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Medial Prefrontal Cortex fNIRS Activity while Viewing Nature and Urban Scenes: The Search for Neurological Evidence of Nature's Transcendent Self-Diminishment Effect

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Medial Prefrontal Cortex fNIRS Activity while Viewing Nature and Urban Scenes: The Search for Neurological Evidence of Nature's Transcendent Self-Diminishment Effect

By

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Thesis Title: Medial Prefrontal Cortex fNIRS Activity while Viewing Nature and Urban Scenes: The Search for Neurological Evidence of Nature's Transcendent Self-Diminishment Effect

This thesis by Haylee Snyder is recommended for approval by the student's Thesis Committee and Department Head in the Department of Psychological Science by the Dean of Graduate Studies and Research.

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Abstract

Prior research suggests that exposure to nature increases prosociality. One of the theories as to why this happens is that nature can elicit self-diminishment which leads to the positive experience of paying less attention to oneself. To better understand the neural processes behind this, this study used functional near-infrared spectroscopy (fNIRS) to measure activity in the medial prefrontal cortex (mPFC) which is related to the self-concept. Participants were shown 12 images divided into four blocks separated by image types. Six were entirely natural scenes (three pleasant and three unpleasant), and six were entirely urban scenes (three pleasant and three unpleasant). After each image block participants took a brief questionnaire to measure their level of immersion. A Flanker task was used to separate the image blocks after each immersion questionnaire. There was no significant difference in HbT between nature and urban scenes, but a significant main effect of valence was found. Unpleasant stimuli compared to pleasant stimuli were associated with lower average HbT in the mPFC. This might suggest that negative images resulted in more correlates of self-diminishment, however, more research is needed to support this.

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Introduction

Currently, the planet is in a great stage of distress, with economic downfall, climate change, poverty, and political unrest. The Global Risks Report 2023 predicts that soon the world will be facing the threat of “polycrises,” which is a group of related global disasters happening simultaneously (Heading & Zahidi 2023). One of the most potentially disastrous upcoming polycrises is the threat of climate disaster. Rising water levels will push people out of their homes, warmer weather will damage crops and cause food scarcity, and natural disasters will only become more frequent and increasingly dangerous. The compounding effect of these crises is predicted to be an increase in the global cost of living, natural resource scarcity, geopolitical distress, natural habitat loss, and death and injury as a direct result of natural disasters. Climate change will inevitably affect all of the world's inhabitants regardless of location, wealth, and species. To mitigate the potential damage of these looming polycrises, global cooperation is needed to enact significant change (Heading & Zahidi, 2023).

In preparation for the potential polycrises threatening the planet, there is a vital need for a stark increase in prosociality to help solve the many problems currently ailing the world and its inhabitants. Prosociality is defined as behaviors enacted with the intent to help others (Jensen 2016). To enhance global cooperation, it is necessary to continue to deepen understanding of prosociality and ways to promote prosocial behaviors and attitudes. Research on prosociality has found a promising way to increase people’s desire to help one another; nature. Even just brief exposure to green space can increase helping behaviors (Guéguen & Stefan, 2016). Although nature is typically thought of as the natural wilderness outside, nature delivered in human-made settings is still effective in increasing prosociality. After exposure to indoor nature in the form of pictures of even house plants, people are found to be more generous with money and more inclined to help other people (Weinstein et al., 2009; Zhang et al., 2014). The ability to provide nature to people in non-traditional forms such as videos, pictures, virtual reality, or house plants is incredibly useful as it opens the door for those who may not have easy access to the natural world. Not only does nature have the ability to make people more likely to help one another, but it also may decrease the risk of harming another. Frequenting areas with more green space have also been shown to decrease risk of individuals committing crimes (Schertz et al., 2021). There is some evidence that nature may not only change the way we behave towards others but also towards ourselves. Being in nature has been shown to improve self-perception. Swami and colleagues (2018) found that participants were more likely to have a more positive body image after engaging with nature. This effect was found whether the participants were viewing nature images, walking through nature, or being in a structured green space.

The exact reason why nature can prompt prosocial behavior is yet to be determined. One idea as to why this phenomenon may occur is the biophilia hypothesis that suggests humans have an innate attraction to the natural world which might induce positive emotions when exposed to elements of nature (Wilson, 1986). Guéguen and Stefan (2016) found that people are more likely to want to help another person after spending time in green spaces, and they suggest that this effect was mediated by positive affect. This argument is supported by research that shows people are more likely to be prosocial while experiencing positive affect (Schnall et al., 2010). This line of reasoning appears sound until it is contrasted with research suggesting that people are more prosocial after viewing nature regardless of the affect state it elicits being positive or negative, implying that affect may not be the only factor involved in this phenomenon (Guan et al., 2019b). If nature's impact on affect is not the mechanism in which nature prompts prosocial behavior, then something else must be at play. Another potential explanation is the concept of self-diminishment, a term used to describe the generally positive, and transcendent, experience of one paying less attention to their self and more towards the world or others. This attention towards others and the world leads to an increased motivation to help others. Self-diminishment is a mental state often considered a byproduct of experiencing a self-transcendent emotion such as compassion, gratitude, or awe (Stellar et al., 2017). Awe that is elicited from exposure to nature is especially known to decrease one's attention on oneself and then lead to an increase in prosocial behavior (Piff et al., 2015).

Although relatively extensive research has shown that nature can increase prosocial behavior, potentially by inducing self-diminishment, few studies have investigated the neurological processes of this relationship (Piff et al., 2015; Guan et al., 2019a; Zhang et al., 2014; Park et al., 2016). The medial prefrontal cortex (mPFC) has been identified as a region of the brain related to self-referential processing and is part of the default mode network, which means that there is a generally a decrease in activity during external, attention demanding tasks (Keller et al., 2015). Research has shown that when people are asked to think more about themselves, neural correlates of activity in their mPFC increases (Kelley et al., 2002; Wagner et al., 2012). Correlates of activity in the mPFC also decrease during attention-demanding tasks (Keller et al., 2015). Much is still unknown about the inverse of this effect. When experiencing feelings of self-diminishment it is possible that correlates of activity in the mPFC would decrease. This study aims to bridge the neurological link between nature and self-diminishment, providing a stronger understanding of how nature exposure may increase prosocial behavior. Understanding the neural correlates of self-diminishment after exposure to nature could provide helpful insight to elicit prosociality using the help of the natural environment.

Literature Review

Nature and Prosociality

The effect that nature has on human wellbeing and behavior has been a topic gaining a lot of traffic in recent years. Exposure to nature has been shown to have a myriad of physiological and psychological benefits. Walking through a coniferous forest may decrease risk of cancer and bolster the immune system (Li, 2010). Having a hospital room facing green spaces has been shown to decrease length of hospital stays (Ulrich, 1984). Growing up in an area with more green space and access to nature may decrease risk of psychological disorders later in life (Engemann et al., 2019). Spending time outdoors has been shown to improve symptoms of attention deficit hyperactivity disorder (Faber Taylor & Kuo, 2011). It is clear that spending time in or with nature has clear and tangible benefits to an individual's wellbeing, and it can also help improve the state of the world. Nature's effect on prosocial behavior is a promising area of research with results that indicate exposure to nature may have a significant effect on increasing helping behaviors. Simply being in a room with houseplants can increase the likelihood that someone will be more generous with money in an economic game (Weinstein et al., 2009). Viewing images of natural scenes has been shown to have a similar effect of prosocial behavior in economic games (Piff et al., 2015). In addition to increasing prosocial behavior, nature may also decrease antisocial behavior, but not all nature is equal. Ha and colleagues (2024) found that in Chicago, violent crime was negatively associated with areas with tree cover while open grassy spaces were positively correlated. A study conducted on green space and crime in South Africa found that for every 1% increase in greenspace, there was a 1.2% reduction in violent crime in that area (Venter et al., 2022). The exact reason why nature may have such a dramatic impact on pro and antisocial behavior is unknown, but it may be related to attention to the self (Zhang et al., 2014).

Self-Referential Processing

The medial prefrontal cortex has been identified as one of the primary regions in the brain that are responsible for processing self-concept (Kelley et al., 2002; Wagner et al., 2012). Correlates of activity in this region have been shown to increase when an individual performs a self-referential task such as assigning traits to themself as opposed to someone else. Using event-related functional magnetic resonance imaging (fMRI) Kelly and colleagues (2002) found that during a self-referential task where participants were asked to assign traits to either themselves or another person, their BOLD (blood oxygen level dependent) response in the mPFC was associated with an increase of activity in this region when they were assigning traits to themselves. Additionally, self-referential processing in the mPFC has been found to be related to a sense of self-importance, which may suggest that the inverse, less activity in this area, may be associated with self-diminishment (Levorsen et al., 2023). If the BOLD response indicates an increase in activity in the mPFC during tasks that require thinking about the self, then it is likely that this correlate of activity would decrease if a person is experiencing feelings of self-diminishment. The mPFC is found within the larger region in the brain known as the prefrontal cortex (PFC). Using fNIRS, Park and colleagues (2016) found that while participants viewed a small houseplant, fNIRS activity in their PFC decreased. This study did not look specifically at the mPFC and instead focused on the PFC as a whole. If the decrease in fNIRS activity in the mPFC was significant after viewing these houseplants, this could potentially be indicative of self-diminishment.

Self-Diminishment

One of the leading theories as to how nature leads to prosocial behavior is the concept of self-diminishment. Self-diminishment is a self-transcendent emotional experience that turns the attention away from oneself and towards others or the world (Stellar et al., 2017). It has been suggested that the diminished sense of self may lead people to behave in ways that are less extrinsically motivated and support others around them (Kahn & Cargile, 2021). This may provide a case for the existence of authentic altruism as it suggests that when the concept of self is less salient, one may act in a more prosocial manner, perhaps not thinking about the benefits that their behavior may have for themselves. Piff and colleagues (2015) compared the effects of feeling awe or pride on prosocial behavior. The researchers' rationale for choosing these two emotions was that both pride and awe are considered to be arousing and generally positive emotions, yet pride is elicited from self-appraisal and awe from external stimuli. Participants in this study were asked to recount a time that they had experienced awe or pride before answering questions about their worldviews and situations in which they could act in a prosocial manner. The results showed that participants who experienced pride in the laboratory setting were less likely to respond in a prosocial manner on the questionnaire than those who experienced awe. Those who were told to remember a time that they experienced awe also reported a smaller sense of self than those in the pride condition. Although limited by methodological issues including low experimental realism for the emotional experience, likely single time-point testing effects, and the reliance on self-report measures of self-diminishment, Piff et al., (2015) provides preliminary evidence that self-diminishment mediates the relationship between awe and prosociality.

Studying self-diminishment is a challenging task as it is not possible to view the size of a person's self-concept, so researchers must resort to other methods. In an attempt to measure the size of one's self after feeling awe, Bai and colleagues (2017) showed participants images of Fisherman's Wharf in San Francisco or a landscape view of Yosemite National Park. After viewing one of the images the participants were given a sheet of paper with a grid pattern and asked to draw themselves in the photo and label the drawing "Me." Those in the Yosemite condition drew themselves significantly smaller on the page than the Fisherman's Wharf viewing counterparts. The results of this study may indicate that viewing vast natural scenes may induce self-diminishment, or it could be a result of the perceived distance given the image's perspective. The Yosemite photo used in the study was taken from a great distance and includes a large area of land, while the photo of the wharf was taken much closer to the focal point. The participants could instead be drawing themselves at the scale in which they are viewing the photos instead of feeling as though their sense of self is less important. Clarification is needed to confirm that viewing nature scenes will induce self-diminishment more than the urban condition while controlling for the visual scale of the images.

Nature Exposure and Self-Diminishment

Although the present study will not be directly investigating the role of awe on prosocial behavior, it is operating under the assumption that nature-based awe facilitates prosociality by inducing feelings of self-diminishment (Piff et al., 2015; Zhang et al., 2014; Castelo et al., 2021; Stellar et al., 2017; Rudd et al., 2012). Typically, awe is evoked by viewing vast natural scenes, but can also be observed in situations where people are experiencing less intense forms of nature such as sitting in greenspaces (Ballew & Omoto, 2018). Self-diminishment has been well studied in relation to the emotion of awe. Although awe is typically invoked by natural scenes, it can be elicited by a variety of stimuli (Keltner & Haidt, 2003). One study investigated how exposure to nature influences people's materialistic desires and extrinsic motivations. The participants in this study were asked to focus their attention on either a grove of trees or an urban building for one minute before filling out a scale measuring their materialistic values (Joye et al., 2020). After viewing the grove of trees for one minute, the participants in that condition demonstrated less materialistic values on average compared to the condition viewing the building. Although decreased materialistic values do not inherently imply that there would also be a decreased sense of self, materialism is largely self-focused as opposed to self-transcendence, which often induces feelings of self-diminishment (Yaden et al., 2017).

Although, intuitively, positive awe that elicits pleasant emotions would lead to the most benefit, negative awe that might lead to feelings of fear, despair, and even disgust may have similar materialism reduction benefits. Guan and colleagues (2019b) investigated the neural correlate differences between positive (beautiful and vast landscapes) and negative (natural disasters) awe-inspiring images and neutral images (non awe-inspiring). This study found that both positive and negative awe have been shown to decrease one’s desire for money yet positive awe was more effective than negative awe. Jiang and colleagues (2018) also found that both positive and negative awe decreased participants' desire for money compared to neutral stimuli, with positive stimuli being the most effective. In addition to decreasing desire for money, positive and negative awe-evoking images also induced more prosocial behaviors such as donating money compared to neutral images that did not elicit awe (Guan et al., 2019a). The appraisal of these images into positive and negative categories does not seem to lessen the impact of nature on prosociality enough to be reduced to that of urban photos’ impact on prosocial behavior.

Another factor that may impact the level of self-diminishment a person might experience in a laboratory setting is immersion. Weinstein and colleagues (2009) suggested that the level of immersion participants feel during exposure to nature moderates the effect that nature has on prosociality. This study found that participants who were more immersed in the nature images they were shown reported higher levels of intrinsic aspirations which are associated with prosocial behavior. Those who were in the urban image condition and reported high levels of immersion reported higher levels of extrinsic aspirations. In other words measuring immersion in studies using nature and urban images is crucial as it can affect the level of impact nature has on participants. There are many factors that must be considered in determining how nature increases prosocial behavior. Much more research is needed in this area to continue understanding this phenomenon.

Present Study

Understanding that nature's role in increasing prosociality is linked to self-diminishment, it is crucial that this relationship be explored further to bridge the gap between nature and prosociality (Weinstein et al., 2009; Zhang et al., 2014). Self-diminishment is not the sole link between nature and prosociality, it is merely a stepping stone, but could be an important psychological mechanism that can help explain this connection. The neural mechanisms of self-diminishment are vastly under-researched and poorly understood. The present study aims to continue the journey of untangling the web of nature and prosociality by focusing on the role of self-referential processing in the mPFC, without a focus on the emotion of awe. Functional near-infrared spectroscopy was used to measure correlates of activity in the mPFC by collecting data on the total oxyhemoglobin (HbT) present in that area. Based on the knowledge that self-referential processing increases fNIRS activity in the mPFC, a decrease in fNIRS activity would imply that one would be thinking less about oneself (Kelley et al., 2002; Wagner et al., 2012).

Additionally, the present study took into consideration variables that might affect the level of impact nature has on mPFC blood oxygenation such as immersion, and image valence. Immersion has been suggested to moderate the effect that nature images have on prosociality by altering how much a person feels they are present in the images shown to them and become engrossed in the stimuli (Weinstein et al., 2009). To maximize experimental control, the present study used images of various natural and urban scenes, even though they might not be as immersive as other types of stimuli such as videos or experiencing nature in the outdoors. For this reason, immersion was measured as a potential covariate to account for varying levels of self-diminishment between participants due to different levels of engagement with the stimuli. Positive image valence may have an impact on affect, which has been shown to increase prosocial behavior (Schnall et al., 2010; Zhang et al., 2014). Additionally, negatively valenced images have been shown to increase fNIRS activity in the mPFC compared to neutral images (Ozawa et al., 2014). To account for the possibility that nature may increase prosocial behavior by eliciting positive affect, the present study used both positive and negative images within each of the nature and urban scene types.

Hypotheses

1. Nature images will be associated with lower average HbT in the mPFC.
2. Pleasant stimuli compared to unpleasant stimuli will be associated with lower average HbT in the mPFC.
3. The HbT difference in the mPFC between pleasant and unpleasant stimuli will be less in the nature condition.

Methods

Participants

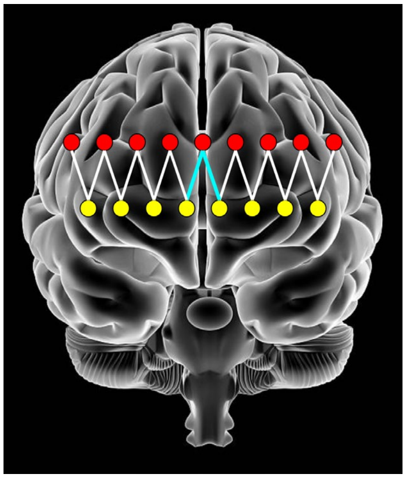
The participants in this study consisted of 48 undergraduate and graduate students from a rural Midwestern university with all but 3 participants in the 18-24 age range (two were 25-34 and one was 35-44). These students were recruited from undergraduate and graduate psychology courses and received extra credit in these courses for participating in this study.

Materials and Measures

fNIRS

Hemodynamic information was collected using a TechEN Continuous Wave 6 (CW6; Milford, MA) Functional Near Infrared Spectroscopy (fNIRS) system and recorded data to an HP ProDesk 600. The fNIRS measures the blood oxygenation level of specific areas in the brain by emitting harmless infrared lasers using two wavelengths of light 690 nm (deoxygenated blood) and 830 nm (oxygenated blood) through the skull and onto the brain (Kleinschmidt et al., 1996). The level of oxygen in that area determines the amount of light reflected back onto the sensors estimating the amount of brain activity across a period of time. A head probe was used to examine the mPFC using an 8x9 array with 3-cm separation of eight laser emitters and nine detectors placed using the 10-20 system (Figure 1). The medial prefrontal cortex blood oxygenation was measured using the center 4th and 5th laser and the 5th detector. The fNIRS was placed on the participant's forehead centered on the frontal pole z (Fpz) and attached using a series of velcro and elastic headbands to provide a secure fit and reduce slipping during the experiment. Prior to application, participants' skin was prepared by using an alcohol wipe to remove any oil or debris to reduce interference with the sensors.

Hemodynamic data was prepared for analysis via MatLabR2021a (The Mathworks, Inc., Natick, MA) Homer 3v1.80.2 (Huppert et al., 2009). The data file for each participant was trimmed to start at the first baseline period and end after the last Flanker task to preserve the integrity of the data. In other words, trimming excluded the part of the data file where participants were waiting to begin the program or have the equipment removed. Post trimming, the fNIRS signals of 690 nm and 830 nm were converted to optical density (OD). A Bandpass filter between 0 and .5 Hz was applied to the optical density data. Morlet wavelet transformation was performed on the OD data in MatLab using Homer 3 to correct any artifacts by smoothing the data. The OD data was then converted to hemodynamic concentrations using the modified Beer-Lambert law (Huppert et al., 2009). The optical density from 690 nm and 830 nm were converted to HbR and HbO respectively. HbT is then calculated by summing the two values together. The center two channels were averaged together by block and baseline corrected by subtracting the value of each 10-second baseline period that occurred prior to each block from the average HbT across the corresponding block. All statistical analyses were completed using SPSS 29.0. The total oxyhemoglobin (HbT) data from each 90-second block of three images of similar valence and scene type was averaged, baseline corrected, and compared between conditions (image type and valence).



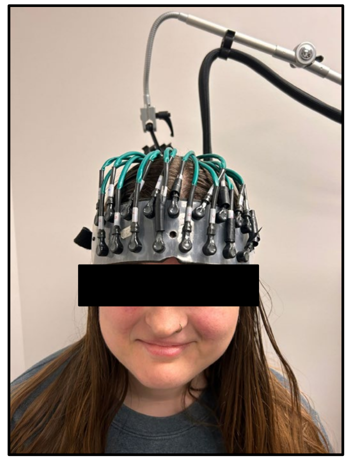


Figure 1: The figure on the left shows the placement of the lasers (red) and sensors (yellow) on the cortex. The image on the right shows the placement of the fNIRS sensors and lasers on a participant's forehead.

Stimuli

The stimuli consisted of 12 images of landscape scenes that were presented in slideshow format using E-Prime (images available upon request). Instructions were presented on the screen before each block of images. Of the 12 images, six were mainly natural scenes with no evidence of direct human impact (three pleasant and three unpleasant), and six were mainly urban scenes with as few elements of nature as possible (three pleasant and three unpleasant) (Figure 3). Images in the urban conditions included, trash piled on a street, smoke stacks with air pollution, a street with heavy traffic (negative), read and white painted arches inside of a building, a small Bavarian town with colorful buildings, and St. Basil's Cathedral in Russia (positive). Images in the nature condition included, a forest fire, dead trees after a drought, a tornado in a field (negative), a stream in Ghana, a landscape view of canyon in Zion National Park, and a view looking out of a cave framed with lush vegetation (positive). Each block type contained one close (eye level perspective), one medium, and one far-distance image (vast landscape), presented for 30-seconds each. Images were matched between each condition for opposing valence. Approximate valence was determined by conducting pilot testing where volunteers ranked the images on a 10-point Likert scale of how natural or urban and how positive or negative each image was. The most extremely rated images at each distance and for each category were selected for the study.

Table 1

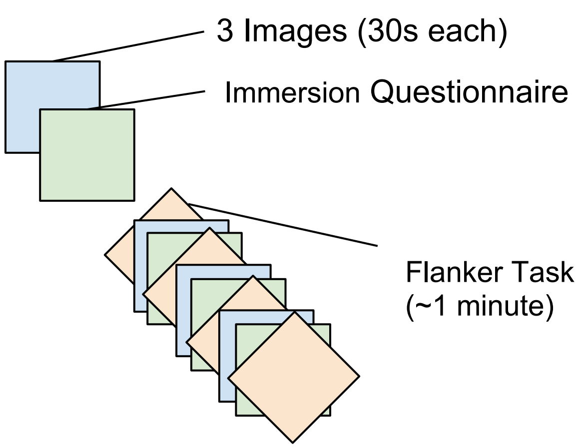
Means and Standard Deviations of Ratings from Pilot Testing

	Scene		Valence	
Image	**M**	**SD**	**M**	**SD**
PN Close	.47	2.01	8.79	2.60
PN Mid	.74	2.41	7.96	2.72
PN Far	.24	1.42	9.38	1.19
NN Close	.60	1.71	1.92	2.64
NN Mid	.82	1.87	2.2	2.51
NN Far	1	2.66	3.12	2.71
PU Close	8.45	1.80	7.38	1.76
PU Mid	8.46	2.17	7.96	2.07
PU Far	8.27	1.62	7.26	2.37
NU Close	9.7	1.45	.03	.95
NU Mid	9.52	1.98	.92	1.81
NU Far	9.26	2.18	.80	2.16

Note. All ratings were on a scale of 0-10. For scene type ratings 0 indicated fully natural scene and 10 indicated fully human made. For valence 0 indicated entirely negative and 10 indicated entirely positive. PN = Positive Nature, NN = Negative Nature, PU = Positive Urban, NU = Negative Urban.

Task

Each image was presented for 30 seconds before showing the next image. Prior to viewing each image block participants were presented with the following instructions on the laptop computer used for the task: "It is very important that you read every word on the screen as it is presented to you to make sure that you have the same experience as everyone else participating in this study". Once moving to the next slide, participants were given a second set of instructions: "Engage deeply with the images and focus on the content of the images as they are presented to you and what they may make you think of " to promote immersion. After each of the immersion questionnaires, participants completed a one-minute Flanker task to separate the blocks and decrease any carryover effects between blocks. The Flanker task required participants to determine the direction of the central arrow in a series of arrows as quickly and as accurately as possible.



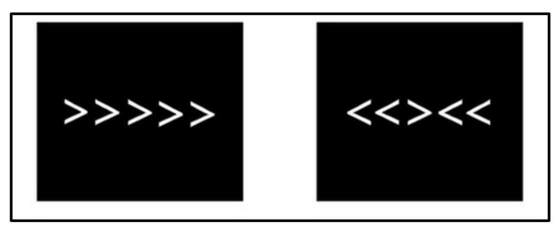


Figure 2: The figure left demonstrates the order of events during the experiment.

Figure 3: The figure to the right shows an example of the Flanker task. The left photo is a congruent trial, showing all of the arrows facing the same direction, and the right is an incongruent trial with the center arrow pointing the opposite direction as the others.

Immersion Questionnaire

To measure the level of immersion participants felt while they were viewing the images, after the presentation of each image block they were presented with a modified version of the Player Experience of Need Satisfaction Physical Presence scale originally created by Ryan and colleagues, then modified by Weinstein and colleagues (Ryan et al., 2006; Weinstein et al., 2009). Each question was presented on a 5-point Likert scale. The questions used in this modified version included “How completely were all your senses engaged?” “How much did you feel that you were in the places you saw?” and “How much did the visual aspects of the environments involve you?”

Climate Anxiety Scale

The Climate Anxiety Scale created by Clayton & Karazsia (2020) was used to measure participants' perceived climate anxiety. Each question was reported on a five-point Likert scale ranging from “Never” to “Always.” This questionnaire contains 13 questions. Some questions include “I have nightmares about climate change” and “My concerns about climate change make it hard for me to have fun with my family or friends.”

Nature Relatedness Questionnaire

The Nature Relatedness Questionnaire developed by Nisbet and colleagues (2009) was used to measure participants’ levels of nature relatedness. The 21 questions were presented on a five-point Likert scale ranging from “Strongly Disagree” to “Strongly Agree.” Some questions in this questionnaire included “The state of non-human species is an indicator of the future for humans” and the negatively scored “Conservation is unnecessary because nature is strong enough to recover from any human impact.”

Procedure

Prior to their arrival at the lab, every participant was asked to complete an informed consent form and a series of questionnaires including demographics, climate anxiety, and nature relatedness (Nisbet et al., 2009; Clayton & Karazsia 2020). Upon arrival at the lab, participants were instructed to sit in a chair positioned in front of a desk with an open laptop in front of them. Participants were given an alcohol wipe to cleanse their forehead to remove oil, dirt, make-up, or debris from their skin. While the participant was seated, the experimenters equipped the participant with the fNIRS head probe and fastened it securely with headbands. To ensure proper placement, experimenters measured centimeters from the inion to the nasion, then took 10% of that measurement up from the nasion to the center of the forehead and marked the location with a wax crayon. This mark acted as the central placement for the head probe. Experimenters checked to make sure that all of the lasers and receivers were functioning properly and made adjustments as needed. Once the fNIRS head probe was properly equipped and the lasers had been turned on, the experimenter opened the E-Prime program and instructed the participant to begin the slide show once the experimenter had exited the room.

Once the program had started, the first slide the participant viewed contained instructions asking them to engage deeply with the images and focus on the content of the images as the images are presented and what they may make them think of while viewing the different scenes. This prompt appeared before each block of images. After each image block, participants answered the modified Player Experience of Need Satisfaction Physical Presence scale to measure the level of immersion they experienced while viewing the images. Next, participants engaged in a one-minute Flanker task before starting the next block of images, repeating this sequence until the four image blocks and four Flanker task sessions had been completed. After the participants had gone through the four image blocks and the four Flanker tasks, the study was completed.

Results

A 2x2 repeated measures ANOVA was performed to analyze the main effects and interactions of image valence (positive or negative) and scene type (nature and urban) on total oxyhemoglobin in the mPFC (HbT) (see Table 1 for descriptive statistics). The analysis to test hypothesis one showed that there was no significant main effect for scene type, $F(1,47) = 0.11$, $p = .746$, partial $\eta^2 = .002$. In the testing of hypothesis two there was a significant main effect for image valence, $F(1,47) = 5.58$, $p = .022$, partial $\eta^2 = .106$, however this finding is in opposition to the direction of the original hypothesis as positively valenced images resulted in higher concentrations of HbT (Positive nature: m = 86.78, SD = 146.09, Positive Urban: m = 91.77, SD = 132.36) than negatively valenced images (Negative nature: m = 44.92, SD = 149.68, Negative urban m = 27.72, SD = 152.82) (see Figure 5). Additionally, hypothesis three was tested by assessing the interaction between the two variables. There was no significant interaction between image valence and scene type, $F(1,47) = 0.30$, $p = .585$, partial $\eta^2 = .006$.

Table 2

Means, Standard Deviations, and Standard Error of HbT Concentrations by Block Type

Block Type	**M**	**SD**	**SE**
Negative Nature	44.92	149.68	21.60
Positive Nature	86.78	146.09	21.08
Negative Urban	27.72	152.82	22.05
Positive Urban	91.77	132.36	19.04

Note. Descriptive statistics per each block type converted to parts per million.

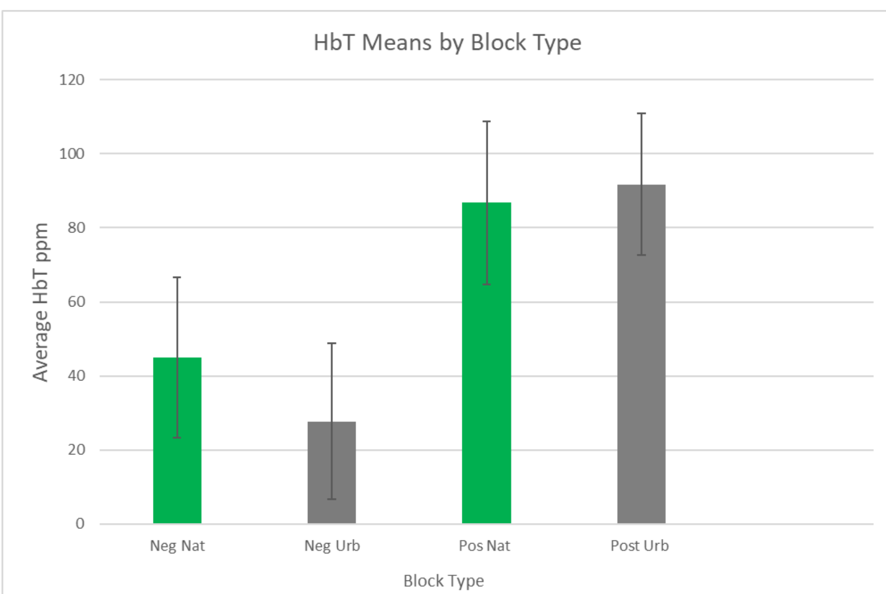


Figure 4: The graph above is a display of the average HbT concentration in parts per million per block. Error bars represent standard error.

Individual Differences

After the primary analysis of the three hypotheses, individual differences were assessed for exploratory analysis by performing a Pearson's correlation. Scores from the Nature Relatedness Questionnaire and the Climate Anxiety Scale were moderately positively correlated r (46) = .33, p = .021. Immersion scores during the Negative Nature block exhibited a positive correlation and were significantly positively correlated with immersion scores during the Negative Urban Block r (46) = .49, p < .001, and immersion scores in the Positive Nature block r (46) = .41, p = .004. Positive Nature immersion scores also showed a positive correlation with Positive Urban immersion scores r (46) = .30, p = .04. When analyzing the correlations of HbT with questionnaire responses and immersion, no significant results were found.

Table 3

Correlates of Immersion by Block with Nature Relatedness and Climate Anxiety

Variable	1	2	3	4	5	6
1. Negative Nature Immersion	—					
2. Negative Urban Immersion	.49**	—				
3. Positive Nature Immersion	.41**	.23	—			
4. Positive Urban Immersion	.18	.15	.30*	—		
5. Nature Relatedness	-.03	.00	.16	.08	—	
6. Climate Anxiety	.09	.10	.01	.05	.33*	—

Note. N = 48. The intercorrelation results of the immersion data by block and scores from the Nature Relatedness Questionnaire and the Climate Anxiety Scale.

*p < .05, **p < .01

Table 4

Means, Standard Deviations, and Standard Error of Immersion Scores by Block Type

Block Type	**M**	**SD**	**SE**
Negative Nature	3.59	.67	.09
Positive Nature	3.85	.73	.11
Negative Urban	3.56	.77	.11
Positive Urban	3.28	.91	.13

Table 5

Correlations of immersion by block and HbT, and questionnaires

	Immersion					
	Nature		Urban			
HbT	Negative	Positive	Negative	Positive	CAS	NRQ
- Nature	-.25	-.19	-.14	-.14	-.14	-.06
- Urban	-.17	.13	-.26†	-.06	.07	.09
+ Nature	.07	-.07	.00	.189	.06	.03
+ Urban	-.04	-.02	.08	-.25	-.16	-.01
Nat-Urb[a]	.01	-.21	.02	.19	.03	-.06
Pos-Neg[b]	-.21	.01	-.22	-.09	-.02	.00

Note. $N = 48$. [a]Average HbT present in nature blocks, determined by subtracting the average HbT in the two urban blocks from the average of the nature blocks. [b]Average HbT present in positively valence blocks, determined by subtracting the average HbT in the negatively valenced blocks from the positively valenced blocks. † Indicates marginal correlation of $p = .08$

Order Effects

To check for order effects a one-way repeated measures ANOVA was performed to analyze the effects of block order (time) on average HbT concentrations. The results of the ANOVA suggested that there were time-based differences throughout the experiment. There were differing results across blocks due to order, regardless of image type being shown, $F(1,47) = 12.43$, $p = .032$ partial $\eta^2 = .094$. Pairwise comparisons confirmed that there were differences between the first block and the second block (t (47) = -3.67, p =.004), the third block (t (47) = -4.18 , p <.001), and the fourth block (t (47) = -3.43, p =.008). No other pairings were significant.

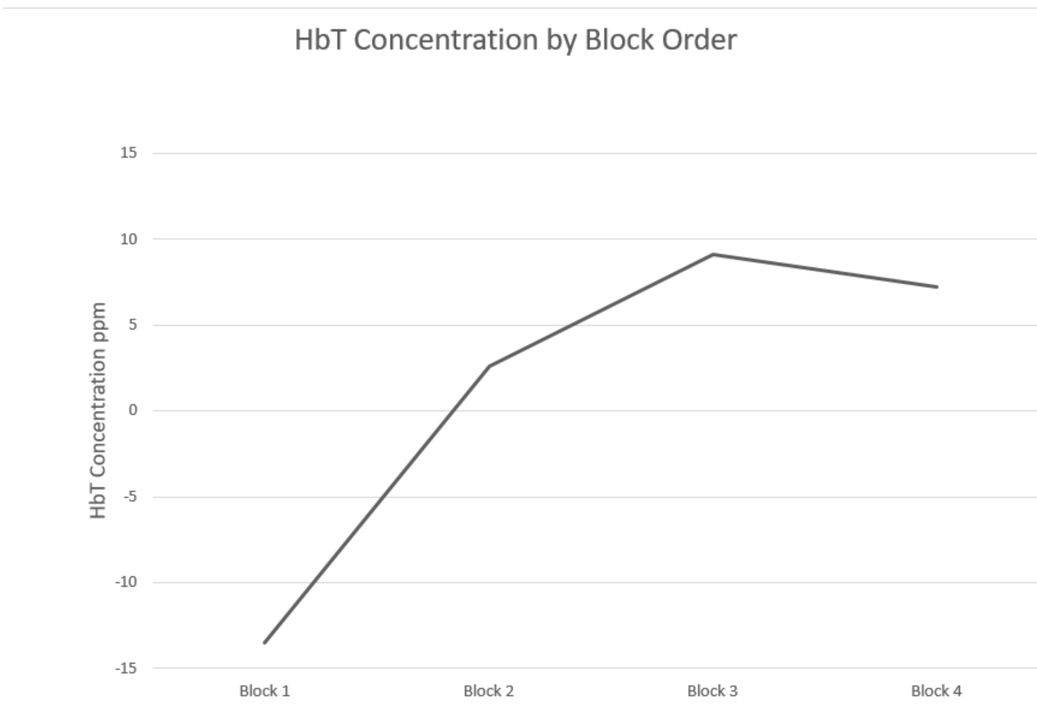


Figure 5: The figure above shows the non-baseline correct data of average HbT in parts per million (ppm) present at each block regardless of picture stimulus type.

Discussion

The neurological processes underlying nature's role in prosociality are largely unknown, but the understanding that nature can increase prosociality and generosity is well-established (Weinstein et al., 2009; Zhang et al., 2014; Castelo et al., 2021; Joye et al., 2020). Weinstein and colleagues (2009) found that even just being in a room with houseplants, participants were more likely to be generous with money in an economic decision-making task. The present study aimed to establish fNIRS correlates of self-diminishment as foundational research to further investigate potential mechanisms in which nature may increase prosocial behavior. Self-diminishment is often studied as a result of experiencing the emotion of awe, as an effect of nature, leading to an increase in prosocial behavior (Kahn & Cargile, 2021). Piff and colleagues (2015), compared the effects of awe and pride on prosocial behavior. Participants in this study who experienced awe were significantly more likely to behave in a prosocial manner than their prideful counterparts while participating in a dictator game. Those in this study who were asked to recall an awe-inspiring experience reported a diminished sense of self, suggesting that self-diminishment may mediate the relationship between awe and prosocial behavior. Awe can be a positive or a negatively valenced emotion, fueled by a sense of wonder or feelings of threat, both of which can result in prosociality, with positively valenced stimuli seemingly more effective than negative (Jiang et al., 2018; Guan et al., 2019a; Guan et al., 2019b). It is likely that thinking more about others and less about one's self is the method in which nature increases prosociality, however there is a major gap in the literature concerning the neuroscience of this phenomenon.

Self-referential Processing and Scene type

The medial prefrontal cortex (mPFC) is predominantly associated with social and self-processing (Courtney & Meyer, 2020; Harris et al., 2007; Kelley et al., 2002). Previous neurological studies using fMRI or fNIRS have found that a decrease in activity in this region is associated with less self-referential processing (Kelley et al., 2002; Wagner et al., 2012). As activity in the mPFC is shown to increase during tasks that require one to think more about themselves, a decrease in activity in this region would indicate less self-referential processing, or self-diminishment. It was expected that viewing nature scenes would decrease activity in this region as previous studies have shown that after exposure to natural stimuli such as house plants, or natural images, participants' activity in the prefrontal cortex has been shown to decrease, yet this result was not replicated in the present study (Park, et al 2016; Zhang et al., 2020). There was no significant main effect of scene type and no significant interaction between valence and scene type. Zhang and colleagues (2020) found that participants had significantly less oxygenated hemoglobin (HbO) present in their prefrontal cortex while viewing positively valenced nature scenes compared to a short relaxation period. It is possible that the results of the present study were not consistent with prior research as these studies mentioned previously examined the PFC broadly, instead of the more specific area of that region, the mPFC. The present study however did not corroborate these findings.

While studying nature's impact on prosocial behavior in a trust-based game, Zhang and colleagues (2014) found that those who scored higher in a stable tendency to perceive beauty in nature images and who viewed beautiful nature images were more likely to act in a prosocial manner. Those who had a low tendency to do so did not differ significantly in prosocial behavior regardless of whether they were shown beautiful nature images. The present study did not look into the effect this, and instead looked at nature relatedness, which theoretically would have a similar moderating effect. However, these are two distinct concepts which which may explain the lack of effect of scene type in the present study. Additionally, the present study did not specifically look at awe inspiring images, but instead was looking for an effect of nature images more broadly. Another explanation of why the expected results may not have been yielded, could be due to not specifically manipulate or measure awe, as self-diminishment is most commonly studied in regards to awe (Piff et al., 2015; Guan et al., 2019a; Guan et al., 2019b). It is also possible that the level of awe perceived between the different scene types may have have not been significant. Additionally, negative images may have been more awe inspiring than the positive images, or vise versa. Future research should consider measuring awe, even if it is not manipulated, to account for this possibility.

Further exploration of the data was conducted to identify any individual differences from questionnaires that may have had an effect on fNIRS activity while viewing the images. The questionnaire responses were not correlated with any of the neurological. Scores on the Climate Anxiety Scale (CAS) and the Nature Relatedness Questionnaire (NRQ) were positively correlated. These findings are consistent with previous research, although the correlation of r = 0.33 is slightly larger than the correlation found by Whitmarsh and colleagues (2022) which found a correlation of r = 0.21. The results of either questionnaire were not found to be correlated with the HbT or immersion measures. In other words, participants were similarly immersed regardless of their nature relatedness scores or climate anxiety scores. The lack of correlation between the NRQ, the CAS, and HbT suggests that the brain of the participants implicitly responds to these images similarly, regardless of their explicit level of nature relatedness or climate anxiety. However more research is needed to confirm or refute this explanation.

Self-Referential Processing and Valence

Although a main effect of scene types was not found, a main effect of valence is still an interesting finding. It was hypothesized that positively valenced nature images would decrease total oxyhemoglobin in the mPFC, yet the results showed a main effect of valenced images. This was hypothesized due to previous research suggesting that positive and negatively valenced nature images both were effective in increasing prosocial behavior (Jiang et al., 2018; Guan et al., 2019a; Guan et al., 2019b). While unexpected in regards to the present study, this the finding that positively valenced images might be related to greater mPFC activity than negative images. Using fMRI, Harris and colleagues (2007) found that negatively valenced images of objects or people produced lower correlates of activity in the mPFC compared to positive images of people and suggested that the mPFC is more sensitive to social stimulus than non-social stimulus.

It is important to note that the mPFC is not only responsible for self-referential processes as it has many more cognitive functions in addition to self-reference. A notable function of the mPFC that could be responsible for these findings is the role it plays in attention and cognitive control (Alexander & Brown 2010). The mPFC is one of the main structures that makes ups the default mode network (Raichle et al., 2001). Scheibner et al (2017) found that the mPFC is more active when participants were focused on internal or external stimuli, compared to when they were letting their mind wander. It is possible that when participants in the present study were allowing their minds to wander while viewing positive scenes and maintained more focus during the negative scenes, due to the emotional intensity of the negative images. Another important function of the mPFC is its role in motivation and reward seeking behaviors. The mPFC has been shonw to be more active during reward seeking cognitive processes (Bogg et al., 2012). While viewing positive nature scenes, participants may have been experiencing feelings of reward which have been associated with greater mPFC activity.

Negative images resulted in more neural correlates of potential self-diminishment which could indicate an increase in prosocial behavior (Kahn & Cargile, 2021). This could possibly be explained by a feeling of empathy for the organism affected by the distressing factors in the images being presented. Further research will be needed to more confidently establish the relationship between fNIRS correlates of self-diminishment and feelings of empathy to draw this conclusion. Stellar and colleagues (2020) found that when participants were shown images of physical suffering compared to emotional suffering, they were more likely to report feelings of anxiety or distress. The negatively valenced images presented in the present study do not show suffering of any humans or animals directly, yet the threat is more physical than emotional to any unseen organism present in the scenes or to the viewer. This threat of harm to the viewer or other organisms could increase prosocial tendency possibly due to feelings of one's self focused worries being less important due to the threat of harm. This is supported by research suggesting that death anxiety positively predicts prosocial tendencies (Chang et al., 2021). A main effect of nature might not have been present due to the severity of emotion present in the negatively valenced images. The negative images presented to the participants in this study may have carried more emotional weight and could have overshadowed the effect of scene type. Future research using similar methods should consider using some form of qualitative data collection such as “talk out loud” statements to assess the participants interpretation of the images. Additionally, the present study did not use neutral images as part of the stimuli which hinders the strength of the claim that positive images increased HbT and negative images decreased HbT.

Neutral images being added to this methodology would help determine this, as it is possible that only one of the valence conditions had an effect on HbT while the other had no effect.

The positive images resulted in an increase in HbT which is associated with self-referential thinking (Kelley et al., 2002; Wagner et al., 2012). Self-serving bias could also explain the increase of HbT while viewing positively valenced images as people tend to attribute more control over their circumstances in situations resulting in successes compared to failures (Zuckerman, 1979). Although the present study did not involve direct implications of personal success or failures, it is still possible that self-serving bias could cause participants to associate themselves with pleasant stimuli more than negative, leading to more self-referential thinking during the viewing of positive images than they experienced during the negative ones. This could potentially have evoked more attributions of others' failures, such as contributing to pollution, or starting a forest fire. However, this does not inherently mean that the participants were self-centered, and lacking concern for others when viewing positive images. Rameson and colleagues (2012) found that when participants were asked to recall experiences that made them feel empathy, they observed an increase in activity in the mPFC. This study highlights an important point to be made, correlates of self-referential activity may not translate directly to behavior. Gaesser and colleagues (2015) suggest that certain types of self-referential processing, such as imagining one's future self, may actually increase prosocial behavior. With this in mind, self-reference and self-diminishment may not actually be opposing concepts, in relation to their impact on prosocial behaviors. Self-diminishment may not be explained best by a small sense of self, but a shift of perspective on the self and how it fits into the world.

Limitations

The lack of significant results regarding scene type does not necessarily imply that nature does not cause differential activity in the brain, the area in which this study chose to focus on may have just not been an appropriate target. Although the mPFC has been shown to be active during self-referential tasks, stimulating the mPFC may not affect these same types of processing (Kelley et al., 2002; Wagner et al., 2012). At least in one study transcranial direct stimulation of the mPFC did not have an effect on self-referential processes (Mainz et al., 2020). It is possible that the mPFC is active during self-referential tasks, but not solely responsible for these types of tasks. The orbitofrontal cortex (OFC) is also associated with self-processing which could be another area of interest (Beer et al., 2010; Rushworth et al., 2007). Yamashita et al (2021) used urban and nature images to investigate differential fNIRS activity and did find significant results between the two conditions while observing the right OFC. Other areas of interest that involve self-referential processing include the left parietal lobe, left insula, inferior frontal gyrus and the left anterior cingulate (Kircher et al., 2000).

In fNIRS literature, studies report their results showing concentrations of oxygenated blood (HbO), deoxygenated blood (HbR), or total hemoglobin (HbT). These different ways of reporting results may lead to conflicting findings. Ozawa and colleagues (2014) found an increase of fNIRS activity in the mPFC while showing participants negative images, but used HbO instead of HbT as their measurement of activity. The present study used HbT which is the sum of oxygenated and deoxygenated hemoglobin present in the area. It is possible that Ozawa and colleagues would have found similar results to this study if HbT was used instead. The present study used HbT as the measurement of fNIRS activity as it accounts for both oxygenated and deoxygenated hemoglobin. It is also important to note that while compared to fMRI, fNIRS is not as precise nor does it have the ability to go as deep into the cortex, still the results of each are still highly correlated (Cui et al., 2011). This lack of precision in the measurement of HbT could also have impacted the results of this study.

A significant limitation of this study was due to the Flanker task being only administered after every trial and not before, leading to an increase in recruitment of HbT after the first block (see Figure 5). This resulted in the first block having lower levels of HbT across participants. When this issue was identified, it was also discovered that the occurrence of each image type block was not evenly distributed across participants, due to the blocks being presented to each participant in a truly random order instead of a pre-programmed counterbalancing. To correct this and maintain proper counterbalancing, five participants were excluded using a random number generator from the overrepresented group who had positive nature as their first block, and additional data were collected to bring all of the other first blocks image type occurrences up to 12. At the time of analysis reported herein, negative nature, positive nature, negative urban, and positive urban were each shown first to participants a total of 12 times.

Conclusion

In summary, it was hypothesized that nature images would result in decreased concentrations of HbT in the mPFC, potentially signifying the experience of self-diminishment, as the mPFC is associated with self-referential processing (Kelley et al., 2002; Wagner et al., 2012). Although a significant result of nature was not found in the present study, a main effect of valence was. Negative images produced lower concentrations of HbT compared to positive images, opposite to the hypothesized results, potentially suggesting that negative images may have a self-diminishing effect. However, the present study did not confirm that self-diminishment elicited from nature images can be observed in the mPFC, at least maybe not with fNIRS. Future research should consider the limitations in methodology as noted previously to continue the search for neurological evidence of nature’s self-diminishing effect.

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APPENDIX A

NORTHERN MICHIGAN UNIVERSITY

Graduate Studies and Research
Marquette, MI 49855-5301
906-227-2300
www.nmu.edu/graduatestudies/

MEMORANDUM

TO: Jon Barch
Department of Psychology

Haylee Snyder

DATE: September 26, 2023

FROM: Lisa Schade Eckert
Dean of Graduate Studies and Research

RE: Modification to HS23-1370
Original IRB Approval Date: 3/14/2023
Modification Approval Date: No CHANGE
"Investigating Activity in the Medial Prefrontal Cortex and Prosocial Behavior after Exposure to Nature"

Your modification for the project "Investigating Activity in the Medial Prefrontal Cortex and Prosocial Behavior after Exposure to Nature" has been approved by the Northern Michigan University Institutional Review Board. Please include your proposal number (HS23-1370) on all research materials and on any correspondence regarding this project.

Any additional personnel changes or revisions to your approved research plan must be approved by the IRB prior to implementation. Unless specified otherwise, all previous requirements included in your original approval notice remain in effect.

If you have any questions, please contact the IRB at hsrr@nmu.edu.

APPENDIX B

NORTHERN MICHIGAN UNIVERSITY

Graduate Studies and Research
Marquette, MI 49855-5301
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Memorandum

TO: Jon Barch
Department of Psychological Science

Haylee Snyder
Elijah Neiman
Makayla Mattson

DATE: March 14, 2023

FROM: Lisa Schade Eckert
Dean of Graduate Studies and Research

SUBJECT: **IRB Proposal** HS23-1370
IRB Approval Date 3/14/2023
Proposed Project Dates: **3/14/2023-April 2023**
"Investigating Activity in the Medial Prefrontal Cortex and Prosocial Behavior after Exposure to Nature"

Your proposal "Investigating Activity in the Medial Prefrontal Cortex and Prosocial Behavior after Exposure to Nature" has been approved by the NMU Institutional Review Board. Include your proposal number (HS23-1370) on all research materials and on any correspondence regarding this project.

A. If a subject suffers an injury during research, or if there is an incident of non-compliance with IRB policies and procedures, you must take immediate action to assist the subject and notify the IRB chair (dereande@nmu.edu) and NMU's IRB administrator (leckert@nmu.edu) within 48 hours. Additionally, you must complete an Unanticipated Problem or Adverse Event Form for Research Involving Human Subjects.

B. Please remember that informed consent is a process beginning with a description of the project and insurance of participant understanding. Informed consent must continue throughout the project via a dialogue between the researcher and research participant.

C. If you find that modifications of investigators, methods, or procedures are necessary, you must submit a Project Modification Form for Research Involving Human Subjects before collecting data. Any changes or revisions to your approved research plan must be approved by the IRB prior to implementation.

Until further guidance, per CDC guidelines, the PI is responsible for obtaining signatures on the COVID-19 Researcher Agreement and Release and COVID-19 Research Participant Agreement and

PHOTO RELEASE FORM

I hereby grant permission to Haylee Snyder to use photographs of me taken on *August 29,2023* in Weston Hall in the publication Medial Prefrontal Cortex fNIRS Activity while Viewing Nature and Urban Scenes: The Search for Neurological Evidence of Nature's Transcendent Self-Diminishment Effect

____

(Signature of Adult, or Guardian of Children under age 18)

Name ____

Address ____

____

Phone _________________________Email Address _________________________

Thank you!