Chapter 4
An Environmental Neuroscience Perspective on the Benefits of Nature

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The field of *environmental neuroscience* offers an important opportunity to study how and why interacting with nature has beneficial psychological effects. Environmental neuroscience is a field devoted to understanding the bi-directional interplay between the physical environment and individual brain processing that produces behavior (Berman, Kardan, Kotabe, Nusbaum, & London, 2019; Berman, Stier, & Akcelik, 2019). The environmental neuroscience approach is multidisciplinary, drawing from various fields such as psychology, neuroscience, genetics, sociology, anthropology, economics, and computer science. It is also a multi-scale science, meaning that the spatial levels of analysis that it explores can be as small as molecules to as large as cities and spans time scales as short as milliseconds to as long as years or centuries.

Simultaneously, there has been enormous growth in the field of *environmental psychology* examining how interacting with different physical environments, such as natural environments (e.g., parks and other more natural areas vs. more built or constructed areas such as a mall), can be salubrious to human psychological functioning. Experimental research has shown that going for nature walks or interacting with real natural environments can increase attention and working memory performance (Berman, Jonides, & Kaplan, 2008; Berman et al., 2012; Berto, 2005; Bratman et al., 2012; Bratman, Daily, Levy, & Gross, 2015; Stenfors et al., 2019), reduce rumination (Bratman, Paul Hamilton, Hahn, Daily, & Gross, 2015), reduce ADHD symptoms (Faber Taylor & Kuo, 2009), reduce breast cancer symptoms (Cimprich & Ronis, 2003), and improve mood (Berman et al., 2008; Bratman, Daily, et al., 2015; McMahan & Estes, 2015). Similar effects have been demonstrated when utilizing more artificial nature stimuli such as pictures (Berman et al., 2008; Berto, 2005), videos (Bourrier, Berman, & Enns, 2018), and sounds (Van Hedger et al., 2018).

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Other impressive studies have shown the benefits of nature in less experimentally controlled, but more ecologically valid settings. Researchers have found a positive relationship between green space around schools and cognitive development in children (Dadvand et al., 2015), as well as an association between green views at home and self-control behaviors in young girls (Faber Taylor, Kuo, & Sullivan, 2002). In a study with adults, researchers also found that residents living in greener public housing buildings showed higher attentional functioning (Kuo & Sullivan, 2001a) and reduced aggression and criminal behavior (Kuo & Sullivan, 2001b). All of these results point to significant effects of interactions with nature on human psychological well-being.

With that said, it is still unclear exactly why interactions with nature have such effects. In this chapter, we outline how an environmental neuroscience perspective may be fruitful in elucidating the mechanisms for why interactions with nature have salubrious effects on human psychological functioning.

4.1 A Multi-Scale Science

Environmental neuroscience considers how processes and factors that vary across multiple scales of temporal and spatial resolution interact to produce behavior. In order to explicitly model the dynamics of these environment-by-brain interactions, environmental neuroscience borrows some of the ideas from other multi-level frameworks such as social neuroscience (Cacioppo & Decety, 2011) and network neuroscience (Bassett & Sporns, 2017). These frameworks focus on using multiple levels of analysis in order to qualitatively guide and interpret research. Here, it is important to model interactions within a level (e.g., brain network connectivity) and also between levels (e.g., the relationship between brain network connectivity and genomic function). Environmental neuroscience builds on these ideas by measuring the spatial and temporal dynamics of interactions between levels of analysis, such as how being a carrier of certain genetic polymorphisms (Belsky et al., 2009) may affect how interactions with urban green space may benefit an individual (Berman, Kardan, et al., 2019; Berman, Stier, & Akcelik, 2019). We believe that examining all of these levels at different temporal and spatial scales will lead to advances in understanding much of human and non-human animal behavior. In addition, the collection of data across these scales and measuring their interactions will generate rich datasets that will continue to yield insights as new ways to model complex multi-level systems are developed.

The goals of environmental neuroscience include: (1) placeing the physical and social environment at the forefront and to link human and non-human animal research together by finding brain measures that could be compared across species (e.g., network properties, nonlinear dynamics); (2) identifying the qualitative and quantitative relationships between different levels of biological and environmental analyses; (3) examining humans across the life span; (4) comparing complex human physical and social environments to other species' native complex physical and social environments and to potentially manipulate those non-human environments in ways that humans have manipulated their own environments; and (5) using this information to design physical environments to improve human psychological functioning (Berman, Kardan, et al., 2019; Berman, Stier, & Akcelik, 2019).

The vast spatial scales, from synapses to cities, and vast temporal scales, from milliseconds to millennia, over which interactions between the socio-physical environment and our brains occur presents environmental neuroscientists with a large phenomenological space to explore (Berman, Stier, & Akcelik, 2019). For example, understanding the impact of urban green space on human behavior and well-being (Berman et al., 2008; Kardan et al., 2015) requires understanding what types of behaviors urban green space mediates (e.g., individual cognition, psychopathology, family dynamics, neighborhood crime levels), the amount of exposure required for the effects to manifest (e.g., individual effects may be realized after seconds of exposure; Van Hedger et al., 2018; Kotabe, Kardan, & Berman, 2016a) or after years (Chetty, Hendren, & Katz, 2016; Kardan, Gozdyra, et al., 2015), how the effects may vary for individuals (e.g., different genetic sensitivity or different personality variables), and how urban green space may induce structural or functional changes in the brain. In general, the processes that environmental neuroscience aims to study operate across various spatial and temporal scales.

4.2 Theories for Nature's Psychological Benefits

Before delving into an environmental neuroscience approach to examine how and why interacting with nature has psychological benefits, it is important to briefly review some of the theorizing about why interacting with nature is beneficial. Stress reduction theory (SRT), proposed by Ulrich (1983), suggests that a positive emotional response to nature allows a person to return from a stressful state to a more relaxed state. According to SRT, interacting with non-threatening natural environments can reduce stress and negative affect, while increasing positive affect. These changes in affect and reductions of stress then allow a person to maintain higher levels of sustained attention, which leads to cognitive benefits (Ulrich, 1983). While a recent meta-analysis shows evidence for improvements in mood following exposure to nature (McMahan & Estes, 2015), our analyses have shown that mood effects are not correlated with the cognitive benefits (Stenfors et al., 2019), thus countering the proposition that mood changes drive the cognitive effects as posited by SRT.

Attention restoration theory (ART), on the other hand, claims that perceptual features of natural environments capture one's bottom-up involuntary attention, while simultaneously allowing finite, top-down directed attention resources a chance to replenish (Kaplan & Berman, 2010; Schertz & Berman, 2019). This perceptual feature of natural environments is called "soft fascination." Other features of restorative environments posited by ART are environments that provide: (1) a sense of being away (i.e., mental separation); (2) a feeling of extent (i.e., large enough environments to be explored); and (3) compatibility with goals (Kaplan, 1995). The feature of compatibility is thought to be one of the ways that the same environment could have different restorative effects for different people, or even for the same person at different times (Schertz & Berman, 2019). For example, if you have a walking commute through a park, you are unlikely to feel the same restorative benefits on days when you are running late for work (Schertz & Berman, 2019). Thus, compatibility can be thought of as how a person interacts with their environment at any given time and how it matches with their current goals and state.

The perceptual fluency account (PFA) relates our positive affective responses to natural stimuli to the ease of processing such stimuli and posits that attention restoration and stress reduction are by-products of this processing fluency (Joye & van den Berg, 2011). For example, fractalness is proposed to be influential in determining how fluently a scene is processed as it increases perceptual predictability. The idea is that fluency would induce less effortful processing, a concept similar to soft fascination in ART. However, in PFA, effortless processing increases positive affect which increases attention, and in ART, effortless processing acts directly to increase attention (Schertz & Berman, 2019). In both ART and PFA, additional research is needed to determine what features make an environment fascinating/fluently processed and how to measure that fascination/fluent processing in an independent way.

Prospect-refuge theory does not focus on an urban-nature dichotomy, but rather on an aesthetic judgment of landscapes. This theory suggests that people prefer landscapes that offer both prospect (a clear field of view) as well as refuge (places to hide; Appleton, 1975). Supporting this theory, research has shown that nature walks that had high prospect led to higher cognitive restoration compared to nature walks with low prospect (Gatersleben & Andrews, 2013).

The biophilia hypothesis (Kellert & Wilson, 1995) suggests that human preferences for nature arise from humans evolving in natural environments. Though there is disagreement on how this might occur—whether this innate affinity is genetically programmed or works through a form of biologically prepared learning—a common explanation for why nature is preferred is that only a small fraction of evolutionary history has occurred within our current urban environments, and the remainder in more natural environments (Meidenbauer et al., 2020). Therefore, in modern times, as we are more distant from nature, we may not be satisfying these innate urges to commune with nature which can lead to cognitive deficits. As such, if we can interact with nature, we can satisfy these innate nature preferences, which will leads to cognitive benefits. Recently, work has shown that children do not prefer nature, and rather prefer more urban environments (Meidenbauer, Stenfors, Bratman, et al., 2019), which is somewhat problematic for accounts that suggest that humans inherently prefer nature as the mechanism for why interacting with nature yields psychological benefits.

Other theories posit that interacting with natural environments is beneficial because natural environments have more affordances than non-natural environments (Chawla, 2007). Affordances relate to the number of relational properties that an environment or a stimulus may have (Heft, 2010). For example, a tree branch can be climbed, sat on, swung from, etc. These theories posit that more benefits from interacting with nature will be gleaned from interacting with "real" natural environments rather than from interacting with natural environments via images, sounds, or videos because the simulated nature will not carry affordances. The assumption here is that interacting with actual nature vs. viewing pictures of nature lead to qualitatively different outcomes. Here is an example wherein environmental neuroscience approaches could be useful to compare brain processes when individuals interact with vs. more passively view actual vs. simulated environments and measure the diversity or similarity of neural processes activated. Work from embodied cognition approaches and visual imagery suggests that there is a large overlap between taken actions and those imagined (Barsalou, Kyle Simmons, Barbey, & Wilson, 2003; Hauk, Johnsrude, & Pulvermüller, 2004; Kosslyn, Ganis, & Thompson, 2001), suggesting that many psychological benefits can be obtained from processing simulated nature. This is corroborated by the immense literature showing that psychological benefits can be obtained from viewing nature images (Berman et al., 2008; Berto, 2005; Stenfors et al., 2019), listening to nature sounds (Van Hedger et al., 2018), and watching nature movies (Bourrier et al., 2018). This is not to say that the benefits from interacting with real vs. virtual nature are the same (Stenfors et al., 2019), rather that some similar benefits can be obtained, suggesting that some of the effect is due to perceiving the features of natural environments (Schertz & Berman, 2019).

4.3 Examining the Different Scales of Nature Research

Research examining the benefits of nature have varied in terms of temporal and spatial scale. Most experimental studies typically involve recruiting some number of participants, ~20–40, and having them interact with a natural or urban environment, and examining changes in cognitive performance, affect, and other psychological measures before and after the interactions. These interactions typically last between a few minutes and an hour. These are the most common types of studies, and we term them meso-scale studies. Other studies look at nature at smaller scales by trying to decompose nature into its low-level perceptual features (such as curved edges) to try and understand why simply perceiving nature stimuli, such as viewing nature images or listening to nature sounds, leads to benefits. We consider these micro-scale studies. At the other end of the spectrum, there are studies that look at large populations of people who live near various amounts of natural green space, and how living near nature may be related to physical health and many other psychological factors such as working memory, affect, and school performance. These studies have much larger sample sizes, and the exposure duration may be on the order of years depending on how long the residents have lived in those neighborhoods. Typically, these studies are correlational/observational. We consider these macro-scale studies. Next, we outline the results of these different studies that examine the effects of nature from these different spatial and temporal scales.

4.3.1 Meso Scale

The most common form of nature studies has been experimental studies where a small set of participants (around 20–40) are exposed to natural or urban environments for brief exposures (on the order of 10–60 min). Researchers then measure changes in different psychological variables before and after these exposures to assess changes in performance due to environmental exposure. These studies are often a mix of between-subject designs (where participants are only exposed to one environment type) and within-subject designs (where participants are exposed to both environment types, separated by some amount of time).

These experimental studies have used a wide range of stimulus types, including images (e.g., Berto, 2005), sounds (e.g., Van Hedger et al., 2018), and real-world exposure (e.g., Berman et al., 2008, 2012), to show that exposure to natural environments can improve participants' cognitive performance relative to exposure to urban environments. Many of the cognitive tasks that show the greatest improvement are tasks that involve working memory, and the backward digit span is one of the more commonly used working memory tasks (Schertz & Berman, 2019; Stenfors et al., 2019). The backward digit span task requires participants to repeat back sequences of numbers, of varying length, in reverse order (Stenfors et al., 2019; Stevenson, Schilhab, & Bentsen, 2018). In general, cognitive tasks that require working memory and cognitive flexibility improve the most after nature exposures. In addition, tasks requiring attentional control also show some improvements. More mixed results have been seen for tasks that involve impulse control, visual attention, vigilance, and processing speed (Stevenson et al., 2018). It is possible that these tasks may not tax directed attention enough, as is theorized by attention restoration theory as a critical resource that is replenished after interactions with nature (Kaplan & Berman, 2010). Here, too, is a place where an environmental neuroscience approach may be helpful as a way to uncover what brain processes are altered after interactions with nature, which can then be used to predict what types of cognitive tasks might benefit from nature interactions.

4.3.2 Micro Scale

One potential mechanism that has emerged for these effects involves the perception of the low-level features of the environment (Schertz & Berman, 2019). As discussed in the theories section, additional work is necessary to understand what makes an environment softly fascinating (ART) and/or fluently processed (PFA). In the visual modality, low-level features include color properties such as hue, saturation, and brightness (value), as well as spatial properties such as the density of straight and non-straight edges, and entropy (see Fig. 4.1; Schertz & Berman, 2019). Interestingly, these "low-level" features have also been found to carry semantic information (Berman et al., 2014; Kardan et al., 2015; Kardan, Gozdyra, et al.,

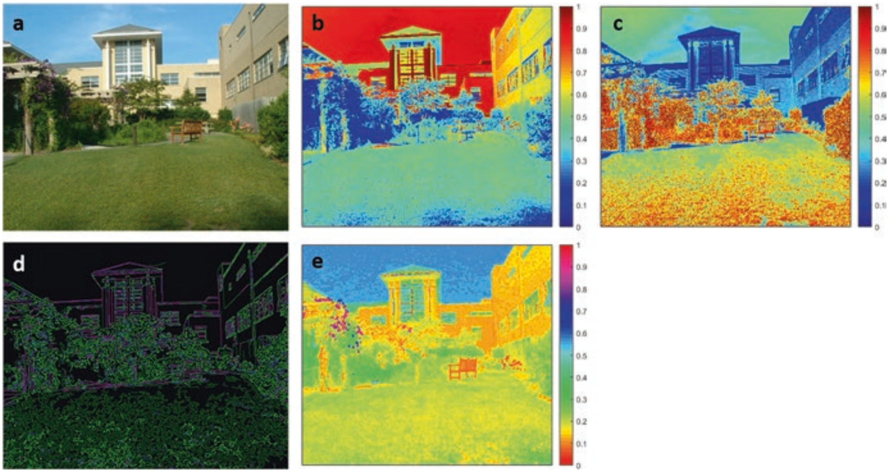

Fig. 4.1 (**a**) Example original image with visualizations of (**b**) brightness (value), (**c**) saturation, (**d**) straight (purple) and non-straight (green) edges, and (**e**) hue. This figure was reproduced with permission from Schertz and Berman (2019)

2015; Kotabe et al., 2016a; Kotabe, Kardan, & Berman, 2016b; Kotabe et al., 2017). For example, some of these visual features can significantly predict people's preference and naturalness judgments for a wide range of images. Natural environments in general have more non-straight edges, less color saturation, and less variability of hues. In addition, perceiving the low-level features of the environment can influence complex cognitive and self-regulatory processes, such as thought content (Schertz et al., 2018; Schertz, Kardan, & Berman, 2020) and the propensity to cheat (Kotabe et al., 2016a). When shown images that were higher in non-straight edge density, people were more likely to think about topics related to spirituality and one's life journey, compared to viewing images with lower non-straight edges, independent of the perceived naturalness of the scene (Schertz, Kardan, & Berman, 2020; Schertz, Sachdeva, et al., 2018).

Just as in the visual domain, participants show increases in working memory performance after listening to nature sounds relative to urban sounds (Van Hedger et al., 2018). There are many low-level acoustic features that can be quantified such as spectral entropy, a measure of noisiness of the sound, and dominant frequency. Importantly, these features often significantly differ between natural sounds and urban sounds and can be used to categorize sounds as originating from nature or urban sources (e.g., nature sounds tend to have higher spectral centroids and higher spectral entropy; Van Hedger et al., 2019). People tend to prefer natural sounds, but only when they can be identified as such. Thus, when urban and natural sounds were presented in an unidentifiable manner (i.e., hearing only a 100 ms duration sound), the low-level acoustic features remained different between nature and urban sounds, but, importantly, preference levels did not differ (Van Hedger et al., 2019). This indicates that the low-level acoustic features alone do not predict preferences, but rather interacted with semantic information. The same could also be true for the cognitive benefits seen after interacting with nature and urban stimulation—where cognitive benefits may or may not be seen after perceiving natural features in isolation from semantic context (Schertz & Berman, 2019).

Aside from perceiving the low-level features of natural environments, others have posited different mechanisms for why nature might be restorative, such as breathing in improved air quality (Dadvand et al., 2015), being exposed to phytoncides (antimicrobial volatile organic compounds; Li et al., 2006; Li et al., 2009) and negative air ions (Li, 2010) as well as being exposed to the diverse microbacteria that exist in nature (Lowry et al., 2007). All of these mechanisms require that an individual be exposed to real nature. While much more research in these areas needs to be done to experimentally link these features of nature to psychological benefits, they suggest a need to study these benefits from a more biological perspective and to look at small scale phenomena that can have implications on psychological performance. This is a topic that is very much aligned with the goals of environmental neuroscience.

4.3.3 Macro Scale

While a large portion of environmental neuroscience studies occur at the meso level of analysis, macro level investigations have produced invaluable contributions to our understanding of how interacting with nature may provide benefits to human well-being, psychological functioning, and behavior. Through transdisciplinary efforts between the fields of psychology, neuroscience, sociology, epidemiology, economics, geography, and ecology, macro-level studies in environmental neuroscience provide an excellent opportunity to generate hypotheses regarding the boundary conditions and minimal and/or necessary conditions required for the positive effects of nature, which can then be tested later at the meso and micro scales. In addition, macro-level investigations allow for the exploration of nature effects in more ecologically valid conditions that contain highly complex and dynamic variables such as social networks, demographic changes, and shifting climate patterns.

Investigations at the macro scale have yielded a large number of results indicating a beneficial association with nature for outcomes such as general health (Dadvand et al., 2016; Kardan, Gozdyra, et al., 2015; Sugiyama et al., 2016), mental health (de Vries, van Dillen, Groenewegen, & Spreeuwenberg, 2013; Engemann et al., 2019; McEachan et al., 2016; Sarkar, Webster, & Gallacher, 2018), obesity (Ellaway, Macintyre, & Bonnefoy, 2005; Lovasi et al., 2013), birth weight (Hystad et al., 2014; Markevych et al., 2014), childhood behavioral development (Amoly et al., 2014; Balseviciene et al., 2014), childhood brain development and cognitive function (Dadvand et al., 2015), mortality (Donovan et al., 2013; Mitchell & Popham, 2008; Villeneuve et al., 2012), development of social networks (Dadvand et al., 2016; Eriksson & Emmelin, 2013; Fan, Das, & Chen, 2011; Maas et al., 2009), and active lifestyle promotion (Almanza, Jerrett, Dunton, Seto, & Ann Pentz, 2012; de Jong, Albin, Skärbäck, Grahn, & Björk, 2012; Fan et al., 2011; Gidlow, Randall, Gillman, Smith, & Jones, 2016; Giles-Corti et al., 2005; Mytton, Townsend, Rutter, & Foster, 2012). While this list may be overwhelming, these studies share several characteristics. Many of these studies are observational, in contrast to interventional, meaning that there is no experimental manipulation by researchers. Thus, while researchers are able to formulate and test hypotheses in these studies using correlational methods, they are unable to make causal inferences. A related consequence of this is that macro-scale studies tend to characterize explanatory mechanisms as occurring over large temporal scales, often on the order of an individual's life course. This is in stark contrast to the more "immediate" temporal scales characteristic of the many studies at the meso and micro scales.

Many of the studies at the macro level have often been reported under the umbrella term of "ecosystem services" which refers to the "many and varied benefits that humans freely gain from the natural environment and from properly-functioning ecosystems" (Carpenter et al., 2006; Millennium Ecosystem Assessment (MEA), 2005). Historically, according to the MEA, "ecosystem services" have been considered along four categories with relevance to research in ecology, economics, and public policy. They are: (1) supporting/habitat services (i.e., maintenance of biodiversity, conservation, conservation of habitats for species); (2) provisioning services (i.e., food, water, and raw materials); (3) regulating services (i.e., air quality, waste treatment, disease control, soil quality); and (4) cultural services (i.e., recreation, tourism, inspiration for art and design, spiritual experience, and sense of being). Research highlighting the benefits of these categories has been reviewed elsewhere (Chiabai, Quiroga, Martinez-Juarez, Higgins, & Taylor, 2018; Markevych et al., 2017). However, there has been much less focus on what Bratman et al. (2019) have termed "psychological ecosystem services," which highlight the positive benefits of engaging with nature on mental health, psychological well-being, and cognitive and affective functioning.

Macro-scale studies vary in the way that they measure "natural features," and many rely on measures such as satellite-based indices and GIS-based land use variables in order to calculate tree canopy or local vegetation indices (Markevych et al., 2017). These measures are limited by the resolution and quality of the data, and also by the strength of the classification methods (e.g., if an algorithm can distinguish between trees, shrubs).

A second consideration for macro-scale studies is the type of exposure, or the amount of contact that an individual has with nature (Bratman et al., 2019). As with the previous step, researchers are limited by the resolution of their data and tend to adopt one of two assumptions: either they will (1) take a cumulative opportunity approach by computing the percentage of an area of interest (such as a zip code or residential block) that is made up of nature elements, or (2) will take a proximity measure, such as a physical distance from an individual's estimated home location using a circular buffer to approximate an individual's roaming space (Ekkel & de Vries, 2017). A recent investigation by Liqing Zhang and Puay Yok Tan (2019) in Singapore indicated that the association between urban green space and health was dependent on the size of the area they investigated around an individual (finding optimal associations between 400 and 1600 m) and the type of land cover variable they used, finding a stronger association when using tree canopy versus the presence of shrubs, grass, or parks. More recently, researchers have quantified how often people in different neighborhoods visit parks outside of their neighborhoods using cell phone trace data (Schertz et al., in press). The authors found a significant correlation between the amount of park visits in different neighborhoods with reduced crime, controlling for age, education, income, and other demographic variables. These results illustrate the importance of choosing an appropriate measure of natural features and exposure when attempting to quantify the characteristics of a nature interaction.

A third important consideration is to try to quantify the "dose" amount of nature "absorbed" by an individual (Bratman et al., 2019). Absorption is a term borrowed from toxicology and epidemiology; the amount of nature "absorbed" by two individuals with the same nature contact will vary according to different levels of attention, preference, and feelings of personal connection with nature (Bratman et al., 2019). It is here where environmental neuroscience investigations at the meso and micro level may elevate and illuminate phenomena observed at the macro level. Such an example can be observed with the cellphone trace data in Schertz et al. (in press) (See *Combining Scales* section), where one can quantify how often one visits a park and for how long.

Research at the macro level has also identified a number of challenges that present interesting opportunities for future environmental neuroscience research. Following the suggestions of studies showcasing the different use of park and green spaces by non-White populations due to sociocultural moderators and uneven spatial distributions of green space within cities (Byrne, 2012; Byrne & Wolch, 2009), a few studies have investigated the connection between green space and health by exploring the moderating effect of racial/ethnic identity and socioeconomic status. Under a broader interdisciplinary body of literature titled "environmental justice," research in this area, as defined by the US Environmental Protection Agency (EPA), focuses on the "fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies" (US EPA, 2012). In support of this approach to prioritizing equity, studies have highlighted that the positive effects associated with nature may be swamped out by structural- and societal-level factors that create social and physical barriers, such as lack of opportunities, inadequate amenities, and racial prejudice (Bratman et al., 2019; Casey, James, Cushing, Jesdale, & Morello-Frosch, 2017; Jennings, Larson, & Yun, 2016; Rigolon, Toker, & Gasparian, 2018). Furthermore, these same studies underscore the inequitable distribution of green spaces and their high spatial correlation with areas of greater socioeconomic prosperity (see Fig. 4.2), which, as a corollary, associate the deprivation of nature to areas already experiencing socioeconomic deprivation. Specific to mental health, some studies have identified what they term an "equigenic effect," such that a greater nature benefit is observed in areas of lower socioeconomic status (Mitchell, Richardson, Shortt, & Pearce, 2015),

Fig. 4.2 Choropleth plot showing the distribution of green space across neighborhood clusters in Chicago. Darker green areas have higher tree canopy. The height of each neighborhood represents how affluent each neighborhood is. Plots like this can be used to examine the equitable or inequitable distribution of green space in large urban areas

suggesting a positive effect to nature exposure even in the context of socioeconomic disparity (Mitchell & Popham, 2008).

Most studies at the macro level are correlational due to the financial and logistical difficulties with executing an experimental study (i.e., increasing green space in certain neighborhoods). One promising study that did achieve this was an experiment reported by South and colleagues (2018), in which the city of Philadelphia took part in a version of a randomized control trial in which a number of city lots were treated with one of three conditions: (1) greening the lot; (2) removing trash; or (3) a no-intervention control. The results of this experiment showed better mental health outcomes for individuals within a close proximity to lots in the greening condition.

In summary, the variety of macro-level studies investigating the positive benefits of nature provide an opportunity to observe effects seen at meso and micro levels within the context of complex sociopolitical variables, and exposures at greater temporal scales. Although these studies are mostly correlational, they likely show the impact of multiple mechanisms occurring at once, such as reductions in stress, increases in social cohesion, increases in physical activity, and restoration of cognitive capacity to name a few. By highlighting these candidate mechanisms at grander scales in ecologically valid contexts, macro-scale studies set the scene for more controlled environmental neuroscience studies at the meso- and micro-scale levels, while also providing enough population-level information to be relevant to public policy, epidemiology, and other fields in the social sciences.

4.3.4 Missing Factors: Neural and Genetic Scales

While certainly not the only missing factors, here we focus on two smaller spatial scales, neural and genetic, that may be important to study to obtain a fuller understanding of how and why interacting with nature may be beneficial. These are two scales to which an environmental neuroscience approach lends itself well.

4.3.4.1 Neural

Many of the theories that posit that nature is restorative claim that processing natural stimulation is more effortless or easier to process. To strongly validate those claims, one should examine if the brain more easily/efficiently processes natural scenes. One way to do so would be to look at some newer research which has found that the brain is in a more scale-free/fractal state when it is exerting less effort (Barnes, Bullmore, & Suckling, 2009; Churchill et al., 2015, 2016; He, 2014; Kardan et al., 2020). Here, scale-free/fractal state is quantified by plotting the spectral power curve of the temporal signal and quantifying the relationship between Power, $P(f)$, and frequency, f, where $P(f) \propto f^{-\beta}$. These types of signals are scale-free/fractal when the exponent, β is close to 1. In other words, for those signals, it does not matter at what temporal window/scale you decompose the signal, the spectral power curve will always have the same $1/f$ shape.

This research implies that when one is processing more natural stimulation, the brain will be in a more fractal state relative to processing more urban environmental stimulation. This has not yet been tested, but a strong experimental result would demonstrate that when one is seeing or listening to nature stimulation relative to urban stimulation, the brain would be in more fractal state and the amount of increase in fractalness would be accompanied by an improvement in cognitive performance (i.e., a behavior change).

Some have even suggested that it is the spatial fractal patterning of nature that may be why processing natural stimulation is restorative. Researchers have found that statistical fractal patterns found in nature induce brain signals related to a wakefully relaxed state (Hagerhall et al., 2015). As such, the fractalness of natural scenes may have an optimal mix of variation and predictability to make them fluently processed, while still interesting enough to hold attention (Hagerhall et al., 2015). However, this study did not have a concomitant behavioral measure to show that these brain signals related to a relaxed state were actually related to improvements in performance, which is critical. Otherwise, it is difficult to interpret a brain effect in isolation and there could be many reasons why a brain state may be induced that may not necessarily produce the same behavioral outcome. Even so, this area of research is quite promising by identifying brain states that may signal less effortful processing, and determining if the brain is more likely to reach these states after an interaction with nature.

4.3.4.2 Genetic

One element that is often overlooked in this research is that of individual differences. For example, interacting with nature may not affect individuals in the same way. Seminal research has shown that individuals may be more or less affected by different environments based on their carrier status of certain genes, such as the seratonin promoter gene, 5-HTTLPR (Belsky et al., 2009). Individuals who are s/s carriers on the 5-HTTLPR gene are more sensitive to the environment in a "for better or for worse" manner, meaning that if an s/s carrier is exposed to a positive environment (loving, enriched, etc.) early in life that person will be less likely to develop depression, but if that same person is exposed to a negative environment (abusive, maltreatment, etc.) early in life, that person will be more likely to develop depression (Belsky et al., 2009). l/l carriers, on the other hand, are less affected by the environment either positively or negatively. As such, individuals who are s/s carries may be more sensitive to the environment in general and hence more affected by natural environments specifically (Berman, Kardan, et al., 2019; Berman, Stier, & Akcelik, 2019). In other words, we would expect that s/s carriers might benefit more from natural environment exposure than l/l carriers. In addition, it would be interesting to see if these differences only manifested themselves when exposed to actual environments, or if these differences could be seen after simply processing the features of nature via videos or sounds. Importantly, it is highly possible that these effects would only be seen after long-term exposures to these environments, but that is an empirical question (i.e., would s/s carriers show larger effects after a brief nature walk or would these gene × environment interactions only show themselves for individuals who reside in more natural vs. more urban environments where the cumulative environmental exposure is much larger). As such, an environmental neuroscience approach would be to take individuals who have different carrier statuses on the 5-HTTLPR gene and measure their exposures to green space or better yet, attempt to manipulate their exposure to green space via some kind of long-term exposure intervention program.

4.4 Environmental Neuroscience: Combining Scales

It is clear that examining the salubrious effects of nature across varied spatial and temporal scales provides a more comprehensive understanding than any singular scale can provide on its own. The programs of research conducted at micro, meso, and macro scales are vitally important, and by aggregating the effects, we can fill in the gaps of knowledge at any particular scale (see Fig. 4.3). For example, meso-scale studies involving walks in natural and urban environments (Berman et al., 2008, 2012; Bratman, Daily, et al., 2015; Bratman, Paul Hamilton, et al., 2015) allowed for empirical testing of the correlation between long-term nature exposures and cognitive functioning (Kuo & Sullivan, 2001a), as well as examining the mechanisms underlying large- (or macro-) scale relationships between nearby green

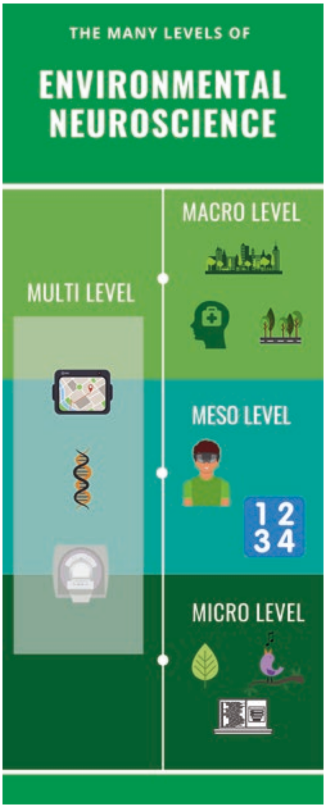

Fig. 4.3 The many different scales of Environmental Neuroscience. At the micro level, studies examine the perceptual features of nature that may drive psychological effects as well as the neural and genetic mediating factors. At the meso level, studies may expose people experimentally to real natural or urban environments or to virtual environments via head mounted displays. In addition, these studies will often measure cognitive performance via tasks like the backward digit span task. At the macro level, studies examine how longer term exposure to green space affects cognitive and affective processing and health (including mental health). Environmental neuroscience stresses the importance of using tools that can link and cross scales, such as brain imaging, genomic measures, and smartphone apps, which will help to elucidate the mechanisms that drive the positive effects of interacting with green space. Understanding these effects will also help with the design of built spaces that can improve psychological functioning

space and mental health outcomes (Beyer et al., 2014; Francis, Wood, Knuiman, & Giles-Corti, 2012; Nutsford, Pearson, & Kingham, 2013). These observational studies, which cover considerable temporal and spatial scales, provide insight into the generalizability and magnitude of the results observed in meso-scale laboratory studies.

Further, the knowledge obtained from one scale can inform research in others. One such example of this approach was conducted by Schertz, Kardan, and Berman (2020) with their analysis of thought content from park visitors' anonymous journal entries, and how these thoughts can be influenced by the low-level visual features of the park that they are visiting. The first study of this multi-step research project was to take ecologically valid but correlational data from over 11,000 journal entries and quantify the main themes or topics of these journal entries. Then the frequency of these topics could be correlated with the visual features extracted from photos of the parks in which the entries were written. For example, the researchers found that the amount of curved edges in the park photographs was correlated with the propensity of the park visitors to write about topics related to spirituality. Schertz and colleagues then replicated this effect in an experimental study, conducted online, showing pictures of other scenes that varied on naturalness and curved edges and had participants select thought topics that matched the scenes. Participants selected thought topics related to spirituality significantly more often if the scene had a high amount of non-straight edges (Schertz, Sachdeva, et al., 2018). To take this even further, in follow-up work, the authors displayed abstract images to participants, which lacked semantic content but varied in the amount of curved edges. The results of this study (Schertz et al., 2020) showed that even with abstract images, the more curved edges, the more people thought about topics related to spirituality. Here the authors began with a correlational study, but then followed up that work with smaller scale experimental studies to isolate the effects and determine causal mechanisms. Importantly, this work shows that the effects may not be due to nature per se, but to a feature of nature, namely perceiving curved edges.

Thus, we can think of combining these scales as creating a body of research that is greater than the sum of its parts. This is especially apparent when employing research methodologies that are designed to span multiple spatial or temporal scales. A recent mobile application developed by Schertz, Kardan, and Berman (2018) was created with this in mind. The app, called ReTUNE (Restoring Through Urban Nature Experience), uses green space data (LiDar data), sound data (SoundScore data), and crime data (taken from the City of Chicago open data portal) as inputs and generates the optimal "restorative" walk from point A to point B, by maximizing green space, minimizing crime, and minimizing sound. The ReTUNE app (Schertz et al., in press; Schertz, Kardan, & Berman, 2018), while in its infancy, employs a novel methodology to influence long-term nature exposure through its suggested routes, and will ideally reach a point where measures of cognitive fatigue or restoration, mood, or thought content can be measured within the app itself. This would allow for large-scale monitoring of the psychological effects of a more or less restorative walk and provide an opportunity for experimentation as parameters of interest (green space, noise, crime) can be adjusted. Thus, the application allows both manipulation of factors thought to influence restoration and evaluation of long-term or dose-dependent responses to nature. In doing so, this approach would allow for a line of research spanning the meso scale via controlled experimentation, and the macro scale via ecologically valid interactions with actual (non-simulated) environments over time.

A related concept to the ReTUNE app is that of experience sampling from individuals either during experimenter-specified walks in natural, urban, or residential areas (Ryan et al., 2010), or by sampling alongside GPS satellite data from individuals' everyday experiences (MacKerron & Mourato, 2013). Experience sampling methods (ESM) typically employ a mobile application or tool which monitors experiences of interest by regularly pinging participants to answer survey questions regarding mental state, and relating responses to environmental factors present at the time of assessment. Research of this type has identified stable, long-term relationships between subjective well-being and spending more time in natural outdoor environments compared to urban ones (MacKerron & Mourato, 2013). An experience sampling technique reduces memory distortions and poor recall associated with retrospective self-reports, allowing for frequent monitoring over long time scales (Doherty, Lemieux, & Canally, 2014). ESM approaches also benefit from the potential to study the role of other relevant variables, such as daylight, amount of physical activity, and weather (Beute & de Kort, 2018; MacKerron & Mourato, 2013; Ryan et al., 2010). Furthermore, these frequent assessments of psychological state can be examined in conjunction with relatively constant, trait-level factors. Due to the repeated measures data gathered within individuals in ESM, such research provides a more reliable examination of what stable, dispositional factors may be important in reaping the benefits of natural environments (Bakolis et al., 2018), which is difficult to examine in studies comparing across groups. By utilizing these experimental designs which span the standard micro, meso, or macro research scales, we can obtain detailed knowledge about the extent and scope of nature's benefits, and better account for individual differences that are hard to examine at a singular scale.

4.4.1 Using Neuroscience Methods Across Scales

One dynamic factor that is important to consider across all scales is that of neural responses to natural environments. Psychophysiological sensors measuring heartrate, blood pressure, or skin conductance allow measurement of peripheral nervous system function, which can be used to assess levels of stress or arousal during and after exposure to different environments (Ulrich et al., 1991). However, to gain insight into how natural environments influence neural processing in humans, functional neuroimaging techniques must be employed.

Because theoretical accounts of nature's cognitive benefits differ in the extent to which changes in affective state are assumed to matter, the use of neuroscientific methods may be particularly helpful to address discrepancies. For example, SRT (Ulrich, 1983) suggests the cognitive benefits arise from changes in mood and reductions in psychophysiological arousal, whereas ART (Kaplan & Berman, 2010) proposes that the affective benefits are unrelated to the cognitive benefits. This debate would benefit from examining the established behavioral measures in conjunction with functional neuroimaging methods to elucidate changes in affective and cognitive processing in the brain. It is also worth noting here that none of the prominent theories of nature's benefits (SRT, ART, PFA, Prospect-refuge, Biophilia) attempt to explain how nature interactions influence neural functioning, and instead, focus solely on behavioral outcomes. Not addressing how the brain processes different environments is a key limitation of these theoretical frameworks, especially considering the variety of other biologically based, health benefits that nature exposure is known to afford (Frumkin et al., 2017).

Unfortunately, while many meso-scale studies rely on behavioral measures such as self-reported mood, performance on cognitive tasks, or other questionnaire data, very few have attempted to identify neural correlates of nature interactions. One study (Bratman, Daily, et al., 2015; Bratman, Paul Hamilton, et al., 2015) examined resting state functional MRI data from participants before and after a 90-min walk in a natural environment compared to an urban walk and found decreased activity in the subgenual prefrontal cortex (sgPFC) and lower self-reported rumination after a nature walk versus an urban walk. The identification of decreased sgPFC activation bolstered the behavioral reports by providing a potential biologically-based explanation for how nature interactions might improve human psychological function. However, this study did not explicitly test whether there was a significant association between rumination change and sgPFC activation, so further evidence would be needed to draw strong conclusions about the neural mechanisms at play.

Another study (Tost et al., 2019) demonstrated the utility of combining neuroscience methods with experience sampling to examine the positive effects of urban green space on mental health in city dwellers. The researchers used location tracking to measure daily exposure to green space and routine assessments of emotional well-being during a 7-day period and related this information to fMRI activity during a task that required regulation of negative emotions. This study found reduced activation in the dorsolateral prefrontal cortex (DLPFC) in regulating responses to aversive stimuli that was linked to increased nature exposure taken from the geolocation data. By combining such approaches, a robust link between emotion regulation and green space was found that could potentially be explained on a neurobiological level. Here, including functional neuroimaging sheds some light on potential mechanisms by which nature exposure may have a positive effect on the processing of negative emotions, with clear implications for the observation of higher psychopathology occurrence in urban centers (Peen, Schoevers, Beekman, & Dekker, 2010). However, as in the study by Bratman, Daily, et al. (2015), a key limitation of this work is the lack of a reported relationship between DLPFC activation and a behavioral index of emotion regulation, which limits what inferences can be drawn. Likewise, a recent EEG study found differences between viewing nature and urban images in several event-related components and alpha power density, which are thought to relate to attentional processing (Grassini et al., 2019). However, this study also failed to relate the electrophysiological results to any performance changes on the cognitive task. Future research is therefore needed to draw stronger conclusions about the interactions between exposure to different environments, brain, and behavior.

While important and informative, these studies did not measure neural activity during exposure to nature nor did they relate the neural activity to behavior, and therefore it remains an open question as to how the brain may differentially respond to natural versus urban environments. Doing so is not trivial, though. Ideally, neuroscience research on the topic would not only measure real-time brain activity during exposure to the environments of interest, but also incorporate behavioral measures with objective (task performance) and subjective (fatigue, perceived restoration, state affect) components, and control for extraneous factors such as aesthetics and preference as in many studies natural environments are confounded with preference, making it difficult to attribute the results to the environment (nature vs. urban) or to preference (simply being exposed to an environment that is more preferred independent of its naturalness; Meidenbauer, Stenfors, Bratman, et al., 2020; Meidenbauer et al., 2019). For example, one approach would be to conduct an EEG or fMRI study which includes an attention-demanding task both before and after exposure to simulated nature and urban environments (using pictures, sounds, videos, VR, etc.) which are equated on aesthetic preference, as well as gathering data on self-reported affect, perceived restoration, or other factors of interest at various points of the study. By examining neural dynamics during nature compared to urban exposure, one could examine patterns of activity linked to reduced cognitive effort, such as the scale-free or fractal state alluded to previously (Churchill et al., 2015, 2016; Kardan et al., 2020), or activation across functional groups of limbic and cortical regions implicated in affective processing (Kober et al., 2008; Lindquist, Satpute, Wager, Weber, & Barrett, 2016).

Still, it should be noted that for all the insight which would be gleaned from lab-based neuroscience experimentation involving virtual nature, analyzing brain function during exposure to real natural environments is still necessary. One approach is to use EEG in naturalistic environments. A recent study examining the effects of nature on children's cognitive functioning collected EEG recordings while children performed attention-demanding tasks in both an outdoor nature and indoor environment. This study found several behavioral and event-related component markers of improved attention in the outdoor setting (Torquati, Schutte, & Kiat, 2017). Though this study had a relatively small sample, it is an encouraging demonstration of how neuroimaging may be used in ecologically valid settings.

Additionally, though fMRI benefits from precise spatial resolution of the whole full brain, studies using this technique are limited to virtual nature stimulation such as sounds, images, or videos. Importantly, research using a method that is also related to blood oxygenation similar to fMRI, functional near-infrared spectroscopy (fNIRS) is gaining traction in cognitive neuroscience research and provides a unique opportunity for the measurement of brain function in naturalistic settings (Yücel, Selb, Huppert, Franceschini, & Boas, 2017). fNIRS uses light spectroscopy to measure metabolic activity associated with activation in neural cortex and has impressive tolerance to motion artifacts and environmental noise (Pinti et al., 2020). This advantage of fNIRS, in particular, engenders the possibility of real-time neural measurement as participants interact with actual nature or urban environments. As both fMRI and fNIRS measure changes in the brain's hemodynamic response—with one limited to virtual nature but allowing for detailed neural activation patterns and the other allowing for ambulatory studies in naturalistic environments with decreased precision—conducting research with both methods has the potential to provide a more comprehensive understanding of how the brain responds to natural environments.

In summary, neuroscience research could be vital in generating mechanistic explanations for many of nature's observed benefits and offers the possibility to disentangle the mechanisms that drive the psychological benefits, and broader health benefits, observed after interactions with nature. With the advancement of mobile neuroimaging technology such as fNIRS, and the combination of these methods with experience sampling (Tost et al., 2019) or longitudinal designs (Dadvand et al., 2018), understanding how nature exposure impacts neural functioning can be explored well beyond meso-scale laboratory experimentation.

4.5 Implications for Other Fields

4.5.1 Urban Planning and Design

Many of the implications of this environmental neuroscience approach to understanding how and why nature is beneficial is to actually alter the built environment to incorporate more natural features to improve psychological functioning. This of course is just a narrow benefit as incorporating more nature into urban areas is not just beneficial for humans, but also for many other species and for the planet in general. Bratman and colleagues described nature's benefits from an ecosystem services perspective, which includes the many contributions of nature to quality of life such as water purification, provision of food, stabilization of climate, and protection from flooding (Bratman et al., 2019). Bratman and colleagues argue, based on the extant literature, that another ecosystem service that nature provides is to directly improve human psychological well-being and mental health (Bratman et al., 2019). This means that urban planners and designers should not only build in nature in urban settings for the more traditional ecosystem services, but also for these psychological benefits. However, this might also require additional support from environmental neuroscientists, who can help to understand and determine what are the features of nature that lead to these benefits in order to design environments in optimal ways (Berman, Kardan, et al., 2019; Berman, Stier, & Akcelik, 2019; Bratman et al., 2019). For example, it is not entirely clear what types of nature, interaction form, or dose are required to obtain these benefits (Bratman et al., 2019).

It is also not entirely clear for some benefits if the nature interaction needs to involve actual nature at all. For example, architects and designers have theorized for a while that built spaces which mimic naturalistic forms and patterns may elicit positive psychological responses (Alexander, 2002; Kellert, 2005). Recent work from our lab has shown that individuals "see" nature in completely built spaces (e.g., building facades and building interiors) if those spaces have features that mimic natural patterns such as having high curved edge density, fractalness, complexity, and scaling (Coburn et al., 2019). In fact, these more "natural" architectural designs are also more preferred by participants (Coburn et al., 2019), suggesting that some psychological benefits may be conferred from completely built spaces that contain no actual nature. This is not to say that architecturally built spaces can replace actual nature. This would be folly for both humans and for the millions of other species with whom we share this planet. However, it is important for researchers to understand what effects are specific to real nature and why, and what effects may be conferred by stimuli that may mimic certain features of nature. This type of understanding should lead to a physical environment that is better designed for psychological functioning. It is also possible that determining what features of nature lead to which benefits may require neuroscientific evidence for how humans process natural environment stimulation.

4.5.2 Conservation

This chapter has focused almost exclusively on how interacting with nature can improve human psychological functioning and why nature may lead to such benefits. Humans and other species are in trouble, though, if we do not make attempts to protect and conserve the nature that currently exists. Understanding how and when humans act in more environmentally friendly ways is an important area of research for an environmental neuroscience approach.

Some researchers have shown that after a positive interaction with nature, people do become more environmentally friendly (Zelenski, Dopko, & Capaldi, 2015). Importantly, the link between nature exposure and pro-environmental behaviors seems to rely heavily on whether an individual feels strongly about his or her connectedness to the natural world (Mayer & Frantz, 2004; Nisbet, Zelenski, & Murphy, 2009). This is true for stable, trait-level tendencies, as demonstrated by the high correlation between scales measuring connectedness to nature and self-reported engagement in sustainable behaviors (Diessner, Genthôs, Praest, & Pohling, 2018; Geng, Xu, Ye, Zhou, & Zhou, 2015; Nisbet et al., 2009). However, these individual differences also impact the efficacy of nature exposure in encouraging pro-environmental behaviors. Studies of adults and children have demonstrated that the relationship between exposure to natural environments and pro-environmental behaviors was influenced by individuals' connectedness to nature (Otto & Pensini, 2017; Rosa, Profice, & Collado, 2018). In one recent study, only participants with high implicit connectedness to nature increased their donation to environmental protection organizations after viewing a nature documentary (Arendt & Matthes, 2016).

Additionally, if acting in more environmentally conscious ways takes more self-control, requiring delay of gratification, we might expect that interactions with nature might increase due to self-control and delay of gratification both utilizing directed attention resources that would be improved after nature interactions (Faber Taylor et al., 2002; Kaplan & Berman, 2010). This latter possibility requires substantial further investigation, but provides a second, complementary account of how nature exposure might have a positive influence on environmental behaviors.

More generally, there is a growing literature on this topic for how willing people are to believe that climate change is occurring, that human activity contributes to climate change, and the importance of protecting our natural environment. These topics range from how scientifically skeptical people are (Lewandowsky et al., 2014) to whether human moral judgments systems are equipped to deal with complex and large-scale problems such as environmental conservation and climate change (Markowitz & Shariff, 2012). In all, motivating people to value nature and protect it may take a lot more than simply having people interact with nature on a regular basis, though simply doing that may have some positive benefits on its own.

4.6 Conclusion

Enormous progress has been made in identifying the many ways in which interacting with natural environments can improve psychological functioning and also determining the strength of the effects. We believe that a next step in this field of research will be to understand more deeply why interacting with nature leads to these benefits. Taking an environmental neuroscience approach to this area of research may be fruitful in uncovering the multi-scale nature of these effects, from viewing photos of nature, to living next to a forest preserve. A thorough understanding of these effects could lead to transformations in the design of the built environment to improve human psychological functioning.

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