

CORRELATES BETWEEN RESIDENTIAL GREEN SPACE EXPOSURE, WELL-BEING,  
AND BRAIN STRUCTURE

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**Abstract**

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The majority of the global population now resides in urban environments. Additionally, natural spaces are being developed at an unsustainable rate. This ever-widening disconnect from the natural world has raised questions about the consequences of such a lifestyle on the human psyche and physiology. This study explores how greenspace access influences human brain development by measuring the correlation between lifelong residential greenspace (RGS) access, brain structure, and well-being/connectedness using satellite imaging, MRI, and survey data. The hypotheses include: 1) lifelong RGS exposure is positively associated with gray matter volume (GMV) in the hippocampus, orbitofrontal cortex, nucleus accumbens, thalamus, and cerebellum; 2) lifelong RGS exposure is negatively associated with GMV in the amygdala; 3) lifelong RGS exposure is positively correlated with well-being and various types of connectedness; and 4) lifelong RGS is negatively correlated with neuroticism. Data collection is part of the STF Neuroimaging Collective at the University of Washington, which will eventually involve around 150-200 participants. This paper serves as a preliminary analysis of an initial 20 subjects. Understanding the interplay between greenness, brain structure, and mental health is vital for improving human health and advocating for nature. Researchers, policymakers, and urban planners should recognize the impact of neighborhood greenness on mental health, create environmentally conscious policies, and design urban areas. This research underscores the importance of preserving wild spaces and prioritizing urban greenspace development, intersecting environmental justice, equity, and human health.

## **Background**

Throughout the course of recent human evolution, mankind has become less connected with the natural world. People are flocking to cities for job, housing, and education opportunities - and overall living in increasingly urban environments. Additionally, wild spaces continue to be developed at an unsustainable rate. As of 2020, approximately 56% of the world's population resided in urban areas, a significant rise from 30% in 1950, and this figure is projected to reach 68% by 2050 (United Nations, 2018). Studies have shown that urban living can negatively impact mental health, with higher rates of anxiety, depression, and other mental disorders reported in cities compared to rural areas (Peen, J., et al., 2010). As this shift away from our natural roots continues, it is crucial to further document how it may impact human health and development, as well as the underlying physiological mechanisms.

Human well-being and the natural environment are linked in numerous ways. One useful way of viewing this connection is through the ecosystem service perspective, which looks at each component as an "ecosystem service." This perspective emphasizes the vital benefits that natural ecosystems provide to human health, framing nature access as an integral and active component of human well-being and survival (Daily, 1997). It recognizes that ecosystems contribute essential services such as clean water, air purification, pollination of crops, climate regulation, and cultural and recreational opportunities. By valuing these services, the ecosystem service perspective highlights the interconnectedness of human and ecological health, promoting sustainable practices and policies that protect and enhance natural environments. This approach advocates for a balanced relationship where humans not only utilize but also steward natural resources, ensuring that ecosystems remain robust and resilient for future generations (Bratman et al., 2019).

When considering residential greenspace environments and mental health in particular, these services include restorative experiences, stress reduction, social cohesion, cleaner air, a sense of belonging, protection from heat waves, and opportunities for physical activity (Bratman et al., 2019). It is clear that residential greenspaces, whether tree canopies, parks, or nature preserves, have a significant impact on the health and well-being of the surrounding residents.

One next important step in deepening our understanding of the relationship between RGS and human well being is to understand the underlying effects that nature exposure has on the structure of the brain throughout the life course. By exploring a clear understanding of these mechanistic pathways, we can improve ecosystem service assessments, better target particular facets of urban design, inform further mechanistic research, and better advocate for neighborhood green spaces.

One common exploratory method of understanding the pathways within the central nervous system is to look at subcortical brain structure as a correlate. It is both a very technical way of confirming individual differences (beyond survey data or subjective well being), and a way of honing in on which regions (and thus systems) are most impacted. The present study aims to take this analytic approach and explore associations between brain structure, RGS, and measures of well-being/ personality by comparing GMV, satellite imaging data, and survey data in a sample of young adults.

## How Does Nature Improve Well-being?

Though the underlying mechanisms are still being understood, there is now a considerably well documented understanding of how nature experience can contribute to well-being. Spending time in nature has been shown to increase attentiveness, boost cognitive functioning, decrease

inflammation, and improve mood (Bratman et al., 2012; Franco et al., 2017). The leading theories behind these benefits include the biophilia hypothesis, attention restoration theory (ART), and stress reduction theory (SRT).

The Biophilia Hypothesis, proposed by Wilson (1984), suggests an innate human affinity for nature and posits that exposure to natural elements is essential for psychological and physiological health. This hypothesis underscores the evolutionary perspective of humans as organisms inherently connected to the natural world. Research inspired by the biophilia hypothesis has shown that adding nature to spaces often has positive health effects. Research has shown that biophilic design can reduce mental health issues in prisons (Söderlund and Newman, 2017), speed up the recovery time of patients in hospitals (Ulrich, 1984), and encourage self-care practices for those living with chronic pain and depression (Huntsman and Bulaj, 2022).

Another influential framework in understanding the psychological benefits of nature experiences is the Attention Restoration Theory (ART) proposed by Kaplan and Kaplan (1989). ART suggests that exposure to nature allows individuals to replenish their cognitive resources, particularly attention and focus, leading to a reduction in mental fatigue and stress. The theory posits that the restorative effects of nature are rooted in its capacity to capture involuntary attention, providing a break from the demands of sustained attention required in urban environments. This process, known as directed attention restoration, allows cognitive resources to replenish, thereby improving focus, mood, and overall mental well-being (Kaplan & Kaplan, 1989).

Numerous studies have also provided empirical support for Stress Reduction Theory (SRT), which posits that exposure to natural environments can alleviate stress and promote psychological restoration. Developed by Ulrich in 1984, SRT has been instrumental in guiding research on the restorative effects of nature and understanding the underlying mechanisms through which it reduces stress. For example, a study by Hartig et al. (2003) found that participants who engaged in nature-based activities reported lower levels of cortisol, a hormone associated with stress, compared to those in urban settings. The restorative impact of nature on stress has been observed across diverse populations and age groups, highlighting the universality of this phenomenon (Keniger et al., 2013).

These theories all support the notion that nature is a powerful healing modality, capable of reducing stress and restoring attention, and that we are evolutionarily primed to seek it out. Although this is relatively well researched, and quite intuitive for many individuals, our current residential layouts are not always designed accordingly. This is especially true for lower income neighborhoods, where there tend to be even less trees, parks, and preserves (Wolch et al., 2014). The present study intends to incorporate what we already know about nature and well-being, and apply it to an equity lens, shining a light on how the disproportionate access to may correlate with well-being and neurodevelopmental factors.

## Both Environmental and Genetic Factors Shape Brain Structure and Behavior

The structure of the human brain resembles a fingerprint, unique to each individual. Unlike a fingerprint though, it undergoes constant changes from birth, influenced by both genetics and the environment. Neurogenesis, the formation of new neurons, contends with neurodegenerative processes that lead to neural damage and death. Life experiences, particularly during

developmental years, shape these processes, exerting powerful effects on brain structure, behavioral differences, and overall well-being. This makes brain structure a useful metric when seeking to understand how experiences shape human physiology.

Genetics also play a significant role, yet there is often an environmental interaction or 'trigger' (Caspi et al., 2003). This is exemplified by the population's genetic variation in the expression of a neurotrophin called brain-derived neurotrophic factor (BDNF). Individuals naturally exhibit varying levels of this molecule, known to enhance neuroplasticity by contributing to dendritic complexity and spine formation, and in turn increasing GMV (Bath & Lee, 2006). Research indicates that BDNF serves as a crucial biomarker of depression, with post-mortem analyses revealing lower concentrations in the hippocampus and prefrontal cortex (PFC) of depressed patients (Karege et al., 2005). Additionally, antidepressants are believed to function by increasing BDNF concentrations, affecting these same subcortical brain volumes, and thus enhancing mood (Duman & Monteggia, 2006). While differing genotypes determine baseline levels of BDNF, a stressful environment has been proven to significantly decrease BDNF expression, leading to neurodegeneration, reduced GMV in the PFC and hippocampus, and symptoms of anxiety and depression (Chakrapani et al., 2020). Thus, an individual's resilience to environmental influences may be genetically determined but the outcomes are still heavily dependent on environmental factors.

### Individual Differences and Brain Structure

There is an expanding body of evidence emphasizing how individual differences in environment correlate with individual differences in brain structure and behavior. For example, cross-sectional studies have revealed that experienced meditators exhibit higher GMV in regions

associated with interoception (right anterior insula) (Hölzel et al., 2008), skilled musicians exhibit higher GMV in the motor, parietal, and temporal regions (Gaser and Schlaug, 2003), and individuals with high trait anxiety have shown increased structural connectivity (fractional anisotropy) between the frontal cortex and amygdala (Kim and Whalen, 2009).

Moreover, longitudinal studies have provided further insights into the dynamic interplay between environmental factors, brain structure, and behavior. For instance, research has demonstrated that participation in cognitive training programs or engagement in physically active lifestyles can lead to structural changes in the brain, such as increased gray matter volume (Engvig et al., 2010; Erickson et al., 2011). These findings highlight the remarkable plasticity of the human brain and underscore the importance of considering environmental influences on human development. This research intends to explore one such environmental influence, residential greenspace, which may have profound impacts on human brain development.

## **Materials and Methods**

This study will use data collected from the STF Neuroimaging Collective, a collaboration between the University of Washington's Center for Human Neuroscience and the Environment & Well-Being Lab (EWB). This collective consists of several collaborators interested in pooling resources together to collect a large sample of generic structural scans paired with survey data. Questionnaires will be collecting a wide variety of data on our participants - ranging from socioeconomic status to information on language acquisition. The survey data from the present study was a part of the first installment of questionnaires, filled out within 48 hours of the fMRI scan.

### ***Study Participants***

Participants, aged 18-30, were recruited from the University of Washington and surrounding communities (see table 1). The study consisted of an 80-minute fMRI session, and a 20 minute survey. Potential subjects were excluded for a significant history of psychiatric disorders, substance abuse, neurological, or cardiovascular disease. Given the current prevalence in young adults, we did not exclude participants based on a diagnosis of depression, anxiety, or ADHD. However, since pharmacologic treatment of these conditions may impact our brain structures of interest, participants were excluded if their psychoactive treatment has ever lasted longer than 12 months. Those who did not fill out at least 75% of their residential address history were not included in the analysis for insufficient data. A total of 20 participants have been scanned thus far, but two did not meet the residential address history requirements, so the final sample size is n=18.

AGE	
Range	18-30
Mean $\pm$ SD	24.75 $\pm$ 3.4
SEX	
Male, %	10, 56%
Female, %	8, 44%

**Table 1.** Participant Demographics.

### ***Survey Data***

Survey data captured measurements to assess how exposure to residential greenness may correlate with a wide range of measurements. Personality measures were sourced from The Big Five personality scale, and included neuroticism, extraversion, and openness (John & Srivastava, 1999). Mental well-being was measured by the Warwick Edinburgh Mental Well Being Scale

(WEMWBS), and the instructions were slightly modified by asking participants how they felt 'in general', rather than over 'the past couple weeks' (Tennant et al., 2007). Connectedness was measured with the Connectedness to Nature Scale (Mayer & Frantz, 2004) and the WATTS Interconnectedness Scale, which looks at connectedness to self, other, and the world (Watts, 2014). The MacArthur Scale of Subjective Social Status was used to measure socioeconomic status (Adler et al., 2000). Demographics, such as age and sex, were also collected as covariates.

### ***Lifelong Greenness***

To assess lifelong residential greenness, we analyzed satellite imaging data using Google Earth Engine. We sourced publicly accessible imaging data from the National Agriculture Imagery Program (NAIP) and Sentinel-2, which have between 1 and 10 meter spatial resolution.

Greenness was measured using the Normalized Difference Vegetation Index (NDVI), which ranges from -1 to 1, with higher values indicating more photosynthetically active vegetation. The NDVI is calculated as a ratio between the red (RED) and near-infrared (NIR) values:  $(\text{NIR}-\text{RED}) / (\text{NIR}+\text{RED})$ .

NDVI scores were computed for the three longest-held addresses of each participant. These scores were then weighted based on the duration of residence at each address, using a weighted average formula, and measured within a 500-meter circular buffer, representing a 10-15 minute walk from each location (see Figure 1). Bodies of water were excluded from the analysis. Due to limited data availability, each NDVI score represents a median vegetation index from the years 2010-2015.



**Figure 1.** These figures represent what a circular buffer with a circumference of 500m looks like. They are random addresses in Seattle, Washington that represent high and low NDVI scores (NDVI > 0.1, NDVI < -0.1). Green shades are showing high vegetation while blue shades are showing low vegetation (and in this case, built environments).

***Perceived Greenness -***

Perceived and objective greenness measures have been known to capture different facets of neighborhood greenness. Although NDVI scores measure the amount of literal greenness, perceived greenness is thought to better represent the quality of and interaction with the residential greenspaces (Leslie et al., 2010). Therefore, for each address provided, participants answered six questions that have to do with perceived greenness. On a four point scale, ranging from “strongly disagree” to “strongly agree”, they rated their perception of how green each of their residences since birth were. The survey asks whether they had, “access to a park or nature preserve”, “access to bicycle or walking paths”, and “the presence of tree cover or canopy along footpaths”.

### ***STF Neuroimaging Collective***

Our brain imaging data is sourced from the STF Neuroimaging Collective, a brain imaging initiative that collects various generic fMRI scans. The entire protocol takes about 90 minutes and the scan types include T1/T2 structural scans, DSI diffusion-weighted structural connectivity scans, and a resting state functional connectivity scan. It is also the first neuroimaging collective to collect multi-parameter quantitative structural scans (qMRI). The scans are then matched with each participant's corresponding questionnaire data to make inferences about how individual differences may correlate with differences in subcortical brain volume, structural and functional connectivity, and quantitative measurements like proton density. The current study will exclusively utilize data from the initial 20 participants scanned and will combine data from both T1 and T2 structural scans.

### ***Subcortical Brain Volume***

Structural MRI data was processed and segmented in Freesurfer 5.30, an open-source program designed for analyzing brain imaging data (<http://surfer.nmr.mgh.harvard.edu>). Prior to segmentation, this data undergoes preprocessing, culminating in the creation of a final image through a series of stages. Freesurfer's "recon-all" function performs a long list of preprocessing steps. It eliminates the skull from the brain volume within the image, corrects for intensity non-uniformity, motion artifacts, and spatial distortion. Next, segmentation between gray and white matter occurs to delineate and distinguish various cortical regions. The borders of these distinct regions are then defined by a standard set of anatomical landmarks described by Duvernoy (1991).

Finally, the prepared image is inflated onto a sphere and compared with a reference sphere, the fsAverage, aligning and delineating different brain regions accordingly. The end result is the

volume of each segmented region of interest. This calculation is based on the number of voxels (3D pixels) within each region and the voxel size of the MRI images, and ends in a measurement of cubic meters. Mathematically, the formula can be expressed as  $V = N \times V_v$ .  $V$  is the volume of the structure,  $N$  is the number of voxels that make up the segmented structure, and  $V_v$  is the volume of each voxel.

### ***Statistical Analysis***

To examine how lifelong residential greenness correlates with our dependent variables, subcortical GMV and survey data, we will employ an analysis of variance (ANOVA) using multiple regression analysis. Residential greenness, both objective (i.e. averaged NDVI scores within 500 meter buffers) and perceived (self report), will be the independent variables in our analysis. To examine our dependent variable, subcortical brain volume, a region of interest (ROI) analysis will be done on a priori defined regions (those most significantly associated with well-being/depression), specifically the hippocampus, prefrontal cortex, lateral orbitofrontal cortex, nucleus accumbens, amygdala, and thalamus (Du et al., 2018; Frodl et al., 2008; Lange and Irle, 2004). Age and socioeconomic status serve as covariates and are regressed out of the model.

## **Results**

### ***Brain Imaging Data***

Of the six subcortical volumes of interest, two showed significant associations with our independent variable, the nucleus accumbens and the amygdala. These correlations were both observed in the hypothesized direction. Nucleus accumbens volume was significantly positively correlated with the objective greenness measure, NDVI ( $p < 0.05$ ) (see Figure 2). Amygdala volume was negatively correlated with the perceived greenness score ( $p < 0.05$ ) (see Figure 3).

GMV in the orbitofrontal cortex is moderately correlated with the perceived greenness score ( $p = 0.061$ ) (see Table 2).

	Amygdala	Hippocampus	Orbitofrontal Cortex	Nucleus Accumbens	Thalamus	Cerebellum
NDVI	0.904	0.640	0.892	0.022	0.492	0.457
Perceived Greenness	0.019	0.307	0.060	0.136	0.832	0.676

**Table 2.** This table represents the p-values in our correlation analysis between greenness and subcortical brain volume in our ROI's.

### *Survey Data*

Of our six surveys, two were significantly correlated with lifelong perceived greenness, the CNS scale and the WATTS interconnectedness scale. The CNS scale was correlated in the hypothesized direction, where lifelong perceived greenness positively predicted connectedness to nature. In opposition to our hypothesis, perceived greenness and WATTS (world) were significantly negatively correlated.

	WEMWBS	CNS	WATTS (self)	WATTS (others)	WATTS (world)	Extraversion	Neuroticism	Openness
NDVI	0.640	0.429	0.395	0.722	0.614	0.436	0.584	0.106
Perceived Greenness	0.792	0.001	0.407	0.231	0.004	0.125	0.313	0.485

**Table 3.** This table represents the p-values in our correlation analysis between greenness and survey data on well-being, connectedness, and personality.

### **Discussion**

The findings of this study provide significant insights into the relationship between neighborhood greenness and brain structure, particularly in regions associated with emotional

regulation and reward processing. Specifically, our results demonstrate a negative correlation between GMV in the amygdala, a key structure involved in emotional processing, and subjective measures of neighborhood greenness. In contrast, a positive correlation was observed between GMV in the nucleus accumbens, a region implicated in reward processing, and objective measures of neighborhood greenness. Furthermore, assessments of lifelong perceived greenness showed significant correlations with feelings of connectedness, with individuals raised in greener environments reporting stronger connections with nature and weaker connections with the broader world.

### ***Amygdala and Perceived Greenness***

The negative correlation observed between the GMV of the amygdala and lifetime perceived greenness underscores the potential influence of environmental factors on the development of emotional processing. The amygdala, a key structure in the brain's limbic system, is pivotal in detecting and responding to threats, including those associated with anxiety, aggression, and fear. Numerous studies have emphasized its role in modulating emotional responses and shaping behavioral outcomes (LeDoux, 2000).

Research has consistently demonstrated the stress-reducing and anxiety-alleviating effects of exposure to natural environments. For instance, Ulrich's seminal study in 1984 found that hospital patients with views of natural scenery experienced lower stress levels and required fewer pain medications compared to those with urban views. This suggests that contact with green spaces can have significant psychological benefits, including stress reduction and emotional regulation.

If natural environments are serving as a resiliency factor against stress, individuals growing up in greener neighborhoods may encounter less chronic stress. This reduction in stress levels could

potentially lead to structural alterations in the amygdala, influencing its gray matter volume. While further research is needed to elucidate the precise mechanisms underlying this relationship, the negative correlation between amygdala GMV and perceived greenness highlights the potential role of access to greenspace in shaping emotional well-being and neural morphology.

### ***Nucleus Accumbens and NDVI***

The association between the volume of the nucleus accumbens, a critical component of the brain's reward system, and NDVI, a metric indicating environmental greenness, suggests a plausible link between environmental richness and reward processing mechanisms. The nucleus accumbens plays a pivotal role in interpreting pleasurable stimuli and facilitating the development of addictive behaviors (Koob & Volkow, 2016). Exposure to settings abundant in vegetation and biodiversity may activate the brain's reward pathways, eliciting positive emotional responses (Berman et al., 2008). Therefore, exposure to nature very well may impact brain morphology in our brain's pleasure centers, offering a neurobiological foundation for the psychological benefits associated with spending time in nature.

Secondly, green spaces offer opportunities for physical activity and outdoor play, which have been associated with neuroplastic changes in the brain (Chaddock-Heyman et al., 2018). Regular exercise has been shown to promote the release of neurotransmitters such as dopamine, which plays a key role in reward processing and motivation (Dietrich & Audiffren, 2011). Thus, individuals growing up in greener neighborhoods may engage in more physical activity, leading to structural adaptations in reward-related brain regions like the nucleus accumbens.

### ***Mechanisms Underlying the Relationship***

The benefits of natural environments may influence human physiology in a myriad of ways. Exposure to diverse natural environments has been shown to promote a more diverse and beneficial microbiome, which in turn can influence brain function and behavior (Borre et al., 2014). Additionally, green neighborhoods may offer cleaner air quality, which has been linked to improved cognitive function and mental well-being (Allen et al., 2015). Moreover, spending time in natural settings is known to reduce stress and promote attention restoration, factors that could contribute to structural changes in the brain (Kaplan, 1995). In summary, nature contact may have the capacity to influence our nervous systems, and alter subcortical GMV through processes of neurogenesis and neurodegeneration.

### ***Survey Data on Connectedness***

Our survey data indicates that individuals who perceived higher levels of greenery throughout their lives reported stronger connections to nature but weaker connections to the broader world. This correlation is sensible, as childhood exposure to natural environments often encourages a lasting affinity for nature. Conversely, urban settings, or those with lower perceived greenery, may promote a sense of connectedness to the wider world due to the presence of larger communities, diverse events, and cultural exchange opportunities. In essence, while access to nature likely benefits human health and fosters nature connectedness, urban environments may act as bustling centers of cultural exchange, facilitating interaction and idea sharing among people from varied backgrounds, thereby enhancing feelings of connection to the world.

### ***Evolutionary Perspective on Human-Nature Relationship***

The identified associations between neighborhood greenery and brain structure suggest that neighborhood greenness may play a crucial role in the brain development of young adults. This

is consistent with the biophilia hypothesis, which posits that humans possess an innate affinity for nature due to our evolutionary history (Wilson, 1984). Throughout millennia, humans have forged intricate connections with the natural world, depending on it for essential resources such as food, shelter, and protection. It is not until relatively recently in our evolutionary history that we have inhabited such urban environments and urbanicity has the ability to negatively impact health due to factors like air and noise pollution, limited access to green spaces, unhealthy food environments, social and economic inequalities, and crowded living conditions, which can lead to respiratory issues, cardiovascular diseases, obesity, and mental health problems.

As the world becomes increasingly urbanized, it is important to remember our evolutionary roots and intrinsic bond to nature. This deep-seated relationship with nature has likely shaped the development of neural structures responsible for processing environmental stimuli. As a result, exposure to green environments may exert a profound influence on brain morphology, reflecting the enduring imprint of our evolutionary past on neural architecture.

### ***Implications for Urban Planning and Public Health***

The outcomes of this research carry significant implications for both urban planning and public health initiatives. As our world undergoes rapid urbanization, it becomes paramount to delve deeper into how these changes affect human health and overall well-being. Particularly concerning is the disproportionate burden borne by individuals with lower socioeconomic status, who face amplified challenges due to insufficient access to greenspaces in urban settings. To address this, it is imperative for city planners and policymakers to prioritize the preservation and establishment of green spaces across all urban areas.

### ***Limitations and Future Directions***

Despite the significant findings of this study, several limitations should be acknowledged.

Firstly, the cross-sectional nature of the study design precludes causal inferences regarding the relationship between neighborhood greenness and brain structure. Longitudinal studies are needed to understand the temporal dynamics of this association. Additionally, while subjective and objective measures of greenness were utilized, other environmental factors, such as noise pollution and social cohesion, were not considered.

This study is underpowered at only 18 subjects. Once the STF Neuroimaging Collective collects more than 50 participants, this analysis will be rerun on a larger number of subjects.

Additionally, since the NDVI data was averaged across the years 2010-2015, and because neighborhood greenness levels may shift as land is developed, it may not have been perfectly representative. A more comprehensive questionnaire will be sent out to study participants that asks questions targeted towards the brain regions that seem to be impacted most by neighborhood greenness.

### **Conclusion**

Our findings provide evidence for the influence of neighborhood greenness on brain structure, particularly in regions associated with emotional regulation and reward processing. Specifically, exposure to green spaces was linked to greater volume in the nucleus accumbens and reduced volume in the amygdala. These results underscore the importance of integrating natural elements into urban environments to support healthy brain development and overall well-being.

Additionally, our survey data indicates that individuals who perceived higher levels of greenery throughout their lives reported stronger connections to nature but weaker connections to the

broader world. Childhood exposure to natural environments may foster a lasting affinity for nature, while urban settings with lower perceived greenery may enhance connectedness to the wider world. More research is needed to understand these nuanced relationships with connectedness, well-being, and brain structure. Longitudinal studies could help establish causal links and inform policies aimed at creating healthier, more equitable urban environments that promote mental health and cognitive development.

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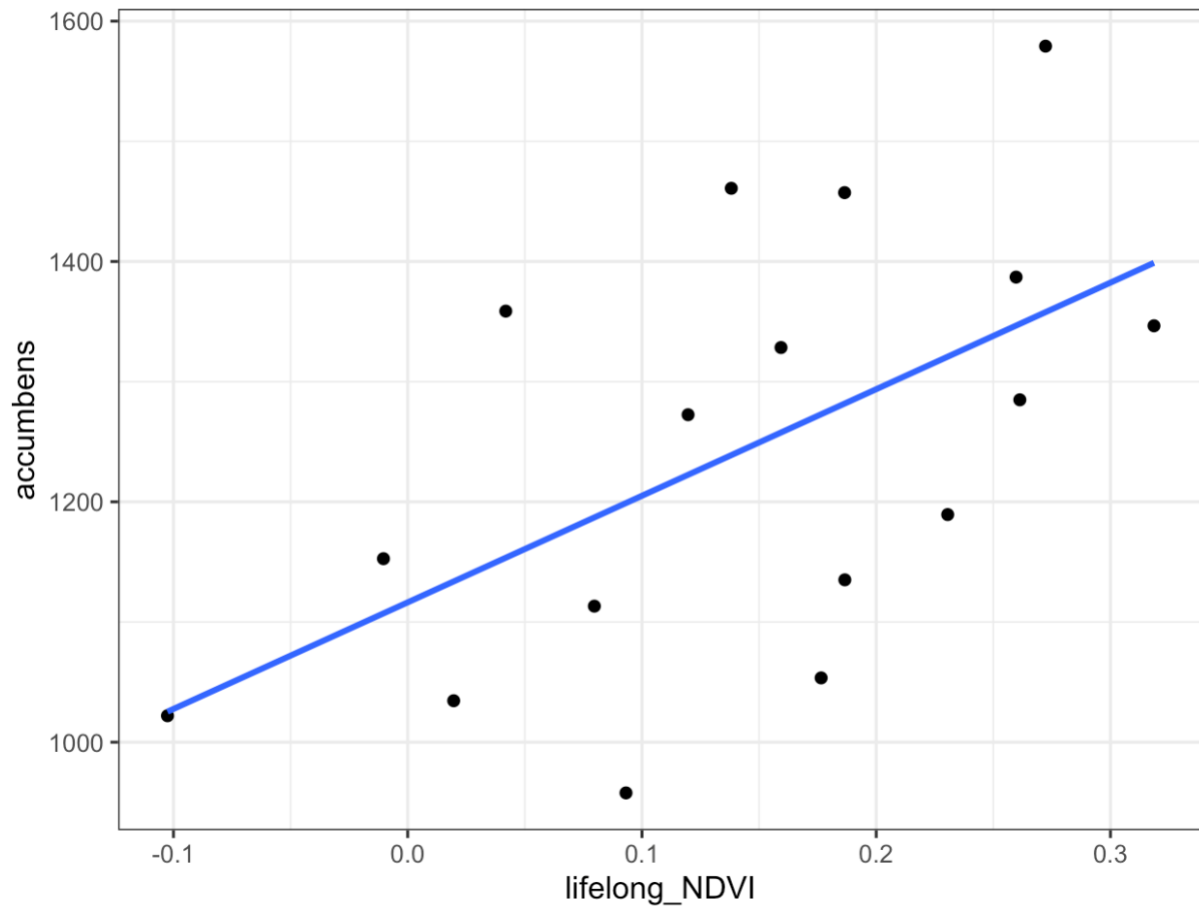
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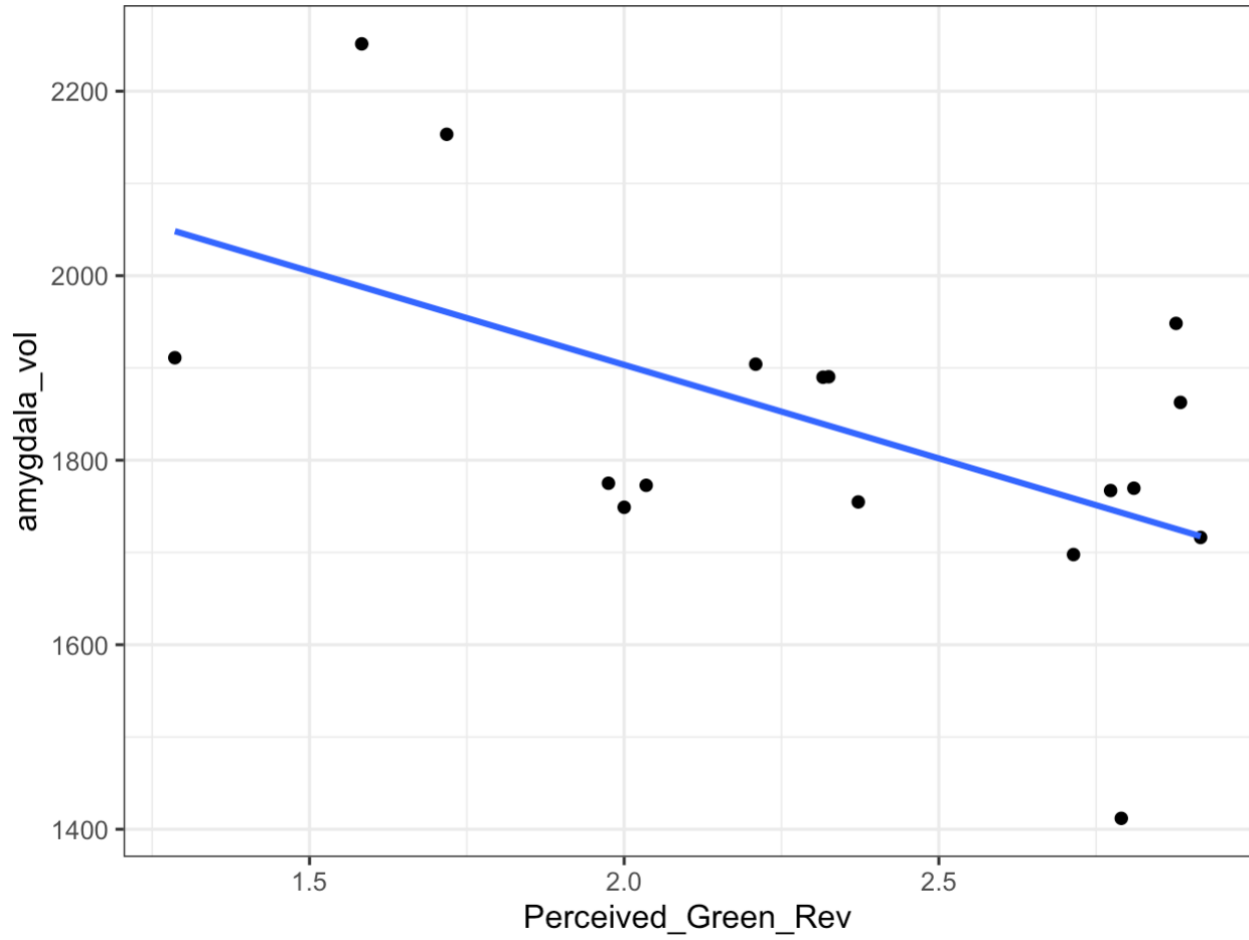
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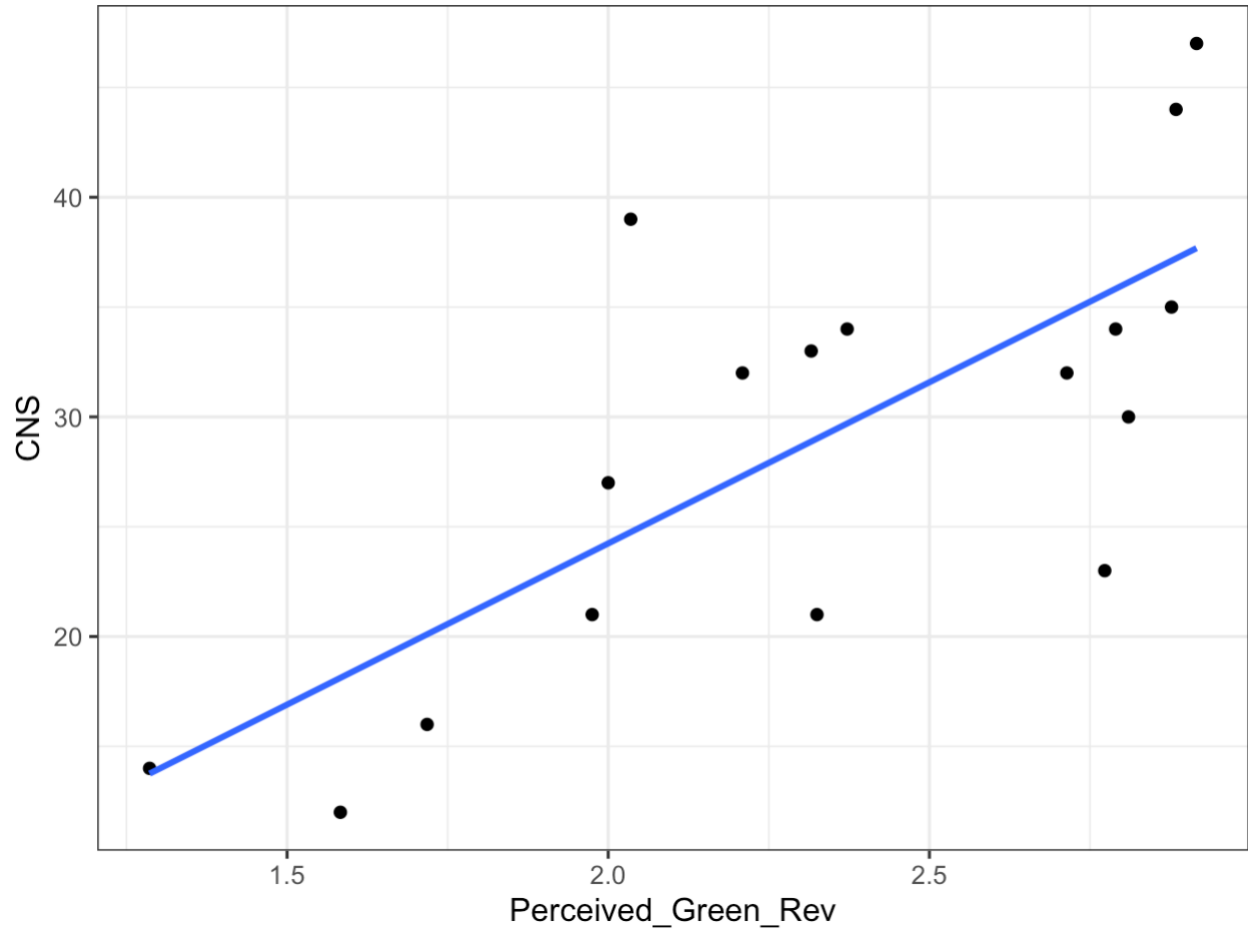
## Appendix



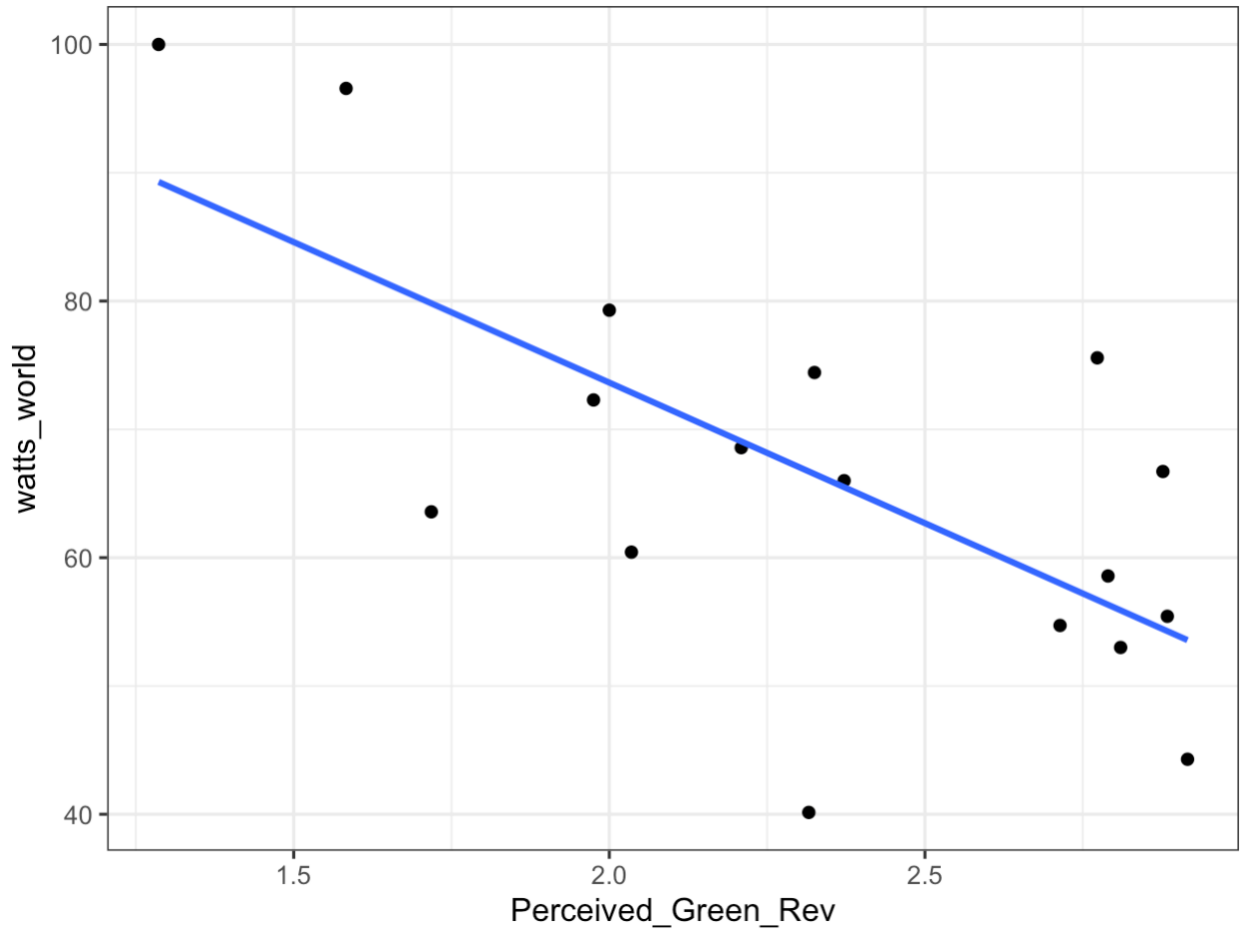
**Figure 2.** A graph representing the positive correlation between lifelong NDVI scores and nucleus accumbens volume.



**Figure 3.** A graph representing the negative correlation between lifelong perceived greenness scores and amygdala volume.



**Figure 4.** A graph representing the positive correlation between lifelong perceived greenness scores and CNS scale.



**Figure 5.** A graph representing the negative correlation between lifelong perceived greenness scores and the WATTS interconnectedness scale (world).