Degree project

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Beneath the Trees: Investigating the Stress-Reduction Potential of Nature Exposure in Young Adults – A Systematic Review

Bachelor Degree Project in Cognitive Neuroscience

First Cycle 22.5 credits

Spring term Year 2023-24

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Abstract

A growing body of research suggests that exposure to natural environments can reduce stress, this notion comes at a critical time, given the increasing prevalence of stress-related problems especially in young adults, emphasizing the pressing need for effective approaches that can offer recovery and restoration. This systematic review aimed to synthesize evidence from studies using functional near-infrared spectroscopy (fNIRS) and electroencephalography (EEG) to investigate the impact of nature exposure on physiological stress levels in this population. A literature search was conducted in Web of Science and Scopus databases for studies published up to February 2024. Studies were included if they involved direct exposure to natural environments, measured stress indicators using fNIRS or EEG, and had participants aged 18-28 years old or a mean age of 20-24. Five studies met the eligibility criteria, with a total of 195 participants among the studies. The included studies exposed participants to various natural settings, including forests, grasslands, and areas with water features, and compared physiological responses to urban environments. The findings across all included studies show significant stress-reducing effects of different natural environments, in young adults. This underscores the promise of nature-based interventions as affordable and accessible resources to enhance mental well-being in this age group.

Keywords: nature, stress, young adults, near-infrared spectroscopy, electroencephalography

Beneath the Trees: Investigating the Stress-Reduction Potential of Nature Exposure in Young Adults – A Systematic Review

The influence of nature on human well-being has long captivated scientific interest, with growing attention directed toward understanding its impact on stress reduction. The symphony of bird songs, the rustling of leaves in the wind, and the scent of blooming flowers all contribute to a sense of tranquillity that transcends the stress of modern living. Nature's ability to soothe the mind and body is a testament to its restorative effects. Research reveals that exposure to natural environments can reduce both physiological and psychological stress (Gaekwad et al., 2023). It has a calming effect on the nervous system promoting relaxation and a sense of well-being (Gaekwad et al., 2023). The importance of nature for human survival and well-being is rooted in our evolutionary history, where our sensory preferences may have originated (Bratman et al., 2012). This indicates that humans may have adapted both physiologically and psychologically to natural environments, in contrast to urban settings (Ulrich et al., 1991).

Stress is a prevalent aspect of modern life, and it is associated with numerous adverse health outcomes, ranging from psychological distress to physiological dysfunction (Gaekwad et al., 2023). The detrimental effects of chronic stress are well-documented and mental health disorders, especially among younger age groups, constitute a significant portion of the overall burden of disease, highlighting the urgency for effective stress management strategies.

A study by Weidner et al. (1996) found that academic stress in young adults was associated with increases in negative emotions, decreases in positive emotions, and deterioration of health behaviors. Bovier et al. (2004) found that perceived stress was negatively associated with mental health in young adults, and it constitutes a big risk factor for developing low mental health. In Sweden, 15.4% of the population stated that they felt stressed in 2022 and young adults account for the highest proportion (Folkhälsomyndigheten, 2024). For 16-29 year olds 37% of women and 17 % of men stated that they feel stressed or very stressed in 2022 (Folkhälsomyndigheten, 2023). Among individuals over 65 years old, the proportion reporting stress is low (5%) (Folkhälsomyndigheten, 2023). Over time, the proportion reporting stress has increased in the ages between 16-29 from 16.9% in 2012 to 26.6% in 2022 (Folkhälsomyndigheten, 2024). Furthermore, stress-related illnesses are increasing, in Sweden sick leave due to stress-related illnesses increased by 29% from June 2019 to June 2023 (Försäkringskassan, 2023). Additionally, nowadays, mental illness (primarily stress-related) accounts for nearly half of all ongoing sick leave. This can be compared to musculoskeletal disorders, which dominated longer sick leaves until the turn of the millennium.

Embracing nature as a therapeutic tool may offer a holistic approach to combating stress and promoting well-being. Understanding the science behind the calming effects of nature and how nature influences stress can propose insights into effective, easily available, and low- or no-cost interventions. Therefore, the focus of this review is to provide insights into how nature can be utilized to reduce stress and improve mental health, specifically in young individuals.

Nature and Humans

Throughout history, humans have spent the majority of time in natural environments, and this may partially explain the well-being people still experience in such environments (Ulrich et al., 1991). According to the biophilia hypothesis proposed by Wilson (1984), humans have a biological love of and need to connect with nature that likely emerged through evolution (Kellert & Wilson, 1993). The idea of biophilia proposes that humans might naturally gravitate towards specific kinds of natural environments that historically aided survival and held critical advantages for early humans such as food, water, and security (Ulrich, 1993). For most of human history, our brains evolved in savannah-like environments where humans lived as hunter-gatherers. While our brains still adapt, they are more attuned to natural settings compared to today's urban landscapes (Kellert & Wilson, 1993). However, certain aspects of nature can also evoke fear or aversion, in other words, biophobia, such as snakes, thunderstorms, or dense forests, which may have posed threats to our ancestors

(Ulrich, 1993). In modern times, biophobic tendencies can manifest as fears of natural settings like forests or wilderness areas, disgust to certain plants, animals or insects, and dislike of untamed landscapes. Yet, these biophobic reactions are often irrational in contemporary societies where such natural "threats" pose little actual risk to human safety (Ulrich, 1993). Thus, not everyone will react equally to a specific environment because of a variance in vulnerability to environmental threats and predation in the past (Kellert & Wilson, 1993).

With the basis in these fundamentals, Bolouki (2023) highlights that different types of natural settings and components can have varying degrees of restorative effects on mental health outcomes. Specifically, green spaces, such as parks and urban forests, offer stress reduction, mood improvement, and cognitive restoration benefits. Exposure to water regions like rivers and coastal areas led to decreased skin conductance levels and muscle tension, suggesting reduced physiological arousal and stress (Wang et al., 2019). Similarly, water features like fountains, ponds, or streams contributed to a sense of tranquillity and were found to elicit reductions in heart rate and muscle tension, promoting physiological relaxation (Bolouki, 2023).

There are a couple of prominent theories that account for the health benefits of exposure to nature. The Stress Reduction Theory (SRT) proposes that being in an unthreatening natural environment triggers physiological and psychological stress reduction through activation of the parasympathetic nervous system (Ulrich et al., 1991). This involves both a more positive emotional state and positive changes in physiological activity such as heart rate and blood pressure. Attention Restoration Theory (ART) posits that spending time in nature can restore cognitive function through the practice of effortless attention (Kaplan & Kaplan, 1989). Being in nature induces a “soft fascination” which allows one to pay attention to the environment in an effortless manner. This enhances involuntary attention and promotes cognitive recovery. In contrast, “hard fascination” captures attention quickly, heightens cognitive load, and is more prevalent in urban environments (Bolouki 2022;

Kaplan & Kaplan, 1989). Essentially, the natural environment allows individuals to rest and restore concentration whereas the urban environment drains attention resources.

Multiple studies consistently demonstrate that exposure to nature, even in small doses such as glimpsing nature through a window, strolling in a park, or viewing nature imagery, has a positive impact on our physical health, well-being, and overall happiness (Bolouki, 2023). Research confirms a range of advantages, including neurobiological benefits, improved mental health, enhanced mood, cognition, and memory, along with increased social cohesion, attention, and longevity (Bolouki, 2023).

Urban Environments

Cities house more than half of the world's population (Dye, 2008), and as of 2020 88% of people in Sweden live in a city (Statistikmyndigheten, 2022). Just 200 years ago it was reversed with 90% of people living in rural areas. The trend toward urbanization is expected to continue in the coming decades, shaping how we live, work, and interact with our environment. This shift towards urban living has raised concerns regarding its impact on mental health. Mood and anxiety disorders are more prevalent in people who live in cities (Peen et al., 2010) and the incidence of schizophrenia is strongly increased in people born and raised in cities (Krabbendam & van Os, 2005). Additionally, it seems that city living alters how the brain reacts to stress. Lederbogen and colleagues (2011) found that current city living is linked to increased amygdala activity and urban upbringing affects the pregenual anterior cingulate cortex, a region important for regulating amygdala activity, negative affect, and stress. Furthermore, urban upbringing has been found to alter the reactivity of the hypothalamic-pituitary-adrenal (HPA) axis, causing it to become more sensitive (Steinheuser et al., 2014). Additionally, changes in the HPA axis have been associated with several psychiatric disorders (Steinheuser et al., 2014).

Stress

Stress, according to McEwen and Gianaros (2010) defined as a dynamic process triggered by actual or perceived environmental demands leading to physiological and psychological reactions, affects individuals differently. Stress encompasses both external factors like lifestyle and relationship dynamics as well as internal elements such as personality traits and cognitive patterns which can trigger negative emotions like worry and fear (Giannakakis et al., 2019). These triggers are often accompanied by physiological changes in the body and manifest differently in each individual, with symptoms ranging from physical discomfort to mental distress (McEwen & Gianaros, 2010; Seo & Lee, 2010). The experience of stress is linked both to the perception of events and the bodily responses they evoke. These responses aim at assessing and responding to the stressors adaptively by preparing the body to cope with increased demands (Giannakakis et al., 2019). An individual's resources and support systems will largely impact how they respond to stressors. Meaning that depending on how well a person copes with their stress will determine whether the experience leads to increased resilience and possibly even health benefits or chronic stress and associated health issues like heart disease and stroke as well as psychological issues like depression and anxiety (Giannakakis et al., 2019; McEwen & Gianaros, 2010; Seo & Lee, 2010).

The stress response begins in the brain, the brain controls stress reactivity, coping, and recovery by determining what is stressful and regulating the behavioral and physiological responses (McEwen & Gianaros, 2010). Three brain regions seem to be crucial players for the stress response, these are the hippocampus, the amygdala, and the prefrontal cortex (PFC) (McEwen & Gianaros, 2010). They are closely connected to each other and regulate functions like the HPA axis and the autonomic nervous system (ANS). The hippocampus is located in the medial temporal lobe and is crucial for learning and memory and it also handles contextual aspects of emotional experiences. Within the hippocampus are receptors for adrenal steroids and metabolic hormones, which can boost cognitive abilities, influence mood, and protect brain cells. However, during prolonged stress, these hormones can harm the hippocampus (McEwen, 2007). The amygdala, situated near the hippocampus in the medial anterior temporal lobe processes stress-related information by quickly assessing the emotional and behavioral significance (McEwen & Gianaros, 2010). It does this by integrating sensory inputs from other brain regions like the thalamus and brainstem. From the amygdala, signals are then sent to various brain regions that regulate behavior and physiological responses to stress, such as the hypothalamus and the PFC. This allows the amygdala to coordinate adaptive responses to stressors. The main task of the PFC (located at the anterior part of the frontal lobes) is higher cognitive functions like working memory and executive control, including top-down regulation of stress responses (McEwen & Gianaros, 2010). Regions within the PFC like the orbital and dorsal medial PFC and the anterior cingulate cortex directly communicate with regions that control the body’s stress response including the hypothalamus.

When encountering stressful audio-visual stimuli these are first processed in the thalamus and then the information is sent through two pathways, the fast and the slow (Giannakakis et al., 2019). The fast pathway goes directly to the amygdala, where immediate threats are determined without the contribution of consciousness and higher cognitive functions, enabling fast reactions like flinching at the sudden blare of a car horn. The slow pathway goes to the PFC, where the information is cognitively analyzed and then sent to the amygdala with more details, enabling a conscious threat assessment (Giannakakis et al., 2019) – was that a car horn signaling danger, or just an impatient driver in heavy city traffic?

The experience of stress is accompanied by activity in two hormonal systems that help the individual cope with the stressor. One is controlled by the ANS and the other by the HPA axis (Romeo, 2013). The ANS regulates automatic bodily functions like breathing, heart rate, digestion, and the hormonal system (Seo & Lee, 2010). The ANS has two branches, the sympathetic nervous system (SNS) which initiates the stress response, and the parasympathetic nervous system (PNS) which is responsible for the relaxation response. When encountering a stressor, the SNS releases epinephrine and norepinephrine which helps the body respond by increasing heart rate, dilating airways, and redirecting blood flow to muscles (Romeo, 2013). This response is known as the "fight or flight" response, preparing the individual to confront or flee from the stressor. Conversely, the PNS works to calm the body down after the stressor has passed, promoting recovery (Seo & Lee, 2010). The intricate interplay between these two systems allows the body to adapt to stressors efficiently while striving for homeostasis. Chronic stress, however, can disrupt this balance, leading to prolonged activation of the SNS and potential health consequences (Seo & Lee, 2010).

The HPA axis regulates stress response via the hypothalamus that releases corticotropin-releasing hormone (CRH), which triggers the pituitary gland to secrete adrenocorticotropic hormone (ACTH), leading to adrenal glucocorticoid (GC) production (Romeo, 2013; Seo & Lee, 2010). GCs facilitate energy mobilization, immune enhancement, and learning/memory, but chronic exposure impairs metabolism, immunity, and cognition due to negative feedback on brain regions like the hippocampus and PFC (Romeo, 2013).

Methods to Measure Stress

Both the subjective experience of stress and the objective, physiological markers of stress can be measured (Seo & Lee, 2010). Questionnaires are commonly used to investigate an individual's subjective experience of stress. Objectively, stress can be measured through the hormones that are secreted such as cortisol, adrenaline, and noradrenaline, the levels of which can be tested using salivary cortisol or urinary adrenaline and noradrenaline. Additionally, stress induces changes in autonomic function leading to increased heart rate and blood pressure which can be measured as a marker of stress. The same goes for heart rate variability (HRV) which measures the variation in time between heartbeats (Seo & Lee, 2010). Finally, stress can also be measured in the brain by using different neuroimaging techniques.

Researchers commonly use functional near-infrared spectroscopy (fNIRS) or near-infrared spectroscopy (NIRS), to provide insights how the brain reacts to stress (Tanida et al., 2007). This review will use the term NIRS for the technique, as it is used in the studies that will be reviewed. NIRS is a non-invasive method that measures changes over time in oxyhemoglobin (Oxy-Hb) and deoxyhemoglobin (Deoxy-Hb) concentrations in the brain's blood vessels (Tanida et al., 2004; Tsunetsugu & Miyazaki, 2005). These changes indicate alterations in blood volume and blood flow. An increase in Oxy-Hb concentration typically indicates increased blood flow and oxygen delivery to active brain regions while a decrease in Deoxy-Hb concentration suggests increased oxygen consumption. NIRS also measures total hemoglobin (Total-Hb) which is the sum of Oxy-Hb and Deoxy-Hb. Changes in Total-Hb indicate changes in blood volume within the measured region (Tanida et al., 2004; Tsunetsugu & Miyazaki, 2005). Essentially NIRS can monitor real-time changes in cerebral blood oxygenation and cerebral blood flow during various brain activities. Studies using NIRS have found that right dominant PFC activity is associated with a heightened stress response, for example, it has been linked to an increase in heart rate during mental stress (Tanida et al., 2004). Furthermore, a reduction in oxygen levels in the PFC suggests a decrease in cerebral activity, indicating a state of relaxation (Park et al., 2007).

Another commonly used method to measure stress in the brain is electroencephalography (EEG). The EEG spectrum can be segmented into frequency intervals, known as rhythms, including delta (0.5-4 Hz), theta (4-8 Hz), alpha (8-13 Hz), beta (13-30 Hz), and gamma (30-70 Hz) (Giannakakis et al., 2019). Studies have found that different frequency bands respond differently depending on the level of stress a person is experiencing (Gaekwad et al., 2023). A stressed state has been linked to a decrease in both delta and theta bands (Gaekwad et al., 2023). Oppositely, increased theta waves are associated with a state of deep relaxation where inspiration and creativity occur easily (Schacter, 1977). The predominance of the alpha rhythm is typically observed during relaxation or in situations with minimal cognitive demands or emotional strain (Giannakakis et al., 2019), alpha waves are also associated with calmness, learning, and mental coordination (Kim et al., 2013). Conversely, conditions characterized by significant processing demands or high alertness levels (stress) tend to exhibit higher frequency rhythmic activity, such as relative beta power (Hayashi et al., 2009). An increase in beta rhythm tends to indicate alertness while a decrease in beta rhythm is associated with drowsiness (Lee et al., 2014). Some studies use the e-Sense index which aims to measure an individuals mental state using an algorithm developed by NeuroSky (Deng et al., 2020). The e-Sense algorithm calculates values that should represent levels of mental states “meditation” and “attention” (see discussion for further analysis).

The Aim

Given the increasing prevalence of mental health issues and stress among young people, the primary aim of this systematic review is to investigate the impact of exposure to various types of natural environments on physiological stress levels in young adults. The review focuses on studies using neuroimaging techniques, specifically NIRS and EEG to measure brain activity and objectively evaluate stress responses. The review specifically targets studies conducted in real natural settings, as opposed to virtual reality or picture-based experiments, to ensure the findings are representative of actual experiences in nature. Finally, by examining the impact of different types of natural environments on stress levels, the review seeks to provide valuable insights into how broadly nature-based interventions can be composed and yet afford stress-reducing effects in young adults.

Methods

Search Strategy

First, to get an overview of the topic an initial search was done which consisted of a combination of different keywords that were found by reading other systematic reviews in the subject. The keywords were for example: forest therapy, nature therapy, natural environment, shinrin-yoku, forest exposure, biophilia, fNIRS, NIRS, EEG, HRV and cortisol. After more thoroughly examining the available research within the field, we decided to focus on physiological measurements of stress in the brain, i.e. studies using NIRS or EEG. The publication search was conducted in English and made in the databases SCOPUS and Web of Science. The final search string used was stress AND ("restorative environment" OR “natural environment" OR "shinrin-yoku" OR "forest therapy" OR "forest bathing" OR "therapeutic effect of forest" OR "forest environment" OR "forest landscape" OR "forest walking" OR "forest exposure" OR "Biophilia" OR "nature connectedness" OR "nature therapy") AND (nirs OR fnirs OR "Functional near-infrared spectroscopy" OR "near-infrared spectroscopy" OR EEG OR Electroencephalography).

In Web of Science, the search was set to topic and in Scopus to article title, abstract and keywords. In Scopus curly brackets were used instead of quotation marks. There were no additional restrictions used in the database search. The last search was conducted on the 26th of February 2024 and yielded 75 publications in total (33 in Scopus and 42 in Web of Science). All publications were obtained, saved, and transferred to Rayyan (Ouzzani et al., 2016). First, 21 duplicates were removed, the remaining 54 articles were screened by title and abstract, and 37 articles were excluded for not meeting the inclusion criteria. The remaining 17 publications were screened by full text and 13 articles were excluded due to wrong study design (5), wrong population (4), wrong publication (2), wrong outcome (1), and wrong measurement (1). One article was added from the background search and the final number of articles included in this systematic review is (5), (see Figure 1).

Inclusion and Exclusion Criteria

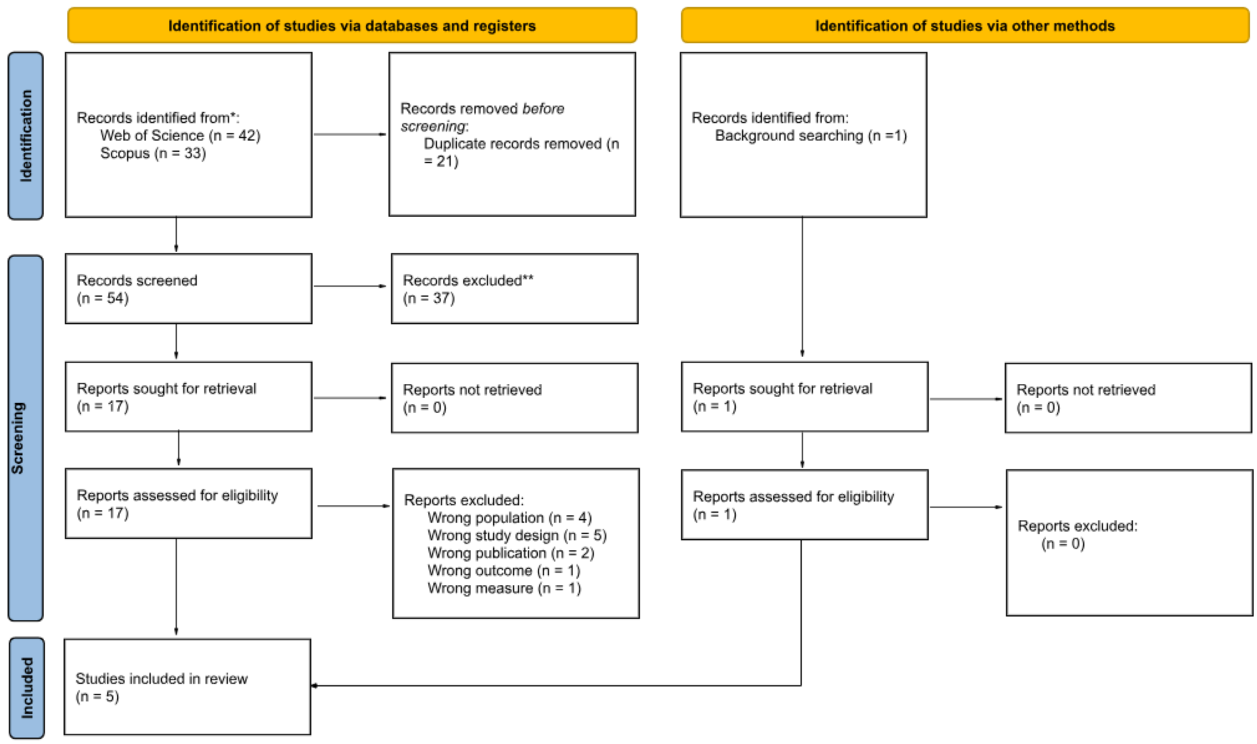
Studies are included regardless of the participant's gender and ethnicity, but they had to be young adults, in the ages of 18-28/or studies with participants of a mean age of 20-24. Thus, all other age groups and animal studies were excluded. The participants can either be with or without stress-related illnesses or issues, but should be otherwise healthy. The inclusion criteria for the intervention are studies where participants were directly exposed to nature environments and include active or inactive interventions. That includes forest therapy, Shirin-Yoku, sitting, walking, viewing, or taking in the atmosphere in a natural environment. Hence, all studies using virtual nature or pictures of nature were excluded. Only studies that measure stress indicators using the neuroimaging methods NIRS or EEG were included. Only peer-reviewed empirical studies and original published articles written in English were accepted in the review. Studies could be either within or between group designs.

Data Extraction

Data was extracted from the five articles that met our eligibility criteria. The extracted data presented in Table 1 consisted of the first author's name and publication date, sample and mean age of participants, study design and location, intervention -description -duration, and -site, outcome measurement and results.

Figure 1

PRISMA Flow Chart



Note. The literature search process followed the PRISMA 2020 guidelines (Page et al., 2021).

Results

This review identified five papers that met the eligibility criteria. The studies include physiological measurements of brain activity (NIRS and EEG) to examine stress outcomes, conducted while participants were being exposed to different types of natural environments.

Characteristics for Included Studies

Two studies used NIRS (Joung et al., 2015; Song et al., 2020), while three of the studies used EEG (Deng et al., 2020; Li et al., 2023; Shuangquan et al., 2023). The NIRS studies were conducted in Japan and Korea respectively, and the studies using EEG were all conducted in China. Four of the included studies were published within the last four years (Deng et al., 2020; Li et al., 2023; Shuangquan et al., 2023; Song et al., 2020) while the oldest one was published in 2015 (Joung et al., 2015). The total number of participants across the five studies was 227 while the collected data analysis is based on the measurements from 195 participants. The sample size ranged from 7-60 with a mean age of 20-24 across the studies (see Table 1). The studies by Deng et al. (2020), Li et al. (2023), and Shuangquan et al. (2023) provide an age range of 18-28, 19-24, and 19-25 respectively whereas the other two studies lacked that information. The study population varies among university and college students, company workers, and civil servants. All are considered healthy and without psychological disorders.

Furthermore, all studies employed a crossover and within-subject design, wherein every participant experienced each environmental setting. Data collection was gathered on-site during the environmental exposure for all studies.

Altogether, the studies were conducted across several different environments. All included a forest or one site of natural environment among their locations. In the studies by Song et al. (2020) and Joung et al. (2015), environmental exposure was observing a forest versus an urban environment while seated. The study by Shuanquan et al. (2023) was conducted only by observing a forest while participants could choose to be seated, walk, or enjoy the scenery. In the study by Li et al. (2023) four different types of environments were included to be viewed, a forest, a grassplot, a square, and a lakeside wherein participants could either walk or be seated. The study by Deng et al. (2020) included three different landscape types of an urban park that were observed during a seated position. There was a water area (Canglang Lake), a topography (Wanshu Mountain) and a lawn area (The Lawn Area). Song et al. (2020) and Shuanquan et al. (2023) performed their studies in the summer time whereas the studies by Joung et al. (2015) and Deng et al. (2020) were conducted during Autumn. The experiment was carried out later for the study by Li et al. (2023), from October to November.

In the condition where participants observed the forest and the urban environments, an inactive exposure in a seated position was implicated in each setting. When participants were walking, they did so in a gentle manner. The duration of environmental exposure during which cerebral activity was measured varied across the studies. For the studies by Song et al. (2020), Joung et al. (2015), and Suanquan et al. (2023) the exposure was fifteen minutes, and the studies by Li et al. (2023) and Deng et al. (2020) included twelve and five minutes of exposure respectively.

Studies Using NIRS

The two studies using NIRS to measure cerebral activity (Joung et al., 2015; Song et al., 2020), used a portable NIRS device to measure changes in Oxy-Hb concentration in the PFC. Joung et al. (2015) also measured Total-Hb concentration in the PFC. The two studies compared participants' responses in a forest environment to an urban environment and found that the forest environment had a more relaxing effect as indicated by lower levels of Oxy-Hb concentration (Joung et al., 2015; Song et al., 2020).

The study by Song et al. (2020) evaluates the effect of viewing real forest landscapes compared to urban areas in young women. The 60 participants were divided into groups of 12 and then they were divided into subgroups of 6 participants each. On the first day, one group performed the experiment in the forest area while the other performed the same experiment in the urban area. On the second day, the group changed sites. The researchers employed ten distinct locations, five forests, and five urban areas. The forest sites were carefully tended and deemed safe, featuring a variety of tree species like red pine, oak, maple, and cherry trees. As for the urban sites, they were positioned either close to a railway station or downtown. The experiments were performed at similar times.

The findings from the study described in Table 1 revealed that individuals exhibit significantly lower Oxy-Hb concentration levels in the right region of the PFC when exposed to natural environments compared to urban settings. Moreover, the concentration of Oxy-Hb in the left region of the PFC was slightly lower when participants viewed a forest scene compared to when they viewed an urban area. Although the difference did not reach conventional statistical significance, it was close to being significant ($p < 0.08$) (Song et al., 2020).

The study by Joung et al. (2015) focused on investigating whether the restorative effects of forest environments compared to city environments are still present when participants are not being viewed by other people, as is common in a city area. Therefore, participants viewed an urban area from the rooftop of a four-story building with no other people present. Participants were informed before the experiment that they could discontinue at any point if they experienced discomfort such as fear of heights or physical distress. The other part of the experiment took place in a forest where participants were asked to sit and watch the scenery. Results revealed that changes in both Oxy-Hb and Total-Hb in the PFC were significantly lower in the forest area than in the city area (See Table 1).

Studies Using EEG

EEG measurements were utilized to assess the impact of natural environments on restoration in the studies by Shuangquan et al. (2023), Li et al. (2023), and Deng et al. (2020). Across these studies, spending time in natural settings, particularly environments containing water elements or a lot of vegetation was associated with significant increases in relaxation.

Shuangquan et al. (2023) investigated the effects of spending time in nature by comparing participants' stress levels before, during, and after a nature-based intervention. They collected EEG data in three phases of their experiment, phase 1 was 24 hours before the nature intervention and consisted of EEG measurements being collected in a laboratory environment. Phase 2 was during the intervention, which took place in Zhangjiajie National Forest Park in China, where participants could lightly walk around or sit and enjoy the scenery for 15 minutes. Phase 3 was 24 hours after the intervention and consisted of once again completing all measurements in the laboratory. The EEG data was analyzed using the e-Sense index and used to describe the degree to which participants entered a state of concentration and relaxation. The concentration score was significantly increased from Phase 1 (before) to Phase 2 (during) and from Phase 1 to Phase 3 (after), with no significant difference between Phase 2 and 3. For the relaxation score, there was a significant increase from Phase 1 to Phase 2, Phase 1 and Phase 3 as well as Phase 2 and Phase 3. Essentially, the forest environment had a positive impact on both concentration and relaxation scores (See Table 1).

Li et al. (2023) examined the restorative benefits of four distinct environmental settings of Xuanwu Park in Nanjing, a grass plot, a square, a forest, and a lakeside. The researcher used a repeated measure approach where each participant took part in all four settings. EEG data was collected at three temporal intervals throughout the experimental procedure, baseline, pressure application, and restoration. During the baseline period, participants were instructed to rest with their eyes closed while wearing headphones. The pressure application period involved participants completing a three-minute math test and being exposed to unpleasant sounds to induce mental and emotional stress. Finally, during the twelve minutes of restoration, participants were allowed to either sit or walk in predetermined areas.

EEG data was recorded using a semi-dry wireless EEG device that captures raw EEG signals from electrodes placed on the parietal (P3, P4), frontal (F3, F4), occipital (O1, O2), and frontal midline (FpZ, Fz) regions. These electrodes are referenced to the linked earlobe (A1, A2) and grounded at the midpoint between Fpz and Fz. The total percentages of alpha and beta wavebands across the period were used in the analysis rather than focusing on isolated points or segments. Results showed significant differences between baseline and pressure application (See Table 1). When comparing pressure application and restoration period significant changes were revealed for all sites aside from the square. Specifically, the alpha wave activity during the restoration stage was significantly higher than during the stress-inducing stage at the grassplot, forest, and lakeside. Additionally, the beta wave activity during the restoration stage was significantly lower than during the stress-inducing stage at the same sites (Li et al., 2023).

The study by Deng et al. (2020) investigates the effects of three different landscape types on restoration using a portable EEG device. Sixty individuals were randomly divided into three groups with twenty individuals in each group. To eliminate order effects the groups switched sites across three distinct visits to the different sites. Furthermore, the experimental sessions were consistently conducted between 9:00 am and 11:30 am to minimize the impact of natural physiological variations throughout the day. The frequency ranges of theta, alpha and beta used in the present study were 4–7 Hz, 8–13 Hz, and 14–30 Hz. The headset records brainwaves from the Fp1 position (frontal lobe) above the eye and consists of four essential components: a headband; an ear clip; a sensor arm containing the EEG electrode; and a Bluetooth device. The raw signal, power spectrum, mediation level, and attention level were measured. The EEG data are detected at a rate of 512 Hz, while others are obtained every second. The study collected raw EEG data at one-minute intervals, and 5-minute averages were compared under three conditions. In total 180 data samples showing the differences in effect were assembled.

Deng and colleagues (2020) observed that during the one-minute observation period, the average values of theta brainwaves were consistently highest at Wanshu Mountain. When comparing these theta values among the sites over the five minutes of the intervention it revealed a significant difference. However, no such difference was found in theta values over time within the groups. When comparing the average theta brainwave values across the three different locations where the study was conducted (Canglang Lake, Lawn Area, and Wanshu Mountain), researchers found significant differences among these locations, and the highest values were found in Wanshu Mountain followed by the Lawn Area. Additionally, both overall mean alpha and overall mean beta values in the three study sites showed significant differences. Furthermore, a significant increase in mean relaxation level was revealed after sit-down viewing under all conditions. Participants' meditation and attention mean scores were most pronounced at Wanshu Mountain and significant between-group differences in mean attention were revealed.

Table 1.

Characteristics of Studies Reporting Physiological Stress Outcomes in Response to Interventions in Natural Environments

First Author & Publication Date	Sample & Mean Age	Study Design & Location	Intervention Description	Intervention Duration	Intervention site	Outcome Measurment	Results
Deng et al. (2020)	60 (30 female, 30 male) 20.8 y (±1.2)	Crossover & within-subject design China	Observing three different landscape types of an urban park while sitting down	5 min (each site)	Three different landscape types water, lawn & topography (Canglang Lake, The Lawn Area & Wanshu Mountain)	EEG eSense relaxation & attention score During	Overall Mean theta brainwave across the sites Canglang Lake (95951.7 ± 5770.3), Lawn Area (108996.4 ± 5708.1) Wanshu Mountain (23789.8 ± 13,363.28) $P < 0.05$ Overall mean alpha values across the sites: Canglang Lake (23497.3 ± 1749.1), Lawn Area (26468.9 ± 1064.3) Wanshu Mountain (31219.4 ± 2651.2) $P < 0.05$ Overall mean beta values across the sites: Canglang Lake (23,585.7 ± 3254.5), Lawn Area (23,585.7 ± 3254.5) Wanshu Mountain (29,249.7 ± 4094.3) P = <0.05 Relaxation score: Canglang Lake (57.6 ± 11.0), Lawn Area (56.0 ± 11.5) Wanshu Mountain (58.5 ± 9.3) $P < 0.01$ Attention score: Canglang Lake (52.5 ± 11.25), Lawn Area (52.5 ± 10.7) Wanshu Mountain (58.2 ± 10.9) $P < 0.01$
Joung et al. (2015)	7 * 22.0 y (±2.2)	Singel-group crossover design Korea	Observing forest vs urban environment (from a rooftop) while sitting down	15 min (each site)	Forest environment vs urban environment from a rooftop	NIRS During	The change in total Hb concentration (−0.014 ± 0.007 A.U.) and in oxy-Hb concentration (−0.007 ± 0.007 A.U.) in the PFC was significantly lower when forest scenery was viewed then urban scenery were viewed (0.006 ± 0.006 A.U.; $p < 0.05$), (0.008 ± 0.007 A.U.; $p < 0.05$)
Li et al. (2023)	39 (female & male) 24.5 y	Crossover & within-subject design China	Observing the park scenery while sitting down or walking slowly, after a suboptimal state had been induced in the participants whereas stimulating audio was playing while participants had to take a math test for three minutes.	12 minutes (each site)	Four different types of natural environments grassplots, square, forest & lakeside	EEG Alpha & Beta brain waves Before (baseline) & during pressure application & the 12 minutes of restoration	Mean difference in alpha waves from pressure application to restoration Grassplot (4.33 ± 1.12; $P < 0.004$.) Square (1.70 ± 1.02; $P < 3.45$.) Forest (4.08 ± 1.33; $P < 0.021$.) Lakeside (5.46 ± 0.92; $P < 0.001$.) Mean difference in beta waves from pressure application to restoration Grassplot (-4.60 ± 1.33; $P < 0.009$) Square (-2.57 ± 1.30; $P < 0.193$.) Forest (-5.55 ± 1.83; $P < 0.023$.) Lakeside (-6.47± 1.35; $P < 0.001$.)
Shuangquan et al. (2023)	60 (30 female, 30 male) 22.0 y	Crossover & within-subject design China	Observing forest while carry out gentle activity (sitting, walking or enjoying scenary)	15 min	Forest environment	EEG eSense concentration & relaxation score Before (Phase 1), during (Phase 2) & after (Phase 3)	Significant differences in concentration between Phase 1 and Phase 2 ($p = .000 < 0.01$), Phase 1 and Phase 3 ($p = .000 < 0.01$), but there was no significant difference in concentration between Phase 2 & Phase 3 ($p = .0502 > 0.05$). Significant differences were observed in all phases regarding relaxation Phase 1 & Phase 2 ($p = .000 < 0.01$), Phase 1 & Phase 3 ($p = .000 < 0.01$), Phase 2 & Phase 3($p = .000 < 0.01$).
Song et al. (2020)	29 (females) 21.0 y (±1.4)	Crossover & within-subject design Japan	Observing forest vs urban environment while sitting down	15 min (each site)	Forest vs urban environment	NIRS During	The mean oxy-HB concentration was significantly lower in the right PFC when viewing the forest compared to the urban area (forest: 0.46 µM; city: 0.90 µM; $p < 0.05$). In the left PFC, the concentration was marginally significantly lower when watching the forest (forest: 0.70 µM; city: 1.10 µM; $p < 0.08$)

Note. Abbreviations: Electroencephalography (EEG) Near-infrared spectroscopy (NIRS) Prefrontal cortex (PFC) Arbitrary units (A.U.) Micrometre unit (µM)
*Gender not reported

Discussion

This systematic review aimed to investigate the intricate relationship between exposure to different types of natural environments and physiological stress levels in young individuals, as assessed through NIRS and EEG measurements. By delving into this topic, we can better comprehend the potential therapeutic benefits of nature and its role in moderating stress, especially as stress-related disorders are on the rise (Folkhälsomyndigheten, 2023).

The findings from this study provide unanimous support that exposure to natural environments can elicit physiological responses associated with stress reduction. As shown by both Song et al. (2020) and Joung et al. (2015) participants exhibited significantly lower levels of Oxy-Hb concentration in the PFC when exposed to forest environments compared to urban settings. In this state, less oxygen is being provided to the PFC indicating a decrease in neuronal activity or metabolic demand that demonstrates a more relaxed state (Tanida et al., 2004). These results are consistent with Park et al. (2007), who found similar effects in participants both walking and sitting in forest environments. In this study, a brief walk in a forest environment led to a decrease in Total-HB concentration in the left PFC contrary to Song et al. (2020) wherein significantly lower Oxy-Hb concentration was found in the right PFC, which included inactivity in seated positions. Remarkably, conditions involving no physical activity resulted in a shift in activity from the left to the right PFC (Park et al., 2007). Given that Oxy-Hb levels can be influenced by changes in skin blood flow due to physical activity (Miyazawa et al., 2013), Song et al. (2020) minimized these effects.

This asymmetry in brain activity suggests complex underlying mechanisms that are not fully understood and need to be explored in future research. Measuring skin blood flow alongside Oxy-Hb concentration could provide further insights into the role of physical activity in these physiological responses. Regardless, while the findings from Song et al. (2020) and Joung et al. (2015) suggest large relaxation effects from nature exposure in a forest, it is essential to consider the limited sample sizes in these studies (See limitations).

Additionally, the studies by Shuangquan et al. (2023), Li et al. (2023), and Deng et al. (2020) that used EEG as the outcome measure consistently demonstrated that exposure to natural environments induced brain wave patterns indicative of increased relaxation, reduced stress, and cognitive restoration when compared to urban settings or baseline conditions. Consistent with earlier findings (see Bolouki, 2023), increased theta and alpha wave activity, indicating a shift towards relaxation, coupled with decreased beta wave activity, suggesting reduced mental strain (Giannakakis et al., 2019; Kim et al., 2013) were consistently observed across the studies.

In the study by Shuanquan et al. (2023), the participant's restorative brain wave patterns were observed not only during exposure to nature but also persisted for some time after the nature experience (e.g., 24 hours) which could indicate that the relaxing effects are extended after the exposure. For instance, one study found that a 3 day forest therapy camp led to reduced cortisol levels at two and four weeks after the camp (Yu et al., 2016).

Furthermore, Li et al. (2023) and Deng et al. (2020) investigated the effects of restorative benefits in various environmental settings. Li et al. (2023) showed significantly higher alpha wave activity paired with significantly lower beta wave activity at the lake side, grass plot, and forest compared to the square. This could be due to the square sites' lack of greenery and water features, and more artificial components. Consisting with the biophilia hypothesis, lakes, grasslands, and forests have historically offered components that all have been vital for human survival (Ulrich, 1993) and, thus, offer enhanced restorative qualities. For example, lakes provide essential resources such as food and water and have also been proposed to induce a relaxed state through the water's visual and auditory stimuli. Open grasslands provided hunter-gatherers with clear lookout points to spot predators from afar. Forests, with their dense vegetation, offered shade, shelter, and food sources (Bratman et al., 2012; Ulrich, 1993). These underlying factors may further explain why the lakeside showed most restorative effects followed by the glass plot then the forest (Li et al., 2023).

Building upon these insights Deng et al. (2020) constantly revealed the highest restorative effects at Wanshu Mountain, the Topography site. Previous research by Sonnetag-Östman et al. (2015), demonstrates that topography can create a sense of privacy and enclosure, promoting contemplation. Notably, Deng et al. (2020) showed a significant increase in relaxation levels during exposure to all different sites (topography, lawn area, and lake area). Thus, aligning with the findings from Li et al. (2023). All mentioned sites consist of either a large amount of water or a variety of plants shown as two important landscape elements for restoration consistent with previous research (Hassan et al., 2018; Wang et al., 2019; White et al., 2010). White et al. (2010) even argue that the most promising restorative environment might be where land meets large bodies of water.

In addition, but not surprisingly, the consistent stress-reducing effects of these natural settings across the studies lend further support to the biophilia hypothesis and how history shapes how humans connect to nature even today. However, in the study by Deng et al. (2020) only physiological responses during exposure to different sites were measured, without a baseline for comparison. This is problematic because it only shows the restorative effects of the sites relative to each other, making it difficult to draw further conclusions about each site's actual restorative effects for participants.

Moreover, ART suggests that perceiving natural environments leads to effortless attention and promotes cognitive recovery (Kaplan & Kaplan, 1989). The studies in this review utilizing EEG measurements (Deng et al., 2020; Li et al., 2023; Shuangquan et al., 2023) provide insights into the cognitive and attentional aspects of restoration, which are central to ART. The observed changes in alpha and beta wave activity during exposure to natural environments suggest that these settings may facilitate the recovery of directed attention and cognitive resources, as proposed by ART. When analysing the findings from the included studies, a lakeside could be offering the most cognitive and attentional recovery aspects among natural sites whereas a topographic site seems to be effective regarding relaxation.

Furthermore, in line with SRT, the included NIRS studies provide support for the idea that nature can trigger physiological stress reduction (Ulrich et al., 1991). The reduced oxygenation levels in the PFC during nature exposure suggest a state of relaxation and decreased stress (Joung et al., 2015; Song et al., 2020), aligning with the principles of SRT that being in or viewing the forest environments can reduce stress and promote relaxation, contrary to the urban locations.

Limitations

This review included only the results of NIRS and EEG measurements from the included studies, while these offer objective assessments of brain activity, they only capture a part of the stress response. The included studies also employed other physiological measurements as well as psychological measures, future reviews could benefit from incorporating these as well to get a broader understanding of the stress response. All studies included in this review were conducted in China, Japan, and Korea, which limits the generalizability of the results to other populations such as in Sweden. Variations in landscapes, weather, and cultural attitudes toward nature could affect the results. Cultural factors such as traditional practices, historical connections to nature, and varying degrees of urbanization could shape how people interact with and perceive natural environments. For instance, research has revealed a cultural difference in how individuals relate to the natural environment in environmental concern and pro-environmental behavior (Milfont & Schultz, 2016). Understanding the differences between cultures can allow researchers to assess the universality of the benefits of nature on mental health and potentially identify unique factors that influence this relationship in specific populations.

The number of participants in the studies varied considerably, ranging from 7 to 60 participants. While two studies had relatively large sample sizes of 60 participants each, the majority had smaller samples. Studies with small sample sizes face several limitations. They often lack statistical power, making it difficult to detect true effects and increasing the likelihood of both type I and type II errors (Fraley & Vazire, 2014). Additionally, small samples are prone to greater variability and sampling error, which can obscure real differences and lead to inaccurate conclusions.

The included studies used varied measurements, making it difficult to compare EEG and NIRS results. EEG studies focused on different frequency bands and some used the e-Sense index, complicating direct comparison. Additionally, one NIRS study detailed measurements in the right PFC, while the other reported only an overall mean for the PFC.

Deng et al. (2020) and Shuanquan et al. (2023) used the e-Sense algorithm in obtaining their data. The e-Sense algorithm appears to be a method developed by NeuroSky for processing single-channel EEG data from their own low-cost headset (Katona et al., 2014). It aims to derive metrics like "Attention" and "Meditation" that can potentially reflect cognitive states like focus and calmness. However, the details and validation of this algorithm are not fully disclosed, as NeuroSky claims them as trade secrets (NeuroSky Inc, 2014). This lack of transparency makes it difficult to critically assess the algorithm's reliability and usefulness from a scientific standpoint. Moreover, NeuroSky's headset is a consumer-grade, dry EEG headset not designed for research-level data acquisition (Rebolledo-Mendes et al., 2009), which could impact signal quality and the algorithm's performance. However, a study by Rebolledo-Mendes et al. (2009) found that NeuroSky's headset data closely matched students' attention levels. Similarly, Crowley et al. (2010) determined that NeuroSky's headset reliably measures attention and meditation levels compared to Stroop and Towers of Hanoi test data.

Furthermore, the study by Deng et al. (2020) did not account for multiple comparisons when analyzing the EEG power values across different frequency bands (theta, alpha, beta), which could increase the risk of type I errors. Taking all this into account, the results from the studies by Deng et al. (2020) and Shuanquan et al. (2023) should be interpreted with caution.

All included studies used short-term interventions with 5 to 15 minutes of nature exposure. Measurements were taken immediately before, during, or up to 24 hours after the intervention. The lack of long-term follow-up makes it unclear if the effects are temporary or lasting. Consistent, extended nature exposure could reveal cumulative benefits and help identify optimal durations and frequencies for lasting stress reduction.

Finally, considering the concept of biophobia, which suggests that some individuals have an aversion to nature, different types of natural settings may evoke distinct physiological and emotional reactions. Other factors to consider are gender differences and individual stress reactivity that can be explored to develop tailored interventions that address the unique needs of diverse populations. By considering these factors, future studies can contribute to a more comprehensive understanding of the relationship between nature exposure and stress reduction.

Societal and Ethical Aspects

Ethical considerations were upheld across all five studies reviewed. All studies, except Shanquan et al. (2023), reported having received ethics committee approval and obtained written informed consent from participants. No conflicts of interest were reported. The research protocols posed no significant risks to participants, who were all healthy individuals without psychiatric or physiological disorders.

Stress constitutes a big problem in today's urban society, with rising sick leave due to stress-related illnesses. Nature-based interventions can promote mental health, potentially reducing the need for mental health services and medications, thus lowering healthcare costs. Additionally, nature exposure enhances cognitive functions, which can improve academic performance and workplace productivity.

This review focused on studies in real natural settings, enhancing real-world relevance. While nature is generally accessible and often free, not all young people have equal access due to geographic or physical limitations. It is therefore noteworthy that many studies investigate the effects of nature through virtual reality, pictures, sounds, and even smells (Gaekwad et al., 2023). Research should continue exploring different ways of making nature easily accessible to all.

Furthermore, it is important to ensure that the use of natural environments for stress relief does not come at the expense of environmental degradation. It is therefore important to explore ways to promote sustainable practices that preserve natural spaces while still providing opportunities for stress reduction. On the other hand, promoting nature-based interventions could also have the effect of raising awareness about the importance of environmental protection. As people develop a stronger connection with nature, they may be more inclined to engage in sustainable practices.

Conclusion

This systematic review presents unanimous neurophysiological support that exposure to various natural environments, like forests, lakes, and topography can induce physiological responses associated with stress reduction and restoration in young adults. Despite variations in study design, environments, and exposure duration, the reviewed studies consistently showed changes in EEG patterns and PFC oxygenation levels related to restoration. However, further high-quality research is needed, including studies using more rigorous methodologies, with stronger statistical analyses, and larger sample sizes to strengthen the reliability and generalizability of the results. While the presented results support the potential of nature-based interventions as accessible and cost-effective strategies for reducing stress in this population, more research is needed to validate these findings.

[Word Count: 7485]

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