicted by ART and SRT, when do such impacts occur? Do they occur as a background effect during academic tasks or do they serve as catalysts for post-task recovery?

### **From experimental to everyday settings – Does the relationship still hold?**

When adolescents participate in experimental and quasi-experimental studies, the environment and activities in which they engage are highly controlled and may not reflect the kind of settings to which they would expose themselves. Experimental and quasi-experimental approaches are unable to take into account – and are likely to miss – the majority of the daily academic and environmental stressors that factor into adolescents' moods. Further, adolescents' choice of places to go and unstructured activities to participate in, which have great impacts on how they feel, are typically not assessed in experimental or quasi-experimental studies. Consequently, it is difficult to understand the effect of nearby nature on adolescents if we use only experimental or quasi-experimental procedures.

The majority of studies regarding nature and health have used aggregated geographic areas as the proxy for people's actual environmental contact. The most frequently used are census block, census tract, residential neighborhood, circular buffers around residences or a circular buffer around the center point of a ZIP code zone (Balseviciene et al., 2014; Markevych et al., 2014). Such an approach is subject to the uncertain geographic context problem (UGCoP) (Kwan, 2012). That is, the environmental setting that is measured likely does not match the actual environment in which people spend their time and thus creates significant measurement error in the assessment of the environmental characteristics found in the buffer area and their relationship to behaviors or health outcomes.

Such a mismatch is especially problematic for adolescents. Mid and late adolescence is the phase of development during which self-governance and autonomy emerge as the strongest developmental needs (Spear & Kulbok, 2004; Zimmer-Gembeck & Collins, 2003). Reaching the age of 14-16, in which young people are legally allowed to obtain a driving permit and license, also increases adolescents' independent mobility. As a result, home and school neighborhood spaces do not exert as much influence on

adolescents as they do on younger children. For example, one study found that half of 15-19-year-olds spent more than 90 percent of their time outside their neighborhoods each day (Basta, Richmond, & Wiebe, 2010). Another study revealed that female adolescents spent one-third of their available time in places more than 1 km from home (Wiehe et al., 2008). Therefore, better assessment of adolescent environments is required in order to capture their complex and dynamic activities.

A further challenge is to quantify adolescents' nature exposure with respect to the concentration of nature, and the frequency and duration of their stay in a variety of environments. Traditional methods often used isolated measures of nature exposure, such as the percentage of green space within a buffered area, the frequency of visiting green space, or the time spent in green space each day. However, in daily activity settings, a highly vegetated setting that is occasionally visited or simply passed by might not be as beneficial as a medium vegetated area that is visited for a prolonged period of time. Without taking into account both the concentration of nature and the duration of exposure, we will not be able to reach valid conclusions about the relationship between exposure to nature and the moods of adolescents in their usual everyday settings.

The two main issues I address – establishing a causal relationship and testing the relationship in everyday settings – reflect the tradeoff between internal and external validity in environment-behavior research. To establish causality, the treatment needs to be isolated from potential confounders in order to establish that the observed outcome is attributable to the treatment; but the degree to which the findings represent what might happen in the real world is unknown. In order to enhance external validity, or generalizability, accurate assessments of participants' activity patterns and the environments is needed, but the influence of confounding variables is inevitable. These confounding variables lower internal validity.

In this dissertation, I use a combination of one experimental study and one field study to address this tradeoff between internal and external validity. I have designed two separate studies – one that maximizes internal validity; another that maximizes external validity. In doing so, I hope to gain a deeper understanding of the relationship between exposure to nature and wellbeing in adolescents. By using a

careful research design and an interdisciplinary set of tools and technologies (e.g. physiological measurements of stress, neuropsychological batteries of attentional assessment, GPS tracking, Google Street View image processing), many of which have not been used to study the impact of nature exposure on children, I hope also to contribute to the methodologies used this area of research.

The definition of nature varies considerably across literature. Van den Berg and Van Den Berg (2001) defined nature as “the environment in which organisms or their biotopes expressly manifest themselves. In addition to nature reserves, this nature included farmland, production forest, urban green spaces and back gardens.” Hartig and colleagues defined nature broadly as “physical features and processes of nonhuman origin that people ordinarily can perceive, including the ‘living nature’ of flora and fauna, together with still and running water, qualities of air and weather, and the landscapes that comprise these and show the influence of geological processes” (Hartig, Mitchell, De Vries, & Frumkin, 2014). In this study, we define nature as all types of vegetation, including trees, shrubs, and herbaceous vegetation.

## **Organization**

This dissertation is organized into five chapters; chapters 2, 3 and 4 are each complete studies by themselves, yet together, tell a comprehensive story regarding nature exposure and adolescents’ psychological well-being. Chapter 2 presents a systematic review of published studies that report on the psychological benefits of nature for children and adolescents. This review analyzed recent literature regarding nature’s psychological benefits, extracted the main categories of outcomes, and identified current research priorities.

Chapter 3 presents a study that examines the effects of visual proximity to nature on adolescents’ attention restoration and stress recovery. Using a random controlled design, this study establishes a causal relationship between views of campus landscape and recovery from mental fatigue and stress.

Chapter 4 presents a study that examines the relationship between adolescents’ day-by-day exposure to nature and variations in their moods. This study uses an approach that combines GPS tracking and Google Street View panorama processing to assess the concentration of nature in an individual’s daily

environments accurately. We employ multi-level modeling to take into consideration the nested structure of the data and to isolate out the intra- and inter-individual variations.

Chapter 5 summarizes the findings from the two studies and discusses the framework of the effects of indoor and outdoor access to nature on adolescents' psychological well-being. The contribution of this dissertation to current theory and methodology of nature and children study is laid out. 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.

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## **Chapter 2**

### **The Psychological and Cognitive Benefits Associated with Children's Contact with Nature – A Systematic Review of Recent Literature**

#### **Introduction**

According to the World Health Organization, mental and substance abuse disorders are the leading cause of disability worldwide. Depressive disorders are now the fourth leading cause of global disease burden, and they are projected to rank the second by 2020 (Murray & Lopez, 1996). The situation is especially alarming for children: around 20% of the world's children and adolescents experience mental disorders. Mental disorders in childhood can have lasting impacts and affect well-being many years or even decades later. Fortunately, nature can promote mental well-being, especially for children. Research exploring the benefits of nature for adult dates back to the 1980s, but similar research examining the psychological benefits for children did not begin until the 1990s (Bandoroff & Scherer, 1994; Faber Taylor, Kuo, Spencer, & Blades, 2006; Kellert, 1998; Taylor, Kuo, & Sullivan, 2002; Wells, 2000).

Studies conducted in the 1990s and 2000s demonstrated the benefits of nature for children and warned that diminishing nature in children's environments might negatively impact children's health (Kahn & Kellert, 2002; Louv, 2005; Spencer & Woolley, 2000). The existence of nature surrounding children's homes, outdoor play settings and summer camps enhances children's cognitive functioning and reduces ADHD symptoms (Kuo & Faber Taylor, 2004; Taylor & Kuo, 2009). Children exhibit more focused and creative play behaviors and are more likely to complete challenging tasks in natural settings (Kirkby, 1989). Contact with nature is associated with feelings of escape from stress and better stress management and coping (Wells & Evans, 2003). Adolescents who participated in a wilderness program gained a positive sense of identity and purpose of life (Bandoroff & Scherer, 1994).

In the recent years, there has been a surging interest in the role of nature in promoting children's psychological and cognitive well-being. In Faber Taylor and Kuo's review (2006) that included studies on

nature and healthy child development between 1980 and 2005, fewer than 20 studies dealt with psychological or cognitive outcomes. In McCurdy's 2010 review, only 13 articles examined psychological or cognitive outcomes. However, the number of empirical research articles published during the past 6 years (Jan. 2010 to Jan. 2016) on the benefit of nature on children's psychological and cognitive well-being almost equals the total number published before 2010.

These studies are inspiring new research and policies, but their findings have not yet been synthesized.

There is a critical need to examine what is known and unknown and identify research priorities.

Building on previous review articles that have investigated the full-breadth of health outcomes from children's nature exposure (Louise Chawla, 2015; Faber Taylor et al., 2006; Gill, 2014; McCurdy, Winterbottom, Mehta, & Roberts, 2010), we focus specifically on the psychological and cognitive aspects of contact with nature. By examining the evidence and comparing it with findings from the adult literature, we gain a comprehensive understanding of the state of the field and also identify questions for future research.

As the first systematic review of nature and children's mental health, the key questions this review addresses include:

1. How is nature conceptualized?
2. What particular psychological aspects are associated with exposure to nature for children, and how confident are we about those associations?
3. From an ecological perspective and taking into account factors at the individual, community and societal levels, what are the mediators and modifiers of the relationships between exposure to nature and psychological and cognitive functioning?
4. What are the substantive and methodological priorities for future research related to contact with nature and children's psychological health?



## **Methods**

### ***Study inclusion criteria***

Studies which met all of the following criteria were included in this review: a) study topic: relationship between nature/variations of natural elements and psychological health; b) study population: children aged from birth to adolescence (18 years); c) study type: empirical studies using quantitative, qualitative and mixed-methods studies; d) publication date: published online between January 2010 and January 2016; e) publication type: peer-reviewed journal articles published in English.

### ***Search strategy***

We searched 5 electronic databases including Medline, PsycINFO, PubMed, Scopus, and ISI Web of Science. Various combinations of the following keywords were used to search in titles, keywords and abstracts.

We used three keyword groups to identify studies for this review. Keyword group One ensured the article examined the presence, quantity or quality of, or human contact with nature. Keywords included green space, nature, natural, park(s), tree canopy, urban forest, vegetation, views to nature, garden(s), landscape, and biodiversity. Keyword group Two ensured the article explored psychological well-being as the outcome. Keywords included psychological health, psychological well-being, mental health, mental well-being, mood states, stress, anxiety, happiness, depression, emotion, therapy, therapeutic, cognition, cognitive, attention, restoration, self-discipline, capacity, autonomy, and efficacy. Keyword group Three addressed the age group of interest. Keywords included child(ren), childhood, adolescent(s), adolescence, youth and school-age. Truncation and wildcards were also used to take account of keyword variations.

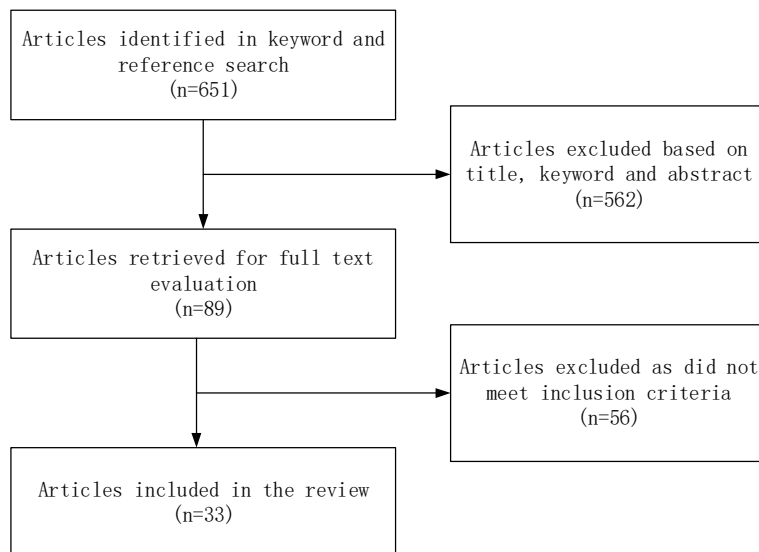
We also conducted a reference list search (i.e., backward search) and cited reference search (i.e., forward search) from full-text articles meeting the study selection criteria. Articles identified through this process were further screened and evaluated using the same criteria. We repeated reference searches on all newly-identified articles until no additional relevant articles were found.

### ***Screening procedure***

Two rounds of screening to the initial collection were conducted by two researchers working independently. The screening results from the two reviewers were compared and any disagreements were resolved by reading the articles together. In the first round, the title, keyword and abstract were reviewed. Articles that were not applicable to green space issues or psychological and cognitive health issues, and articles that were not empirical studies were excluded. In the second round, full articles were reviewed based on the same criteria. We excluded studies that examined outcomes other than psychological or cognitive health, including 1) scientific knowledge, knowledge base, 2) environmental literacy, conservation attitude, 3) physical activity, physical health and fitness.

The initial keyword and reference search yielded 651 titles. After the first round of screening, 89 articles remained. After the second round of full article examination, 33 articles fulfilled the inclusion criteria.

Figure 1. Decision tree for article inclusion/exclusion of articles for this review.



### ***Quality assessment***

We appraised the articles included in this review using separate criteria for quantitative and qualitative (including mixed-methods) studies (Dixon-Woods, Shaw, Agarwal, & Smith, 2004) (Table 1).

Quantitative studies were assessed using an adapted version of Quality Assessment Tool for Quantitative Studies (EPHPP) (EPHPP, 1998) based on the following criteria: i) selection bias, ii) study design, iii)

confounders, iv) blinding, v) data collection methods, vi) withdraws and drop-outs, vii) intervention integrity, and viii) analysis. Qualitative studies were assessed using the CASP checklist for quality appraisal (CASP, 2004), based on the following criteria: question statement, methodology, research design, recruitment strategy, data addressing research question, researcher's role and interaction with the participants, ethical issues, data analysis, presentation of findings, and value of the research. Because of the diverse methods used in both the quantitative and qualitative categories, we decided it would be too arbitrary to exclude studies based on the scoring. As a result, this process was not used to exclude studies but was undertaken to provide in-depth understanding of the strength of each article.

Table 1. Criteria for Quality Assessment.

Type of Research	Criteria	Considerations	
<b>Quantitative Studies</b>	Selection Bias	Were the individuals selected to participate in the study likely to be representative of the target population? What percentage of selected individuals agreed to participate?	
	Study Design	What was the type of study design? Was the study randomized or not? Was the method of randomization described? Was the method appropriate?	
	Confounders	Were there important differences between groups prior to the intervention? What was the percentage of relevant confounders that were controlled?	
	Blinding	Was the outcome assessor aware of the intervention or exposure status of participants? Were the study participants aware of the research question?	
	Data Collection Methods	Were data collection tools shown to be valid? Were data collection tools shown to be reliable?	
	Withdrawals and Drop-Outs	Were withdrawals and drop-outs reported in terms of numbers and/or reasons per group? What was the percentage of participants completing the study?	
	Intervention Integrity	What percentage of participants received the allocated intervention or exposure of interest? Was the consistency of the intervention measured? Did the subjects receive an unintended intervention that may influence the results?	
	Analysis	What was the unit of allocation? What was the unit of analysis? Were the statistical methods appropriate for the study design? Was the analysis performed by intervention allocation status (i.e. intention to treat) rather than the actual intervention received?	
	<hr/>		
	<b>Qualitative Studies</b>		
Research Question	Was there a clear statement of the aims of the research? Was the goal important or relevant?		
Methodology	Was the method appropriate in addressing the research goal? Did the research seek to interpret or illuminate the actions and/or subjective experiences of research participants?		
Research Design	Did the researcher justify the research design?		
Recruitment	Did the researcher explain how the participants were selected? Did the researchers explain why the participants they selected were the most appropriate to provide access to the type of knowledge sought by the study? Were there discussions about recruitment?		
Data Collection Methods	Was the setting justified? Was the data collection procedure clear? Was the form of data clear?		
Research Role	Did the researcher discuss saturation of data? Did the researchers critically examine their own role? How did the researcher respond to events during the study?		
Ethics	Were there sufficient details of how the research was explained to participants for the reader to assess whether ethical standards were maintained? Did the researcher discuss issues raised by the study? Was approval obtained from the ethics committee?		
Data Analysis	Was there an in-depth description of the analysis process? Was thematic analysis used? If so, is it clear how the categories/themes were derived from the data? Were sufficient data presented to support the findings? To what extent were contradictory data taken into account? Did the researchers critically examine their own role, potential bias and influence during analysis and selection of data for presentation?		
Statement of Findings	Were the findings clear? Was there an adequate discussion of the evidence both for and against the researchers' arguments? Was there discussion about the credibility of their findings?		
Value	Did the research discuss the contribution the study makes to existing knowledge or understanding? Did the findings identify new areas of research? Did the researchers discuss whether or how the findings can be transferred to other populations or consider other ways the research may be used?		

### ***Data extraction and synthesis***

We identified and extracted key information from selected studies. The form digitally coded a) general information regarding authors, year of publication and citation; b) study characteristics including main topic, study design, participant characteristics, sample size, treatment type and duration (for experimental designs), data reporter (for self-reported or parent/teacher reported data), geographic area, statistical procedure (for quantitative designs); c) the operational definition of nature, measures of nature, measures of psychological and cognitive well-being, mediators and moderators (for quantitative studies); d) key findings regarding psychological outcomes, mediation and moderation effects (for quantitative studies); and e) notes about the quality of the studies. Findings from research examining the same outcomes were compared and contrasted. The findings and gaps of knowledge were also examined with respect to findings and techniques used in adult literature.

Ideally, a meta-analysis would be conducted to provide quantitative estimates of the effect of contact with nature on children's psychological health based on the quantitative articles. This requires the measures and study designs across the literature to be sufficiently homogeneous. However, among the studies included in this review, the types of research design, interventions, constructs and measures differed substantially. Therefore, this study was limited to a review with key themes identified and discussed.

## **Results**

### ***Characteristics of selected studies***

Characteristics of the studies included in this review are summarized in Table 2.

Table 2. Characteristics of Included Studies.

No.	Author(s), year	Age	Sample Size	Type	Study Design	Statistical analysis	Region	Nature Measure	Outcome Measure	Confounder/Mediation
1	Amoly et al., 2015	7-10	2111	Quan	Cross-sectional	Quasi-poisson mixed-effects model	Europe	-- NDVI (100m, 250m and 500m radius from home) -- Proximity to major green space ( $\geq 0.05\text{km}^2$ ) -- Time spent in green space & beaches	-- Strengths and Difficulties Questionnaires (SDQ-by parents) -- ADHD/DSM-IV questionnaires (by teachers)	Physical activity
2	Bagot et al., 2015	8-11	550	Quan	Cross-sectional	Regression	Oceania	-- Picture ratings of perceived naturalness -- Vegetation volume -- Grass covering -- Perceived affordances	-- Perceived Restorative Components Scale for children (PRCS-C) -- Positive and Negative Affect Scale for Children (PANAS-C)	Playground size, number of play areas, play equipment, playground percentage
3	Balseviciene., 2014	4-6	1468	Quan	Cross-sectional	Regression	Europe	-- NDVI (300m radius from home) -- Distance to nearest park	-- Strengths and Difficulties Questionnaire (SDQ-by mother)	Mother and child sociodemographic factors and parenting stress
4	Barton et al., 2015	~9	52	Quan	Field experiment	ANOVA	Europe	Field dichotomous: -- Concrete playground -- Green playground	-- Rosenberg Self Esteem Scale (RSE)	Physical activity
5	Carrus et al., 2012	1.5-3	16	Quan	Field observation	ANOVA	Europe	Field dichotomous: -- Internal space -- external green space	-- Visual-spatial task -- frequency of small group play -- frequency of dispute-resolution -- interventions by educators -- frequency of crying episodes -- capacity of being quickly comforted in case of crying	
6	Chawla et al., 2014	6-12	152	Qual	Ethnographic observation, semi-structured interviews		North America	Qualitative setting: -- Wooded area -- habitat area -- gardening program		Adjusted for income, physical activity, neighborhood deprivation and population density
7	Dadvand et al., 2015	7-10	2593	Quan	Longitudinal	HLM	Europe	-- NDVI (home, school and commuting route)	-- working memory -- superior working memory -- inattentiveness	Air pollutant
8	Davidson et al., 2010	10-11	3421	Quan	Cross-sectional	Multilevel logistic regression	North America	-- Existence of good neighborhood playgrounds or parks	Confidence to exercise -- when tired -- when there is a lot of homework -- with parents -- most days of the week.	Physical activity
9	Day & Wager, 2010	10-11 & 13-14	56	Qual	Focus group, in-depth interview		Europe			
10	Duncan et al., 2014	~10	14	Quan	Case-control	ANOVA	Europe	Treatment (while cycling): -- no film -- film of a forest environment	-- Systolic blood pressure -- heart rate -- Brunel Mood State Inventory	

Table 2 (cont.) Characteristics of Included Studies.

11	Faber Taylor & Kuo, 2011	5-18	421	Quan	Cross-sectional	ANOVA	North America	Reported usual play place: -- big trees and grass -- indoors -- open grass -- paved /built space -- "wild" place -- indoor place that feels like outdoors -- waterfront --barnyard or farmland -- desert landscape -- public indoor spaces	-- ADD or ADHD symptoms	Family income, gender
12	Feda et al., 2015	~13	68	Quan	Cross-sectional field study	Regression	North America	-- Percentage of parkland (0.80km radius from home)	-- Perceived Stress Scale (PSS)	Physical activity
13	Flouri et al., 2014	3,5,7	6384	10	Cross-sectional	Multilevel growth curve modelling	Europe	-- Percentage of neighborhood green space	-- Strengths and Difficulties Questionnaire (SDQ--by parents)	Neighborhood disadvantage, family poverty and adverse life events.
14	Hordyk et al., 2015	13-17	13	Qual	Drawing and story-telling		North America			
15	Huynh et al., 2013	11-16	14	Quan	Cross-sectional	Multilevel logistic regression	North America	-- Total natural space -- green space (5km radius from school and neighborhood) -- blue space (5km radius from school and neighborhood)	-- The Cantril ladder	
16	Kelz et al., 2013	13-15	133	Quan	Quasi-experimental field study	T-test	Europe	Treatment -- no change in schoolyard -- renovated schoolyard	-- Blood pressure -- Attention Network Test (ANT) -- The Basler Well-Being Questionnaire -- Recovery-Stress Questionnaire (R-SQ) -- Perceived Restoration Scale	
17	Kuh et al., 2013	4-8	90	Mixed-methods	observations, field notes, and interviews with children		North America	Pre-post settings: -- traditional playscape -- natural playscape	-- Attracting power -- holding time	
18	Laaksoharju et al., 2012	7-12	130	Qual	Observation		Europe	Qualitative setting: -- garden		
19	Li & Sullivan, 2016	13-18	94	Quan	Experiment			Treatment (academic tasks) -- no window view -- barren view -- green view	-- Digit Span -- Skin conductance -- Skin temperature -- Heart rate variability	

Table 2 (cont.) Characteristics of Included Studies.

20	Linzmayr et al., 2016	6-10	5	Qual	Sculptures, drawings, photography and sand tray, interview		North America	Qualitative setting: -- botanic garden		
21	Markevych et al., 2014	10	2078	Quan	Cross-sectional	Generalized additive models	Europe	-- NDVI (500m radius from home)	-- Systolic blood pressure	Temperature, air pollution, noise annoyance, altitude and urbanization level
22	Markevych et al., 2014	10	1932	Quan	Cross-sectional	Proportional odds models.	Europe	-- NDVI (500m radius from home)	-- Strengths and Difficulties Questionnaire (SDQ--by parents)	Urban area
23	Matsuoka, 2010	NA (14-18)	101	Quan	Cross-sectional	Regression	North America	Rated naturalness: -- views from school cafeteria -- views from classrooms Objectively measured: -- lawn area -- landscape area	-- standard test score -- graduation rate -- college plan -- criminal behavior	
24	Nedovic & Morrissey, 2013	3-4	18	Qual	Interviews, conversations, photographs and drawings		Oceania	Qualitative setting: Organic garden including a teepee, mulch, greenery, flowers and loose organic materials		
25	Norton & Watt, 2013	13-22	159	Quan	Field study	ANOVA	North America	Pre-post setting: -- wilderness program	-- Developmental Assets Profile (DAP)	
26	Norton et al., 2014	14-19	55	Mixed-methods	Pre-post questionnaires and face-to-face interviews		North America	Setting: -- wilderness program	-- Self-Worth Index-Adapted (SWI-A) -- Identity Complexity Index (ICI)	
27	Reed et al., 2013	11-12	75	Quan	Quasi-experiment	ANOVA	Europe	Treatment settings (while running): -- school campus lap course on flat terrain -- local country park	-- Rosenberg Self Esteem Scale (RSE) -- visual-analogue scale	
28	Roe & Aspinall, 2011	11	18	Quan	Field experiment	ANOVA	Europe	Treatment setting: -- indoor school -- forest school	-- University of Wales Institute of Science and Technology (UWIST) Mood Adjective Checklist (MACL) -- 6-item personal project scale	
29	Samborski, 2011	6-13	761	Qual	Drawings, survey, interview, observation		North America	Qualitative settings: -- biodiverse school ground -- barren school ground		



Table 2 (cont.) Characteristics of Included Studies.

30	Schutte et al., 2015	4-5 & 7-8	67	Quan	Field study	ANOVA	North America	Treatment settings (walking): -- urban -- park	-- spatial working memory task -- Go/No go task --Digit span backward	
31	Söderström, M et al., 2013	3-6	172	Quan	Cross-sectional	ANOVA, MANOVA, PCA	Europe	Outdoor play environment categories (OPEC) scoring: -- total outdoor area -- amount of trees -- shrubbery and hilly terrain -- integration between vegetation, open areas and play structures	-- Saliva cortisol	SES
32	van den Berg & van den Berg, 2011	9-17	12	Mixed-methods	Observation	ANOVA	Europe	Treatment settings: -- natural -- built	-- play behavior: social behavior, cooperative behavior, enthusiasm, aggressive behavior -- inattention, and impulsivity/hyperactivity -- smiley-test: (1) sad – happy; (2) worried – not worried; (3) tired – energetic; (4) angry – not angry; (5) uncertain – certain; (6) scared – not scared. -- ‘Opposite Worlds’ test	
33	Wood et al., 2013	~13	25	Quan	Experiment	ANOVA, MANOVA	Europe	Treatment (while cycling): -- projected built pictures -- projected natural pictures	-- Rosenberg Self-Esteem Scale -- Adolescent Profile of Mood States Questionnaire (POMS-A)	

**Developmental stage.** In this review, we categorized studies using the developmental phases of childhood: infancy (0-18 months), toddlerhood (18 months-3 years), early childhood (3-6 years), middle childhood (6-12 years) and adolescence (12-18 years). The studies reviewed represent every developmental phase except infancy, with a few across two or three phases. The majority of the studies discussed the effect of nature during middle childhood and adolescence (29). Only one study was conducted on toddlerhood. Such an underrepresentation of infancy and toddlerhood might be explained by the limited independent mobility and environmental exposure of infants and toddlers, as well as their limited capability to articulate their feelings and perceptions.

**Geographic region.** In terms of geographic regions, the vast majority of studies were conducted in western settings, with more than half in Europe (17). Among studies conducted in Europe, the majority was set in northern Europe (11), including Britain and Scotland (6), the Netherlands (2), Finland (1), Lithuania (1) and Sweden (1). Among those conducted in North America (14), studies in the United States (10) outnumbered those in Canada (4). Africa, Asia, South America and the Middle East were heavily underrepresented (2). This indicates a geographical bias and points at opportunities to consider a variety of climates, vegetation, living environments and cultural contexts. Since the average area of green space per capita and proximity to forests and natural preserves is much greater in a number of North European cities than the rest of the world, a key question is how applicable findings from Northern Europe are to other regions. In addition, all studies were conducted in subarctic, humid continental or humid subtropical zones. Other climate zones, such as the arid zone, are heavily underrepresented.

**Urban-suburban-rural.** Among the studies that specified environmental settings (26), approximately half were conducted in urban settings (12). Another 8 employed a mixed sample of multiple settings. The number of studies completed within suburban and rural settings were relatively small (3 each).

**Study design and sample size.** Among the 33 studies included, 3 were mixed-method, 7 were qualitative, and the remaining 22 were quantitative.

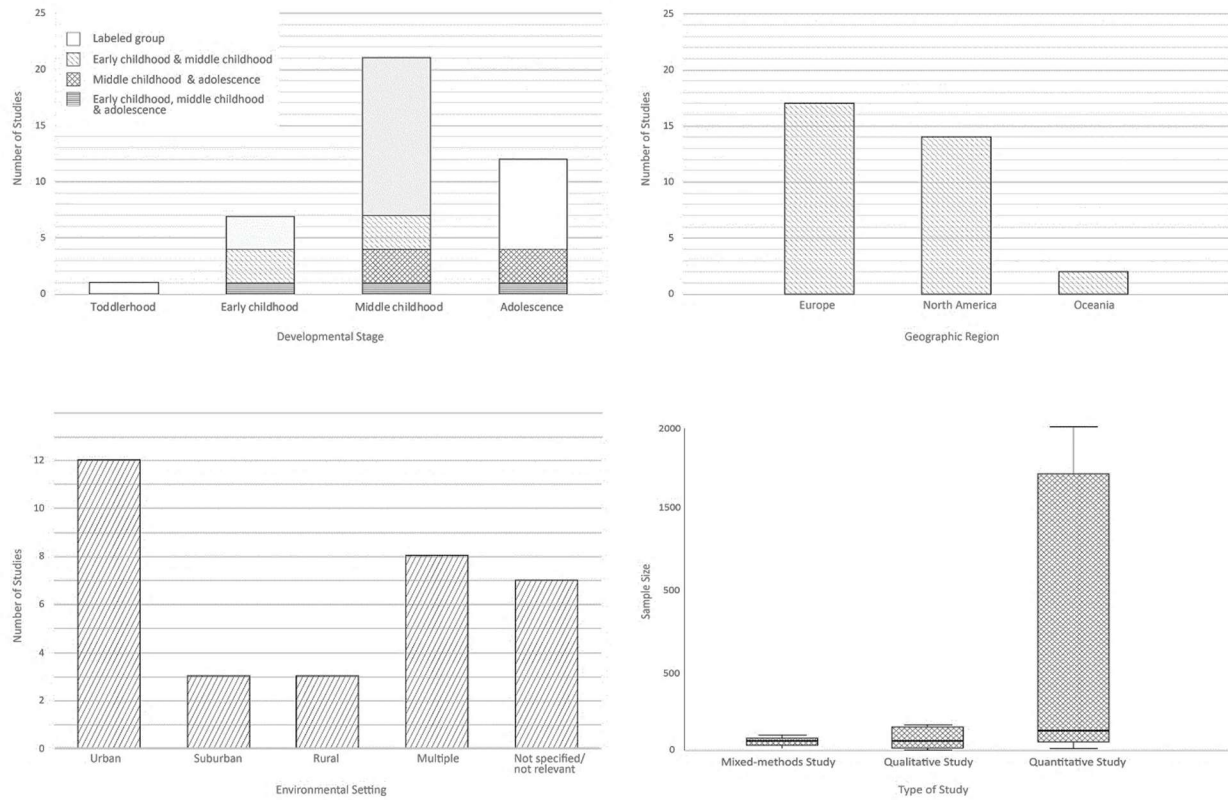
A highlight of the quantitative studies was the use of big datasets to enhance ecological validity. For example,

a number of them used population level cross-sectional, nationally representative, or longitudinal datasets, such as the Brain Development and Air Pollution Ultrafine Particles in School Children (BREATHE), Positive Health Effects of the Natural Outdoor Environment in Typical Populations in Different Regions in Europe (PHENOTYPE), the Raising healthy Eating and Active Living Kids in Alberta (REAL Kids Alberta), and the Millennium Cohort Study. There were fewer experimental and quasi-experimental studies, suggesting a critical gap in establishing causal relationships and understanding the real-world impacts of greening efforts to evaluate policy interventions (Kelz, Evans, & Röderer, 2013; Kuh, Ponte, & Chau, 2013). Qualitative and mixed-methods studies, on the other hand, described a broader range of psychological benefits and revealed the perceptive and behavioral patterns that underly the children-nature relationship.

The average sample size of studies included was 705; despite the highly right-skewed distribution, this average sample size suggests a trend of employing larger sample sizes in recent studies. The range of sample sizes of mixed-methods, qualitative and quantitative designs were 12-90, 5-761, and 14-6384, respectively. Cross-sectional designs, especially the ones using the above-mentioned datasets, reported large sample sizes.

Experimental and quasi-experimental studies, on the other hand, reported smaller sample sizes between 14 and 133.

Figure 2. Characteristics of included studies—developmental stage, geographic region, environmental setting and type of study.



## ***Conceptualization of nature***

### ***Definition and types of nature***

The definition of nature varies considerably across the studies and has long been a contested issue in nature and health research. Van den Berg & Van den Berg (2001) defined nature as “the environment in which organisms or their biotopes expressly manifest themselves. In addition to nature reserves, this nature included farmland, production forest, urban green spaces and back gardens.” Hartig and colleagues defined nature broadly as “physical features and processes of nonhuman origin that people ordinarily can perceive, including the ‘living nature’ of flora and fauna, together with still and running water, qualities of air and weather, and the landscapes that comprise these and show the influence of geological processes” (Hartig, Mitchell, De Vries, & Frumkin, 2014). Although most studies included in this review didn’t take such a broad definition, most still recognized the constructed and managed vegetation as part of nature. In terms of measurement, nature was

most frequently measured objectively, but a few used subjective ratings.

The most common way of identifying nature was to use classified land cover. But there were considerable variations in determining what types of land cover constituted nature. Studies that used existing land cover datasets were constrained by the classification codes of the specific dataset, which further increased the diversity of the definition. For example, a Canadian study that used the CanMap RouteLogistics and Enhanced Points of Interest databases employed a broad definition of nature, including typically included natural elements, such as parks and wooded areas, as well as sports fields, gardens, golf courses, and national wildlife and migratory areas (Huynh, Craig, Janssen, & Pickett, 2013). A Dutch study that used the National Land Cover Classification database (LGN4) included urban green, agricultural green forests and nature conservation areas (A. E. Van den Berg, Maas, Verheij, & Groenewegen, 2010).

Regarding the impact of type of nature on the outcomes, not all types of natural elements yielded the same levels of psychological benefit. For example, vast spans of grass cover have been suggested to be less effective compared to tree canopy in reducing problematic behavior among high school students (Matsuoka, 2010) and are also not associated with children's perceived restorativeness (Bagot, Allen, & Toukhsati, 2015). In addition, the recent findings confirming the restorative effect of blue space in (Bell, Phoenix, Lovell, & Wheeler, 2015; Lengen, 2015) suggests that we should consider other natural elements besides vegetation.

Regarding the setting in which nature is measured, residences and school grounds were typically examined (Kelz et al., 2013; Li & Sullivan, 2016). However, in addition to home and school environments, a variety of settings such as child-care facilities, outdoor classrooms, wilderness camps and other learning settings were found to promote beneficial psychological outcomes (Carrus et al., 2012; L. Chawla, Keena, Pevec, & Stanley, 2014; Dadvand et al., 2015).

### ***Quantity and quality of nature***

A number of experimental and quasi-experimental studies have employed a dichotomous comparison between nature (forest or park settings with dense vegetation) and the built environment (barren or hard surfaces with no or few vegetation) or indoor environments. For example, compared to a play period in an interior space of a child-care building, one outdoors in a green space enhanced toddler's performance in

attention tests and their pro-social behaviors (Carrus et al., 2012).

Cross-sectional research frequently used the amount or percentage of natural land cover, or normalized difference vegetation index (NDVI), which provides an estimate of the density of vegetation based on the reflectance of the ground material. Though NDVI is prevalent, it may represent limited resolution and is incapable of deciding the type of nature. The resolution of NDVI measure depends on the resolution of the available satellite imagery that is used to derive it. As the most openly available source of global imagery is the Landsat TM images with a resolution of 30m, the use of such imagery-derived NDVI to measure fine-grained greenness for micro-scaled units is not possible. Also, NDVI doesn't differentiate among types of vegetation, thus introducing errors from irrelevant or inaccessible types of biomass.

Research also suggests that as the quantity of green space increases, the dose-effect curve describing the psychological effects does not increase linearly. For children or adults, the 3rd quartile of vegetation density induces optimal reactions and the curve decreased or remained flat for the 4<sup>th</sup> quartile (Huynh et al., 2013). This finding is consistent with a preference study examining vegetation density and preference (Bjerke, Østdahl, Thrane, & Strumse, 2006). One explanation might be the highest quartile of vegetation density may consist of inaccessible wooded areas which do not support ideal use as much as parks or recreational areas (Huynh et al., 2013). Another possibility is as density increases, the openness of the environment decreases, which may cause feelings of disorientation and perceived safety concerns (Taylor, Parson, 1995; Hull & Harvey, 1989). Overall, as Wells and colleagues (2006) put it, the most supportive environment, for perceived restoration, stress recovery and attention boost should be both green and contain some level of openness.

The quality of green space has been brought up in children research but not as in-depth as in adult research. For example, a few studies have examined the effect of the quality of nature, such as the integration of vegetation, play structures (Söderström et al., 2013) and affordances (Nedovic & Morrissey, 2013). Findings from adult research also point to the idea that quality may be more relevant to psychological outcomes than quantity (Francis, Wood, Knui-man, & Giles-Corti, 2012; Van Dillen, de Vries, Groenewegen, & Spreeuwenberg, 2012). For example, residents who rated their neighborhood as high quality open space showed lower odds of psychological distress (Francis et al., 2012). Other items reflecting quality of green

space that were considered in adult studies include biodiversity, variation, matureness, colorfulness, shelter, maintenance, absence of litter, spatial arrangement and reported attraction, impression, comfort, safety, atmosphere (Francis et al., 2012; Van Dillen et al., 2012).

While we know much about the benefits of the presence of nature, we have limited information about the effects of quantity and quality of nature on psychological health. For nature and children research to gain more practical significance, the objective and subjective quality of green space, and its ability to provide desired affordances, warrant further research. As any outdoor environment is always a combination of vegetative and non-vegetative elements, the restorative effects of various proportions and spatial arrangements of different elements and affordances, as well as the impact of the way children interact with them are yet to be investigated.

### ***What psychological and cognitive benefits are associated with contact with nature?***

The psychological and cognitive benefits described in these studies covered broad ground. We identified eight main aspects of psychological well-being that were examined in the quantitative and qualitative studies: attention and restoration, stress and mood states, self-esteem and confidence, pro-social behavior and relationships, excitement and creativity, happiness and subjective well-being, identity and independence. While qualitative research described all eight categories of benefits, quantitative studies focused on five of them: attention and restoration, stress and mood states, self-esteem and confidence, overall happiness and prosocial behavior. Among them, the impact of nature on attention and stress were most frequently discussed. Figure 3 represents a catalog of the measures and constructs of psychological and cognitive benefits used in the quantitative studies that were cited in this review. Figure 4 demonstrates the direction of the associations from the findings of these studies.

Figure 3. Psychological constructs and measures used in the studies included.

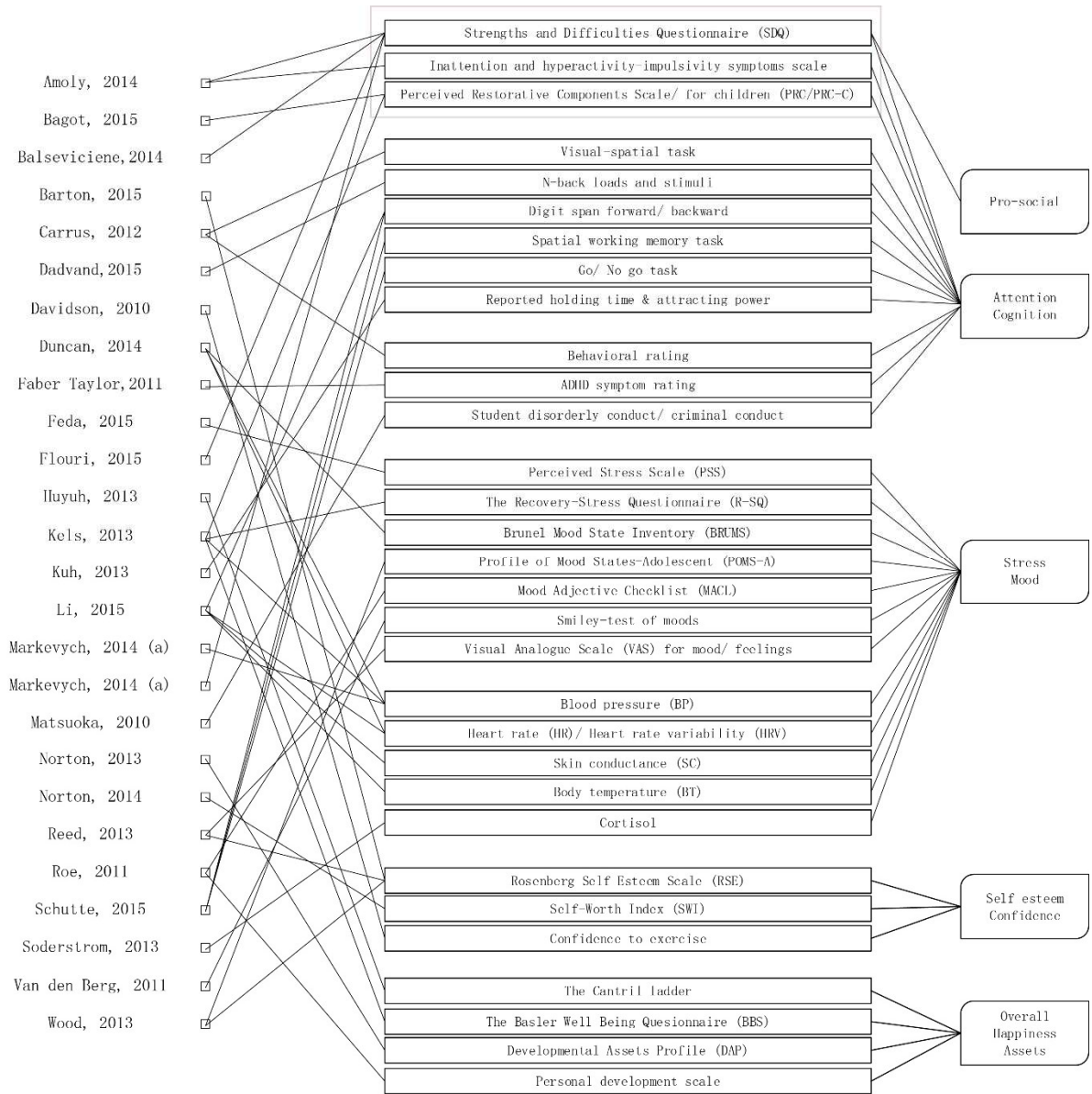
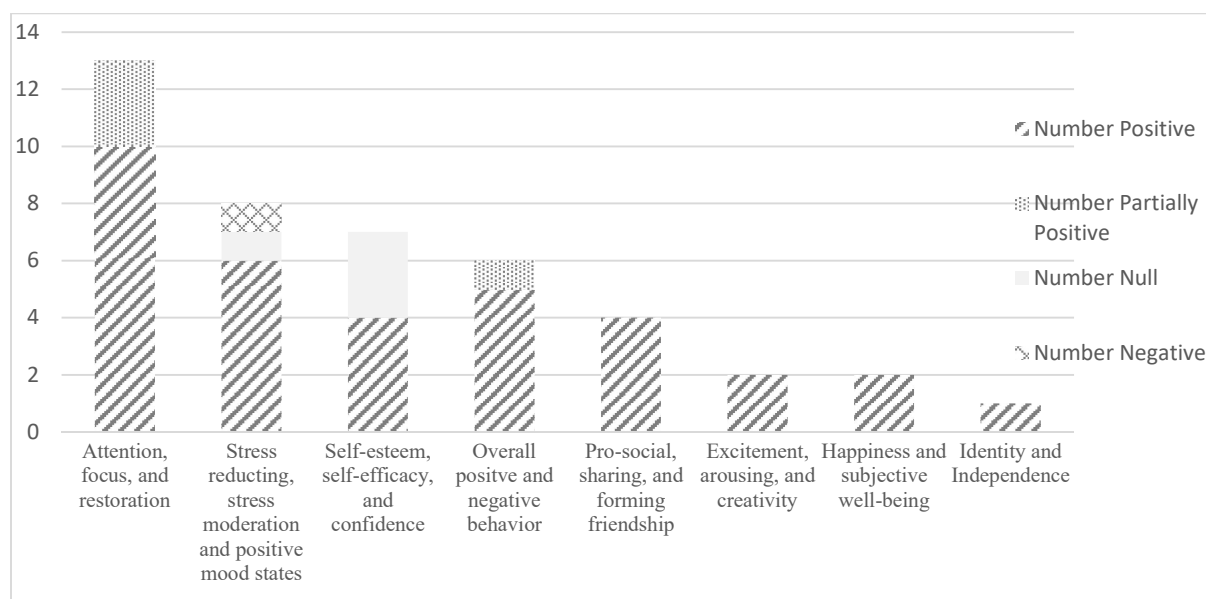




Figure 4. Findings summary: direction of relationships.



***Stress reduction, stress moderation and positive mood states***

Green space in residential neighborhoods and schoolyards can be a significant resource to help children negotiate stressful situations. The effect of nature on children’s stress reduction and management has been demonstrated in two ways: 1) lowering children’s stress levels directly, reducing mood disturbance and fostering positive mood states; and 2) moderating the effect of stressful events and buffering the negative health impacts of these events. For children of a variety of ages, findings have been consistent that spending time in nature is associated with lower levels of systolic blood pressure (Duncan et al., 2014) and diastolic blood pressure (Kelz et al., 2013), hedonic tone (Roe & Aspinall, 2011), and perceived stress (Feda et al., 2015). Moreover, contact with nature helps children build resiliency and cope with adverse situations. It is likely that a number of the benefits children acquire from nature (e.g., increased attentional functioning, pro-social behavior, and self-esteem) form protective factors and reduce the risk of stress. For example, for children in middle childhood and adolescence, green school grounds are places of refuge from stress where they can develop independence and social capacities (L. Chawla et al., 2014). Nature also promotes positive emotions, especially for children who live with challenging family situations or those who report emotional and behavior problems (Norton, Wisner, Krugh, & Penn, 2014). Although theory and experimental results point to the preventive or buffering effects of nature, which has been demonstrated in adult research (Parsons, Tassinary, Ulrich, Hebl, & Grossman-Alexander, 1998), no direct

evidence has confirmed that nature experience can provide immunization for stressful life events that occur any time after a child has been exposed to a natural setting.

On the other hand, some studies, especially those using physiological measures, found that contact with nature is not associated – or is only associated with stress or mood – in specific groups (Balseviciene et al., 2014; Roe & Aspinall, 2011; Wood, Angus, Pretty, Sandercock, & Barton, 2013). For example, Markevych (2014) found that urban, but not rural, children exhibited a relationship between residential greenness and blood pressure. Surprisingly, a negative association was observed in a study where the quality of the environment was measured using a scoring tool integrating total area; amount of vegetation; and integration between vegetation, open areas and play structures (Söderström et al., 2013). They found that a high-quality outdoor environment was associated with higher saliva cortisol levels (indicating higher stress levels). An explanation might be the other factors (play structures, etc.) or the interrelation of factors may have offset the effect of green space.

### ***Attention, focus and restoration***

Research has examined the effect of nature on the following aspects of attention: attentional capacity, sustained attention and executive control. The results were predominantly positive, except some controversies regarding executive control. Multiple measures of attention including self-report inventories, a standard battery of attention tests, and direct behavioral observations conducted by researchers, parents and care-givers add to our confidence in the association.

Nature helps children restore their attentional capacity and focus. A walk in a park helped children recover from mental fatigue and enhanced their performance in tasks that required working memory (Kuo & Faber Taylor, 2004). For high school students who completed mentally fatiguing academic activities, having a green window view during class break was associated with enhanced attentional capacities (Li & Sullivan, 2016). From a development perspective, the green space surrounding school and during the commute was positively related to 12-month progress in working memory and reduction in inattentiveness (Dadvand et al., 2015).

The relationship between nature and executive control is the most contested. Observation studies consistently revealed that children exposed to nature are more likely to come up with complex play and project ideas, and carry out their ideas (Laaksoharju, Rappe, & Kaivola, 2012). However, experimental studies display a mix of

positive and null results on the effect of nature on inhibition control. Girls with greener home surroundings performed better on tasks (e.g. color stroop test, Category Matching) that required selective attention and inhibition control, but no such relationship was observed in boys, possibly due to the measure used in the study (Taylor et al., 2002). Schuttle and colleagues were not able to identify the effect of a park walk on executive control using the Go/no-go task (Schutte, Torquati, & Beattie, 2015). A school renovation that featured natural elements in rural Austria also didn't induce significant change in executive functioning, measured using the Attention Network Test (Kelz et al., 2013).

Sustained attention can be facilitated because of nature's power to hold people's attention. Compared to traditional play, nature play was associated with longer play time and more child-environment interaction (Kuh et al., 2013). Consistent with Attention Restoration Theory (Kaplan & Kaplan, 1989; Kaplan, 1995), studies reported that natural elements catch children's attention easily, hold their attention for a longer span of time, and help them to be persistent and eventually carry out their goals in play (Laaksoharju et al., 2012).

Lastly, children with ADHD exhibited fewer difficulties and displayed fewer symptoms as a result of contact with nature, as measured by IDSM-IV and Likert-scale questions (Taylor & Kuo, 2011). Nature can therefore be an effective ADHD management strategy across developmental stages. Nature in one's immediate environments and planned visits to green space are both associated with better attentional performance, and therefore can be prescribed as treatment for ADD or ADHD (Amoly et al., 2014; A. Van den Berg & Van den Berg, 2011).

### ***Sense of purpose and Self-esteem***

Nature has been demonstrated to enhance children's long-term values, goals and sense of purpose. Wilderness therapy has been used for decades for adolescents at risk for behavioral problems and has demonstrated huge success (Kaplan & Talbot, 1983). Recent evidence continues to support this association. For example, those who attended alternative schools and experienced challenging situations and behavior problems reported feelings of success and confidence, hope for a purposeful future, and an effective transition to a new self-identity after a 25-30-day wilderness program (Norton et al., 2014). A possible concern is that this effect may be related to challenging activities and programs that exploit individuals' strengths, rather than the nature itself (Roe & Aspinall, 2011). Future studies can control the influence of activity programming, presence of instructors, as

well as peer interaction, to isolate the effect of nature on self-worth and sense of purpose.

Driven by the Exercise and Self-Esteem Model (EXSEM), which states that physical activities affect higher levels of self-perceptions of physical competence and attraction, as well as lower level efficacies associated with various physical skills (Robert J Sonstroem, Harlow, & Josephs, 1994; R. J. Sonstroem & Morgan, 1989), another line of research has explored the effect of green exercise (i.e., exercises conducted in green space) on self-esteem and self-efficacy. Evidence suggests green exercise has a significant positive impact on self-esteem in adults. Five minutes of exercise in a green space was able to induce a substantial increase in adults' self-esteem (Barton & Pretty, 2010). However, a study testing the additive effect of nature on top of exercise in children found null results (Reed et al., 2013). Another nature-based play intervention did not result in significantly better self-esteem than a barren playground-based play intervention (Barton, Sandercock, Pretty, & Wood, 2015). More evidence in this area is needed to confirm whether nature-based physical activity provides additive effects on self-esteem, compared to exercise in barren spaces. (Robert J Sonstroem et al., 1994) (Taylor & Kuo, 2011)

### ***Pro-social, sharing, and forming friendship***

Recent qualitative and mixed-method research points strongly at the fact that natural environments help children develop pro-social behaviors and form supportive social relationships (Laaksoharju et al., 2012; Nedovic & Morrissey, 2013). However, the mechanisms through which nature foster pro-social behavior have not been researched as thoroughly as the stress recovery and attention restoration pathways. Three pathways seem plausible: more cooperative play, less egocentric play, and fewer emotional problems. First, nature facilitates cooperative play and complex play where children can work in groups to achieve common goals. In a natural playscape with an abundance of loose parts, children are more likely to initiate cooperation or participate in coordinated constructive play to finish relatively larger projects (Kuh et al., 2013). Second, nature provides a setting for children to develop various perspectives and become less egocentric. The freedom children have in exploring nature's dynamics helps them see things from multiple angles. As they acquire the ability to understand and value others' intentions and feelings, they are more likely to be pro-social. Third, positive emotions and cognitive competence elicited by nature might also impact children's behavior. Adult research has shown that, in line with the broaden-and-build theory, positive emotions broaden people's perspective and motivate them to engage in behaviors with long-term benefits. Happy people are more likely to participate in charity and volunteer

work (Zhang, Piff, Iyer, Koleva, & Keltner, 2014). For children, since they lack experience of ways to deal with their emotions and frustrations, feeling happier and less agitated would result in fewer conflicts and better peer interactions (Carrus et al., 2012). Further examination of these potential pathways will advance our understanding of the relationship between nature and prosocial behavior, and lead to policy interventions to promote this relationship.

### ***Happiness and well-being***

Happiness, assets and subjective well-being are also mentioned in some studies, but not as extensively as in adult literature, due to the varied capability of children to evaluate their well-being. Several studies examining well-being simultaneously evaluated multiple aspects including behavior, affect, cognitive function and social relationships. For example, studies used the Strength and Difficulties Questionnaire (SDQ), which has five subscales: hyperactivity, emotional symptoms, conduct problems, peer problems and prosocial behavior. Outcomes that were less mentioned in research included: arousal (Linzmayr, Halpenny, & Walker, 2014), creativity, independence and autonomy (L. Chawla et al., 2014). More quantitative and mixed-method research is needed to complement the qualitative findings and provide substantial evidence regarding the causal relationships between nature and creativity, independence and autonomy.

### ***Mediators and moderators***

What factors influence the magnitude of the above-mentioned relationships, and what pathways might lead to these relationships? Although not as comprehensive as adult studies, literature on children has identified SES, physical activity and air pollution as factors that influence the outcomes. Studies on children's perspectives have also proposed reasons that contact with nature can make them feel better, including being outdoors in fresh air, feeling connected to nature, interacting with living things, and having time and space for self-reflection (L. Chawla et al., 2014).

Combining recent findings from children's literature and what we already know about adults, we can outline a more comprehensive picture of the factors that might explain or modify the observed relationships between nature and psychological and cognitive well-being. The most salient factors are SES, preference and perceived restorativeness, physical activity and social support. Others that have been examined include expectations and

purpose of visit, neighborhood and living conditions, ambient variables (e.g. temperature, air quality) (Hipp & Ogunseitan, 2011), neighborhood satisfaction, environmental awareness and knowledge (Wassenberg, Goldenberg, & Soule, 2015), and worries and life events.

### ***Socio-economic status***

SES has been examined as a modifier for the nature–well-being relationship in both adult and children studies. Several studies have shown stronger positive effects of contact with nature for children from low SES families (Huynh et al., 2013; Maas, Verheij, et al., 2009). Disadvantaged children who live far away from city parks are more likely to display conditional problems and less prosocial behavior (Balseviciene et al., 2014). Similarly, pregnant women with lower education tend to have fewer depressive symptoms when exposed to nature compared to women with higher education (McEachan et al., 2015). These individuals desire more access to green space and often have a greater need for the restorative power of green space, but they face substantial barriers to access. As a result, they tend to report less green space playing time and less frequent visits (Amoly et al., 2014; Day & Wager, 2010). The imbalance in nature exposure and the effect of access barriers on psychological health are important equity issues. Future research should examine the magnitude of the association between nature and well-being by SES, and the consequences of lack of access for low SES groups.

### ***Preference, perceived greenness and perceived restoration***

Preference has been associated with restorative experiences and can be a mediator or moderator of restoration. Research has identified a positive correlation between preference, perceived restorativeness and psychological outcomes (Berg, Jorgensen, & Wilson, 2014; Carrus et al., 2015; Marselle, Irvine, Lorenzo-Arribas, & Warber, 2015). Other research examining favorite places revealed that the relationship between preference and frequency of visit may be important in explaining why the direction and magnitude of restoration may differ from person to person. More studies on children that examine objective greenness, perceived greenness, preference, perceived restoration and psychological outcomes may shed light on these interrelationships.

### ***Physical activity and physical engagement***

The combination of physical activity and nature often leads to synergistic effects on adults' psychological well-being, suggesting physical activity may moderate the association between greenness and well-being (Annerstedt et al., 2012; Astell-Burt, Feng, & Kolt, 2013). However, few studies have demonstrated such a moderation effect

in children.

An intervention of nature-based playtime didn't lead to significantly more enhancement in self-efficacy than a concrete playground-based intervention (Barton et al., 2015). An experiment comparing self-esteem in children who complete timed runs in rural environments with green space versus urban environments didn't show that the green exposure had an additive effect (Reed et al., 2013). Similarly, insignificant results have been presented for mood states (Duncan et al., 2014; Wood et al., 2013). An exercise session while viewing a film of forest setting didn't result in significantly higher mood states, compared to the control condition with no visual stimulus (Duncan et al., 2014). Is it possible that, in contrast to adults, green environments do not provide children with additive benefits above those observed from exercise in barren conditions? More evidence with children using consistent measures and carefully controlled environmental confounds is needed to confirm this.

### ***Social interaction***

Social interaction hasn't been tested as a mediator or moderator for children's psychological well-being, although the social factor has been suggested to be important in children's place-based experience (Day & Wager, 2010; Hordyk, Hanley, & Richard, 2015). In adult research, however, most evidence converges, suggesting that social interaction at least partially mediates the relationship of greenness and mental health (de Vries, van Dillen, Groenewegen, & Spreeuwenberg, 2013; Maas, Van Dillen, Verheij, & Groenewegen, 2009).

Despite the consistency of evidence in suggesting the significance of social interaction in boosting the effect of nature, such a relationship could still depend on the environmental context. It has been noted that residents who have great residential privacy would seek more encounters and social interactions in nature, whereas residents in high-density urban areas or shared-housing often feel the need to escape the overwhelming built environment and social interaction to find their "personal space" in nature (Hartig et al., 2011; Thomas, 2015).

## **Discussion**

### ***Principal findings and priorities for future research***

This systematic review critically examined research on the psychological and cognitive benefits of nature published during the recent 6 years and drew from evidence from adult literature to identify new understandings and gaps of knowledge. We included 33 studies on children of a variety of ages, which covered a wide range of

psychological and cognitive aspects. Synthesis of the children literature provides evidence of nature's positive health benefits, especially attention restoration, less stress, more positive moods, pro-social behavior and identity formation. Findings also suggest subjective measures such as self-reports are more consistent in supporting the benefits of nature, whereas physiological measures such as blood pressure, cortisol and heart rate variability show somewhat contradictory results.

In the research, we identified gaps of knowledge and future research directions from conflicting evidence in children literature, understudied areas in children literature, relationships that have been identified in adult literature but not yet in children literature and areas where children and adult literature disagree. Key gaps of knowledge we identified include: (i) quality of green space, affordances and children's psychological well-being, (ii) the preventive or immunization effect of nature on stress (iii) the relationship between nature and children's executive functioning, (iv) the additive effect of nature beyond outdoor exercise on children's mood states and self-efficacy, (v) SES and the impact of family affluence scale on the association between nature and children's well-being, and (vi) children's own motivations and preferences and the restorative effect. Among these, (i), (ii), (v) and (vi) are currently inadequately examined in children research, but have been discussed in greater depth in adult research; (iii) shows the most conflicting findings among children literature; and (iv) represents the area where children and adult findings disagree. In the following paragraphs, we discuss some theoretical aspects which might inform future studies. We also provide methodological approaches that may contribute to the exploration of the current gaps in understanding.

### ***Theoretical directions***

#### ***Motivation—discovery and having fun***

Evidence suggests there might be some difference in the motivations of using green space between adults and children. While adults may prefer the restoration and reflection aspects of nature, children concentrate on having fun and hanging out with friends (Huynh et al., 2013). Although there are studies that outline how adolescents reflect and form identities in nature, more studies reveal that children's own perception of nature benefits "peaks around the happiness they derive while playing in nature" (L. Chawla et al., 2014). Other studies demonstrated a similar motivation driving children's visits to green spaces: engage in activities and have fun (Samborski, 2010). Although children also mention the relaxing aspect of nature, they often value "having something to do,"



“discovering and being challenged,” and “having fun with friends” more. For example, a study asking children to nominate their favorite place found children didn’t nominate natural places more often than other places such as sports settings (Korpela, Kyttä, & Hartig, 2002). Therefore, if a green space doesn’t provide a good variation of affordances, it may not attract children’s visits.

The fascination component, in Kaplan’s matrix of restorative environments, may bear more weight for children than for adults. Environments that offer enough fascination can capture children’s interests and hold them in focused play. Some studies also noticed that children rarely mention the low arousal end (e.g. calm, serene, restful) of their affective experience (Linzmayr et al., 2014). Compared to adults who mention relaxation and restoration more, children mention the high arousal more frequently. Nature offers an enormous set of toys for children: things that move to attract attention and train motor skills, to illustrate cause and effect, and things to be hidden to observe object permanence.

Opportunities for sensory stimulation are much more diverse in natural environments. All qualitative articles with children’s own description of their nature experience include sensory references. Elements of the nature, including vegetation, soil, water, and wildlife constantly change and provide vividly changing visual, acoustic, olfactory and haptic experience. Natural environments, as eco-systems, also display dynamics in interrelationships of the elements. Studies have demonstrated there is a pathway between sensory and affective experiences: appropriate levels of sensing, novelty and challenge are arousing (Linzmayr et al., 2014).

Autonomy and freedom of choice is another aspect of nature that brings endless joy to children. In organic environments, children are more likely to engage in self-initiated play and take control of their environment. They feel more satisfied because the variety in structure in nature gives them the choice to move around freely (L. Chawla et al., 2014). According to Behavior Setting Theory, people’s actions in specific environments conform to the established patterns of behavior. For example, children know they are supposed to play games in a basketball court. In nature, however, there are few established patterns of behavior, and children can enjoy the freedom of engaging the environment in any way they can imagine. An abundance of loose parts and organic material that change over time and seasons provide dynamic affordances for children to construct their own imaginative world. Those “abstract” properties of natural elements facilitate child-initiated, imitative, complex,

sustained and social play (Kirkby, 1989; Nedovic & Morrissey, 2013).

### ***Developmental stages and perception***

The growth trajectory of children and their cognitive, emotional and social development is a useful framework for future study. As children mature cognitively and emotionally, outcomes should be measured with respect to the aspects most critical to the specific age period.

Further, children perceive and interact with green space differently as they grow up. For example, as children grow from early to middle childhood, they begin to display preference for playgrounds where they can play sports and structured physical games over natural areas without such affordances (L. Chawla et al., 2014; Samborski, 2010). Such a trend coincides with the increase in their motor skill, self-efficacy and awareness of peer acceptance. More evidence is needed regarding how children perceive and use different types of green space, what affordances they wish to have, and how physical and cognitive development explain dynamics in their choices.

### ***Access and disparity***

As initiatives emerge to prescribe nature to improve children's health, nature's role as a desired resource become increasingly recognized. Andersen's behavioral model of health services use provides a framework in examining access to green space and its psychological and cognitive benefits (Andersen, 1995). According to Andersen, access is divided into four components: potential access (enabling resources), realized access (actual use of health services), equitable access (when the resources meet the needs of the entire population), and inequitable access (which occurs when the social structure, health beliefs, and enabling resources determine whose needs are met). Previous studies have typically used either potential access, examining the presence or proximity of green space, or realized access, looking at how usage of green space or activity occurred in green space induces positive psychological states. However, equitable access and inequitable access aspects were rarely investigated.

Proximity has been widely used as a proxy for potential access to green space. Typical proximity measures include the nearest distance to the closest park or major green space (Balseviciene et al., 2014), the number of parks within a circular or network-based buffer from residence, and travel time measures. An adult research study revealed that visual proximity to green space completely mediates the relationship between neighborhood

greenness and psychological outcomes, thus highlighting the importance of the near-home and the visible aspects of nature (Van Herzele & de Vries, 2012).

Furthermore, the relevant scale in measuring one's environmental access may vary across child demographics, or even from child to child. Girls, for example, were observed to travel shorter distances to play, and thus were more influenced by near-home nature. For example, neighborhood green space was associated with concentration and ability to delay gratification in girls but not boys (Taylor et al., 2002). Similar evidence has suggested younger children were more likely to be influenced by their immediate school surroundings, compared to older kids (Bagot et al., 2015).

Realized access of green space can be measured in terms of frequency and duration of visits. Two questions remain unanswered regarding the extent to which frequency and duration of visits influence the outcomes: 1) what is the optimal, or minimal daily exposure duration for reducing stress, enhancing attention and positive behavior? Adult studies have demonstrated the restorative effect can be obtained starting with a 6 min to a 15 min or 30 min exposure to nature (Duvall, 2011; Jiang et al., 2014; Tsunetsugu et al., 2013; Van Dillen et al., 2012). But for children, the dose-response curve of exposure time and psychological outcomes has not been established. 2) As a buffering experience that helps build capacity and resilience, how long does the effect last after the exposure ends? One study showed a week-long wilderness program enhanced children's emotional and behavioral capacities, and such effect remained significant 90 days after the program (Norton & Watt, 2013). Taking a longitudinal approach, an adult study that examined the change of residential environments showed moving to a greener neighborhood was associated with a significant increased well-being score for the subsequent year, after which the effect leveled off (Alcock, White, Wheeler, Fleming, & Depledge, 2014).

Ethnically and socio-economically disadvantaged groups have been shown to face more barriers in transforming potential to realized access. For example, children from low SES backgrounds, such as those whose parents have lower educational achievement or are unemployed, tend to face more barriers to accessing green space, usually in terms of social constraints. As a result, they tend to report less green space playing time and less frequent visits (Amoly et al., 2014; Day & Wager, 2010). But they need the restorative effect of green space more than children from affluent families and also desire more access. One adult study might shed light on the underlying

cause of such unequal access. For women from low-income backgrounds in Copenhagen, the social-political structure of the urban fabric defines how people should look and act in parks, and not meeting the societal codes made them feel judged and avoid visits to parks (Thomas, 2015). Therefore, a more nuanced understanding of access and use, which examines how access is influenced by socio-political contexts and societal expectations for disadvantaged children, might lead to a better understanding of green space provision, use and psychological benefits.

Another reason why disadvantaged children deserve more research is that they are sometimes at higher risk for psychological and cognitive disorders, and therefore in greater demand of such environmental support. For example, for children diagnosed with ADHD, nature can be a low-cost and safe approach to manage the symptoms. Faber, Taylor and Kuo (2009) have reported a substantial effect of improvement in children's concentration after a walk in the park, comparable to the peak effects of taking methylphenidate. Results from behavioral research suggest that the cognitive and behavioral benefit of contact with nature is greater for children with more attentional and behavioral problems, than those without such problems (Markevych, Tiesler, et al., 2014; Roe & Aspinall, 2011). To broaden the social impact of children and nature research, more studies need to consider not only potential access, but also realized, equitable and inequitable access.

### ***Children-adult relationships***

Children-adult relationships and parenting should also be a theoretical framework for future children research. There is little research that explores how families perceive and engage in activities in green space. However, since parents have great influence on children's environmental exposure, children's psychological and cognitive development cannot be studied in isolation from their family contexts and their parents' attitudes. For children who have limited independent mobility, their exposure to green space is highly influenced by their parents' decisions on travel behavior (Huynh et al., 2013). Even for children' free play, the locations of choices are influenced by parents' perceptions of the quality and safety of the places (Veitch, Bagley, Ball, & Salmon, 2006; Zhou, Li, & Larsen, 2015). Adult literature also shows taking children out ("taking children to play," "taking kids to the park to let them burn off energy," etc.) ranks as one of the top motivations for visiting green space (Irvine, Warber, Devine-Wright, & Gaston, 2013). Future research can examine family-based contact with nature, family well-being outcomes and interventions.

### ***Methodological directions***

Since the psychological benefits of nature on children represent a fairly new area of research, most current studies are observational. A number of topics, including nature and excitement, creativity, identity and independence, have only been identified by qualitative studies. Multiple methods should be employed to test the consistency of findings. Furthermore, in areas that are discussed more, such as nature and stress recovery and attentional restoration, the majority of studies are cross-sectional. Future research with experimental study design is warranted to demonstrate the causal impacts of nature. In addition, some new technologies in data collection and analysis may be used to overcome the methodological limits of current research.

### ***New technologies in exploring children's psychogeography***

Capturing children's experiences with nature and their psychological and cognitive well-being is a complex process. Although self-reported measures may provide the most direct measure, there are circumstances when self-reports are not possible or reliable. For example, toddlers and young children lack the language ability to use the scales or describe their feelings accurately. EEG and MEG provide measures of brain activity associated with cognitive and affective aspects. Real-time in motion EEG, which can record brain activity while the participants engage in outdoor activities, offers huge opportunities to investigate how humans respond to various environments and activities. Neuroimaging techniques such as MRI and fMRI offer measurements to test regional neural activity by examining blood oxygenation. These noninvasive technologies have been used in a wide range of child psychological and cognitive studies, and are especially suited for nature and health topics. Current technologies, such as network tracing, might also significantly add to our understanding.

In addition, children often have limited skills in using spatial reference to record and depict their environmental exposure. New technology like GPS tracking offers us an opportunity to examine in detail children's environments, especially during unstructured activities. The combination of GPS tracking and experience sampling method (ESM) allow us to analyze children's exposed environment dynamically and couple their environmental exposure with subjective feelings and evaluations.

### ***Statistical approaches***

Children's psychological and behavioral development is set within complex environmental and social ecology and influenced by a broad array of contextual factors. Those factors could come from personal and familial, residential and school community, as well as societal levels. The within-level and between-level influences intertwine with each other in bringing about the psychological and cognitive outcomes. Research that is non-scalable across those dimensions would fail to capture the complex relationships and the contextual influence individual children receive from their social and environmental exposure. Therefore, a multi-level research design that takes into account factors at a variety of social and geographic scales would help untangle the relationship. Recent adult literature has increasingly used hierarchical linear models, and we expect this to be the new direction of data syntheses in research on children, too.

Another promising data analysis approach is structure equation modeling (SEM), as well as other latent variable techniques. Because of the complexity of psychological outcomes, there are variables that cannot be directly measured. By representing those psychological terms as latent variables, SEM models allow researchers to test multiple indicators and examine the relationships simultaneously.

### ***Policy implications***

Urban design has long been adult-centered, and children's needs haven't been considered. Designing spaces that meet children's perspectives and facilitate their developmental needs is essential in ensuring the well-being of children. Compared to adults who seek the calmness nature provides, children also concentrate on the joy, challenge and social experiences offered in green spaces. Design for children needs to consider a variety of affordances and spatial flexibility to support discovery, some complexity to induce arousal with appropriate levels of challenge, and combinations of design elements for different stages. For example, designs should include loose parts and dynamic spaces for young children to learn object performance and cause and effect, and a combination of natural and hard playground affordances that fit older children's expectations to practice and demonstrate physical efficacies.

This review also calls for the integration of nearby nature and nature-based programs into general health promotion and psychiatric services for children. Evidence has shown satisfactory effect sizes of nature

interventions on cognitive and psychological health. However, until now, nature has seldom been prescribed to child populations diagnosed with or under high-risk for psychological disorders. Health practitioners can provide effective, evidence-based nature interventions as preventive and treatment solutions.

### ***Limitations***

Several limitations need to be considered when interpreting the findings of the present review study. First, since our goal was to summarize new research, this study did not include published studies prior to 2010.

Although a number of important findings before 2010 were included in the discussion, new insights would likely emerge by integrating all articles published. Similarly, this study did not include published articles in languages other than English, which may be the reason behind the underrepresentation of studies outside Europe and North America. In addition, the review focuses on published peer-review journal articles; work that was unpublished or published through other venues was not included. These limitations may affect the generalizability of the findings.

Second, as the first systematic review on this topic, the present study was largely exploratory in understanding the potential psychological outcomes of children's contact with nature. Due to the relatively small number of research studies in this field and the great variations of study designs used (controlled experiments, quasi-experiments, cross-sectional studies, pre-post studies, case studies and various other qualitative methods), we decided there was no quality assessment tool that provided consistency in evaluating the broad range of studies included. Future studies may consider adopting more rigid quality assessment tools and carrying out a more focused synthesis of findings, or evaluating the pooled effect sizes using meta-analysis.

### **Conclusion**

While theory and evidence point to the impact that contact with nature has on children's psychological health, the recent increase in studies in this area require a fresh look at the evidence suggest a need to synthesize the new findings. This review examined studies published in the recent half decade and identified the conceptualization of nature, the emerged psychological well-being domains that are associated with contact with

nature, and mediation and moderation effects. Our findings suggest contact with nature affects attention, stress and mood states, self-esteem and confidence, pro-social behavior and relationships, excitement and creativity, happiness and subjective well-being, and identity and independence. Questions related to nature and executive functioning and the interaction between nature and exercise, as well as children's own environmental perceptions and activities have not been fully explored. There is a need for future research to explore children's access to nature, their developmental stages and family-based nature exposure.



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## Chapter 3

# Impact of Views to School Landscapes on Recovery from Stress and Mental Fatigue

### Introduction

Context impacts learning. It is well-documented, for instance, that physical characteristics of school environments such as lighting, noise, indoor air quality and thermal comfort, building age and condition all impact learning (Aturupane, Glewwe, & Wisniewski, 2013; Cheryan, Ziegler, Plaut, & Meltzoff, 2014; Roorda, Koomen, Spilt, & Oort, 2011). There is growing evidence that we have overlooked the impact school landscapes have on student academic performance. The cost of this oversight is that millions of children are trying to learn in settings that may be significantly less supportive than they might otherwise be.

Recent studies examining students' exposure to nature found the amount of vegetation within a campus significantly predicted school-wide student performance (i.e., standardized test scores, graduate rates) (Matsuoka, 2010; Wu et al., 2014). These exciting findings are correlational and thus the extent to which exposure to green school landscapes causes increased student performance remains unclear and unsubstantiated. We also do not know the mechanism or pathways through which green landscapes might influence student performance. Finally, if there is a causal relationship, we lack information regarding when the benefits of exposure to green campus landscapes might occur for students. The study reported here is designed to address these questions.

We begin by examining theory and evidence suggesting two possible pathways through which exposure to landscapes might result in better student performance—attention restoration and stress reduction. Next, we report a new study involving a randomized controlled experiment and end by discussing the implications of the findings for a variety of stakeholders.

## **Theoretical framework on nature and student performance**

### ***The influence of green space on children and adolescents***

Exposure to green space has been shown to have a variety of positive impacts on children and adolescents. These benefits include enhanced physical activity and play (Barton, Sandercock, Pretty, & Wood, 2014; Dymont & Bell, 2008), reduced chances of obesity and other chronic diseases (McCurdy, Winterbottom, Mehta, & Roberts, 2010), enhanced mental health and resilience (Chawla, Keena, Pevec, & Stanley, 2014; Corraliza & Collado, 2011; Flouri, Midouhas, & Joshi, 2014; Wells & Evans, 2003), improved environmental awareness (Chawla, 2009; Cheng & Monroe, 2012; Collado, Staats, & Corraliza, 2013; Wells & Lekies, 2006), and enhanced self-discipline and ability to concentrate (Faber Taylor & Kuo, 2009; Faber Taylor, Kuo, & Sullivan, 2002).

In education settings, recent studies have described a restorative effect associated with direct or indirect exposure to trees and other forms of vegetation on students across age groups. For elementary school students, the perceived restorativeness of school playgrounds is positively associated with vegetation volume and naturalness (Bagot, Allen, & Toukhsati, 2015; Collado & Corraliza, 2015). In a quasi-experimental study, middle school landscape renovation that increased the amount of vegetation was associated with reduced stress levels and enhanced psychological well-being (Kelz, Evans, & Röderer, 2013). Real and simulated views of natural elements were positively related to measures of attention and perceived restorativeness of college campus settings (Felsten, 2009; Laumann, Gärling, & Stormark, 2001; Tennessen & Cimprich, 1995). These studies suggest that students show objectively measured and anticipated restoration when exposed to greenness.

Green space offers restorative potentials, but to what extent does exposure to landscapes containing vegetation impact student performance? Two recent studies shed light on this question. One examined the relationship between vegetation condition surrounding schools and school-based student performance on math and English as measured by the Massachusetts Comprehensive Assessment System and found a positive association between vegetation cover and academic performance (Wu et al., 2014). Another study



measured high school environments including the amount of vegetation visible from classroom and cafeteria windows, the size of the windows, and the density of vegetation in each part of the campus, to predict student performance (i.e., standardized test scores, graduate rates, percentage of students planning to attend college). The findings demonstrated a positive relationship between nearby nature and school-wide academic performance (Matsuoka, 2010).

Although these two studies reveal a promising association between green campus landscapes and student academic performance, they are cross-sectional, correlational studies that cannot draw conclusions regarding the causal impact of greener campuses on student performance. It is possible, for instance, that these findings occur in part from self-selection. Perhaps more involved parents seek out greener settings and thus self-select into neighborhoods and school districts that have more trees. If this were the case, the association between exposure to green landscapes and student performance would be spurious. Thus, to determine if there is a causal link, we conducted a randomized controlled experiment to examine *how* green space affects academic performance. Why do students perform better when they were exposed to greener views? Two pathways seem most promising.

### ***Possible pathways between landscape and student performance***

Two theories have been proposed that might explain the effect of exposure to green landscapes on student performance: Attention Restoration Theory (ART) (Kaplan, Kaplan & Ryan, 1998; Kaplan, 1995) and Stress Reduction Theory (SRT) (Ulrich et al., 1991).

Sustained attention is the most important resource for learning. For students, inattention often results in academic underachievement (Demaray & Jenkins, 2011; Rapport, Scanlan, & Denney, 1999), and access to nature has been demonstrated as crucial for restoring attentional capacities (Schutte, Torquati, & Beattie, 2015). Therefore, restored attention may be a pathway through which green landscapes lead to better performance.

ART proposes that people use voluntary control to inhibit distraction and remain focused, and this capacity to remain focused fatigues over time. After a short exposure to a green space, the cognitive

capacity to focus attention is renewed because contact with nature enhances the inhibitory mechanism on which directed attention depends (Kaplan et al., 1998; Kaplan, 1995). Exposure to nature has been found to restore the cognitive resources supporting both executive functioning and self-regulation (Kaplan & Berman, 2010), which are also critical to learning.

Stress is predictive of reduced performance for children and adolescents. Studies have repeatedly shown that students who report lower personal and school-related stress attain higher GPAs (Gillock & Reyes, 1999), show more academic achievement (Grannis, 1992), and are less likely to engage in behaviors that lead to lower performance (e.g. truancy, dropping out of school) (Hess & Copeland, 2001). Therefore, reducing the stress that students experience might be a pathway through which green landscapes impact student performance.

SRT proposes that exposure to nature supports psychophysiological stress recovery, resulting in reduced blood pressure and lower levels of stress hormones (Ulrich et al., 1991). Recent studies also show positive physiological responses to nature including better neuroendocrine functioning (Van Den Berg & Custers, 2011), immune system functioning (Li, 2010), meditative brain wave activities (Aspinall, Mavros, Coyne, & Roe, 2013), and recovery from stressful experiences (Jiang, Chang, & Sullivan, 2014; Jiang, Li, Larsen, & Sullivan, 2014). A study involving elementary schools in Baltimore, Maryland, reported that students find green school yards a safe retreat from stress, because the natural areas allow students to build competence and form supportive relationships (Chawla et al., 2014).

The possible relationship between attention restoration and stress recovery has been mentioned but not empirically tested. One theory is that attentional fatigue is an aftereffect of stress (Ulrich et al., 1991), and therefore the attentional restoration effect is based on emotional and physiological changes. Kaplan and Kaplan (1995), on the other hand, argue that stress can be caused by the human perception of inadequate resources. When one's attentional resources are reduced by a demanding task, an individual's appraisal of inadequacy may trigger physiological stress. To date, however, no research has tested the mediation effect of stress recovery on attention restoration, or vice versa. Therefore, in addition to testing the two potential

pathways, we might advance our understanding of the relationship between these two mechanisms by testing the extent to which the relationship between green campus spaces and attention restoration depends on recovery from stress.

### ***The effect of daylight on student performance***

It is possible that the stress recovery and attention restoration effect of a window view, as well as student performance, is influenced by daylight entering the window (Collins, 1976; Plympton, Conway, & Epstein, 2000; Slopach, 2011; Zadeh, Shepley, Williams, & Chung, 2014) rather than, or in addition to, the greenness of the view. For many people, low levels of daylight can lead to seasonal depression, often called seasonal affective disorder (Beauchemin & Hays 1996). The symptoms of seasonal depression include sadness, anxiety, irritability, loss of interest in usual activities, withdrawal from social activities, and inability to concentrate (American Psychiatric Association, 2012). Clearly, these conditions are not conducive to learning.

Studies of daylighting in schools have demonstrated that full-spectrum daylighting in classrooms can promote overall health, reduce stress hormones, and enhance student performance (Küller & Lindsten, 1992; Nicklas & Bailey, 1997). These studies compared performance of students who learned in classrooms with different skylight and window light conditions. Thus, we wonder, is it enough to have access to daylight in classrooms or do views of green space enhance attentional functioning and help students recover from stressful experiences above and beyond exposure to daylight?

In order to examine the possible underlying mechanisms driving this relationship between campus greenness and student performance, we conducted an experiment using a randomized controlled design. We examined three main hypotheses – that views of green space from classrooms: 1) restores students' attentional functioning; 2) reduces students' stress levels; 3) reduces students' stress levels and restore attentional functioning above and beyond any effect from daylight. We also examine the magnitude and timing of the two effects, as well as the mediation effect of stress in the relationship between window view and attention.

## Methods

### *Experiment setting and participants*

Five public high schools in central Illinois were selected based on the criteria that they contained three classrooms that were identical in terms of room size, window size, lighting and furniture, but different in window views. To increase the generalizability of our findings, we selected two schools that were located in urban areas and three that were in suburban or rural areas. In each of the participating schools, we selected three classrooms for the experiment: a classroom with no windows, a classroom with windows that opened onto a built space, and a classroom with windows that opened onto a green space (Figure 1). Before the experiment, we arranged the classrooms to ensure similar classroom layout.

Ninety-four high school students (53 female and 41 male) were randomly assigned to one of the three classrooms in the school where they attended. The no window, barren window and green window classroom conditions had 32, 30, and 30 participants respectively. The experiment was conducted with one student at a time between 9 am and 5 pm on sunny days with room temperatures approximately 70°F. All rooms had all lights turned on. After giving consent, participants reviewed the inclusion criteria to ensure that they had no major health conditions or drug use that would influence their physiological or cognitive performance. To account for any confounding variables, a general information questionnaire was administered to collect data about participants' age, gender, race, grade, health information, self-reported chronic stress levels, self-reported chronic mental fatigue, and preference for their school landscape.

Figure 5. Examples of classroom window view conditions: no window (left), windows opened on to built spaces (middle), and windows opened on to green space (right).



School No.1



School No.4

### ***Procedure***

Each participant was randomly assigned to one of the three classrooms and completed the experiment with two examiners in the room. No other students or teachers were present during the experiment. All examiners were trained to follow the same experimental procedure, and they rotate to administer the three conditions. Students were instructed to sit in seats with identical orientation and distances to a window or, in rooms without windows, to the wall. To simulate classroom activities and induce moderate levels of stress and directed attention fatigue, all participants underwent a modified Trier Social Stress Test (TSST)

procedure (Kirschbaum, Pirke, & Hellhammer, 1993). First, participants had a 5-minute rest (time 1: baseline). Then, they engaged in 30 minutes of classroom activities that included a proofreading task to find given sequences of letters in a page of random English letters, a speech task in which they were instructed to talk in front of two examiners about their dream job, and a subtraction task in which they were given a four-digit number and asked to subtract 16 from that number, and then to continue subtracting 16 from each subsequent answer for five full minutes (time 2: class activity). They then had a 10-minute break during which they remained seated and awake in the classrooms (time 3: break). Questionnaires and attentional tests were administered at each time period.

### ***Constructs and measures***

#### ***Attention***

*Subjective attention.* Participants' baseline attentional functioning was assessed using a Visual Analogue Scale (VAS) questionnaire. VAS has been tested for construct validity and reliability, and has been shown to be well suited for the clinical assessment of self-reported psychological conditions (Lesage, Berjot & Deschamps, 2012). The VAS consisted of a 10-cm horizontal line. The left end of the line was marked "not at all" (0) and the right "extremely" (100). After hearing the instructions, participants placed a mark (X) on the line indicating the degree of mental fatigue they felt at that moment. By measuring the distance from the left end of the scale to the mark, we identified the value for the self-reported attention measure.

*Objective attention.* Participants were also asked to take the Digit Span Forward (DF) and the Digit Span Backward (DB) tests (Wechsler, 1981) of attentional functioning twice—once after the classroom activities, and once after the break. The DSF and DSB tests required participants to repeat increasing lengths of digit sequences in normal and reversed order until they make two consecutive failures. The tests have been used in a number of studies to assess attentional capacity, short-term memory and working memory (Yudofsky & Hales, 2008). We created a summary score for DSF and DSB to be used in the statistical analyses.

## ***Stress***

*Subjective stress.* Participants' baseline stress level was also assessed using a Visual Analogue Scale (VAS) questionnaire assessing the degree of stress they felt at that moment.

*Objective stress.* To record physiological measures of stress, participants were equipped with wrist and finger receivers of Electrocardiography (EKG) and Blood Volume Pulse (BVP), Skin Conductance Level (SCL) and body temperature (BT) throughout the experiment by the clinical biofeedback device Procomp Infiniti Physiological System. These measures are the most widely employed methods for measuring physiological stress, and are often used together in research related to exposure to nature and stress recovery (Jiang et al., 2014; Chang, Hammitt, Chen, Machnik & Su, 2008).

Heart rate measurement. Heart rate variability (HRV) was extracted from EKG and BVP data. Raw EKG data were reviewed to correct missed beats and extra beats. HRV represents the variation in the time interval between one heartbeat and the next (inter-beat interval), and has been shown to be one of the most reliable indicators of stress (Task Force of the European Society of Cardiology, 1996). The inter-beat interval (IBI) data were examined with Kubios HRV analysis software (University of Kuopio, Kuopio, Finland) to detect artifacts. Cubic spline interpolation was applied to replace missing IBI's. Data were also detrended using the smoothness priors method (Tarvainen et al., 2002). Time-domain measure pNN50 and frequency-domain measure LF/HF ratio were calculated at three times during the experiment. NN50 measures the number of pairs of successive normal inter-beat intervals that differ by more than 50 ms, with a smaller value indicating more stress and anxiety. pNN50 is the percentage of NN50 count within the total RR interval. LF/HF ratio is the ratio between the LF band power (0.04-0.15 Hz) and the HF band power (0.15-0.4 Hz), and a larger value indicates a hyper sympathetic nervous system which is related to increased acute stress and anxiety (Malik et al., 1996).

Skin conductance level (SCL) and body temperature (BT) measurement. Skin conductance (SCL) and body temperature (BT) have also been widely used to measure mental stress in laboratory and real life settings (Healey & Picard, 2005). SC and BI were collected with a sampling rate of 2048 measurements

per second. Raw SCL and BT data were processed to remove noise.

### ***Control variables***

Since students' chronic levels of stress, mental fatigue and landscape preference might influence our acute measures of stress levels and attentional functioning, we included Likert scale questions assessing chronic stress, chronic mental fatigue and the extent to which participants preferred their campus landscape.

## **Results**

Results are presented in four sections. First, we compare the baseline attention and stress levels among the three window-view groups to ensure there are no pre-treatment group differences. Second, we explore the effect of window view on students' ability to pay attention during class activities and after the break.

Third, we examine the same window-view effects on students' stress levels during class activities and after the break. In the last section, we investigate the extent to which stress recovery mediates the relation between green view and attention restoration.

### ***Baseline attention and stress***

Were there differences among the baseline levels of attention and stress for students who were randomly assigned to the three window conditions? There are no significant differences in the baseline attentional functioning levels ( $F=0.54$ ,  $p=0.59$ ), stress levels ( $F=0.98$ ,  $p=0.38$ ), chronic mental fatigue ( $F=1.33$ ,  $p=0.27$ ), chronic stress ( $F=1.13$ ,  $p=0.33$ ), or landscape preference ( $F=0.02$ ,  $p=0.98$ ) measures across the three groups at the beginning of the experiment. Overall, students' stress levels increased during the class activities and decreased after the break. Their attentional capacity declined during the class activities and rebounded after the break.

### ***Effect of window view on attentional functioning***

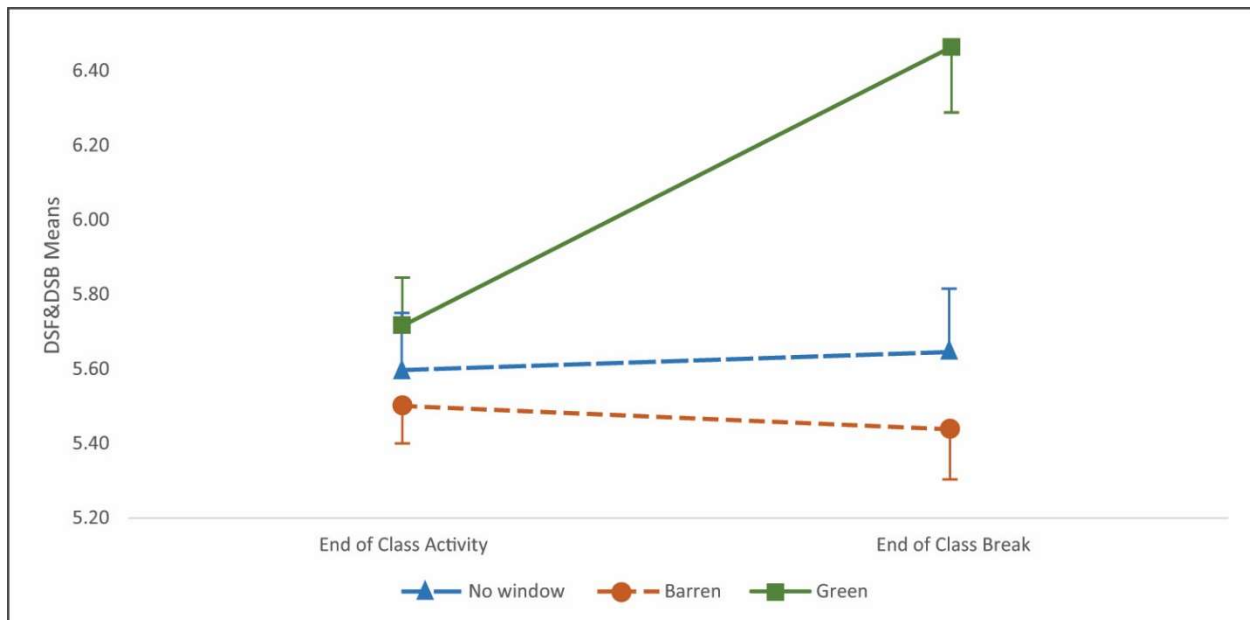
To what extent did the window view effect students' attentional functioning during class activities and after the break? To answer this question, we created a summary attention score using two objective measures of attention, digits forward and digits backward, and examined the repeated-measures ANOVA result during the baseline, after class activities and after the break.



Did the window view affect attention? Yes, a repeated-measures ANOVA with window view as the between-subject factor and class activity and break as the within-subject factors revealed both significant main effects and an interaction. Students' capacity to pay attention decreased during class activities and increased after the break ( $F_{1,90}(\text{time})=10.50, p<0.01, \eta^2 = 0.10$ ). Second, the window views differed in terms of their impact on student attentional functioning ( $F_{1,90}(\text{treatment})=4.43, p<0.05, \eta^2 = 0.09$ ). Third, the recovery effects of performing the activities and having a break differed based on the window view ( $F_{2,90}(\text{time}*\text{treatment})=11.14, p<0.001, \eta^2 = 0.20$ ).

Did the difference in attentional capacity occur after class activities, or after the break? To answer this question, we conducted univariate ANOVAs examining the impact of window views at the end of class activities and after the break. There was no difference among the groups at the end of the class activities ( $F_{2,90}(\text{activity})=0.51, p=0.60, \eta^2 = 0.01$ ), but there was a significant difference at the end of break ( $F_{2,90}(\text{break})=8.98, p<0.001, \eta^2 = 0.17$ ) (Figure 2). The attentional capacity in the green window view condition was 14.33 percent higher than the other two conditions combined.

Figure 6. Attention scores at the end of class activity and break (Means and SE.).



Which window view condition caused the attention restoration effect? To answer this question, we made

pairwise comparisons using Tukey's HSD (Tukey, 1949). The results demonstrate that after the break, the mean attention score for the green window view condition was significantly greater than the barren condition ( $p < 0.001$ ) and the no window condition ( $p < 0.01$ ). The barren and no window groups, however, showed no difference in attentional functioning after the break ( $p = 0.69$ ). Overall, students in the green window view condition demonstrated a 13.12 percent increase in attentional functioning.

What was the magnitude of the attention restoration effect after controlling for confounding variables? To answer this question, we regressed the change in attention scores (after break scores minus after class activity scores) onto the window view conditions (Table 1). The models controlled for demographic factors, chronic stress, chronic mental fatigue, and landscape preference. Taken together, these factors explained 18 percent of the variance in individual attention restoration (Model 1). After adding in classroom window view, the model improved significantly ( $p < 0.001$ ) and explained 31 percent of the total variance (Model 2). Students with green window views achieved attentional functioning restoration of 0.7 units higher than their peers who were randomly assigned to a barren window view, after controlling for the other variables. But the difference in attention restoration between the no window condition and the barren condition was not significantly different ( $p = 0.67$ ).

Table 3. Regression Analysis for Window View Conditions Predicting Attention Restoration and Stress Recovery.

Variables	Attention Model				Stress Model			
	Model 1		Model 2		Model 3		Model 4	
	B	SE	B	SE	SE	SE	B	SE
Intercept	-0.13	1.56	-0.10	1.46	-3.29	4.36	-4.26	4.27
Demographics								
Male	0.48**	0.17	0.46**	0.16	-0.19	0.48	-0.21	0.46
Age	0.04	0.09	0.00	0.09	0.15	0.26	0.13	0.26
Race								
African American	-0.01	0.21	0.16	0.20	-0.72	0.59	-0.42	0.59
Hispanic	-0.01	0.40	-0.10	0.38	0.49	1.23	0.21	1.21
Asian and Pacific Islander	-0.21	0.40	0.06	0.38	-0.39	1.08	-0.04	1.07
Other	-0.89*	0.37	-0.59+	0.35	-0.75	1.11	-0.13	1.10
Other Controls								
Chronic Stress Level	0.11	0.12	0.10	0.11	0.40	0.34	0.40	0.33
Chronic Attentional Problems	-0.31+	0.17	-0.20	0.16	-0.65	0.47	-0.48	0.46
Landscape Preference	-0.01	0.13	0.02	0.12	0.54	0.35	0.61 <sup>+</sup>	0.34
Treatment (barren view as reference)								
No Window			0.08	0.18			0.98 <sup>+</sup>	0.54
Green View			0.70***	0.20			1.36*	0.57
Stress Level change								
R2	0.18		0.31		0.10		0.17	
ΔR2			0.13***				0.07*	

+p<.1

\*p<.05.

\*\*p<0.01

\*\*\*p<.001

### ***Effect of window view on stress***

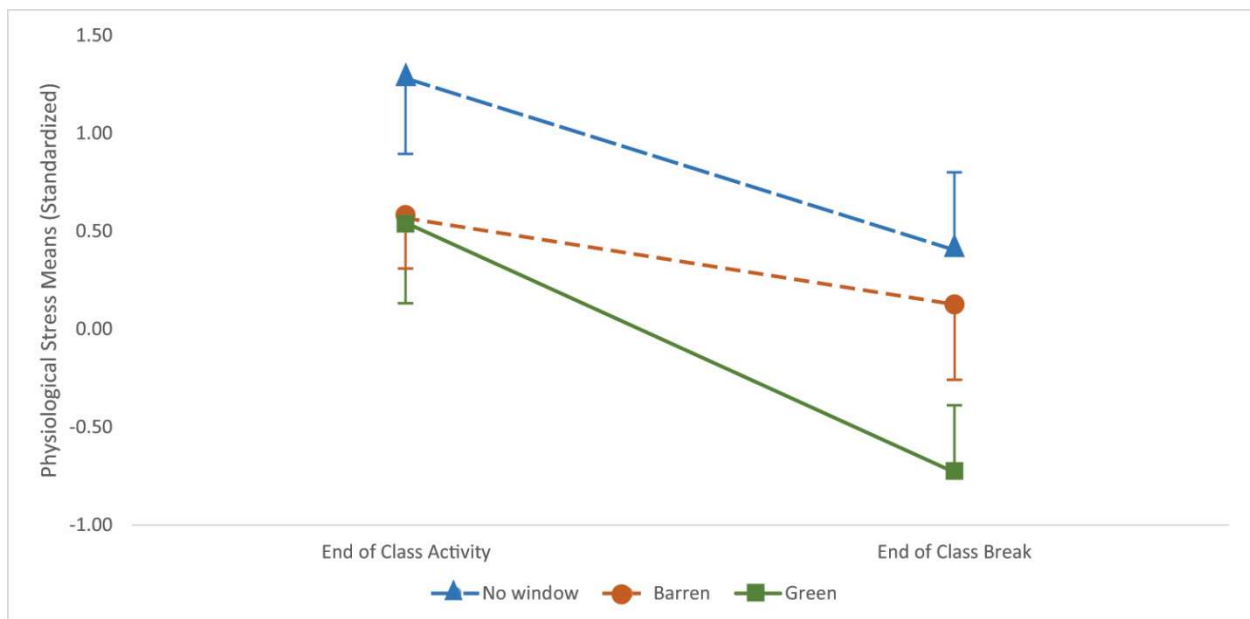
Does the window view have a significant effect on student's stress level during class activity and after the break as on attention restoration? To answer this question, we created a standardized summary physiological score (Cwir, Carr, Walton, & Spencer, 2011; Jiang, Chang, & Sullivan, 2014; Rosenthal & Rosnow, 1991; Rutledge & Linden, 1998) from skin conductance (SC), body temperature (BT), percentage of NN50 (pNN50) and ratio between low-frequency peak and high frequency peak (LF/HF) and performed repeated-measures ANOVA.

The repeated-measures ANOVA results show the effect of window views at different points in the

experiment. First, similar to the attention results, students' stress levels changed significantly during class activity and after the break ( $F_{1,84}(\text{time})=19.6, p<0.0001, \eta^2 = 0.19$ ). Considering all time periods, there was no significant difference in stress across the window view conditions ( $(F_{1,84}(\text{treatment})=1.93, p=0.15, \eta^2 = 0.04$ ). There were, however, changes in stress levels across the three window view conditions, though the effect size was small and the effect was only marginally significant ( $(F_{2,84}(\text{treatment})=2.73, p=0.07, \eta^2 = 0.06$ ) (Figure 3).

Because the time effect suggested stress recovery and the interaction effect was marginally significant, we compared the changes in stress levels (summary of changes of the four stress indicators) during class activities to the period immediately after the break across the groups using univariate ANOVA. The result showed a significant treatment effect in stress recovery ( $F_{2,84}(\text{stress recovery})=3.69, p<0.05, \eta^2 = 0.08$ ). Overall, the effect of window view on stress was similar to the pattern of change in attentional capacity, but the effect size was smaller.

Figure 7. Physiological stress at the end of class activity and break (Mean and SE.).



To what extent did classroom window view predict stress recovery above and beyond demographic

factors and baseline conditions? To answer this question, we regressed the summary stress recovery scores onto the environmental window conditions (see Table 1). Demographic factors, chronic stress, chronic mental fatigue, and preference explained 10 percent of the variation in stress reduction at the end of the break (Model 3). After adding in classroom window condition, the model significantly improved ( $p < 0.05$ ) and explained 17 percent of the total variance (Model 2). Stress reduction in a green condition was 1.36 units higher than that of the barren condition. But the comparison between no window and barren conditions was only marginally significantly different ( $p = 0.07$ ).

### ***Did stress recovery mediate the relationship between window view and attention?***

In the analyses above, we found that window view caused significant variations in both stress recovery and attention restoration. It is possible, therefore, as some have suggested (Ulrich et al., 1991) that the impact of window view on attention restoration is mediated by stress recovery. That is, the effect of window view on attention restoration may occur *through* stress recovery. If this were the case, stress recovery should be systematically associated with attention restoration. And adding in stress recovery in the regression model of window view predicting attention restoration would make the attention pathway completely or partially disappear. To test this possibility, we conducted a one-tailed Pearson Correlation and found that stress recovery and attention scores are not correlated ( $r = .08$ ,  $p = .23$ ). Thus, in this study, stress reduction did not mediate the relationship between window view and attention restoration.

## **Discussion**

In this study, 94 students from five high schools were randomly assigned to classrooms without windows, with windows that opened on to built space, and with windows that opened on to green spaces. Students in the green window view condition scored significantly higher on tests of attentional functioning and recovered significantly faster from a stressful experience than their peers who were assigned to rooms without views to green spaces. Accounting for confounding variables, the findings establish a causal relationship: green views produced better attentional functioning and greater recovery from stress. We found no beneficial impact of daylighting alone. Finally, there was no evidence that stress mediated the

relation between view to green landscapes and attention restoration, suggesting these are two distinct pathways influencing students' psychological and cognitive functioning.

### ***Contributions***

This is the first study to use a randomized controlled experimental design to examine the effect of views to green campus landscapes on students' attentional functioning and stress levels during class activities and breaks. Since sustained attention and free of stress have been proved to be critical for learning, our findings suggest the possible mechanism between greener campus and better student performance: green views promote attention restoration and recovery from stressful experiences. In this experiment, at the end of the class activities, there were no differences among the students in the three window view conditions with respect to attentional functioning or stress. But by the end of the break, students in the green window view condition performed significantly better on standard tests of attention and showed significantly greater stress recovery than their peers who were assigned to classrooms without a green view.

'driving the different outcomes between window lighting conditions and no window conditions (Plympton, Conway, & Epstein, 2000; Slopack, 2011).

### ***Implications***

The evidence presented here points to environmental factors that designers, planners, and policy makers can manipulate in order to enhance students' well-being and their likelihood of learning. We discuss the implications of these findings below.

### ***School site selection***

For planners working to identify sites for new schools, the result here suggests that sites that already have trees and other forms of vegetation are likely to have positive impacts on student learning. In the last few decades, there has been a dramatic shift in the location of high schools in North America. Whereas almost all high schools more than 50 years old are located in urban and suburban areas, almost all newer high schools (those less than 30 years old) are located at the rural-urban fringe or in rural areas. The hidden cost of siting schools on what was recently an agricultural field is that the lack of nearby trees will likely

have negative consequences for learning. One easy solution is to be sure that a portion of the school design and development budget is reserved for site improvements that include planting a considerable number of trees on the site.

### ***School ground and building design and renovation***

Architects should work to ensure that every classroom has views to green space. Landscape architects should consider the locations of classroom, cafeteria and hallway windows in the development of their campus designs. Historically, campus design has been approached from the perspective of visitors to schools—landscape features are designed to enhance the view to the school and give visual identity to the main entrance. The findings of this study, however, indicate that campus landscapes should serve more purposes than merely aesthetic appeal, and that designers should also consider the access to green space and green views from the angle of students and teachers who interact with the spaces on daily basis, especially those spaces that students and teachers interact with during their breaks. In addition to classroom views, views to green landscapes from hallways and the cafeteria seem particularly important. Providing views to green space in such areas will help students recover from mental fatigue and stress during their breaks and prepare students for their next class. Similarly, during renovations, designers should pay more attention to greening efforts on school grounds especially in areas where student activities and recess take place.

The views from classroom and cafeteria windows should be filled with natural features such as trees and shrubs. Classroom window views of large expanses of parking lots and athletic fields lacking natural elements should be minimized or screened by vegetation. Compared to most of the interventions aimed at relieving stress (e.g., emotional skill building, anger management, positive behavior programs), placing trees and shrubs on the school ground is a modest, low-cost intervention that is likely to have long-lasting effects on generations of students.

Further, our findings suggest a 10-minute break would suffice in restoring students' attentional capacities and help them recover from stressful tasks. School bell schedule should be designed to include short

break periods to allow students to restore their attentional capacities.

### ***Limitations and future research***

To assess the effect of window view on student's stress level and attentional capacity, we carefully controlled a number of factors including setting, classroom activities, and break conditions (e.g., students remained seated during the break). This design, which allowed us to ensure that all participants received the same treatments, increased the internal validity of this work. One limitation of such an approach, however, is that we could not take into account students' interactions, students' physical activities and their immersive experiences out on the school ground during the break, or their exposure to green space during physical education classes or after school. This limits the ecological validity of the findings presented here. Studies have demonstrated how immersive experiences in green school grounds help students recover from stress, build coping strategies, and form supportive social networks (Chawla et. al, 2014). Exercise in green space in school may also help students negotiate stress, regain attentional capacity and enhance mental health (Burdette & Whitaker2005). Future studies should examine how physical exposure to green schoolyards affect students' stress levels and attentional functioning. Future research might measure the combined impact of having green views from the school and green immersive experience, such as exercises on the school ground, on student performance.

The current study under-represents both the academic demands placed on students and the extent to which students may be exposed to green settings. A 40-minute experimental period far under-represents the academic and non-academic events that occur during an academic year that influence student's stress and attentional functioning. And the school ground is only one part of students' daily exposure to landscapes and thus cannot represent the variety or extent of landscapes to which students are exposed. Thus, future studies should expand the geographic and temporal aspects of landscape exposure and examine how other spaces impact student's psychological well-being and academic performance.

We made sure that the experiment resembled typical learning situations by including a 10-minute break in the study design. Most high schools in the US have breaks of 10 minutes or less. Clearly, a break of 10



minutes was long enough to demonstrate the impact of green views on attention and stress. Would a longer break have shown a larger effect on stress recovery? Would increasing the frequency of breaks also show an effect? What is the effect of the interaction between the duration and frequency of breaks with green view on students' stress recovery and attention restoration? Future research should examine these possibilities.

It is also possible that the relationship between green views and stress recovery is not linear. That is, in the first few minutes of a green view, stress recovery may be slow, but over time, recovery may speed up. To our knowledge, no research has established the time-course of stress recovery associated with green views. This is a promising area for future research.

We found no differences in stress recovery or attention restoration for students randomly assigned to classrooms without windows and to classrooms with windows that allowed sunlight to enter but did not provide views to vegetation. We did not measure the intensity of sunlight or make any effort to ensure that the sunlight in either the barren window or green window condition was at all similar. This presents some slight threat to internal validity. Future research might explore the impact of varying levels of sunlight under barren and green conditions on stress recovery and attention restoration.

This study examined the effect of classroom window views on high school students. Although this study did not measure academic performance and therefore cannot fully explain the pathway from greenness to academic performance, the findings suggest that stress recovery and attention restorations are pathways through which school landscapes influence student performance. Future study can test the mediation effect of attention and stress on academic performance directly. The findings add to the evidence demonstrating that green views have powerful effects on the productivity of students at various ages (Faber Taylor & Kuo, 2009; Matsuoka, 2010; Wu, 2014). Since cognitive functioning is critical to understanding, learning and performing different types of activities, views to green landscapes may also impact the productivity of workers (Bringslimark, Hartig, & Patil, 2007; Bringslimark, Patil, & Hartig, 2006). These pathways suggest rich possibilities for future studies.

## **Conclusions**

We close by noting the importance of enhancing students' psychological and cognitive health by providing classrooms with green window views. This study demonstrated that classroom views to green landscapes have significant, positive impacts on recovery from stress and mental fatigue. These findings can provide guidance to parents, teachers, school administrators, architects, landscape architects, planners and policy makers interested in creating more supportive environments for learning.

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## Chapter 4

# Moving Beyond the Neighborhood: Daily Exposure to Nature and Adolescent's Mood

### Introduction

Adolescence is a stage during which some of life's most rapid and challenging transitions occur. Adolescents struggle to cope with biological as well as rapid emotional and cognitive development (Collins, 2001; Davis, 2003). These struggles result in stress and mood swings, frustration, sadness, fatigue, and tension. Persistent negative moods can lead to depression, chronic stress, and anxiety disorders, which not only cause acute health problems but also are associated with increased risks for chronic conditions that will manifest later in life (Kuh & Shlomo, 2004; Miller, Chen, & Parker, 2011). Stressful experiences also effect dynamic brain maturation, which may give rise to behavioral issues and psychopathology in adulthood (Romeo & McEwen, 2006).

Negative moods in adolescents can be brought on by several normative and non-normative stressors as well as the pressures of daily life. Among them, academic pressure, interpersonal relationships, home life, financial pressure, uncertainty about the future, and an emerging sense of the looming responsibilities of adulthood are considered the most prominent (Byrne, Davenport, & Mazanov, 2007). These stressors, paired with a changing physiology, can result in turbulent changes in mood, commonly noted among adolescents. All adolescents experience these mood fluctuations, although some negative moods are more intense and persistent. According to a CDC survey conducted between 2005 and 2010, nearly two million adolescents in the United States reported at least half of their days (more than 14 days within the past month) being mentally unhealthy (Centers for Disease Control and Prevention, 2011). For this reason, understanding the potential interventions that can help enhance mood resilience in adolescents is important.

One intervention that is especially promising for enhancing adolescent mood is exposure to nature. Recent studies have shown that an exposure to natural settings can enhance positive moods and emotions, provide a retreat from daily hassles, and reduce psychological and physiological stress in children and adolescents (Corraliza, Collado, & Bethelmy, 2012; Li & Sullivan, 2016; Markevych et al., 2014; A. E. Van den Berg, Maas, Verheij, & Groenewegen, 2010; Wells & Evans, 2003). For example, Chawla et al. (2014) found that green school grounds were refuges for children and adolescents and helped them develop independence and social capacities. For adolescents in particular, exposure to nature offers an opportunity to build positive emotions and self-esteem (Feda et al., 2015; Norton, Wisner,



Krugh, & Penn, 2014). The benefits of natural exposures can manifest in both psychological and physiological measures of stress. For example, middle school and high school students have shown a significant association between access to nature and lower levels of blood pressure, heart rate variability and skin conductance (Kelz, Evans, & Röderer, 2013; Li & Sullivan, 2016). In addition, physical activities in green space can also lead to an increase in positive feelings (Reed et al., 2013).

Hartig and colleagues point out, however, that the relationship between contact with nature and health is hard to assess in free-ranging populations (Hartig, Mitchell, de Vries, & Frumkin, 2014). To date, most of the work on the relationship between nature and health has been conducted in artificially-controlled settings, which are not easily generalizable to a larger setting or the population level. In addition, very little of this research has been aimed at adolescent age groups. In fact, we know very little about the extent to which an adolescent's actual exposure to nature is related to their physiology or moods. We also do not have a good understanding of adolescents' day-by-day mood variability or the role of nature in effecting these changing moods.

This lack of knowledge costs us. If we do not understand the relationship between exposure to nature and variations in adolescent mood, we risk creating urban spaces that fail to respond to the specific psychological and emotional needs of young people. We also lose an opportunity to positively affect a difficult transitional life stage. Therefore, it is necessary to establish an ecologically valid approach to quantify adolescents' day-by-day contact with nature and examine how it is associated with their moods. Such an approach depends on analyses of the locations where young people engage in activities along with accurate assessments of the concentrations of nature at those locations.

### ***Mechanisms by which nature impacts mood***

In psychology, mood is considered a set of feelings that are ephemeral in nature, vary in intensity, and encompass more than one emotion or affect (Lane & Terry, 2000; Lane, Terry, & Fogarty, 2007). The evaluative aspects of mood often involve a range of characteristics, such as aroused to unaroused or pleasant to unpleasant (Lane & Terry, 2000). Many theoretical and empirical studies have explored nature's effect on aspects of mood, including stress and depression. In this study, we have adopted Profile of Mood States scale (McNair, 1971) to evaluate mood disturbances as a global measure of feelings of tension, depression, anger, fatigue, and vigor.

Attention Restoration Theory (ART) and Stress Recovery Theory (SRT) provided the basis for investigating the benefits associated with being in a natural environment. Kaplan and Kaplan argued that exposure to some forms of nature helps replenish a person's attentional capacity (R. Kaplan, Kaplan, & Ryan, 1998; S. Kaplan, 1995; S. Kaplan & Berman, 2010). Ulrich (1983) notes that being around some

forms of nature was associated with faster recovery from psychological and physiological stress. A plethora of recent studies have pointed to the positive impact of exposure to nature on various aspects of mood for adults, including stress, anxiety, depression, and hedonic tone. Viewing a slideshow of natural pictures on a screen induced significant increases in hedonic tone (Beute & de Kort, 2014). Watching natural videos or sitting outside in a green space led to a significant reduction in psychological stress (Beil & Hanes, 2013; Zhang, Piff, Iyer, Koleva, & Keltner, 2014). Compared to sitting in an urban environment, sitting for 15 minutes in a forest is associated with less tension, fatigue, confusion, and more vigor, as well as less mood disturbance (Lee et al., 2011). Using new technologies, such as mobile electroencephalogram (EEG), research results have suggested that walking in a natural area is associated with lower frustration, lower arousal, and higher meditation (Aspinall, Mavros, Coyne, & Roe, 2015). For children and adolescents, contact with nature is also associated with less stress or emotional problems (Chawla et al., 2014; Feda et al., 2015; Flouri, Midouhas, & Joshi, 2014), along with enhanced working memory and reduced inattentiveness (Dadvand et al., 2015). However, studies focusing on mood are scarce, and they have reported conflicting findings. One study showed that adolescents (11 years old) with ADHD displayed significant positive mood changes in the forest education program. However, when another group of children with ADHD (9-17 years old) were tested on their mood after activities in a wooded area versus a built setting, only the children who preferred the woods showed enhanced moods in the woods (A. Van den Berg & Van den Berg, 2011).

In spite of the extensive literature on connections to nature and health, some important questions remain. For example, to what extent are high concentrations of nature associated with more positive moods? Does this relationship differ across demographic and socio-economic groups? Understanding the relationship between the concentration of nature to which people are exposed and their psychological health is an important gap in the literature (Sullivan, Frumkin, Jackson, & Chang, 2014).

### ***Extending experimental evidence using an ecologically-valid design***

Some recent experimental studies have examined the psychological effects of access to nature on adolescents. In experimental settings, taking a 10-min break in a classroom that provided a view of natural landscapes induced significant stress recovery (Li & Sullivan, 2016). In quasi-experimental or field situations, a 25-min nature walk or a 7- to 30-day nature camp were associated with less stress, greater emotional affinity, and self-worth (Aspinall et al., 2015; Norton et al., 2014).

While experiments that control environmental exposures artificially are well suited for examining causal relationships, findings from such studies may not be representative of the larger patterns of exposure to nature, and thus represent limited ecological validity. Under experimental and quasi-experimental conditions, the environment and activities in which adolescents engage are highly structured and are

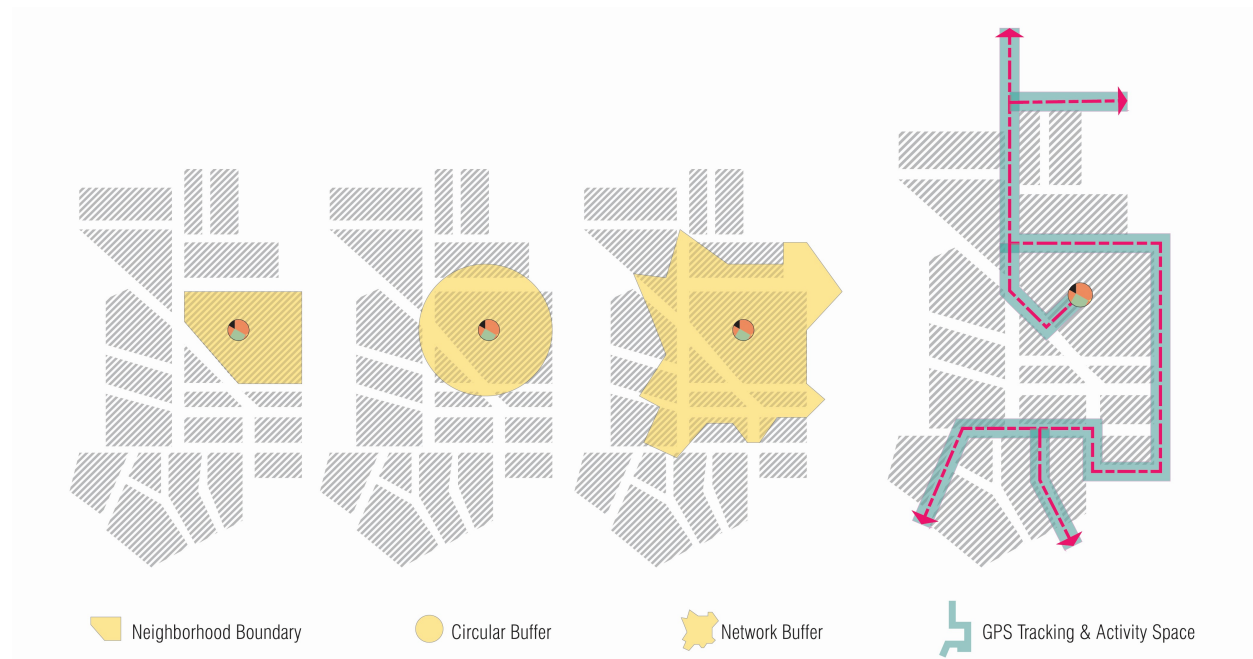
likely to be devoid of the daily social and environmental stressors that factor into adolescents' moods. Real environments also provide more complex and dynamic affordances; therefore, individuals can experience a broad range of emotions. Further, adolescent choices of places and (unstructured) activities, can greatly impact how they feel at any given moment. These, however, are typically not taken into consideration in experimental or quasi-experimental studies. Consequently, we are left to question whether the experimental findings can be applied to real-world situations, i.e., "To what extent do increased levels of nature enhance mood in real, everyday situations for adolescents?"

### ***Capturing adolescents' actual environmental exposure***

The majority of studies regarding nature and health have used aggregated geographic areas as the proxy for people's actual environmental contacts. The most frequently used are census blocks, census tracts, residential neighborhoods, circular buffers around a residence, or centroids of ZIP code zones (Balseviciene et al., 2014; Markevych et al., 2014). Such an approach is subject to the uncertain geographic context problem (UGCoP) (Kwan, 2012). That is, the environmental setting that is measured does not match the actual environment an individual is exposed to in real life – the one that affects behavioral and health outcomes. This creates significant measurement error.

This mismatch is especially significant for adolescents. Traditional approaches that rely on static boundaries or buffer areas often fail to capture the set of environments that adolescents actually occupy. Mid and late adolescence are the phases in human development when self-governance and autonomy emerge as the most important developmental needs (Spear & Kulbok, 2004; Zimmer-Gembeck & Collins, 2003). In the U.S, by age 16, young people are typically allowed greater autonomy and independence in their mobility patterns. They are allowed to obtain a driver's license, for example, dramatically increasing their independent geographic reach. They are also more likely to bike, walk, and take public transportation further and more often, expanding the world around them. As a result, home and school neighborhood spaces do not exert as much influence on adolescents as they do for younger children. For example, one study found that half of 15-19 year olds spent more than 90% of their time outside of their neighborhoods each day (Basta, Richmond, & Wiebe, 2010). Another study showed that even female adolescents spent one-third of their time in places more than 1 km from home (Wiehe et al., 2008). Consequently, a better assessment of adolescent environments is required to capture their complex and dynamic activities.

Figure 8. Neighborhood-based approaches of assessing environmental exposure and the activity space approach used in this study.



Approaches to incorporating daily mobility in health studies include activity surveys (Kestens et al., 2012) or surveys of regular destinations or favorite places (Chaix et al., 2012c). Recently, global positioning system (GPS) tracking has emerged as a way to monitor people’s movements (i.e., the places people where people spend time during the course of their daily activities). This “activity space approach” (Kwan, 2004; Sherman, Spencer, Preisser, Gesler, & Arcury, 2005) differs from approaches that use static neighborhood boundaries or buffer areas (Figure 8). It accurately captures the locations and times of people’s travel and the environmental context of behavioral or health outcomes (Kestens, Lebel, Daniel, Thériault, & Pampalon, 2010; Kwan, 2009, 2012; Kwan et al., 2009). Although activity space is a recognized approach in geospatial research, it has not been used in studies examining people’s contacts with nature and the effects on their psychological health.

***Assessing the concentration of nature at the street level***

To assess the impact of nature on mood in the spaces where adolescents travel, it is important to consider the extent to which nature exists in those spaces. The most widespread approaches to assessing the concentration of nature use existing land cover datasets, satellite imagery, or ortho-aerial photographs (Abkar, Mustafa Kamal, Mariapan, Maulan, & Sheybani, 2010; Garipey, Blair, Kestens, & Schmitz, 2014; Richardson et al., 2012). The strength of such technologies is that they offer objective ways to assess the presence and density of vegetation over large areas. Such measures, however, are subject to the

modifiable areal unit problem (MAUP) (Openshaw & Openshaw, 1984). That is, the results of the analysis depend on the arbitrarily aggregated unit of analysis. Another major weakness of this approach is its inherent exogenous or birds-eye view. These viewpoints can differ greatly from endogenous or eye-level perspectives that people typically experience in their environments. A recent study confirmed this mismatch between remotely-sensed measures and eye-level assessments in an analysis of people's response to tree cover (Jiang et al., 2017). The work supports the necessity for finding alternative ways of capturing the concentrations of nature and potential exposure.

One alternative has been the field audit. It is a frequently-used approach in evaluating the concentration of nature that can take endogenous characteristics into account (Boarnet, Day, Alfonzo, Forsyth, & Oakes, 2006; Day, Boarnet, Alfonzo, & Forsyth, 2006; Pikora et al., 2002). Field assessments require visiting a study area to observe and document a variety of characteristics of the built environment (some studies have included vegetation and other natural features) (Francis, Wood, Knuiman, & Giles-Corti, 2012). As important as field audit tools are in understanding environmental exposure, they are sometimes cumbersome, often expensive, always time-consuming, and may be susceptible to researcher bias.

A newer technology that shows some promise is Google Street View. Street View provides panoramic and omnidirectional views of street scenes. Because of the scale at which they are taken, these are direct representations of the environmental stimuli and endogenous visual experiences of individual viewers. These images can be used to calculate the density of vegetation objectively in each scene. A collection of scenes for a given location can provide an accurate assessment of the concentrations of nature for the place. And when connected to specific geographies, pathways, or activity spaces, it can also provide a more ecologically valid determination of potential exposure.

### ***Research objectives***

This study examines the impact of exposure to nature on an adolescent's mood using an ecologically valid research design. We examine exposure to nature by carefully measuring the concentrations of nature in the places that adolescents actually occupy. We then assess the extent to which this exposure predicts their mood. Specifically, we ask the following questions:

1. What is the average concentration of nature that a typical adolescent experiences in their environment?  
Do these vary across demographic or socio-economic groups?
2. To what extent is this concentration of nature related to their mood, after controlling for the inter- and intra-individual variables?

## **Methods**

### ***Participants***

We recruited 155 adolescents from four central Illinois metropolitan areas: Champaign-Urbana, Danville, Peoria, and Springfield. We enlisted volunteer participants through the public high schools. We recruited participants by sending mail and email invitations to all high school students on the school registration lists for 2014. We also posted fliers at each high school and made information about the study available through school-wide announcements. A participating student was accepted into the study only after he or she had signed an assent agreement and a parent or guardian signed parental consent. The study procedure was approved by the Institutional Review Board.

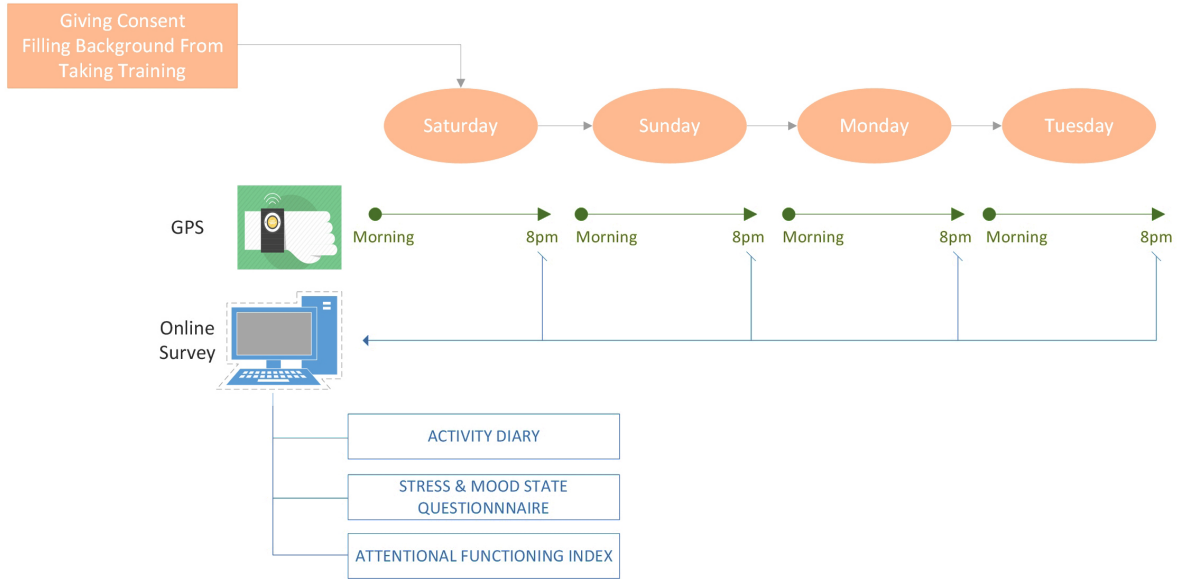
### ***Procedure***

We collected three types of information from each study participant regarding their activities, the location of those activities and their self-reported moods. Each participant used GPS tracking, activity diaries, and mood reporting tools for a consistently specified four consecutive day period – Saturday through Tuesday. Participants were asked to choose the preferred dates of their four-day sequence within a two-month window from late August to late October to ensure there was no out-of-town travel or special social event during the four-day period.

In order to collect detailed data about each participant's movements during these four days, each participant wore a Garmin Foretrex 301 receiver from when they got up in the morning until 8:00 P.M. We set the GPS unit to record data at a time resolution of every 15 seconds. The GPS data were stored in the memory of the GPS receiver, and the participants uploaded the data each night during the study period.

Participants kept a detailed activity diary and completed a self-reported online questionnaire delivered through Survey Gizmo every night between 8:00 P.M. and 12:00 A.M. During the day, the participants were asked to keep activity-travel diaries of all activities that lasted longer than 30 minutes. Ten categories of key information were requested for the online questionnaire for each activity: 1) starting and ending locations, 2) starting and ending times, 3) travel mode to the location where the activity occurred 4) the type of activity, 5) the purpose of the activity, 6) the extent to which the activity was flexible or obligatory, to which participants responded using a 5-point likert with 'flexible' and 'required' as the two extremes), 7) whether they were alone or had company, 8) attractiveness and restorativeness of the environment, 9) stress levels and 10) narrative feelings during the activity. Figure 9 outlines the data collection procedure.

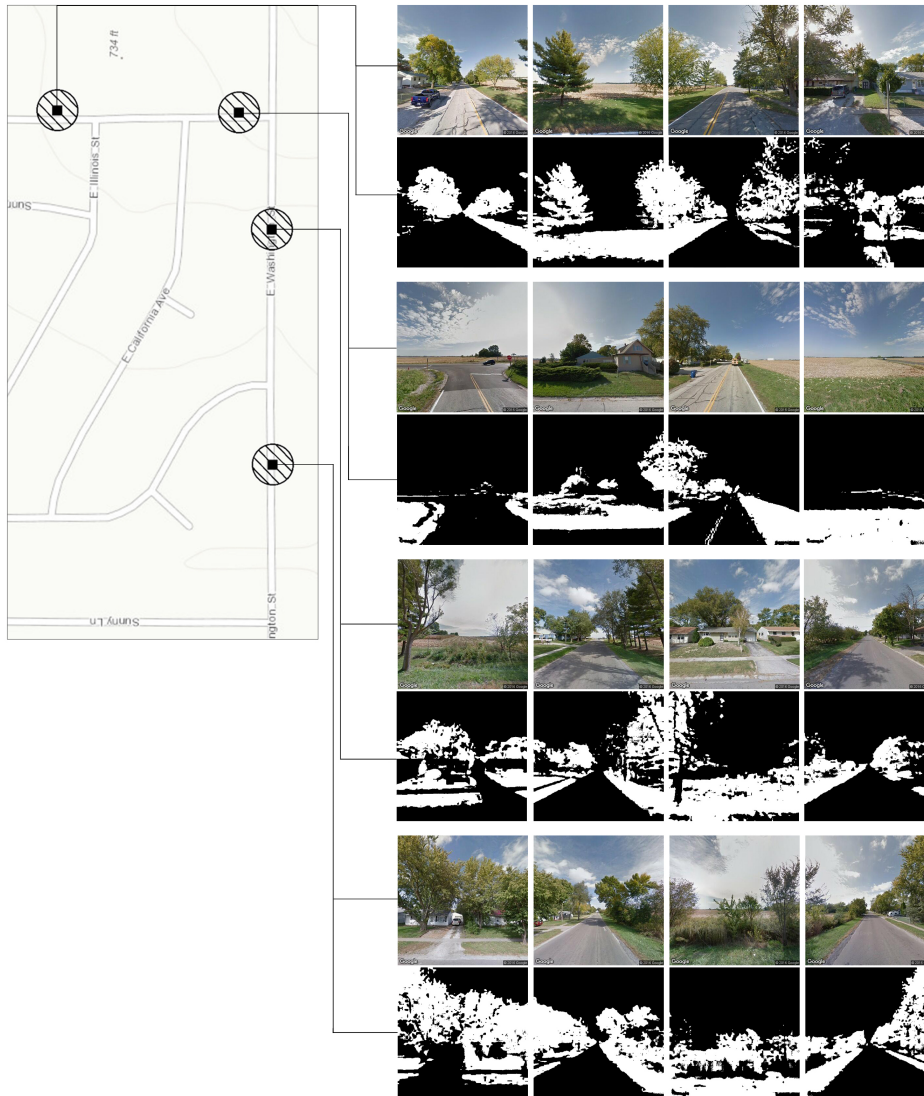
Figure 9. Study data collection and reporting procedures over the chosen Saturday - Tuesday participation sequence.



### **Measures**

**Concentration of nature.** We measured the concentration of nature to which each of the participants was exposed in four steps. First, GPS tracking data were classified into indoor and outdoor activities based on a review of the data and information provided in the activity diaries. Second, we fetched Google Street View images around each point location. We retrieved eye level images for each of the cardinal directions, i.e. four images (N,S,E,W) per location. Each pixel in each image was classified into two categories, vegetation or non-vegetation (Figure 10). This procedure was accomplished through a rule-based algorithm which was assessed using a test dataset that was manually classified using Adobe Photoshop. We then calculated the percent of vegetation visible in each image as our measure of vegetation density. Finally, the vegetation density for all images at all points on a given path was averaged to determine a vegetative index of the route taken. An overall vegetative index was then calculated across all routes an individual took for the entire day. An equally spaced time sampling was used (15-second intervals) to ensures places associated with longer stays or more frequent visits were weighed more heavily in the daily concentration and exposure index.

Figure 10. Extracting Google Street View images along routes and calculating the concentration of nature.



**Mood.** To measure mood, we used an adapted Profile of Mood States; 2nd Edition–Youth (POMS-Y) as part of the online questionnaire completed each evening by each participant. The questionnaire was used to evaluate both an enduring mood state (in the past week) along with transient feelings (current mood). The scale has been tested for validity and reliability and demonstrated acceptable sensitivity for a quick assessment of mood states (Curran, Andrykowski, & Studts, 1995). We evaluated five subscales: a) tension-anxiety, b) depression-dejection, c) anger-hostility, d) fatigue-inertia, and e) vigor-activity, using 20 questions on a 5-point Likert scale (Curran, Andrykowski, & Studts, 1995). A typically included 6th subscale – confusion-bewilderment, was not included in this study because it was developed to assess



illness-related cognitive dysfunctions that are not a part of this study. The subscale has also exhibited lower factor loading in previous research (Shacham, 1983). Then, a total mood disturbance score was calculated by reversing the vigor scale score and summing the scores across the five factors. A lower mood disturbance score indicates a better mood. We calculated Cronbach's Alpha for each subscale across all participants to estimate of the reliability of the scale: tension (.75), depression, (.82), anger (.85), fatigue (.75) and vigor (.79). The Alpha coefficient for the overall study mood score was .85. These scores demonstrate that the subscale measures are a reasonably good measure of overall mood.

**Control Variables.** Information was also collected on potential confounding variables. Individual control variables included demographic, socio-economic information (including a continuous SES variable and a dichotomous low-income variable), automobile access, pet-ownership, recent challenging events, and chronic mental disorders. The day-by-day level control variables included school day, total free time, total screen time, total physical activity time, and special events.

### ***Statistical analysis***

Analyses were conducted to investigate the relationship between the concentration of nature and mood using SAS 9.4 Statistical Software.

Descriptive statistics were examined to identify the overall range and distribution of the concentration of nature by participant, the five sub-scales of mood, and total mood score. Pearson's pairwise correlations were examined for the association between the concentration of nature and the scores on each mood subscale, as well as the overall mood score for of each participant.

Given the existence of data hierarchies, we used multilevel modeling (MLM) to predict day-by-day mood, allowing for residual components at each level. Since each participant completed four days of surveys, the day-by-day variances were modeled as intra-individual (level 1) variables, whereas the inter-individual variances (level 2) also were considered in the model. We fitted two MLM models to examine the association between the concentration of nature and mood. We first tested an unconditional model to estimate the inter- and intra-individual variances in reported mood. The inter-individual differences accounted for approximately 40% of the variation (Formula 1), which justified our decision to use a two-level model.

$$ICC = \frac{\sigma^2_{\text{individual characteristics}}}{\sigma^2_{\text{individual characteristics}} + \sigma^2_{\text{day-by-day exposure}}} = 0.40 \quad \text{Formula 1}$$

In Model 1 (M1), after plotting the data and conducting model selection using fit statistics (-2Log Likelihood, AIC, BIC, AICC) and chi-squared tests, we found that a random intercept model fit the data best. In addition to concentration of nature, we also included the controlled variables in predicting mood

(see Formula 2). To further examine the relationship between varying degrees of concentration of nature and mood, we used an individual mean-centered concentration and individual average concentrations of nature to predict mood in Model 2 (M2). Other Model 1 variables and parameters remained the same (see Formula 3). Both models proved significantly different from null models. We also tested cross-level interactions between the concentration of nature and individual-level variables.

M1:

Level 1: Formula 2

$$Y \text{ (Mood disturbance)}_{ij} = \beta_{0j} + \beta_{1j} \text{ (Green concentration)}_{ij} + \beta_{2j} \text{ (Outdoor time)}_{ij} + \beta_{3j} \text{ (Day of week)}_{ij} + R_{ij}$$

Level 2:

$$\beta_{0j} = \gamma_{00} + \gamma_{01} \text{ (Gender)}_j + \gamma_{02} \text{ (Race)}_j + \gamma_{03} \text{ (SES)}_j + \gamma_{04} \text{ (Access to car)} + U_{0j}$$

$$\beta_{1j} = \gamma_{10}$$

$$\beta_{2j} = \gamma_{20}$$

$$\beta_{3j} = \gamma_{30}$$

$$\beta_{4j} = \gamma_{40}$$

M2:

Level 1: Formula 3

$$Y \text{ (Mood disturbance)}_{ij} = \beta_{0j} + \beta_{1j} \text{ (daily increase in concentration)}_{ij} + \beta_{2j} \text{ (Outdoor time)}_{ij} + \beta_{3j} \text{ (Day of week)}_{ij} + R_{ij}$$

Level 2:

$$\beta_{0j} = \gamma_{00} + \gamma_{01} \text{ (Gender)}_j + \gamma_{02} \text{ (Race)}_j + \gamma_{03} \text{ (SES)}_j + \gamma_{04} \text{ (Access to car)} + \gamma_{05} \text{ (Individual average concentration)} + U_{0j}$$

$$\beta_{1j} = \gamma_{10}$$

$$\beta_{2j} = \gamma_{20}$$

$$\beta_{3j} = \gamma_{30}$$

$$\beta_{4j} = \gamma_{40}$$

## Results

### *Descriptive statistics*

Descriptive statistics of the variables are presented in Table 4 below. The gender breakdown of all study participants (n=155) was 42% male (n=65) and 58% female (n=90). 50% of the participants were from low-income families. The majority of the participants identified as white (60%), 20% identified as Black, and the remaining 20% identified as multi-racial, Asian, or Hispanic. Regarding mobility, approximately 75% of the participants had access to a car and 50% used an automobile to travel from home to school daily (including driving and as a passenger). Geographically, the sample included 67 from Champaign-Urbana, 36 from Danville, 31 from Springfield and 21 from Peoria. The participants' GPS tracks covered broad areas of the four cities (Figure 11).

The participants engaged in an average of five activities, and on average, spent a little less than an hour

outdoors every day. We found the average time spent outdoors to be 50 minutes on weekdays and 61 minutes on weekends. The difference in weekday and weekend outdoor time was found to be statistically significant ( $t$ -Satterthwaite = 2.25,  $p = 0.03$ ). The majority of the participants spent more than an hour watching TV or using other electronic devices each day, with 33% of the participants averaging more than three hours in these 2 activities each day.

Study participants exposed themselves to a broad spectrum of environments, with the concentration of nature scores ranging from 3.80 to 40.30% ( $m = 18.35\%$ ,  $SD = 6.32$ ). There was no significant difference in the concentration of nature between weekday and weekend environments ( $t = 0.90$ ,  $p = 0.37$ ).

Figure 11. Areas covered by participants' GPS tracks in Yellow: Champaign-Urbana above; Springfield below left; Danville below center; and Peoria below right.



Regarding mood, the sample showed, on average, low-to-medium levels of tension, depression, anger, and fatigue, which did not significantly vary between weekdays and weekends (Wilcoxon Test = 82301.50,  $p = 0.25$ ). However, individual mood scores displayed a spread pattern ( $m = 7.94$ ,  $SD = 11.52$ ) and varied from -14 to 49 on a scale between -16 and 64. Compared to males, females displayed poorer overall mood (Wilcoxon Test = 62811.00,  $p < 0.01$ ) in our sample population.

Table 4. Means and Standard Deviations for Variables Used in the Analysis Predicting Adolescents' Day-by-Day Mood States.

Variables	Metric	Mean	SD	N
<b>Response Variables</b>				
Tension	0-16	3.52	3.28	585
Depression	0-16	2.36	3.13	585
Anger	0-16	3.62	3.76	585
Fatigue	0-16	4.10	3.65	585
Vigor	0-16	5.66	3.88	585
Mood Disturbance	-16-64	7.94	11.52	585
<b>Explanatory Variable</b>				
Concentration of Nature (%)	0-100	18.35	6.32	495
<b>Level 1 Control Variables</b>				
Number of activities	1-28	5.80	2.60	585
Overall stress	0-100	37.47	27.45	585
Outdoor time (min)	0-840	55.26	56.00	585
<b>TV and computer time</b>				
Less than half hour	1=<0.5 hours, 0=other	0.15	0.36	585
Half an hour to an hour	1=0.5-1 hour, 0=other	0.17	0.38	585
An hour to three hours	1=1-3 hours, 0=other	0.33	0.47	585
More than three hours	1=>3 hours, 0=other	0.35	0.48	585
<b>Level 2 Control Variables</b>				
Gender	1=male, 0=female	0.42	0.50	155
Age (years)	13-19	15.72	1.06	154
SES (summary)	0-80	32.13	14.95	150
Income	1=low-income, 0=others	.4967	0.50	151
Car access	1=car access, 0=no access	.7597	0.43	154
Dog ownership	1=own dog, 0=no dog	.5260	0.50	154
<b>Ethnicity</b>				
White	1=White, 0=others	.5800	0.50	150
Black	1=Black, 0=others	.1933	0.40	150
Asian	1=Asian, 0=others	.0533	0.23	150
Hispanic	1=Hispanic, 0=others	.0467	0.21	150
Native American	1=Native American, 0=others	.0133	0.12	150
Multi-racial	1=multi-racial, 0=others	.1133	0.32	150
<b>Primary travel model to school</b>				
Automobile	1=Automobile, 0=others	.5419	0.50	154
Public Transit	1=public transit, 0=others	.1032	0.31	154
Bus	1=school bus, 0=others	.1613	0.37	154
Walking	1=walking, 0=others	.1226	0.33	154
Biking	1=biking, 0=others	.1032	0.31	154
Multi-mode	1=multi-mode, 0=others	.1032	0.31	154

Does the density of vegetation in one's environment differ across socio-economic groups? To test this supposition, we conducted t-test analyses to assess the correlation between the concentration of nature by income group. This test was also used to assess the bivariate correlation between the continuous Socio-

economics (SES) variable and the concentration of nature.

The bivariate correlation showed a positive association between SES and the concentration of nature ( $r = 0.31, p < 0.0001$ ). That is, the higher the SES, the greater the concentration of nature to which adolescents were exposed. Adolescents from low-income families were exposed to places with lower concentrations of nature than the other adolescents ( $t\text{-pooled} = 5.23, p < 0.0001$ ). The average concentration of nature for those from medium and high-income households was approximately 20%, while low-income adolescents were exposed to environments with a concentration of nature of approximately 16%.

***The association between the concentration of nature and moods***

To determine the relationship between the concentration of nature and moods, we investigated the correlation matrix between the concentration of nature and the mood subscales. Bivariate correlation analyses showed that the concentration of nature was associated significantly and negatively with depression ( $r = -0.09, p < 0.05$ ), anger ( $r = -0.16, p < 0.01$ ), fatigue ( $r = -0.12, p < 0.01$ ), and overall mood ( $r = -0.13, p < 0.01$ ) (Table 5). That is, the greater the concentration of nature, the less depression, anger, and fatigue that were reported, and the better the overall mood was reported.

Table 5. Bivariate correlation between the concentration of nature and the indices of mood.

	Tension	Depression	Anger	Fatigue	Vigor	Mood Disturbance
Nature concentration	-0.03	-0.09*	-0.16**	-0.12**	0.02	-0.13**

\*. Significant at the .05 level

\*\*. Significant at the .01 level

The models help further explain the magnitude of the association between concentration of nature and mood (Table 6). The results of M1 (random-intercept model) showed that the concentration of nature was negatively associated with mood, indicating that the greener one’s environment is, the less he or she experiences mood disturbances after controlling for all other variables ( $B = -0.2151, p < 0.05$ ).

In addition to concentration of nature, the only daily activity variable that marginally predicted mood was the time spent in outdoor activities ( $B = -0.01576, p < 0.1$ ). Adolescents who spent more time outdoors were marginally more likely to have fewer mood disturbances. Somewhat surprisingly however, other variables, including the number of activities, special events, TV time, weekday-weekend did not predict mood. This result can be seen in both the parameter estimates and the model comparison procedure; removing these variables from the model did not produce significant likelihood ratio test results.

Similarly, removing each variable from the model one at a time did not yield significant improvements in the estimates of the parameters in any of the steps we used to compare the models. Three level-two

variables – gender, race, and access to cars – significantly or marginally significantly predicted mood. Female and multi-racial participants reported more mood disturbances than male ( $B = 3.6988, p < 0.05$ ) and white participants ( $B = 4.275, p < 0.1$ ). Adolescents who did not have access to a car also had significantly higher mood disturbances than their peers who had access to a car ( $B = -4.3599, p < 0.05$ ). We tested the extent to which these relationships were explained by SES or poverty by running chi-squared tests and substituting access to a car for SES or poverty in the model. The results suggested that access to a car was associated significantly with being in a higher SES group (chi-square = 13.0609,  $p < 0.01$ ), but it was not associated with poverty (chi-squares = 1.0839,  $p = 0.2978$ ). Substituting SES for access to a car yielded insignificant estimates of parameters for SES and produced an overall worse model fit. This suggested that access to a car made a unique contribution to mood states independent of SES.

The results of M2 (random intercept model with centered variable) also confirmed a positive association between concentration of nature and mood. Increase in the daily concentration of nature was only marginally associated with less mood disturbances ( $B = -0.2419, p < 0.1$ ), but increases in the average concentration of nature (across all days) were significantly associated with fewer mood disturbances on any specific day ( $B = -0.2953, p < 0.05$ ). The overall direction of the control variables stayed the same, slightly decreasing in magnitude.

Table 6. Results of multi-level model predictions of day-by-day mood states.

	Model 1		Model 2	
	B	Standard Error	B	Standard Error
Fixed Parts				
Intercept	8.1632*	2.5952	11.5345**	3.0865
Nature concentration	-0.2151*	0.09493		
Increase in daily concentration			-0.2419 <sup>+</sup>	0.1312
Increase in average concentration			-0.2953*	0.1411
Outdoor time	-0.01576 <sup>+</sup>	0.008247	-0.01356 <sup>+</sup>	0.00812
Day of week				
Weekday	0.9869	0.8532	1.035	0.8572
Access to car				
Yes	-4.3599*	1.8275	-3.4519 <sup>+</sup>	1.8521
Gender				
Female	3.6988*	1.5054	2.1034	1.6481
Race				
Black	-0.6656	2.0373	-0.3623	2.105
Asian	-0.3267	3.1664	0.3142	3.2502
Hispanic	4.0025	3.4127	4.0589	3.5108
Native American	0.7848	6.6091	-0.1164	6.7668
Multi-racial	4.275 <sup>+</sup>	2.3739	4.5989 <sup>+</sup>	2.4394
SES				
SES high	1.8006	1.7371	2.1091	1.7955
SES low	-0.9705	1.8352	-0.628	1.9132
Random Parts				
$\tau^2$	45.5044**	8.7158	49.4252**	9.1734
$\sigma^2$	77.5380**	6.1517	77.4705**	6.1569

<sup>+</sup>. Significant at the .1 level

\*. Significant at the .05 level

\*\* . Significant at the .01 level

None of the cross-level interactions between concentration of nature and individual characteristics were significantly better than the random intercept model, and the estimates of the cross-level terms were not significant. Thus, for adolescents, every one percent increase in concentration of nature in their environments is associated with the same amount of mood enhancement, regardless of their demographic backgrounds.

## Discussion

The main purpose of this study was to examine the association between exposure to varying concentrations of nature on a daily basis and adolescent mood. We studied this relationship using an innovative methodology that combines GPS tracking, Google Street View, imagery processing, and survey techniques. Multi-level modeling analysis revealed negative relationships between the concentration of nature and daily mood disturbances in participating adolescents, even after controlling for intra-individual and inter-individual level confounding variables. We found the greener the



environments that the adolescents were exposed to on a daily basis, the better their mood states. In the paragraphs that follow, we describe the theoretical and methodological contributions of this research and identify future questions that might build upon this work.

### ***Contributions***

Our findings suggest that exposure to nature can be an effective psychological health intervention for all adolescent groups. One strength of this study was the ecological validity associated with the everyday settings and the fine-scaled assessment of individuals' environmental exposures. The findings contribute to our understanding of the extent to which varying concentrations of nature are related to the moods that young people experience on a daily basis. Given the noted variability in adolescent's mood (Larson & Ham, 1993), it is striking that exposure to nature and the intensity of that exposure can effect these moods. But these findings are consistent with a range of studies demonstrating the impact that exposure to nature has on people in their everyday lives: increased exposures to nature is associated with lower levels of aggression and violence (Kuo & Sullivan, 2001); lower levels of stress (Roe et al., 2013; Thompson et al., 2012, Jiang, Li, Larsen & Sullivan, 2014; Jiang, Chang, & Sullivan, 2014); milder symptoms of ADHD for children who have been formally diagnosed (Faber Taylor & Kuo, 2011); higher levels of well-being (Sullivan & Chang, 2011); and reduced feelings of distress (White, Alcock, Wheeler, & Depledge, 2013).

The findings presented here help to extend the relevant environmental setting for studying adolescent behavior from residential neighborhoods or school surroundings to places associated with daily activities and travel patterns. Our findings suggest that an individual's average contact with nature (usually in their neighborhood) and the occasional visited green space can both affect mood. Such a finding is consistent with the favorite places study which suggested that adolescents often retreat to their favorite places to calm down and relax after experiencing threatening or emotionally negative moods (Korpela, 1992, 2003). Such places can include neighborhoods, as well as department stores, shopping malls, streets, green space, sports facilities, and others (Korpela, 1992; Vanderbeck & Johnson, 2000). Our findings call for a more nuanced examination of adolescents' preferences in places and activities. We emphasize the importance of nature within third places (Putnam, 1995) in adolescents' emotional regulation and well-being.

Researchers have posited that the beneficial effects of nature may be moderated by socioeconomic status or ethnicity, with greater benefits seen in disadvantaged groups (McEachan et al., 2015). Other studies however, have presented contradictory findings (Dadvand et al., 2014; Mitchell & Popham, 2008). Our findings suggest that the impact of the concentration of nature on mood does not vary across ethnicity or socio-economic groups. This may conflict with a recent study of pregnant women that found there were

stronger associations between green space and fewer depressive symptoms only for women with lower education levels (McEachan et al., 2015). One explanation for these findings is that pregnant women and girls from low-income families may spend more time close to their homes, and therefore measures of nature in their immediate environment are more important predictors of mood (Dadvand et al., 2014; Taylor, Kuo, & Sullivan, 2002). Our results were less influenced by immediate context since our measure of nature exposure was not confined to the immediate neighborhood of the participant, but rather included their entire daily environmental context.

**Methodological contribution.** There is a growing consensus in human-environment research that a systematic focus on residential neighborhoods presents a considerable limitation (Chaix et al., 2013). For a mobile group, such as adolescents, this limitation invokes the uncertain geographic context problem (Kwan, 2012) which must be addressed if we are to better understand the impact of environmental characteristics on human health and well-being. The GPS tracking and daily activity diary used in this study represents a promising approach to solving the contextual limitation. These methods were particularly useful in assessing the changing environmental contexts to which our adolescent participants were exposed. We found the locations of participant activity to be highly variable and spontaneous, which calls into question the reliability of data collected by self-recalled and subjective assessments tools. The approach we used in this study has been proposed as a promising method for geographic and human relationships research (Groenewegen, van den Berg, Maas, Verheij, & de Vries, 2012; Wu et al., 2014). Our study demonstrated the feasibility of using such methods for determining adolescents' contact with nature and its effect on psychological well-being. It also demonstrated its potential in deriving fine-grained environmental assessments.

An important contribution of this work is our approach to measuring an individual's exposure to nature in everyday settings. The use of Google Street View, image processing using machine learning techniques, and GPS tracking devices are novel. Similar approaches can be used in future studies to create more realistic and ecologically valid representations of individual interactions with a host of environmental variables.

Capturing the varying concentrations of natural exposures has been a challenge in environmental health research. Traditional methods using satellite and aerial imagery rely on exogenous images and measurement. This approach ignores important issues associated with people's endogenous experiences in an environment, such as eye-level views, volumes, and visual obstructions. The Google Street View measures have demonstrated high agreement with field audits (Odgers, Caspi, Bates, Sampson, & Moffitt, 2012). Using Street View and quantifying the vegetation of the panoramic view of every point along a travel path and at an activity location, we were able to recreate a reasonable representation of people's

actual visual experience. This more realistic assessment allowed us to create reliable models to predict mood states. We believe these methods will be useful in addressing a range of issues related to the impact of environments on human health and well-being.

### ***Policy implications***

**Urban Greening Interventions.** The results of this study add to the body of work suggesting that urban greening might be a good investment for cities that want to create a positive influence on the psychological health of people – in this case, young people. Previous studies have proposed neighborhood-level interventions to take advantage of the salutogenic effects of green space in improving health (Beyer et al., 2014). We found that spending time in greener places on any particular day was associated with reduced mood disturbances for that day. Our findings support the effectiveness of neighborhood-level interventions that promote young people’s psychological health and call attention to the importance of nature in accessible public spaces, i.e., home-to-school routes, parks and plazas, commercial areas, and playgrounds, as well as other third places. One promising approach emphasizes small-scale interventions, such as pocket parks, parklets, and rain gardens, which can transform an existing urban space and bring nature’s benefits to the places people visit every day. For instance, Branas et. al. (2011) showed that greening vacant lots decreased Philadelphia residents’ stress levels.

**Resurrecting Nature Play.** The findings here suggest that exposure to nature can be an effective treatment for adolescents who experience mood disturbances and potentially other mental disorders. For adolescents, the psychological need to find refuge from daily hassles and get restored has been recognized by a growing body of research. In addition to the psychological benefits described our study, nature play is also associated with more physical activity, greater creativity, and other beneficial developmental outcomes (Burdette & Whitaker, 2005; Louv, 2008; Taylor, Wiley, Kuo, & Sullivan, 1998). Traditional types of extracurricular activities, such as sports, band, and clubs, usually do not offer adequate opportunities for teenagers to interact with nature. Structured activities, such as outdoor classes, nature-based physical activity, wilderness programs, and nature camps, should be provided as alternatives. In addition to structured nature play, the importance of unstructured nature play should be noted. Since adolescents have been noted to value autonomy, independent decision making and control over the place (Vansteenkiste & Ryan, 2013), school and extracurricular schedules should be flexible enough to incorporate free play in nature. Developing more natural play spaces, diversifying the affordances of existing spaces, improving maintenance and safety, and creating community coalitions can foster outdoor play and improve the psychological health of adolescents.

### ***Future research***

There are a number of ways that future studies might build on this work. In our study, we focused on the

impact of the concentration of nature as it related to the frequency and duration of a visit to a place. Other work, however, suggests that the types of nature, activity affordances, and the quality of space with respect to its spatial layout and maintenance have significant influences on users' satisfaction (Hadavi & Kaplan, 2016) and psychological responses (Francis et al., 2012; Laaksoharju, Rappe, & Kaivola, 2012; Rogerson, Brown, Sandercock, Wooller, & Barton, 2015; Van Dillen, de Vries, Groenewegen, & Spreeuwenberg, 2012). With GPS tracking and accurate recording of the places where activities take place, future research can incorporate in-depth evaluations of the type and quality of green spaces and yield a more comprehensive analysis of the effects of green space.

Another priority concerns the issues of access and equity. Our study found that low-income adolescents have less contact with vegetation in their accessible environments than their peers from medium and high-income households. Do low-income individuals simply live in less-green neighborhoods, or do they face other types of barriers that prevent them from accessing in green spaces? What spatial, temporal, and social constraints might explain such results? More detailed and focused analysis are needed to reveal the patterns of activity, preferences, and constraints that contribute to equity and access to urban green space.

Some limitations to our study should be addressed in future research. First, to achieve better ecological validity by using the everyday behavioral context of young people, this study is subject to self-selection bias. Similar to the selective residential bias in studies of residential neighborhoods, such a bias has recently been identified in the environmental determinants of the physical activity literature as “selective daily mobility” (Chaix et al., 2012; Chaix et al., 2013). Participants who experience certain types of outcomes might choose to go to places that have particular characteristics, e.g., stressed teenagers may choose to go to a relaxing place, or retreat to home or indoors and avoid going outside. Similarly, those who are more aware of the benefits of nature or feel more attached to nature might visit natural places more frequently or stay longer. Although our study used multi-level modeling to reduce the impact of self-selection bias, our research design prevents us from making causal inferences between the concentration of nature and mood. Experimental and quasi-experimental studies that might establish cause-effect relationships will be important in advancing the knowledge regarding nature and mood states.

Next, GPS tracking in areas with signal shading from dense canopy or tall buildings can be limited and or inaccurate. In our study, we used the activity diary to triangulate and complement the GPS data. For better GPS data, future studies can explore dedicated devices that reduce positional error in urban areas. For better travel activity information and real-time assessments of psychological well-being, an approach that utilizes an ecological momentary assessment (EMA) (Moskowitz & Young, 2006) appears most promising.

A third limitation of our study was the homogeneity of urban environments we sampled. We tried to maximize the generalizability of the study by including participants from four different cities. Yet, all four were medium sized cities (populations between 30,000 and 150,000) in central Illinois. The urban environments and vegetation types also were similar. Future studies should expand the geographic and environmental settings and examine the effects on adolescents who live in medium to large cities in a variety of climates.

## **Conclusion**

Our study suggests that exposure to nature can be an effective psychological health intervention for adolescents. It offers new insights into the effects of daily exposure to nature on adolescents' mood. The findings demonstrated a significant negative association between the concentration of nature within one's environments and her or his daily mood disturbances. These findings held even after controlling for individual characteristics and daily activities. Using GPS tracking and Google Street View imagery, we made fine-grained assessments of the concentrations of nature in the environments that adolescents visit. Consequently, our approach has better ecological validity than most experimental and quasi-experimental studies, and it offers insights into urban planning and has design implications for young people's psychological health. We found that for adolescents, every one percent increase in the concentration of nature in their environments is directly associated mood enhancement, regardless of demographics. These findings have a broad range of implications. Our findings support urban-level greening efforts that enhance frequently-used urban spaces and harness the salutary impact of nature to create healthier environments in which adolescents can thrive.

A better understanding of the relationship between exposure to nature and adolescent mood helps guide the design of urban spaces that can positively respond to the specific psychological and emotional needs of young people. These findings present an opportunity to positively affect a difficult transitional life stage and promote the well-being of young people.

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## **Chapter 5**

### **Conclusion**

The purpose of this dissertation research was to test analyze the association between contact with nature and adolescent's psychological well-being in both experimental and observational settings. As an often ignored health intervention, nature has been proposed to relieve stress, restore attentional capacities and promote positive mood. However, no causal relationships could be derived from correlational studies, which represents a major theoretical gap in our understanding. To fill this gap, the Window View Study employed a random controlled experiment and demonstrated that viewing green campus landscapes caused significant attention restoration and stress recovery for participants. Based on the finding that contact with nature influences stress and mood, we further asked, whether such an association would hold in everyday situations? Without testing such a relationship in ecologically valid settings, we won't be able to propose effective planning and design interventions to promote positive affect and reduce mood disturbance in adolescents. To fill this gap, the Nature Tracking Study was designed to accurately assess the nature concentration in adolescents' daily environment and test its association with their mood.

The most important findings from this research project were that being exposed to nature is consistently associated with improved psychological well-being, regardless of whether or not it happened under experimental conditions or in uncontrolled everyday settings. The finding held whether their exposure was visual (indirect) or immersive (direct) and using objective and subjective measures of well-being. The consistency of the findings suggests that there is considerable potential for a variety of planning and design strategies and school-based and everyday interventions that would promote the mental health and well-being of adolescents.

In this chapter, I provide a summary of the major findings of the systematic literature review, the Window View Study and the Nature Tracking Study, and then discuss their contributions to theory, as well as the methodological significance of this work. I conclude with a discussion of the practical implications of the two studies and provides an example of how the research methodology and findings can be used to design

better environments for adolescents.

## **Main findings**

Are there significant impacts of green window views on stress recovery and attention restoration? The Window View Study provided positive answers. Participants engaged in academic tasks followed by a ten-minute break in one of the three conditions: a classroom with no windows, a classroom with windows that opened onto a built space, and a classroom with windows that opened onto a green space. At the end of the break, compared to the barren window view and no view conditions, adolescents' in the green window view showed significant stress reduction and attention restoration. However, comparing the barren window view with the no view condition, neither the attentional capacity or the stress levels were significantly different, suggesting the presence of window view itself, the depth of view, or daylight may not be enough to produce positive impacts on attention restoration or stress reduction. In our findings, having a view to vegetation was necessary to produce such outcomes.

Inspecting the timing of the recovery effects, we found that significant differences across conditions were only detected at the end of the break. No significant differences were observed during the time when students were engaged in the academic tasks. This was consistent with the underlying mechanisms of attention restoration theory (ART) that suggests that distinguishes voluntary and involuntary attention.

Did stress recovery mediate the relationship between window view and attentional functioning? A non-significant mediation effect suggested that that attention restoration and stress recovery were separate pathways through which nature affects psychological well-being. Exposure to nature impacted cognitive performance directly, rather than through the mediation effect of stress recovery. Although both processes occurred during this experiment when students had window views of a green space, the changes in participants' attentional capacity and stress levels were not correlated.

To what extent did day-by-day exposure to nature influence adolescents' mood states, after controlling for individual characteristics and daily events? Our Nature Tracking study suggested that daily nature

exposure affected adolescents' mood states. Not only did the average concentration of vegetation in a participant's typical environment positively predict his/her mood; the day-to-day variations in nature exposure also affected their moods.

What was the average nature concentration in adolescent's environments? On average, adolescents were exposed to environments where 18% of their entire view shed was covered by vegetation. No statistical differences were found between weekday and weekend environmental exposure to nature. However, there was a significant difference in nature concentration across participants from different income groups. Adolescents from low-income families were exposed to significantly less nature compared to their peers from medium and high-income families.

To what extent was nature concentration correlated with tension, depression, anger, fatigue and vigor? Bivariate correlations showed significant negative associations between nature concentration and depression, anger and fatigue. The composite mood disturbance score was also significantly associated with green concentration. Surprisingly, we did not find significant associations between nature concentration and participants' tension levels.

Using a multi-level model to predict total mood disturbance and control for a number of intra and inter-individual variables, we found that nature concentration remained a significant predictor for daily mood. The greener the environment one was exposed to, the better his or her mood was. After centering the variable using sample mean and individual mean, an increase in average nature concentration was still significantly associated with mood states. An increase in daily concentration was also marginally associated with mood.

No cross-level interactions were found between individual characteristics and nature concentration regarding mood states. That is, belonging to a specific demographic or socio-economic group did not modify the relationship between exposure to nature and mood. This suggests that the relationship between exposure to nature and mood enhancement is fairly consistent across different age, gender, and socio-economic groups of adolescents.

## **Contributions**

The most important contribution of this dissertation is to interrogate the relationship between exposure to nature and adolescents' psychological well-being through research using experimental and naturalistic methodologies. By combining an experimental study in a controlled setting where the cause and effect can be isolated from other background factors with a field study where results can be applied to practical interventions, the study broadened our knowledge and increased the confidence of the findings across settings.

The primary contribution of the Window View study is to have established causality between views of green campus landscapes and students' attentional performance and recovery from stress. Previous studies demonstrated a positive association between the greenness of school landscapes and student performance. This is the first study, however, to present evidence establishing a causal relationship between exposure to nature on campus and student's capacity to recover from attentional fatigue and stress.

Several aspects of the study design and procedure ensured the internal validity of our findings. The study employed random assignment, a control group, and measures to ensure identical procedure and setting, as well as multiple measures for the outcomes. First, participants were randomly assigned to the three window view conditions. Our baseline tests also showed no significant difference in attentional capacity or stress levels among the three groups. Second, the study included two treatment groups (green and barren window view) and a third control group (no window view) to make sure the effect of having a window, daylight, and the depth of the view were accounted for. Third, to ensure all participants experienced identical experimental procedures, all researchers received a two-week training and followed the developed procedure and script for each step of the experiment. The two research groups rotated the administration of the three types of conditions, making sure that any differences in experiment administration was balanced among the three conditions. We also rearranged all the experimental rooms to ensure consistent room layout, furniture, lighting and distance from seat to the window (or the wall). Finally, the use of multiple measures, including psychological and physiological ones, enhanced the

construct validity of the measures. Since the window condition became obvious once the researcher entered the room, it was not possible to conduct a double-blind procedure. However, we ensured that participants were unaware of the research hypothesis and made no mention of the window conditions being the experimental treatment in the study.

The Window View Study also contributes to the understanding of the interrelationship between attention restoration and stress recovery. The study tested the possibility that stress recovery was the pathway through which nature affected attention. A non-significant association between stress and attention suggested that although the stress and attention pathways occurred simultaneously during the break period, exposure to nature impacted cognitive performance directly, rather than through the mediation effect of stress.

The Nature Tracking Study found a significant association between exposure to varying levels of nature and adolescents' moods. This finding helps move the field beyond the nature-built environment dichotomy and suggests that in similar urban environments, exposure to areas with higher concentrations of vegetation might induce significant psychological benefits.

The findings from the Nature Tracking Study suggest that landscape interventions for adolescents could focus on the places they typically visit and the places they visit only occasionally. The findings demonstrated that exposure to nature in both types of places was significantly related to participants' moods. Living in a densely vegetated neighborhood, going to a school that has a green landscape, or regularly visiting parks or gardens were all positively related to the moods adolescents experienced on any particular day. Moreover, occasional visits to natural areas are also positively related to mood – the more nature dense the area, the better the mood students reported having. Such findings echoed results from studies that focused on residential neighborhoods and those that emphasized favorite places (K. Korpela, Kyttä, & Hartig, 2002; K. M. Korpela, 1992).

A final contribution of the Nature Tracking study concerns the methodology used. The nature concentration measure developed based on GPS trajectory and Google Street View processing is unique

in Environment-Behavior research. The GPS tracking and activity space approach provided accurate assessments of adolescents' exposure to nature and reduced the measurement error associated with using arbitrary geographic boundaries. The Google Street View imagery helped the researchers gain an accurate representation of what people's visual experiences were when they were outdoors, and thus captured the concentration of nature that was most relevant on the street-level.

## **Practical implications**

A number of policy and design implications can be derived from this study. Here I briefly discuss the implications for school selection and design, urban design, and programmatic interventions that can promote adolescent well-being. The section concludes with a design example that showcases how the activity space approach can be used in developing urban environments to enhance adolescents' mood and mental health.

In the United States, it is far too often believed windows in classrooms serve as distractions and undermine the productivity of students. Schools built after the 1960s have typically featured small windows or windows with frosted glass. The evidence presented in this dissertation suggests that green campus landscapes are profound assets that should be recognized in building and site design. In developing or renovating campuses, landscape architects should consider the locations of classroom, cafeteria and hallway windows and create landscapes that can be readily viewed by students. Parking lots and barren grounds should be minimized or screened by vegetation. Compared to most of the interventions aimed at relieving stress (e.g., emotional skill building, anger management, positive behavior programs), placing trees and shrubs on the school ground is a modest, low-cost intervention that is likely to have long-lasting effects on generations of students.

The findings presented here suggest that any green space might have significant, positive impacts on well-being, if the space is well-used or at least easy to see. This calls for the implementation of design interventions that transform the everyday spaces used by urban residents into what we call "nature at



every doorstep”. Also, designers should carefully examine different population groups’ activity patterns, travel paths and space-time specific psychological states, in order to develop design proposals that are responsive to human experience and that help ensure people have easy, immediate access to nature outside their homes, work places, schools, shopping areas, and other places that they visit.

In addition, educators and parents should help insert nature exposure into adolescents’ daily activities by optimizing the time between classes at school and during adolescents’ unstructured time. The time between classes at school should provide ample opportunity for students to get visual or immersive nature experiences to recover from the stress of the last class period and restore students’ attentional capacities. Regular visits to parks and vegetated areas, as well as selecting greener routes for traveling to school are likely to enhance adolescents’ overall mood states. For adolescents who are undergoing adverse life events, display high mood variation or acute stress, a one-time dose of nature would show restoration effects in combating short-term mental issues.

### ***A design example***

#### ***Background***

Landscape architecture is a negotiation of human-environment relationships. Designers often strive to create landscapes that enhance the experiences that people have in the design they generate. As we move toward a variety of possibilities in experiential design and turn our emphasis to the role of design reception of and public participation, we face a critical challenge: how to design in ways that are sensitive to people’s motion and emotion, thus creating experientially-responsive places that promote health and well-being?

The findings of this study suggest a new method to complete the design-reception feedback loop by analyzing urban environments through a critical aspect of mental well-being, mood states. Employing an interdisciplinary set of approaches (e.g., environmental psychology, spatial modeling, geo-visualization), this research captures the complexity of urban space, human motion, and the moods that people experience. Yet it does more than simply assess any one of these issues by itself. Taken together, this

research allows landscape architects to create an urban mood footprint, which displays a surface showing a mood scale from positive to negative, based on data about people's reported mood at different locations. By reading the urban mood footprint, designers can create place-specific design interventions that promote mental well-being.

We selected adolescents as our population, a group of people vulnerable to wide mood swings. Stress and mood variation in adolescents generate psychological and biological responses that lead to increased vulnerability to disease and mental disorder, as well as decreased academic performance. Environmental stressors also affect dynamic brain maturation, which influences behavior and psychopathology in adulthood. Creating landscape interventions to promote positive mood and mental health has the potential to achieve substantial educational gains and health care cost savings for adolescents.

### ***Urban mood footprint—an analytical approach***

This is a case study for determining what an urban mood footprint might look like for one metropolitan area, Urbana-Champaign. Below, I briefly describe the data collection and analysis methods, and explain the process for tying the location-specific understanding of design schemes to an enhancement of the psychological experience of adolescents.

#### *Capturing Space-Time Motion*

The researchers collected travel trajectory and activity data from adolescents from Urbana-Champaign. Participants each wore a Garmin Foretrex GPS receiver, kept a detailed activity journal, and completed online questionnaires including quantitative and narrative descriptions over a 4-day period from a Saturday to a Tuesday. Participants recorded every single activity they engaged in, their subjective mood states, and their self-described feelings during those days.

#### *Constructing Urban Mood Surface*

The locations for outdoor and indoor activities were classified according to GPS locations and travel journals. We analyzed the spatio-temporal patterns of outdoor activities using ArcGIS, ArcPy, and R.

First, we conducted the Kernel Density Estimation to identify hot spots of outdoor activities as well as time-period segmentation of temporal patterns. We then conducted spatial interpolation to develop the mood footprint surface for the entire city. After that, we clustered the narrative data based on locations onto 10ft\*10ft grid patterns, calculated the word cloud based on the frequency which participants used to describe their subjective feelings in a given location, and produced a geo-tagged word cloud that showed the narrative feelings associated with each place. We then identified places where a variety of positive and negative feelings were exhibited.

### *Investigating Place-Specific Affective Dimensions*

Based on the mood footprint and narrative analysis, we examined the places dominated by negative moods. Employing Russell's affective circumplex from neuroscience, we developed a set of design interventional strategies that serve as catalysts for mood transitions along four axes of the affective circumplex: low activation – high activation (active), inactive unpleasant – active pleasant (stimulating), unpleasant- pleasant (happy), and active unpleasant – inactive pleasant (tranquil).

### ***Mood and health enhancing design***

Using the mood footprint data and the affective circumplex, we propose small-scale interventions that endow new meaning to ordinary urban spaces. The interventions will be inserted in places where negative moods are dominant. All interventions will be sensitive to the temporal dimensions of adolescents' activities.

*“I’m frustrated”: Empowerment and Autonomy*

To transform the landscape from low activation to high activation, physical activity-enhancing features are designed to provide adolescents with a sense of autonomy and control over the space. A rooftop skate ground provides a vista of the urban space. As teenagers skate through, they acquire feelings of freedom and self-efficacy. Other intervention strategies also provide places for physical activity, active engagement, and interaction with the environment.

*“I’m bored”: Stimulation and Affordances*

To transform the landscape from inactive unpleasant to active pleasant, landscape textures and affordances are manipulated to stimulate human sensory experiences. A graffiti park that provides a variety of tools and paint colors allows teenagers to paint freely.

*“I’m sad”: Dynamics and Enjoyment*

To transform the landscape from unpleasant to pleasant, we offer dynamic landscape features and enhance the kinesthetic and haptic quality of the space. The temporality of design is considered with respect to the pattern of people’s motion. An otherwise normal street is transformed into waterfall seating from 3:30 pm to 6:00 pm along home-to-school paths for adolescents to enjoy.

*“I’m stressed”: Restoration and Tranquility*

To transform the landscape from active unpleasant to inactive pleasant, we create a slow landscape that welcomes restoration, recovery, and meditation. A canopy pavilion with a dense overhead canopy creates a tranquil atmosphere where adolescents find refuge from stress. Vegetation, water features, space definition, and sound manipulation all contribute to this goal.

***Next step of research: a mobile application with real-time urban mood monitoring***

We propose a mobile application to automate the entire process and achieve real-time urban mood

monitoring. This would allow people to participate in the design process by providing data about their motions and emotions in urban areas. Managers and designers could use this data to create landscapes that respond to people's moods and spatio-temporal patterns. The app would collect data from users, calculate the urban mood surface in real time, and identify hotspots of negative mood for interventions. The application would then produce results for three groups.

#### *Space Users*

Imagine an app that would allow users to trigger space transformation based on their own feelings and provide them with real-time information regarding places to enhance mood, operation hours, and route recommendations.

#### *Designers*

Imagine an app that would allow designers to gather mood and space/time data easily to show how designs are being received, test design ideas, and provide evidence-based recommendations to regenerate a completed project. Real-time comments and sensory data could be provided for feedback and as information for future design.

#### *Open Space Managers*

Imagine an app that gives managers real-time information about the usage of space, user experience in these spaces, and recommendations for public space operations and artistic installations, such as on-off controls.

Figure 12. Adolescent mood variation.

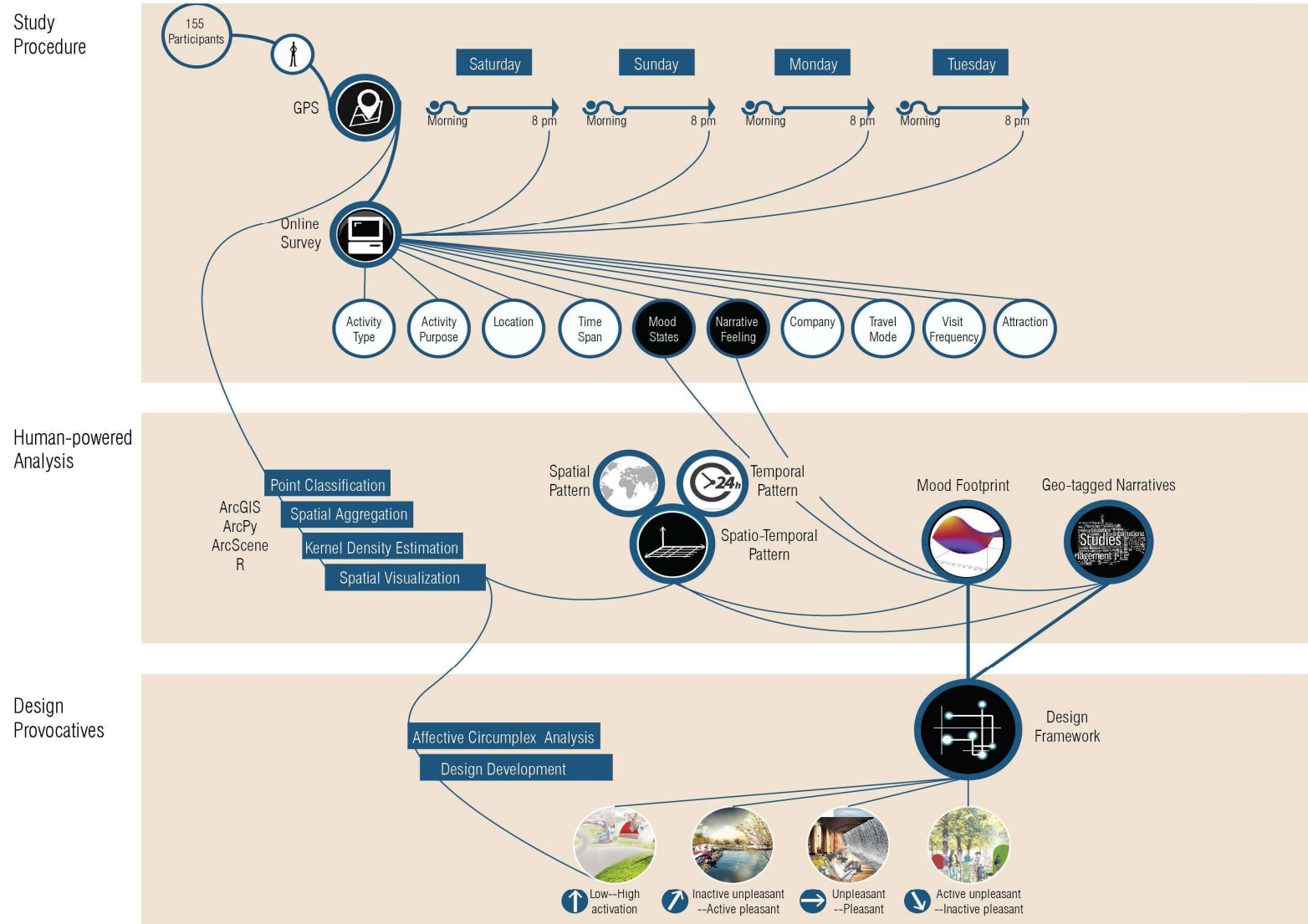


Adolescent Mood Variation

Adolescents are most vulnerable to stress and mood variation. Their mood states are weaved into their space-time motion patterns and experience of the landscape.

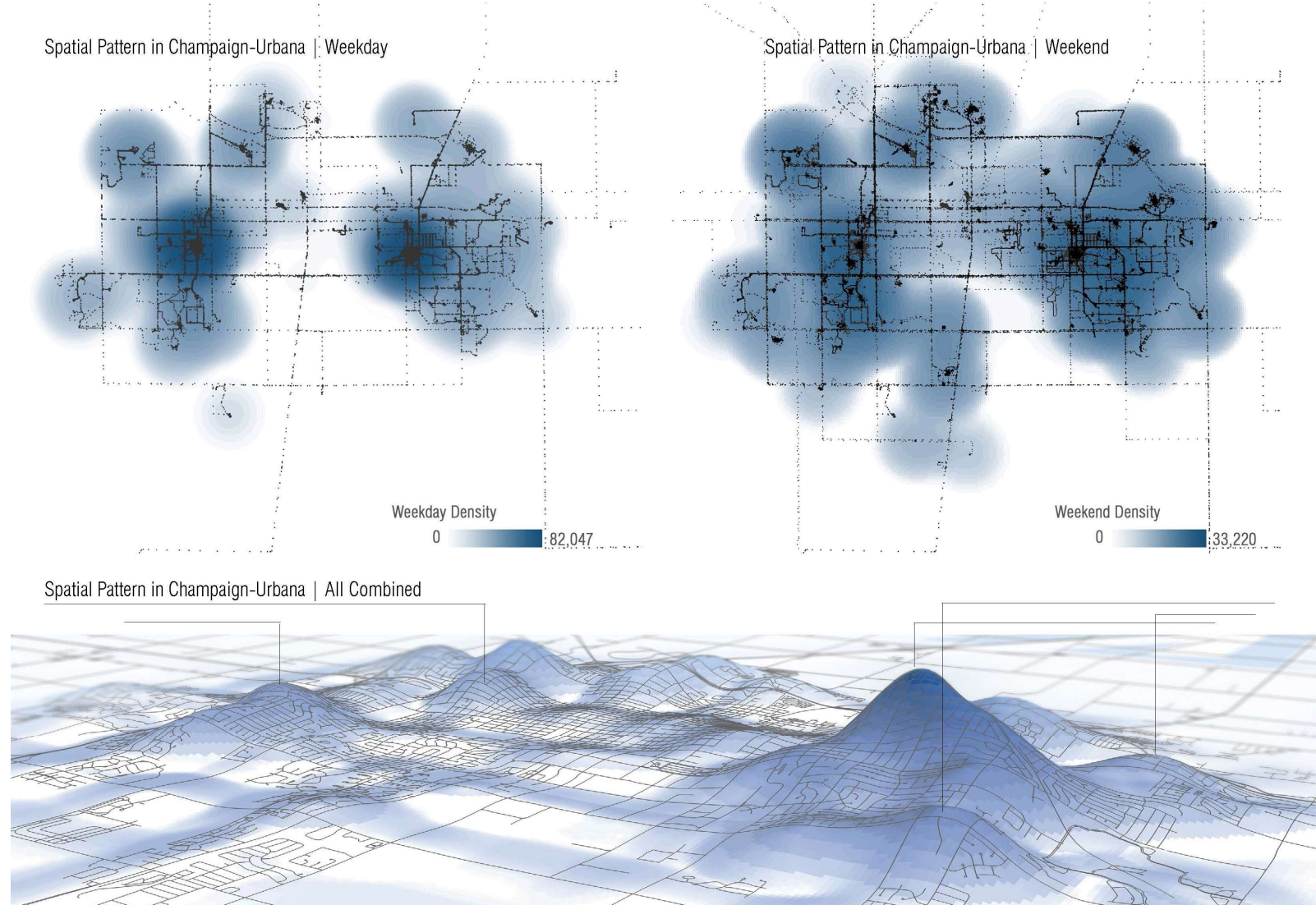


Figure 13. Methodologies of human-powered space-time analysis.



Methodologies of Human-Powered Space-Time Analysis | This research proposes a new method to analyze adolescents' experiences of the urban environment and propose design interventions via an interdisciplinary set of approaches (psychology, spatial analysis, planning and design, etc.).

Figure 14. The spatial pattern of motion.



The Spatial Pattern of Motion | We analyzed travel trajectories to identify the density of motion and activities across the urban space.

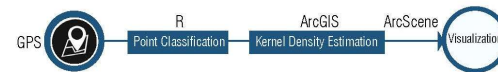
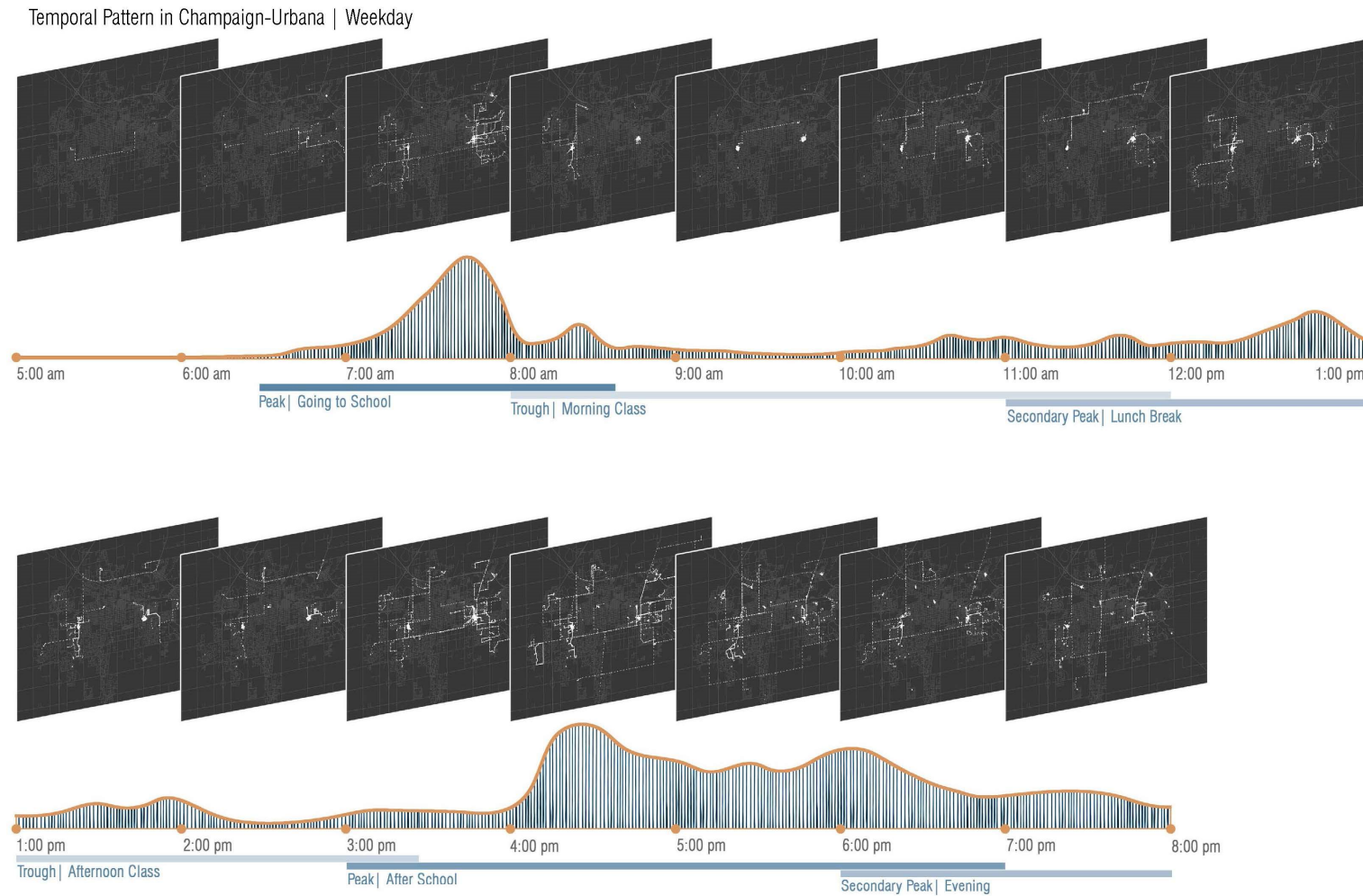




Figure 15. The temporal pattern of motion.



The Temporal Pattern of Motion | The temporal pattern of motion is analyzed with respect to adolescents' school-day schedule.

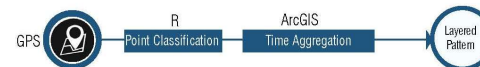
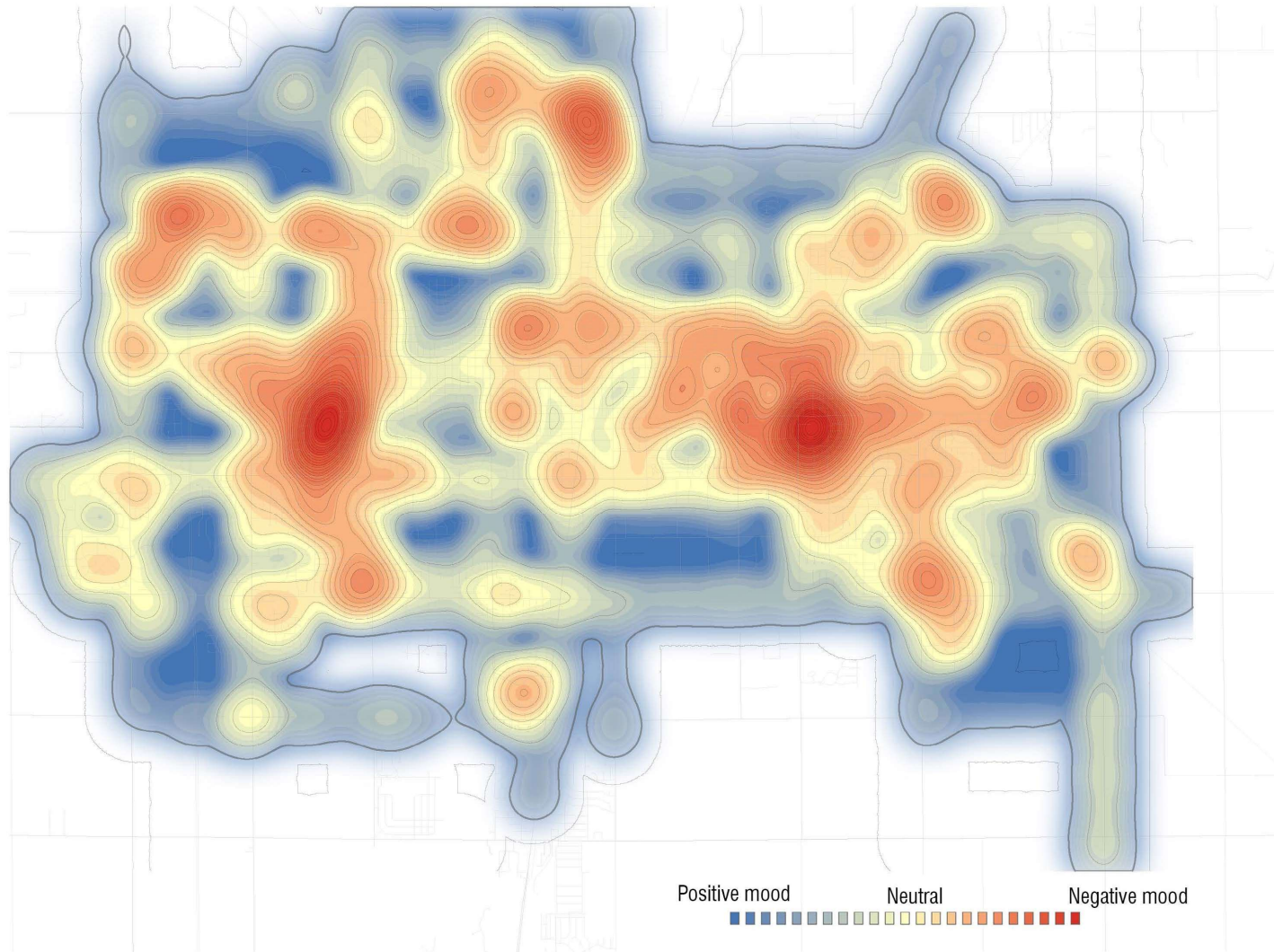


Figure 16. Urban mood footprint.

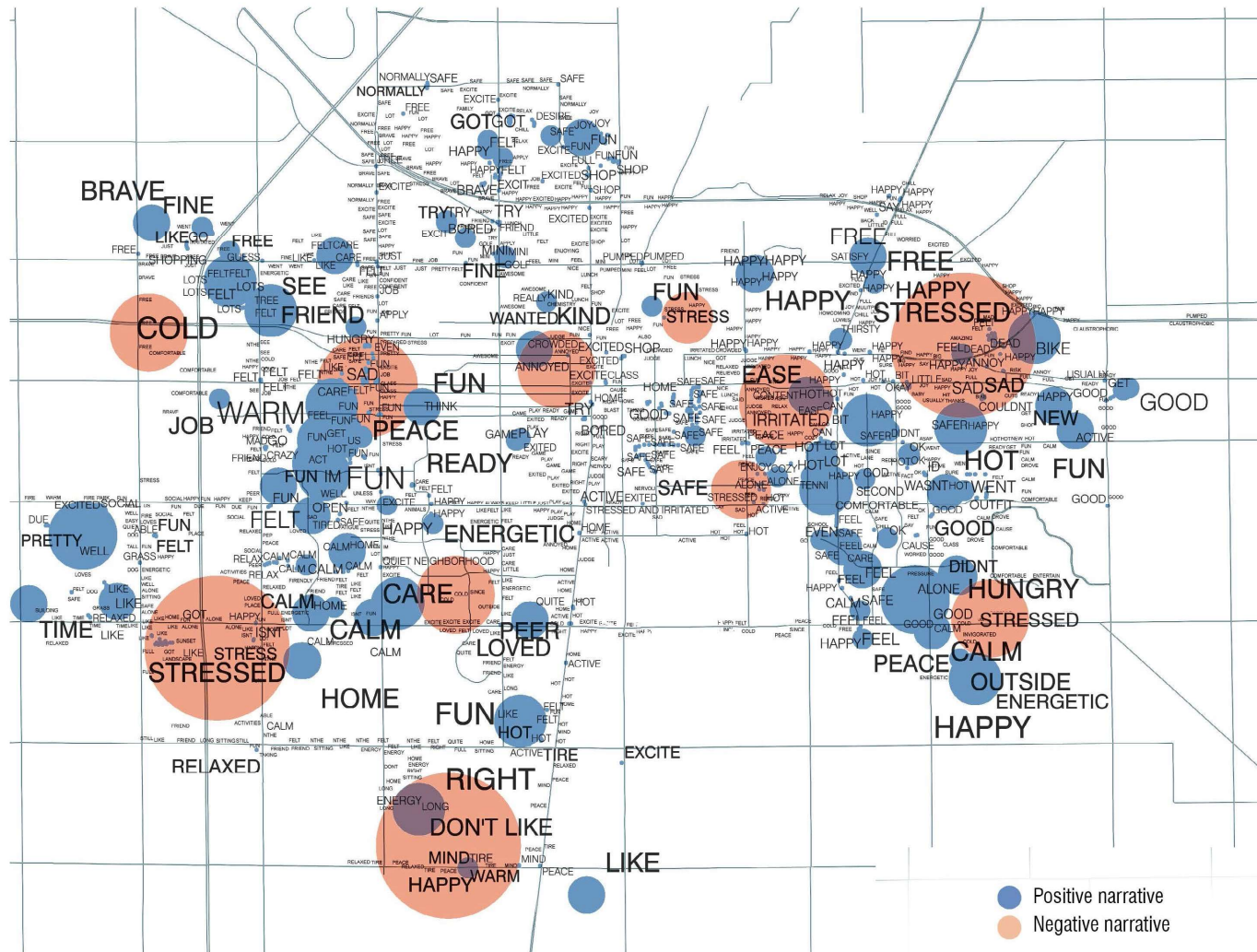


### Urban Mood Footprint

We created the urban mood footprint surface using the place-based mood scores and spatial interpolation methodology.



Figure 17. Urban mood word cloud.



Urban Mood Word Cloud

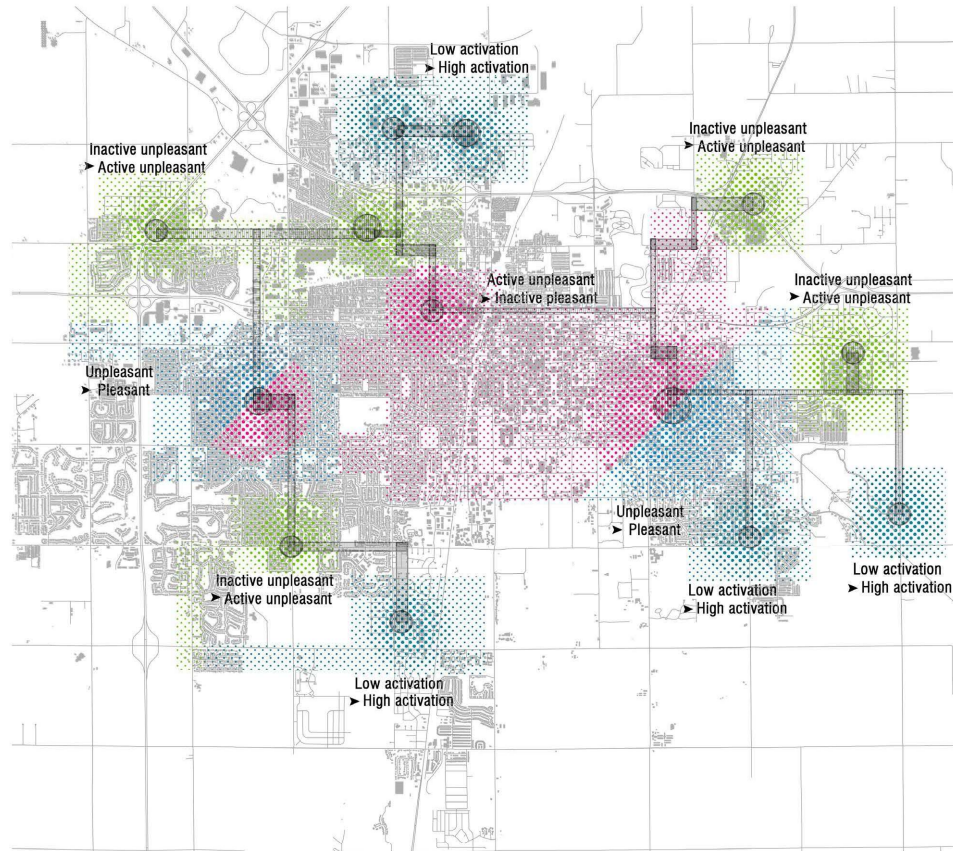
We analyzed place-based narratives of human experiences to create geo-word clouds showing the specific feelings associated with spaces.



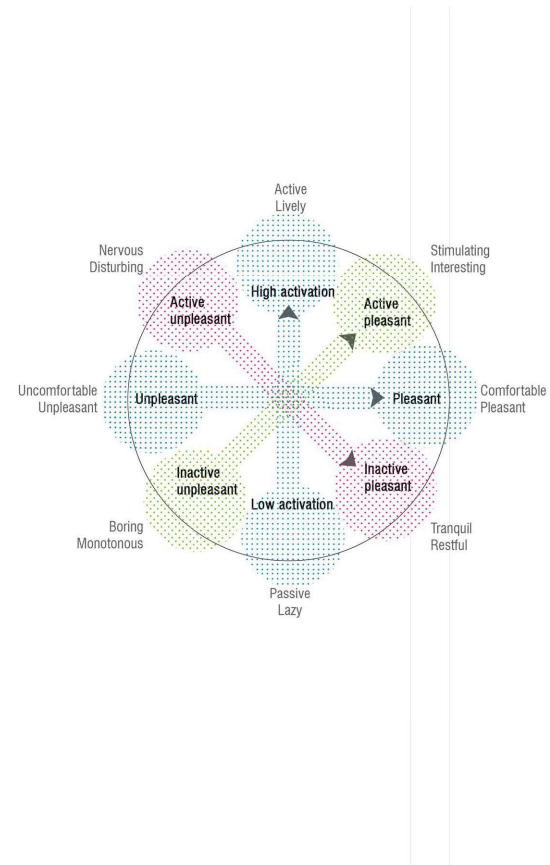


Figure 18. Mood enhancing design framework (completed with Yaxuan shi and Jingyi Zhao).

Mood Enhancing Design

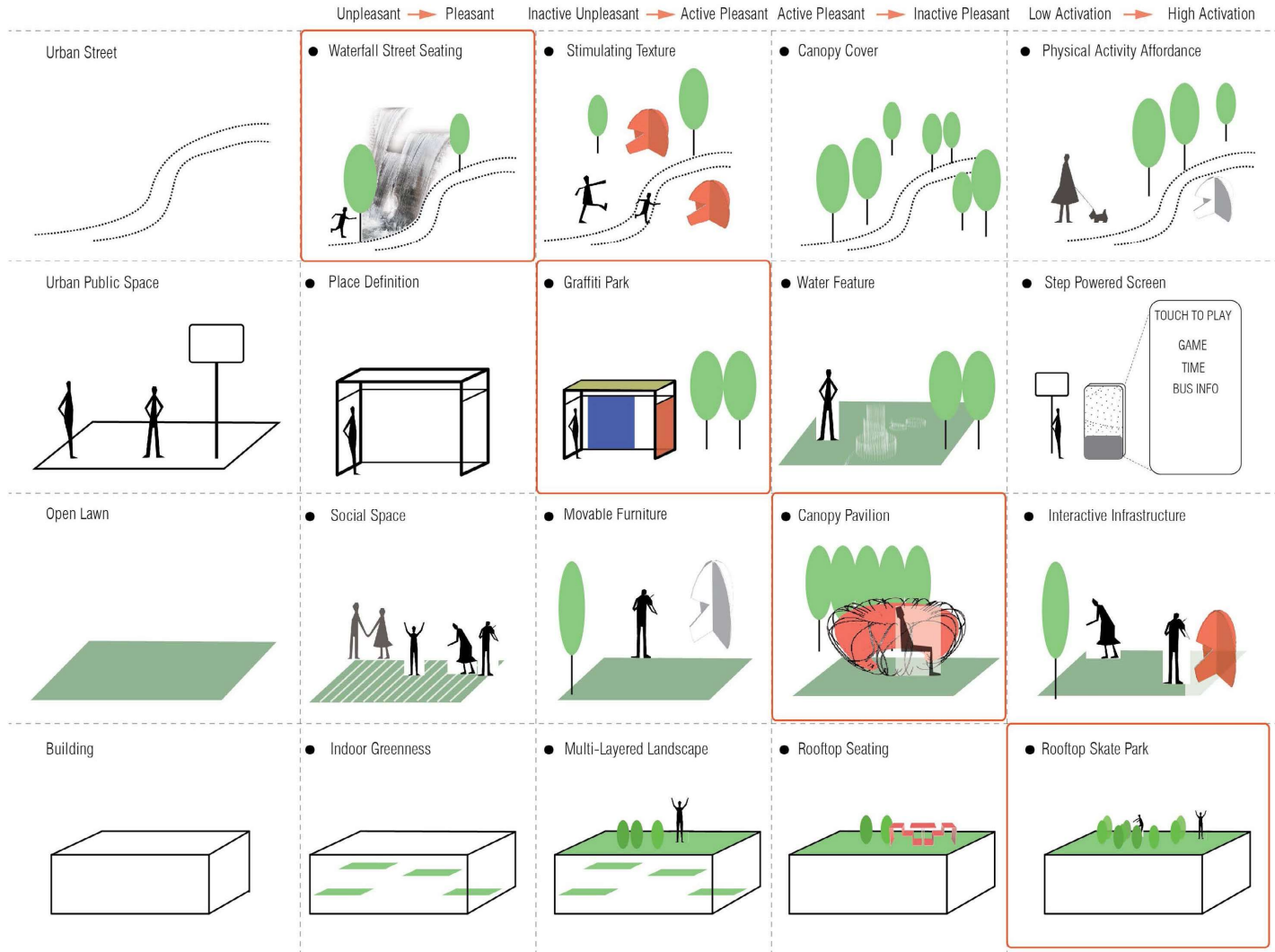


Interventions Based on Affective Circumplex



Mood Enhancing Design Framework | Employing the affective circumplex from neuroscience, we developed a design framework that serves as a catalyst for mood transitions along four axes.

Figure 19. Examples of design interventions (completed with Yaxuan shi and Jingyi Zhao).



Examples of Design Interventions

We developed a set of interventions for each of the four types of mood enhancement: low activation – high activation (active), inactive unpleasant – active pleasant (stimulating), unpleasant – pleasant (happy), and active unpleasant – inactive pleasant (tranquil).

Figure 20. Intervention 1: Rooftop skate park.

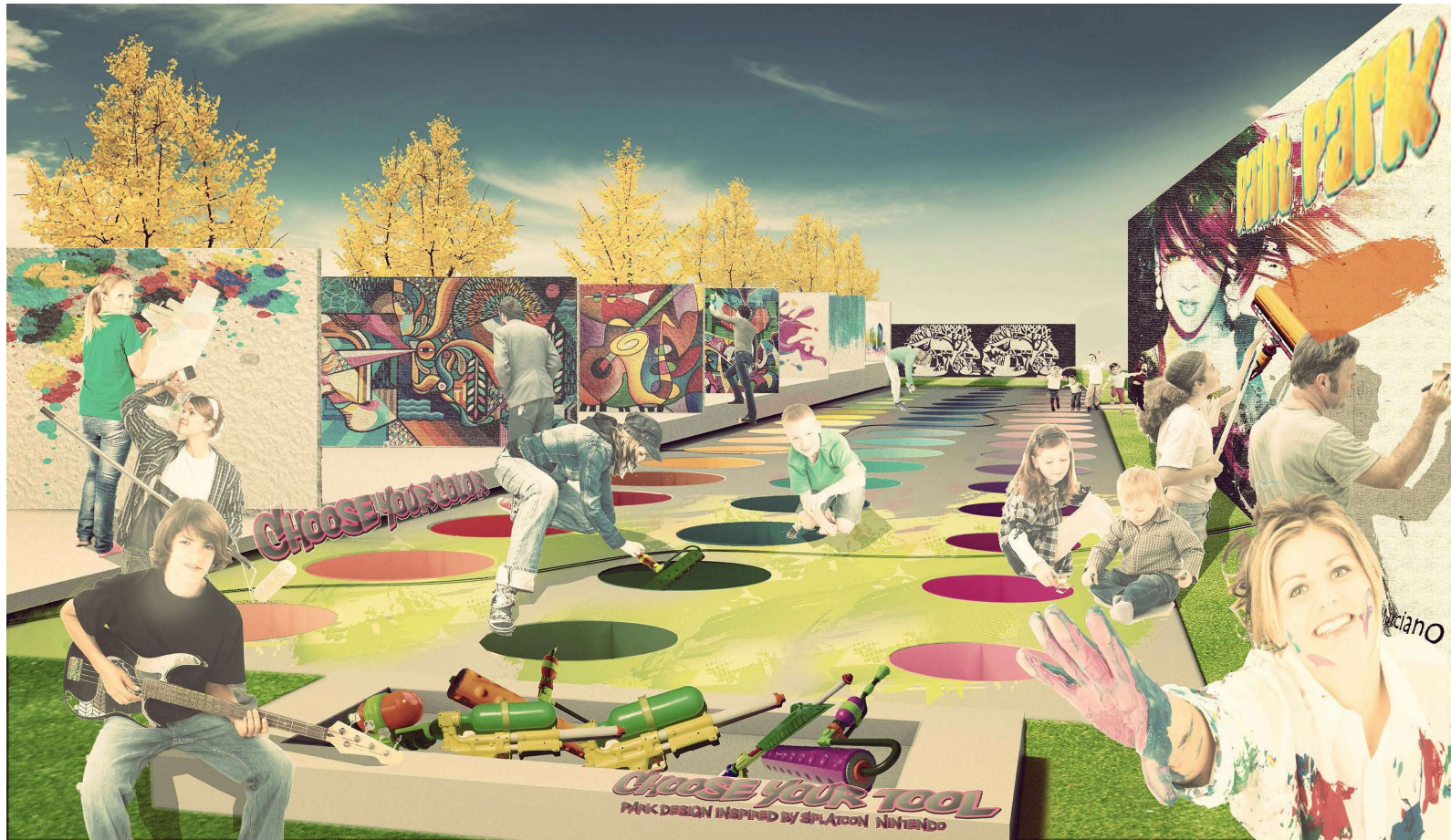


Rooftop Skate Ground

A rooftop skating garden provides a vista of the urban space. As teenagers skate through, they develop feelings of autonomy, freedom, and self-efficacy.



Figure 21. Intervention 2: Graffiti and painting park.



### Graffiti and Painting Heaven

The painting heaven is a place where everyone can help design and shape. Vivid color and texture, as well as active interaction with the environment, help stimulate mood.



Figure 22. Intervention 3: Canopy pavilion.



Canopy Pavilion

| A seating with a dense overhead canopy creates a tranquil atmosphere where adolescents find refuge from stress.



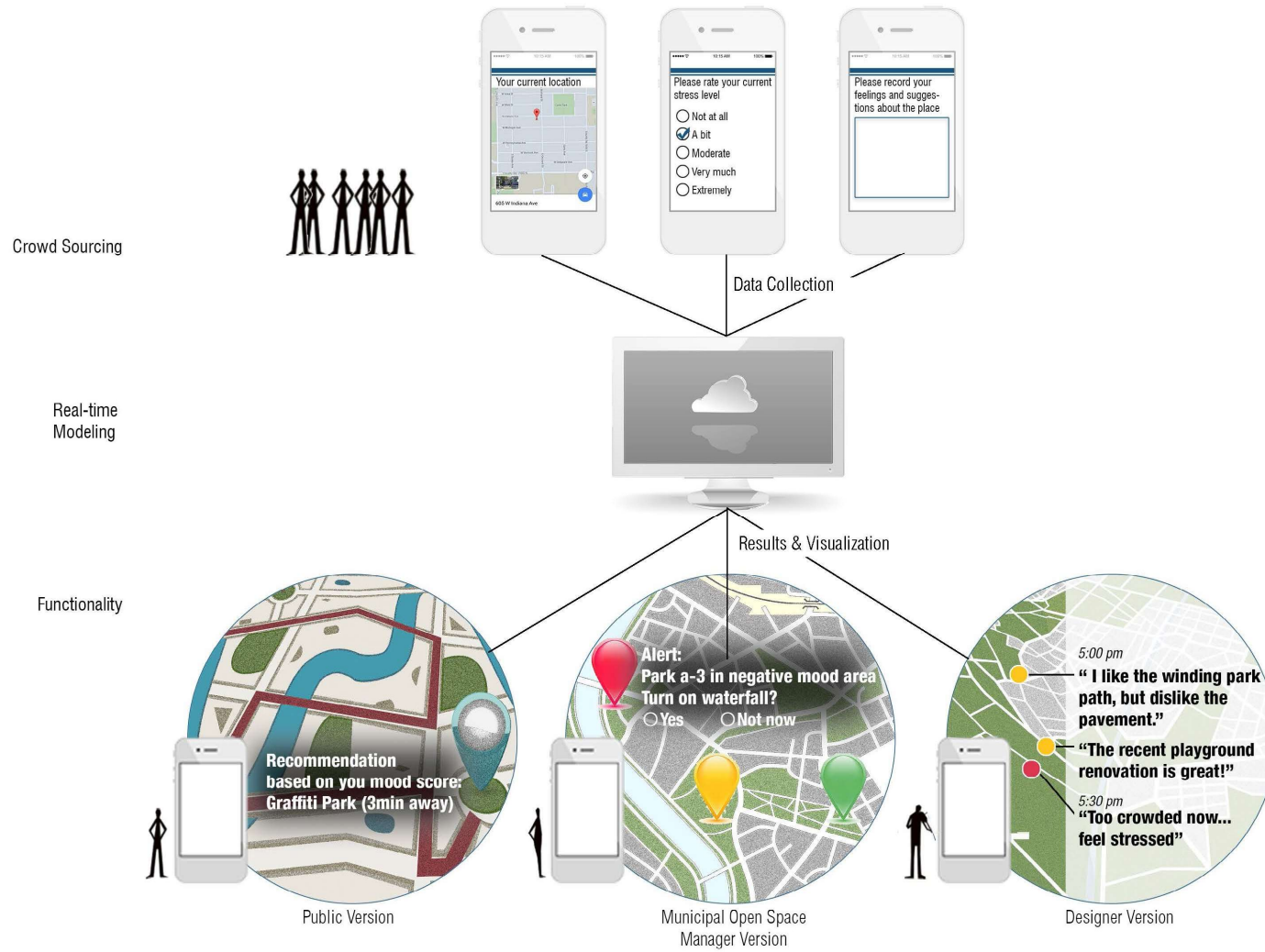
Figure 23. Intervention 4: Waterfall street seating.



Waterfall Street Seating

Waterfall street seating is activated after school along adolescents' home-to-school paths for their enjoyment.

Figure 24. The Next step of design research.



Next Step of Research

We will design a mobile application to automate the whole process of this research: real-time urban mood monitoring and recommendation development. This app will be customized for three groups: designers, urban park and open space managers, and the general public.

## **Future research directions**

The findings presented in this dissertation open the door to a number of possibilities for future research. The current study established the nature-stress recovery and nature-attention restoration pathways in educational settings, but more evidence is needed for the nature-stress recovery & attention restoration-better performance pathways. Without strong evidence, we miss the opportunity to propose policy interventions that reduce the environmental barriers for better student performance. Mediation effects that directly test the stress and attention pathways should be examined. In addition, since children at different stages experience different physical, psychological and cognitive capacities and needs, the effect of nature at different developmental stages should also be examined. For the examination of activity space and access to nature, more sophisticated analysis of travel chain and activity patterns can be investigated with respect to nature exposure and mental states. Mixed-methods and qualitative studies could be conducted to reveal the factors that encourage or hinder access to green space and everyday natural settings.

The window view study carefully controlled for a number of background factors. However, the study did not take into account students' interactions in the classroom, students' physical activities and their immersive experiences out on the school ground during their breaks, or their exposure to green space during physical education classes or after school. This limits the ecological validity of the findings presented here. Studies have demonstrated how immersive experiences in green school grounds help students recover from stress, build coping strategies, and form supportive social networks (Chawla et. al, 2014). Exercise in green space in school may also help students negotiate stress, regain attentional capacity and enhance mental health (Burdette & Whitaker, 2005). Future research might measure the combined impact of having green views from the school and green immersive experience, such as exercises on the school ground, on student performance.

Future studies could also explore the effect of varying the duration of exposure to nature. Our findings showed a break of 10 minutes was long enough to demonstrate the impact of green views on attention and stress. Would a longer break have shown a larger effect on stress recovery? Would increasing the frequency

of breaks also show an effect? What is the effect of the interaction between the duration and frequency of breaks with green view on students' stress recovery and attention restoration? Answering these questions could impact how schools and perhaps even work places structure breaks or other opportunities to gain exposure to nature.

Although our Window View Study did not measure academic performance and therefore cannot fully explain the pathway from viewing green landscapes to academic performance, the findings suggest that stress recovery and attention restoration are pathways through which school landscapes influence student performance. Future research can test the mediation effect of attention and stress on academic performance directly.

The findings add to the evidence demonstrating that green views have powerful effects on the productivity of students at various ages (Faber Taylor & Kuo, 2009; Matsuoka, 2010; Wu, 2014). Since cognitive functioning is critical to understanding, learning and performing different types of activities, views to green landscapes may also impact the productivity of workers (Bringslimark, Hartig, & Patil, 2007; Bringslimark, Patil, & Hartig, 2006).

For the Nature Tracking Study, we designed a study that emphasized ecological validity by examining the everyday activity spaces of adolescents. Although the strength of the study was its ecological validity, an associated weakness was that we were unable to eliminate self-selection bias. Participants who favor more vegetation might have decided to go to (self-select) greener environments, and by doing so acquire more positive moods. Although we used a multi-level modeling to account for the self-selection bias, the research design prevented from making causal inferences. Future experimental and quasi-experimental studies will advance the understanding of the causal relationship between exposure to nature and the changes in moods of adolescents.

The accuracy of GPS tracking is unstable in areas with signal shading from dense canopy or tall buildings. In this study, the activity diary was used to triangulate and complement the GPS data. For better GPS data, future studies can explore dedicated devices that reduces position error in urban areas. For better travel

activity information and real-time assessments of psychological well-being, ecological momentary assessment is most promising.

In our study, we tried to maximize the generalizability of this study by including participants from four different cities. Yet all four are small cities in the Midwestern United States. Studies with the adult population showed that people from other regions experience nature in different ways. Future studies should try to reduce geographical bias and consider a variety of climate, vegetation, living environments and cultural contexts.

## Conclusion

Around 20 percent of the world's children and adolescents have mental disorders or problems (World Health Organization, 2014). In the United States, approximately 4.4 million children suffer from Attention Deficit/ Hyperactivity Disorder (ADHD) (Faber Taylor & Kuo, 2011). Emotional and cognitive disorders in childhood can have lasting impacts and affect well-being many years or even decades later. According to the National Institute of Mental Health, half of all lifetime cases of mental illness begin by age 14 (National Institute of Mental Health, 2013). Promoting emotional and cognitive health as part of healthy child development must therefore be a national priority.

The studies presented here strongly suggest that contact with nature could significantly reduce children and adolescents' stress and enhance mood in both educational and everyday settings. A 10-minute study break with a green window view induced significant stress recovery and attention restoration for participants when compared with participants who had a study break in a room with a barren view or a room with no view. A greener everyday environment was associated with significantly lower levels of negative mood for all teenager groups. These findings not only add to our theoretical understanding, but also highlight the huge potential of using planning and design measures to enhance children and adolescents' environments.

It is time that cities take action to resurrect nature in children's daily environments and bring them outdoors. Planners and designers should be aware of the intrinsic and supportive roles natural landscapes can play in children's healthy development. We should develop design proposals that are responsive to children's needs. Educators, public health providers and policy makers should consider nature-based learning and programs as preventive interventions for psychological well-being. Together, we can build cities places where all children thrive.

*“Time in nature is not leisure time; it's an essential investment in our children's health (and also, by the way, in our own).”*

— Richard Louv, *Last Child in the Woods: Saving Our Children from Nature-Deficit Disorder*

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