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Short Communication

Engagement with nature and proinflammatory biology

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A R T I C L E I N F O

Keywords:
Nature contact
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Well-being

A B S T R A C T

Background: Prior evidence indicates that contact with nature improves physical health, but data explicitly linking engagement with nature to biological processes are limited.
Design: Leveraging survey and biomarker data from 1,244 adults (mean age = 54.50 years, range = 34–84 years) from the Midlife in the United States (MIDUS II) study, we examined associations between nature engagement, operationalized as the frequency of pleasant nature encounters, and systemic inflammation. Concentrations of interleukin-6 (IL-6), C-reactive protein (CRP), and fibrinogen were measured from fasting blood samples. Analyses adjusted for sociodemographic, health behavior, and psychological well-being covariates.
Results: More frequent positive nature contact was independently associated with lower circulating levels of inflammation.
Conclusions: These findings add to a growing literature on the salubrious health effects of nature by demonstrating how such experiences are instantiated in downstream physiological systems, potentially informing future interventions and public health policies.

1. Introduction

Engagement with nature, encompassing exposure, interaction, and connectivity with natural environments, has demonstrable impacts on well-being (Bratman et al., 2019; Frumkin et al., 2017; Hartig et al., 2014). Leading theories suggest that nature exerts restorative effects on mental processes and elicits emotional and physiological responses that promote health and well-being. Attention restoration theory (R. Kaplan and Kaplan, 1989; S. Kaplan, 1995) suggests that interactions with nature replenish capacities for directed attention that become depleted by modern life demands. Stress reduction theory (Ulrich, 1983; Ulrich et al., 1991) proposes that contact with nature enhances positive emotions and induces calmer physiological activity by providing respite from taxing environmental stimuli. Complementing these frameworks, Fredrickson's (2001) broaden-and-build model posits that positive emotions, like those arising from immersion in nature, can catalyze gains in psychological and biological resources over time (e.g., Kok et al., 2013; Ong et al., 2018), enhancing overall health and resilience.

Empirical research increasingly supports these theories, highlighting the mental and physical health benefits of nature engagement. Meta-analyses of observational and intervention studies show moderate to large effects of nature exposure on heightening positive affect (McMahan and Estes, 2015; Twohig-Bennett and Jones, 2018). Moreover, neural imaging studies show that walking in nature activates the subgenual prefrontal cortex, suggesting a genuine reduction in distress rather than mere attentional redirection (Bratman et al., 2015). Proximity to greenspace has also been linked to reduced obesity, diabetes, and cardiometabolic disease risks (e.g., Dalton and Jones, 2020; De la Fuente et al., 2021; Doubleday et al., 2022; Shanahan et al., 2016). Nevertheless, significant gaps remain in our understanding of how nature influences health.

One critical area that warrants further investigation is the potential of nature engagement to alleviate inflammation, a key driver of numerous chronic diseases (Furman et al., 2019). Additionally, much of the current research has been conducted outside the United States (Bikomeye et al., 2022), raising questions about the generalizability of findings across populations. Lastly, the interplay between different dimensions of nature exposure, such as frequency and quality, needs further clarification.

This study addresses these gaps by drawing on survey and biomarker data from a national sample of 1,244 adults in the Midlife in the United States (MIDUS) study. Our objectives are threefold. First, we aim to

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expand the conceptualization of nature engagement beyond mere frequency to include the quality of experience. Specifically, we investigate whether more frequent pleasant nature encounters confer greater health benefits than neutral or unpleasant ones. Second, we model inflammation as a latent construct to capture systemic effects while accounting for measurement error. Finally, we adjust for a wide array of health-related covariates to isolate the unique links between nature engagement and inflammation.

2. Methods

2.1. Sample and procedures

Participants were men and women from the second wave of the Midlife in the U.S. (MIDUS) survey, a longitudinal study of health and aging in the United States. The initial wave of the study (MIDUS I) was conducted in 1994 –1995, when a national sample of 7,108 individuals was surveyed via telephone using random digit dialing. All participants were noninstitutionalized, English-speaking adults aged 25–74 in the U. S. Among the original participants, 4,963 (70 %) individuals were followed up at the second MIDUS wave (2004–2005).

The current analyses focus on the subset of individuals who participated in a biomarker sub-study at MIDUS II (N = 1,244; mean age = 54.50 years, range = 34–84 years), during which they were assessed for physical health and provided comprehensive biological assessments. Sub-study participants were assigned to data collection sites based on their place of residence, and data were collected during a 24-hour stay at one of three General Clinical Research Centers (Washington, D.C., Los Angeles, CA, and Madison, WI) between July 2004 and May 2009. The protocol included a physical exam, a 12-hour overnight urine sample, and a fasting morning blood draw (see Love et al., 2010). All study procedures were reviewed and approved by the Education and Social/Behavioral Sciences and the Health Sciences Institutional Review Boards at the University of Wisconsin-Madison. Data and documentation for MIDUS are publicly available from the Inter-university Consortium for Political and Social Research (https://www.icpsr.umich.edu/icpsrweb).

2.2. Measures

2.2.1. Nature engagement

Nature engagement was assessed using 3 items (i.e., *appreciating nature*, *breathing clean air*, and *seeing beautiful scenery*). Participants indicated how often each experience occurred in the past month using a 3-point scale (0 = *never*, 1 = *1 to 6 times in last month*, 2 = *7 or more times*). Participants also indicated how much they enjoyed or were pleased by each experience using another 3-point scale (0 = *neutral or unpleasant*, 1 = *somewhat pleasant*, 2 = *very pleasant*). To create the nature engagement index, we first recoded the pleasantness ratings into a dichotomous scale, with 0 representing neutral/unpleasant experiences and 1 representing somewhat/very pleasant experiences. We then multiplied these recoded pleasantness ratings by their corresponding frequency ratings for each item. This approach yielded a composite score that captured both the frequency and quality of nature engagement, with higher scores indicating more frequent and pleasant encounters. Finally, we summed the resulting products across the three items to produce an overall nature engagement index ranging from 0 to 6. This approach, which incorporates the respondent's appraisal of the experience as positive or not, aligns with the definition of positive events involving pleasant appraisals (Lazarus, 1984; Macphillamy and Lewinsohn, 1982).

2.2.2. Inflammation

Proinflammatory outcomes included circulating concentrations of interleukin-6 (IL-6), a cytokine closely involved in the regulation of systemic inflammatory processes; C-reactive protein (CRP), a protein synthesized in the liver and other tissues in response to stimulation by IL-6 and other proinflammatory cytokines; and fibrinogen, a soluble protein present in blood plasma (Singh and Newman, 2011).

2.2.3. Sample collection

Fasting blood samples were collected in the morning by trained staff following standardized protocols (Love et al., 2010). Samples were frozen at −60 °C to −80 °C, batch shipped on dry ice to the study laboratory, and stored at −65 °C until analysis.

2.2.4. Assays

Serum IL-6 levels were measured with the Quantikine high-sensitivity enzyme-linked immunosorbent assay kit (R&D Systems, Minneapolis, MN). Plasma CRP levels were measured using the BNII nephelometer (Dade Behring Inc., Deerfield, IL) with a particle-enhanced immunonepholometric assay. Fibrinogen antigen was measured using the BNII nephelometer (Dade Behring Inc.). All assays were completed according to the manufacturer's instructions. The intra-assay and interassay coefficients of variance were all in an acceptable range (<12 % variance).

2.2.5. Data preparation

The distributions for interleukin-6 (IL-6) and C-reactive protein (CRP) were positively skewed and thus natural log-transformed to normalize them. To minimize the influence of outliers, IL-6 and CRP values were winsorized by limiting extreme values to 3 standard deviations from the mean. Fibrinogen values were standardized to have a mean of zero and variance of one. The transformed IL-6, CRP, and fibrinogen values were then used as indicators in a latent variable model of inflammation, where higher scores represented greater systemic inflammation.

2.2.6. Covariates

Demographic factors, health behaviors, medication, and well-being were included in models to account for confounding influences. Sociodemographic covariates included age (in years), gender (Ref: male), race (white vs. nonwhite), and household income (in quintiles). Health behavior covariates included body mass index (BMI; in kg/m^2, taken by clinic staff), self-reported number of chronic conditions, exercise (dichotomized as yes vs. no to engaging in regular exercise), and subjective sleep quality over the past month (1 = *very good*, 4 = *very bad*). Medication covariates included antihypertensive, cholesterol-lowering, steroid, and antidepressant medications to lower clinical risk. Hedonic and eudaimonic well-being measures at MIDUS II were also included as covariates. Eudaimonic well-being was assessed based on Ryff's theoretical model (Ryff and Keyes, 1995) with two scales: Personal Growth (e.g., "For me, life has been a continuous process of learning, changing, and growth") and Purpose in Life (e.g., "I have a sense of direction and purpose in life"). Each scale had seven items, and internal consistency was 0.75 for personal growth and 0.69 for purpose in life, respectively. Hedonic well-being was assessed via positive affect and life satisfaction. Positive affect was an average rating of how much of the time respondents felt "enthusiastic," "attentive," "proud," and "active" in the last 30 days on a five-point scale ($\alpha = 0.85$; Mroczek and Kolarz, 1998). The life satisfaction scale contained five items (e.g., "If I could live my life over, I would change almost nothing") and was rated on a seven-point scale ($\alpha = 0.88$; Diener et al., 1985).

2.3. Statistical analysis

Analyses were conducted using structural equation modeling (SEM) in R (lavaan package; Rosseel, 2012).

2.3.1. Missing data

Full information maximum likelihood estimation was employed to handle missing data (Enders and Bandalos, 2001). Only participants with available data for at least one inflammation biomarker were included.

2.3.2. Models

Two SEMs examined associations between nature engagement and the latent inflammation variable indicated by IL-6, CRP, and fibrinogen. Model 1 tested the unadjusted bivariate association. Model 2 adjusted for sociodemographic factors (age, gender, race, income), physical health indicators (BMI, chronic conditions, exercise, sleep quality), medication usage (blood pressure, cholesterol, corticosteroid), and psychological well-being measures (purpose in life, personal growth, life satisfaction, positive affect).

2.3.3. Model evaluation

Fit was evaluated using standard criteria (Briesch et al., 2020; Hu and Bentler, 1999; McCoach and Cintron, 2022): χ2 test, Comparative Fit Index (CFI $\geq$ 0.95), Root Mean Square Error of Approximation (RMSEA $\leq$ 0.08), and Standardized Root Mean Square Residual (SRMR $<$ 0.08).

2.3.4. Supplementary analyses

As the distinct inflammatory biomarkers may also provide unique insights, supplementary path analysis regressions predicted IL-6, CRP, and fibrinogen indicators separately.

3. Results

3.1. Descriptive statistics

The sample (N = 1,244) had a mean age of 54.50 years (SD = 11.70) and was 57 % female. Most participants were white (93 %), with average income in the third quintile. The average BMI was 29.74 (SD = 6.63), and 37 % used blood pressure medications. Relatively high levels of positive affect (M = 3.62, 0.73), purpose in life (M = 5.66, SD = 0.93), life satisfaction (M = 4.78, SD = 1.31), and personal growth (M = 5.67, SD = 0.94) were reported.

3.2. Associations between nature engagement and inflammation

As shown in Table 1, SEM analyses indicated acceptable model fit across indices (CFI $\geq$ 0.90 and SRMR $\leq$ 0.08). Aligning with hypotheses, participants who reported more frequent pleasant nature encounters had lower levels of systemic inflammation in both unadjusted (B_{std} = −0.13, p = <0.01) and fully-adjusted (B_{std} = −0.07, p =.02) models.

3.3. Supplemental analyses

Path analysis regressions predicting individual biomarkers partially aligned with latent model results. In fully-adjusted models (see Table 2), greater nature engagement was associated with lower CRP (β = −0.06, p =.03). However, non-significant effects emerged for IL-6 and fibrinogen, suggesting the association may be specific to CRP.

4. Discussion

Our findings demonstrate a significant link between nature engagement and reduced systemic inflammation, assessed via IL-6, CRP, and fibrinogen. More frequent positive contact with nature was related to lower systemic inflammation, even after adjusting for a wide range of

Table 1
Associations of Nature Engagement with Latent Inflammation: Structural Equation Model Results.

Predictor	Model 1 (Unadjusted)				Model 2 (Adjusted)			
	Ustd	Std	SE	p	Ustd	Std	SE	p
Inflammation								
IL6	1.00	0.65	0.02	<0.01	1.00	0.68	0.02	<0.01
CRP	2.37	0.80	0.02	<0.01	2.24	0.79	0.02	<0.01
Fibrinogen	1.76	0.65	0.02	<0.01	1.66	0.64	0.02	<0.01
Regression(s)								
Nature Engagement	-0.03	-0.13	0.03	<0.01	-0.02	-0.07	0.03	0.02
Age					0.00	0.12	0.03	<0.01
Female					0.11	0.14	0.03	<0.01
Nonwhite					0.02	0.01	0.03	0.76
Income					-0.01	-0.05	0.03	0.15
BMI					0.03	0.49	0.03	<0.01
Chronic Conditions					0.01	0.08	0.03	0.02
Exercise					-0.10	-0.11	0.03	<0.01
Sleep Quality					0.01	0.02	0.03	0.45
Rx Blood Pressure					0.07	0.09	0.03	<0.01
Rx Cholesterol					-0.05	-0.05	0.03	0.08
Rx Corticosteroid					0.05	0.04	0.03	0.16
Positive Affect					0.02	0.03	0.04	0.40
Life Satisfaction					-0.02	-0.05	0.03	0.13
Purpose in Life					0.01	0.02	0.04	0.58
Personal Growth					-0.02	-0.05	0.04	0.24
Intercepts								
IL6	-0.02	-0.03	0.07	0.68	−1.2	−2.4	0.27	<0.01
CRP	0.74	0.68	0.08	<0.01	−1.9	−2.1	0.31	<0.01
Fibrinogen	0.25	0.25	0.07	<0.01	−1.7	−2.0	0.25	<0.01
Variances								
IL6	0.19	0.58	0.03	<0.01	0.18	0.54	0.03	<0.01
CRP	0.42	0.35	0.04	<0.01	0.44	0.37	0.03	<0.01
Fibrinogen	0.58	0.57	0.03	<0.01	0.59	0.59	0.03	<0.01
Inflammation	0.14	0.98	0.01	<0.01	0.09	0.59	0.03	<0.01
Model fit statistics								
$\chi^2(df)$	(2) = 0.196, p =.91				(32) = 196.92, p = <0.01			
CFI	1.00				0.89			
RMSEA	0.000[0.000,0.022]				0.064[0.056,0.073]			
SRMR	0.00				0.02			

Note. N = 1244; *Ustd* – unstandardized coefficient; *SE* – standard error; *Std* – standardized path coefficient; p – p-value; *df* – degrees of freedom; CFI – comparative fit index; RMSEA – root-mean-square error of approximation.

Table 2
Associations of Nature Engagement with Individual Inflammation Biomarkers: Path Analysis Results.

	IL-6			CRP			Fibrinogen		
Predictor	*Std*	*SE*	*p*	*Std*	*SE*	*p*	*Std*	*SE*	*p*
Nature Engagement	-0.04	0.03	0.10	-0.06	0.03	0.03	-0.05	0.03	0.12
Age	0.21	0.03	0.00	-0.00	0.03	0.98	0.12	0.03	<0.01
Female	0.01	0.03	0.66	0.11	0.03	<0.01	0.18	0.03	<0.01
Nonwhite	0.01	0.03	0.78	-0.02	0.03	0.48	0.06	0.03	0.05
Income	-0.05	0.03	0.12	-0.03	0.03	0.33	-0.03	0.03	0.39
BMI	0.33	0.02	<0.01	0.41	0.02	<0.01	0.28	0.03	<0.01
Chronic Conditions	0.06	0.03	0.05	0.05	0.03	0.10	0.06	0.03	0.06
Exercise	-0.09	0.03	<0.01	-0.10	0.03	<0.01	-0.04	0.03	0.16
Sleep Quality	0.02	0.03	0.40	0.04	0.03	0.13	-0.03	0.03	0.27
Rx Blood Pressure	0.09	0.03	<0.01	0.07	0.03	0.02	0.01	0.03	0.68
Rx Cholesterol	-0.01	0.03	0.67	-0.08	0.03	<0.01	0.01	0.03	0.66
Rx Corticosteroid	0.01	0.03	0.82	0.09	0.03	<0.01	-0.07	0.03	0.02
Positive Affect	-0.03	0.04	0.41	0.06	0.04	0.07	0.01	0.04	0.79
Life Satisfaction	-0.05	0.03	0.09	-0.03	0.03	0.31	-0.03	0.03	0.29
Purpose in Life	0.00	0.04	0.92	0.03	0.04	0.53	0.02	0.04	0.68
Personal Growth	-0.04	0.04	0.30	-0.04	0.04	0.32	-0.03	0.04	0.52
Residual SE	0.49			0.94			0.92		
Adjusted R^2	0.25			0.27			0.16		

Note. $N = 1244$; Rx – prescription. *Std* – standardized coefficient; *SE* – standard error; *p* – p-value.

health and demographic covariates. Supplemental analyses provide further insights. While the CRP finding aligns with research linking greenspace exposure to reduced inflammation (Bikomeye et al., 2022), non-significant effects emerged for IL-6 and fibrinogen. This suggests that the inflammation-dampening role of nature engagement may be specific to CRP pathways. Additional research should investigate these differential relationships.

By capturing emotional appraisals, our findings extend mere exposure to show that pleasant nature encounters are associated with reduced inflammation. Specifically, more frequent positive nature experiences were linked to lower CRP. This pattern supports theories positioning positive emotions as promoters of tangible health gains (Fredrickson, 2001). Moreover, the observed associations between nature engagement and lower CRP align with research connecting positive psychological states to dampened proinflammatory signaling (Ong et al., 2018). Such patterns resonate with stress reduction (Ulrich et al., 1991) and attention restoration (R. Kaplan and Kaplan, 1989) frameworks but add specificity regarding the role of pleasant nature encounters in reducing inflammation.

5. Strengths and limitations

A key strength of our study is the use of a nature engagement index that integrates both the frequency and quality of nature experiences. By combining exposure frequency with subjective appraisals of pleasantness, this index provides a more comprehensive assessment of an individual's overall engagement with nature. This approach is consistent with the growing recognition that the quality of nature engagement, not just the quantity, is crucial for understanding the health benefits of nature exposure (Bratman et al., 2019; Frumkin et al., 2017). Another strength of our study is the use of a large, nationally representative U.S. sample, enhancing generalizability beyond smaller existing studies (Bikomeye et al., 2022). Furthermore, modeling inflammation as a latent construct and adjusting for a wide range of health and demographic factors strengthens our confidence that the observed effects are specifically due to pleasant nature engagement.

However, some limitations should be noted. Experimental work manipulating nature exposure is needed to confirm causal impacts on inflammation. The reliance on self-reports and lack of real-time sampling also limits the inferences that can be drawn. Moreover, investigating individual differences, situational factors, and interactions between nature engagement and psychological conditions could enrich the understanding of underlying mechanisms.

6. Conclusion

Our analyses revealed that a higher frequency of positive nature experiences was associated with lower levels of systemic inflammation in a large, national U.S. sample. These findings lay the groundwork for future investigations exploring the complex interplay between emotions, health, and the natural environment. Integrating regular contact with nature into daily experience may provide a potent means of promoting public health and fostering resilience amid the myriad challenges of modern life.

7. Author Note

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CRediT authorship contribution statement

Anthony D. Ong: Conceptualization, Writing – review & editing, Supervision. **Dakota W. Cintron:** Writing – review & editing, Formal analysis. **Gabriel L. Fuligni:** Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data and documentation for MIDUS are publicly available from the

Inter-university Consortium for Political and Social Research (https://www.icpsr.umich.edu/icpsrweb).

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