An Association between Nature Exposure and Physiological Measures of Emotion and Cognition

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Nature environments have significant benefits for human psychological functioning, in both the cognitive and emotional domains. These positive effects have been found primarily with questionnaires, performance measures, and transient physiological measures. This study explores the long-term relationships between degree of nature exposure and physiological states. With a publically available dataset, multiple hierarchical regressions were conducted testing the relationship between reported nature exposure and two physiological measures of cognition and emotion, including alpha band EEG asymmetry and degree of eyeblink startle reflex (EBR). A significant relationship was found with nature exposure and these measures, suggesting that nature has enduring positive effects for human functioning via measured physiology.

Modern work environments are mentally demanding and stressful, contributing to poor mental functioning and burnout (Sonnentag, 2012). Nature environments appear to benefit human mental functioning. This benefit occurs for cognitive performance (Kaplan & Berman, 2010), stress recovery (Ulrich, Simons, Losito, Fiorito, Miles, & Zelson, 1991), and emotional state (Craig, Menon, & Klein, 2015).

After a walk in nature environments or after exposure to digital nature images, individuals typically show improved performance on cognitive tasks associated with attention control (Kaplan & Berman, 2010). Some of these tasks include the backwards digit span, the Sustained Attention to Response Task, the Necker Cube Control task, and the controlled attention portion of the Attention Network Test. Furthermore, after a period of high stress, individuals shown nature images have greater immediate reductions in stress response as measured by both subjective questionnaires and physiological indices, relative to individuals shown urban images (Ulrich et al., 1991). Finally, individuals with relatively higher frequency of nature exposure also tend to report having higher positive affective states and greater satisfaction with their life and profession (Craig, et al., 2015).

The mechanisms behind this benefit in functioning (called "restoration" in environmental psychology) are thought to occur on two timescales (Kaplan & Berman, 2010; Staats, 2012). First, there is a relatively quick process, a proposed mild attention capture driven by the properties of nature stimuli, which alleviates mental fatigue. The possible theoretical reasons behind this capture are beyond the scope of this article (see Kaplan, 1995). Second, there is a relatively longer proposed process, in which the properties of a nature environment give individuals a unique opportunity to engage in "reflection", to cognitively change how they perceive, interpret, and cope with difficult life situations. Reflection may have long-term effects, positively influencing how those individuals deal with current and related future challenges, along with other benefits (Kaplan & Berman, 2010; Staats, 2012).

Physiological considerations

Previous research (Craig et al., 2015) explored several predictions based on the different mechanisms of quick mild attention capture and sustained reflection, finding that both positive affect, perceived stress, and perception of work value benefitted from increased nature exposure. However, these effects were found via subjective questionnaire measures, leaving open the question of whether positive effects would be found with physiological measures.

Ulrich and colleagues (1991) found immediate positive effects of nature imagery with physiological measures related to stress response. This raises the question of whether these positive effects of nature exposure, with proposed long-term psychological benefits, would also contribute to long-term, stable physiological effects. This is an underexplored question. Negative emotions, rumination, and worry have been found to be related to relatively unhealthy physiological states, including somatic complaints, poorer immune and cardiovascular system functioning, and maladaptive neurovisceral functioning associated with involuntary, rigid defensive behavior (e.g., "fight/flight"; Brosschot, Gerin, & Thayer, 2006). Because nature exposure is linked to improved cognitive performance, greater positive affect, and reflection, nature exposure may also be linked to different stable physiological states. Here, utilizing publically available data from the National Survey of Midlife Development in the United States (MIDUS II; http://www.midus.wisc.edu/) Project Five (Ryff & Davidson, 2010), we investigate the relationship of nature exposure with two physiological measures associated with emotional response and cognition: eyeblink startle reflex (EBR), and electroencephalography (EEG). The original purpose of MIDUS II Project 5 (Neuroscience) was to investigate physiological and neural measures of emotional reactivity and emotional regulation and explore their relationship to middle-aged health. These measurements provide a useful avenue to explore the present research questions.

Eyeblink startle reflex

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The eyeblink startle reflex paradigm has been used to investigate human psychological states by measuring the degree of reflexive startle during a startling stimulus such as a loud noise (Hugdahl, 2001). Two particular dimensions of the eyeblink startle paradigm have been manipulated: (1) the lead time or length of time between the onset of a lead stimulus and the onset of the startling stimulus, and (2) the affective valence of the lead stimulus, such as the presentation of a happy, sad, or neutral picture prior to the startling noise.

Short lead times and the magnitude of the startle response are associated with sensory and attentional processes. During long lead times (intervals longer than 500-800 ms), the affective valence of the lead stimulus predicts the magnitude of the startle response (Filion, Dawson, & Schell, 1998). During presentation of negative or aversive lead stimuli (e.g., pictures of dead bodies), the magnitude of the startle response increases, as if the lead stimulus leads to fear-potentiation and a heightened defensive reflex. This leads to a relatively straightforward prediction that individuals experiencing heightened negative affect and worry would produce an increased startle response, and those experiencing positive affect and less worry would produce a reduced startle response.

EEG

The MIDUS II Neuroscience project (Project 5) recorded baseline (no task) electroencephalography (EEG) measurements from the scalp and measured the hemispheric asymmetry of both lower and upper alpha band powers (8-12 Hz), which can be referred to as alpha 1 (lower) and alpha 2 (upper) bands (Ryff & Davidson, 2010). These measurements lead to two explanatory models associated with cognitive and emotional states relevant to the present research question: (1) asymmetry differences between the left and right hemispheres, and (2) differences in cognitive function attributed to the alpha frequency bands.

First, the differences in hemispheric contribution to cognitive and emotional functioning is relatively well studied (Hellige, 1993). For the purposes of this study, the left hemisphere is relatively more associated with language production, and the right hemisphere is thought to be more associated with emotion perception and visuospatial processing (Hellige, 1993). For alpha bands measured at rest, instead of being indicative of “less” neural activity, these bands have been associated with cognition and memory (Petsche, Kaplan, von Stein, & Filz, 1997). The lower alpha band (alpha 1) tonic state is associated with heightened attention allocation, and this tends to be globally topographic across the head. The higher alpha band (alpha 2) tonic state is associated with improved semantic memory performance and verbal processing, and this is localized primary to the left hemisphere. Individuals with higher resting alpha 1 power tend to have better attention performance, and individuals with higher resting alpha 2 power tend to demonstrate better semantic memory (Klimesch, 1999).

Predictions

Taken together, these relationships lead to several predictions for individuals varying in their degree of nature exposure. First, nature is related to positive affect and reflection (Craig et al., 2015; Staats, 2012); therefore individuals with relatively higher levels of nature exposure should have a reduced startle response to negative stimuli. Second, if reflection is a key process during restoration, then individuals with higher levels of nature exposure should demonstrate higher activity of the alpha 2 band on the left hemisphere associated with semantic memory and verbal processing. No prediction is made for the alpha 1 band as the activity of this band is globally topographic so there are no expectations for asymmetric measurement of the lower alpha band. These predicted relationships would demonstrate stable physiological changes related to emotion and cognition as a likely consequence of nature exposure.

Method

Participants

In the dataset there were three-hundred and thirty-one (331) participants with a mean age of 55.41 (SD = 11.12) years, ranging from 36 to 84 years. The participants comprised 148 men and 183 women. There were 308 right-handed individuals and 23 left-handed individuals, the latter of whom were excluded from the EEG analysis.

Measures

Dispositional Positive Affective Scale (Shiota, Keltner, & John, 2006). This questionnaire was designed to measure positive disposition and assess the first prediction. The questionnaire presents participants with a series of statements, and the participant must indicate on a 7-point scale whether they strongly disagree (1) or strongly agree (7) with each statement. To investigate how often the participant was exposed to nature, the present study focuses specifically on item number 65, part of the Awe subscale: “I have many opportunities to see the beauty of nature.”

Eyeblink startle reflex (EBR). Two passive electrodes were put under one eye on the inferior orbicularis oculi muscle, in order to measure blink startle after acoustic startle probes (50 ms at 105 dB) presented 2.9 seconds after picture onset, 0.4 seconds after picture offset, or 1.9 seconds after picture offset. Raw EMG signals were amplified and digitized at 1000 Hz, and processed with Matlab with a 30 Hz highpass filtering and rectification and integration with a time constant of 20 ms. Eyeblink startle magnitude was analyzed for the present study, which includes non-startle response trials valued at zero when averaging across trials (Blumenthal, Cuthbert, Filion, Hackley, Lipp, & van Boxtel, 2005). Reflex magnitudes in microvolts were determined by subtracting the EMG at the reflex onset from that at the maximum amplitude. For more details, please refer to the documentation provided by Ryff and Davidson (2010). These startle responses were provided to further assess the first prediction on positive affect.

Electroencephalography (EEG). EEG channels (128) were recorded via a dense array geodesic electrode net (http://www.egi.com). Recording was done as participants were instructed to rest, either with eyes open or closed (three 1-minute periods each). Impedances were less than 100 KΩ, and the signal was sampled and amplified at 500 Hz, with the reference point at vertex (Cz). After 0.5 Hz high-pass filtering, bad channels were removed. Spectral power density was calculated for each sensor, and an alpha power band was computed based on each individual's alpha peak frequency. Measurements were then computed for each individual's lower alpha (alpha 1) and upper alpha (alpha 2) bands. Log alpha power for each alpha band was then averaged across multiple sites to approximate the 10-20 system, with log alpha power in the left hemisphere subtracted from log alpha in the right to create a laterality index, with larger scores indicating more alpha power in the right hemisphere. For more details, please refer to the documentation provided by Ryff and Davidson (2010). The EEG measures were used to assess the second prediction on reflection.

Procedure

After consent, participants completed a battery of questionnaires including the Dispositional Positive Affective Scale, and were then measured for baseline EEG scores. Then participants underwent the startle response procedure. Afterwards, participants completed a second set of questionnaires (not presented here). These tests were performed primarily at the Laboratory for Brain Imaging and Behavior, at the UW-Madison campus (Ryff & Davidson, 2010).

For the EBR startle response procedure, each trial comprised of 1 second of fixation with a white central cross, a 4 second presentation of a picture, and a random inter-trial interval between 14 and 18 seconds. Up to 2 seconds after the picture presentation, a startle probe (50 ms at 105 dB) would play. This probe would either play 2900 ms after the picture onset (Early), 4400 ms after picture onset (Middle), or 5900 ms after picture onset (Late). Pictures comprised of 30 positive, 30 negative, and 30 neutral images. A more complete description of the protocol can be found elsewhere (Ryff & Davidson, 2010; van Reekum, Schaefer, Lapate, Norris, Greischar, & Davidson, 2011). The first two stages in the procedure (questionnaires and EEG) were correlational in nature, while the third stage (EBR) used startle probe timing and emotional valence of pictures as experimental manipulations.

Results

Analysis

In order to determine whether nature exposure was related to the physiological and neural variables of interest, multiple hierarchical regressions were conducted. Age and gender were included as control variables and entered at the first step of each regression. For the eyeblink startle reflex analyses, startle magnitudes for the early (2900 ms), middle (4400 ms) and late (5900 ms) probes were included in the second step. For the EEG analyses, alpha 1 and alpha 2 asymmetries were entered in the second step. The EEG analysis only included individuals that identified as right-handed. The measurement of nature exposure, question 65 of the Dispositional Positive Affective Scale, was used as the predicted variable for each analysis.

Eyeblink Startle Reflex (EBR)

The EBR regression considering magnitude of response after negative pictures was significant at the first step with the control variables, and the second step with the EBR was also significant (Table 1). $R^2 = .034$, $F(2, 213) = 3.80$, $p = .024$, R^2 change = .040, $F(3,210) = 3.05$, $p = .030$. As shown in Table 1, the startle reflex for the middle probe is negatively related to nature exposure ($p = .006$).

The regression for magnitude of response to probes for neutral pictures was significant at the first step with control variables, but not significant for the second step. $R^2 = .032$, $F(2,214) = 3.57$, $p = .030$, R^2 change = .009, $F(3, 211) = .64$, $p = .589$.

The regression for magnitude of response to probes for positive pictures was significant at the first step with control variables, but not significant at the second step. $R^2 = .031$, $F(2,210) = 3.39$, $p = .036$, R^2 change = .019, $F(3,207) = 1.39$, $p = .246$.

Table 1

Regression analysis for EBR with negative pictures

Variables and Steps	R^2	ΔR^2	B
EBR Magnitude			
Step 1	.034*	.034*	
Step 2	.075*	.040*	
Early Probe			-.074
Mid Probe			-.187**
Late Probe			-.013

† p < .10, * p < .05, ** p < .01

Electroencephalography (EEG)

The EEG regression considering frontal asymmetries was significant at the first step with control variables, but not significant at the second step. $R^2 = .042$, $F(2,285) = 6.22$, $p = .002$, R^2 change = .032, $F(6,279) = 1.62$, $p = .141$.

The regression considering central and temporal asymmetries was significant at the first step and marginally significant at the second step (Table 2). $R^2 = .042$, $F(2,285) = 6.22$, $p = .002$, R^2 change = .030, $F(4,281) = 2.28$, $p = .061$. As shown in Table 2, nature exposure is significantly related to more right Alpha 1 band power and more left Alpha 2 band power at the C7/C8 electrode region.

The EEG regression considering parietal asymmetries was significant at the first step with control variables, but not significant at the second step. $R^2 = .042$, $F(2,285) = 6.22$, $p = .002$, R^2 change = .002, $F(4,281) = .133$, $p = .970$.

The regression considering occipital asymmetries was significant at the first step with control variables, but not significant at the second step. $R^2 = .042$, $F(2,285) = 6.22$, $p = .002$, R^2 change = .013, $F(2,283) = 1.94$, $p = .146$.

Table 2

Regression analysis for EEG asymmetry at central region

Variables and Steps	R^2	ΔR^2	B
EEG Asymmetry			
Step 1	.042**	.042**	
Step 2	.072*	.030†	
C3/C4 Alpha 1			.289
C3/C4 Alpha 2			-.242
C7/C8 Alpha 1			.388*
C7/C8 Alpha 2			-.335*

† p < .10, * p < .05, ** p < .01

Discussion

This study considered the relationship between nature exposure and measures of emotional reactivity and cognition with a publically available dataset. The predictions were that greater nature exposure would be associated with both reduced emotional reaction to negative stimuli, and increased semantic processing characterized by higher upper alpha band in the left hemisphere. The results indicated that for pictures intended to elicit negative affect, there was a negative relationship between measure exposure and the magnitude of the startle reflex to the middle probe. Furthermore, increased nature exposure is associated with increased resting alpha 2 power for the left hemisphere, and increased resting alpha 1 power for the right hemisphere. These significant EEG measurements were found for the C7/C8 electrodes near the temporal region (Pizzagalli, 2007).

Nature exposure has immediate stress reducing effects along with a tendency to elicit positive affect (Craig et al., 2015; Ulrich et al., 1991). Furthermore, that time spent in nature may lead to a reflective process that has long term effects for improved coping with difficult negative situations (Staats, 2012). The present finding that more opportunities to experience nature is associated with a reduced defensive reflex after being exposed to negative affective stimuli provides support for the claim of long-term benefits for coping with difficulty via reduced defensiveness to negative information (Filion et al., 1998). This arguably occurs because of repeated opportunities for reflection, which provides a mental framework for accommodating negative information in the environment (Kaplan & Berman, 2010). Furthermore, the measures are physiological instead of questionnaire-based, which provides converging evidence as well. One interesting finding to be explored in the future is that this pattern was found for the middle time startle probe and not the early or late probes. This may be because the early probe is too early for an effective coping response, while the late probe provides time for other possible processes to influence the startle response and washing out any contribution from being in nature.

While the EEG asymmetry findings must be carefully interpreted due to the overall model for the central/temporal electrodes being marginally significant, the direction of the significant beta values fit well with the prediction derived from the nature and reflection hypothesis. The left hemisphere, particularly the temporal region, is associated with language perception and production (Hellige, 1993), and higher resting alpha 2 power is both typically localized to the left hemisphere and associated with better semantic memory and judgment (Klimesch, 1999). The finding that more nature exposure is associated with heightened alpha 2 power in the left hemisphere near the central and temporal measurement regions provides some support for the proposed reflection process. Reflection is presumably heavily semantic and verbal in nature, and increased opportunities to reflect should be associated with greater resting activity in regions involved with semantic processing. The present results are promising and suggest that reflection in nature could be an interesting avenue for future research.

Greater nature exposure was also associated with increased alpha 1 power in the right hemisphere. This finding was not expected and is somewhat difficult to interpret. Greater alpha 1 power is related to greater attentional resources or reflects heightened attention allocation to a task (Klimesch, 1999). This would be consistent with the cognitive and attentional benefits of nature environments (Kaplan & Berman, 2010). However, this pattern of higher resting alpha 1 power and attention is topographically associated with the entire cortex, making the finding of a right hemisphere bias with nature exposure difficult to directly attribute to attentional resources. As the right hemisphere is traditionally associated with both visuospatial processing and emotional expression (Hellige, 1993), perhaps the finding of greater rightward alpha 1 power is due to increased attentiveness to personal emotional state or the visual details of the surrounding environment.

Limitations

The primary limitation constraining interpretation of these results is the correlational nature of the study. Both the casual relationships and their directionality cannot be derived from the present design. While the supposition is that increased nature exposure leads to the physiological and neural effects, it may be that the physiological and neural effects indirectly lead to more nature exposure, or that both are related to an unknown third variable.

Second, the nature exposure variable in question is not a direct measure of nature exposure. The measurement is an imprecise estimate. Furthermore, the question is specifically phrased “have many opportunities to see the beauty of nature”. This does not specifically ask whether the individual has actually experienced nature, only whether the opportunity exists.

Conclusion

Work can be demanding and stressful, with many potential sources of negative affect (Sonnentag, 2012). Proximity to nature environments may provide one means of alleviating these effects and improving well-being. This research extends prior findings on the emotional and cognitive benefits of nature environments by identifying a relationship between physiological measures of emotion and cognition and nature exposure. These relationships provide initial support for some proposed processes underlying these benefits, including reflection. Future research should directly explore the implications of these findings by manipulating verbal processing during long duration environmental exposure.

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