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Green exercise, mental health symptoms, and state lockdown policies: A longitudinal study

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ABSTRACT

Lockdown policies aimed at decreasing the transmission of COVID-19 showed unintended mental health consequences; however, natural settings may offer a respite for individuals suffering from depression or anxiety symptoms. Previous cross-sectional literature reports protective effects of outdoor exposure on mental health during the COVID-19 pandemic. We longitudinally assess whether green exercise corresponded with a decline in adverse mental health symptoms, controlling for state lockdown policies. We also examine whether the relation differed by state lockdown status. As our exposure variable, we specificized participation in an outdoor walk, jog, or hike (green exercise). We used, as the outcome variable, the 4-item Patient Health Questionnaire (PHQ-4) to measure anxiety and depression symptoms. We utilized the Understanding America Study (UAS), a nationally representative sample of 8253 adults across 50 states in the US, surveyed biweekly between March 10, 2020–May 26, 2021. Linear fixed effect analyses controlled for time-invariant individual factors, as well as employment status, and household income. Regression results indicate a modest decline in PHQ-4 scores of approximately 0.10 (less mental health symptoms) as a function of green exercise, controlling for state lockdown status. We also find a slightly greater protective effect of green exercise on mental health symptoms during state lockdown policies. Additionally, we find that green exercise, as opposed to indoor exercise, corresponds with a decrease in PHQ-4 scores during lockdown. Contact with nature may improve mood and decrease mental health symptoms, especially during stress-inducing periods such as the COVID-19 pandemic. Green exercise as a recommended behavioral intervention may hold relevance for greater public health.

1. Introduction

In 2020, state lockdown policies and stay-at-home orders in the US significantly limited population mobility and restricted community activities (Mervosh, Lu, & Swales, 2020). Substantial changes to daily life coupled with economic strain, social isolation, and possible virus contraction created greater uncertainty and fear (Vigo et al., 2020). Lockdown policies aimed at decreasing the transmission of COVID-19 showed unintended mental health consequences (Das et al., 2022). Populations experienced greater depressive and anxiety symptoms, with some scholars speculating the potential for a 'parallel pandemic' (Das et al., 2022; Vigo et al., 2020). Greater psychological needs have prompted public health experts to investigate potential protective factors associated with mental health (Riehm, 2021; Vos et al., 2021).

As the COVID-19 pandemic persists, scholars and journalists have pointed to urban parks, particularly those serving high density areas, as a key component of public health infrastructure (Frumkin, 2021; Karlamangla, 2021; Razani et al., 2020; Slater et al., 2020). Natural settings offer a respite for individuals suffering from increased loneliness, anxiety, and depression under stay-at-home orders (Brooks et al., 2020; Frumkin, 2021). Analyses of spatiotemporal changes in activity patterns show that, while shopping and other non-essential trips diminished during lockdowns, engagement in outdoor recreational activities including visits to urban parks, green roofs, and other natural landscapes, increased (Hamidi & Zandiatashbar, 2021; Tsang, 2020; Venter et al., 2020).

The biophilia hypothesis posits that humans have an innate instinct to affiliate with, and respond positively to, natural landscapes (Wilson, 1984). Prominent restorative environments theories, including Attention Restoration Theory (ART) and Stress Reduction Theory (SRT), suggest that contact with nature can restore an individual's "adaptive resources" (Hartig et al., 2014; Kaplan & Kaplan, 1989; Ulrich Simons,

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Losito, Fiorito, Miles, & Zelson, 1991). Under antecedent conditions of stress, SRT holds that nature exposure elicits a positive emotional response that mitigates the physiological sequelae of stress (Ulrich Simons et al., 1991). ART posits that contact with nature replenishes cognitive resources, resulting in reduced mental fatigue (Kaplan & Kaplan, 1989). Time spent outdoors, therefore, may buffer against the deleterious psychological effects of lockdown policies.

Natural settings may also provide a venue for physical activity while allowing individuals to comply with social distancing measures. Parks, trails, and other outdoor areas offered an alternative to gyms as restrictions limited access to indoor facilities. Physical activity in the presence of nature, or "green exercise," may have additive positive effects on mental health, owing to the concurrent restorative influence of nature and well-documented benefits of physical activity. Supporting this hypothesis, a meta-analysis of 10 green exercise interventions shows that short bouts of outdoor physical activity correspond with improved mood and self-esteem (Barton & Pretty, 2010). However, this meta-analysis did not examine changes in mental health outcomes as a function of outdoor exercise when compared to indoor exercise. The benefits of physical exercise, more generally, may confound these results. A more recent review of this literature finds weak evidence that green exercise provides health benefits beyond those conferred by indoor exercise (Lahart et al., 2019).

Several cross-sectional studies outside of the US have examined relations between greenspace and mental health during the COVID-19 pandemic, adjusting for individual demographic and socioeconomic characteristics that may influence access and availability of green areas. Robinson et al. (2021) find that residential greenspace (i.e., greenness within a 250m buffer surrounding the home) corresponded with greater mental wellbeing in the UK. Research in Japan shows inverse relations of greenspace use and residential views of nature through windows with anxiety and depression during periods of lockdown (Soga et al., 2020). Studies in Germany, Austria, Italy, and Ireland report that exposure to the outdoors varied inversely with negative emotions during stay-at-home mandates (Lades et al., 2020; Lehberger et al., 2021; Spano et al., 2021; Stieger et al., 2021). A large multi-national study with data on 77 countries indicates that, in areas with restricted access to public outdoor spaces, private outdoor spaces or blue-green nature views corresponded with fewer symptoms of depression and anxiety (Pouso et al., 2020). Scholars also find evidence of stronger protective associations between greenspace and mental health in areas with stricter lockdown policies (Pouso et al., 2020).

Although suggestive, the current literature appears limited in several ways. First, scholars note that cross-sectional designs remain vulnerable to confounding by unmeasured (or poorly measured) factors (Hartig et al., 2014; James et al., 2015). For example, low socioeconomic status (SES) individuals may live in neighborhoods with limited access to high-quality greenspace, which contribute to poor mental health through other stress pathways. Neighborhood greenspace may also correlate with additional area-level factors (e.g., social cohesion, urban sprawl, access to healthcare) that confound associations with mental health (Richardson et al., 2012). Cross-sectional studies attempt to address this issue by adjusting for SES; however, multidimensional characteristics such as SES remain difficult to measure (van den Berg et al., 2015). Scholars suggest that one way to minimize unmeasured confounding involves using longitudinal data with repeat measures. This approach, combined with the use of individual-level "fixed effects", adjusts for unobserved social and health-related factors that may confound the relation between the exposure and the outcome.

In addition, although several studies have examined exposure to greenspace during the COVID-19 pandemic, prior work has not tested the hypothesis that green exercise varied with better mental health symptoms during this period. Given that the proposed additive effects of green exercise remain unclear, we view an examination of the mental health benefits of green exercise, as opposed to indoor exercise, as an important contribution (Barton & Pretty, 2010; Lahart et al., 2019).

Finally, scholars have not examined the relation between outdoor activity and mental health during stay-at-home orders in the US. State lockdown policies varied substantially across place and time in the US (Status of lockdown and stay-at-home orders, 2020). The US may also differ from European and Asian countries in terms of lockdown severity (Kupferschmidt, 2021; The Washington Post, 2020). Certain European countries, for example, limited outdoor exercise to once per day, whereas the US did not restrict outdoor activity (Ledsom, 2020).

We address these limitations and examine novel research questions in an understudied national context. We use the Understanding America Study (UAS), a nationally representative sample of adults across 50 states in the US, to longitudinally assess whether: 1) green exercise corresponded with a decline in adverse mental health symptoms, controlling for lockdown policies; and 2) the relation between green exercise and mental health symptoms differed in lockdown vs non-lockdown periods. Importantly, our identification strategy allowed us to examine associations between green exercise and mental health symptoms while accounting for the rival hypothesis that indoor exercise would deliver similar benefits. The UAS surveyed the same participants between March 10, 2020–May 26, 2021, enabling rigorous longitudinal analysis and fixed effects methods to control for social and health confounders that may bias past cross-sectional work on greenspace and mental health. Results from our study hold relevance to understanding how outdoor physical activity may have protective effects on population mental health.

2. Materials and methods

2.1. Study population

The study population comprised participants from the UAS. As a probability-based Internet panel of adults in the US, the study drew respondents from the universe of US postal addresses. (*Understanding America Study, 2021*) The UAS also provided participants with internet-connected tablets if their household did not already have internet. The study paid participants $20 for each completed survey. The UAS issued its first longitudinal survey on COVID-19 on March 10, 2020 and issued subsequent rounds beginning April 1, 2020 and every two weeks thereafter. Further details regarding methodology appear on the UAS website. We used data from 27 waves of the study, between March 10, 2020 and May 26, 2021, from respondents across all 50 states in the US. Of the 8544 panel members eligible for the survey, our analytic sample comprised 8253 who provided complete data on the variables of interest (96.6% completeness) (*Understanding America Study, 2021*). Table 1 provides information on the diverse sociodemographic characteristics of the study participants by age, gender, and race/ethnicity.

2.2. Study measures

As our mental health outcome, we used the Patient Health Questionnaire-4 (PHQ-4), which measures depression and anxiety symptoms. The PHQ-4 asked participants about mental health symptoms through a series of four questions, "Over the last two weeks, how often have you been bothered by the following problems: 1) Feeling nervous, anxious or on edge; 2) Not being able to stop or control worrying; 3) Feeling down, depressed, or hopeless; and 4) Little interest or pleasure in doing things." Total scores range from 0 to 12, in which a higher score indicates greater depression and anxiety. The PHQ-4, which shows high validity and reliability, enjoys popular use in the mental health literature (Kroenke et al., 2009). Within the UAS dataset, the PHQ-4 has high internal consistency and scale reliability (Cronbach's alpha = 0.917).

We specified, as our exposure variable, participation in green exercise. We obtained data on green exercise from the following survey question in UAS: "In the last seven days, have you gone outside to walk, hike, or exercise?" (*Understanding America Study, 2021*). Responses to

Table 1
Sociodemographic characteristics and descriptive statistics among 8253 respondents in the Understanding America Study, March 10, 2020–May 26, 2021.

Variable	
Sociodemographic characteristics	(%)
Age (years)	
<35	16.2
35-44	18.7
45-54	17.9
55-65	20.7
65+	26.5
Gender (%)	
Male	41.0
Female	59.0
Race/Ethnicity (%)	
White[a]	66.6
Black[a]	7.4
Hispanic	15.2
Other[a,b]	10.8
Highest Education (%)	
Below 12th grade	4.3
High school diploma	15.6
Associate's degree and some college	36.1
Bachelor's degree	25.3
Graduate degree	18.7
Study measures	**Mean (SD)**
PHQ-4 Score	1.87 (2.83)

[a] Non-Hispanic.
[b] Other includes American Indian/Alaska Native, Asian, Hawaiian/Pacific Islander, and Mixed race.

the question included "yes," "no," or "unsure" (*Understanding America Study, 2021*). We categorized "unsure" as "no" and created a binary indicator for green exercise (0 = no; 1 = yes) (*Understanding America Study, 2021*). Additionally, we utilized a question on participation in any exercise to isolate the influence of outdoor exercise as opposed to indoor exercise: "Out of the past 7 days, what is your best estimate of the number of days that you got extra exercise?" Further details on the identification of outdoor versus indoor exercise appear below. We also retrieved, from the UAS survey, characteristics of individuals and households that may change over time and affect frequency of green exercise and/or mental health symptoms. These measures include household income and employment status.

We obtained data on the timing and duration of state lockdown and stay-at-home orders from Ballotopedia. Ballotopedia, a non-profit organization, provides information on American politics and elections as a digital encyclopedia. Ballotopedia collected official state lockdown mandates and closures, issued by state governors, in 43 of the 50 states that enacted policies. State mandates included information on closure of non-essential businesses, travel restrictions, and public health practices. Previous work has also utilized these data as they provide aggregated information on dates for all state lockdown orders, as well as access to each state's executive order for validation. (Status of lockdown and stay-at-home orders, 2020). (Kettl, 2020; McCannon, 2020). We linked these data to UAS based on participants' state of residence and date of survey. We created a binary indicator for whether participants completed their survey during their state lockdown policy or not (0 = no lockdown; 1 = lockdown). We categorized respondents in the seven states that did not implement lockdown policies (Arkansas, Iowa, Nebraska, North Dakota, South Dakota, Utah, and Wyoming) as '0' for the entire study period.

2.3. Statistical analysis

We first tested whether mental health symptoms decline during survey waves in which participants reported engaging in green exercise. We used Ordinary Least Squares (OLS) regression with individual-level fixed effects specification. Our individual-level fixed effects analysis exploits the longitudinal nature of the survey and measures within-individual changes in mental health as a function of changes in green exercise. Fixed effects control for time-invariant characteristics that may correspond with the exposure and/or outcome. These characteristics may include genetic predisposition to mental disorder, propensity to participate in exercise or outdoor activities, help-seeking, and consistent sociodemographic characteristics (e.g., race/ethnicity, educational attainment). The panel structure of our data (same individuals surveyed biweekly) leads to more strongly correlated responses within an individual than observations across individuals. As such, the fixed effects specification forces "within individual" identification, addressing potential autocorrelation from repeat measurements, by individual (Bell et al., 2019). Examination of mental health following ecological shocks, such as the COVID-19 pandemic, may suffer from confounding from inherent individual-level attributes. This strategy limits confounding from unobserved, individual-level characteristics that may also influence participation in green exercise and mental health (Wooldridge, 2012 © 2012).

Unemployment and economic strain may also worsen mental health symptoms during the COVID-19 pandemic, confounding our analysis (Goldman-Mellor et al., 2010). As such, we used questions from the UAS regarding employment status and household income as control variables in our analysis. In order to control for changes over time, we included responses to these questions for each study wave.

Next, we examined whether the relation between green exercise and mental health symptoms differed by state lockdown status. We used the same individual-level fixed effects specification as described above but stratified by lockdown status (0 = no lockdown; 1 = lockdown). We also estimated whether the relation between green exercise and mental health symptoms varied by lockdown status by adding an interaction term (green exercise*lockdown).

Participation in any form of physical activity serves as a rival hypothesis in that it may explain observed associations between green exercise and mental health. Accordingly, we examined whether outdoor exercise, over and above indoor exercise, corresponded with a reduction in mental health symptoms. "We used two questions to create a binary indicator for outdoor as opposed to indoor exercise: 1) "In the last seven days, have you gone outside to walk, hike, or exercise?"; and 2) "Out of the past 7 days, what is your best estimate of the number of days that you get extra exercise?". For each study wave, we assigned a '1' to individuals who participated in green exercise and a '0' to individuals who did not participate in green exercise but did participate in extra exercise (implying indoor exercise). This restricted our study sample to only those who had exercised.

We adjusted for heteroscedasticity in residuals by using robust standard errors and performed all analyses using Stata SE version 16.0. The University of California, Irvine, Institutional Review Board deemed this study exempt owing to the use of publicly available, de-identified data.

3. Results

Over the 27 survey waves, 8253 respondents provided complete data for the variables of interest. Table 1 provides information on the diverse sociodemographic characteristics of the study participants by age, gender, and race/ethnicity. Participants average a PHQ-4 score of 1.87 across 27 waves of the survey. Fig. 1 shows that PHQ-4 scores initially increase (indicating worse depressive and anxiety symptoms) after Wave 1 in March 2020. PHQ-4 scores then drop to initial levels and remain stable through the remainder of the study waves.

Fig. 2 shows the proportion of individuals who participated in green exercise from Waves 2–27 (question not asked at Wave 1). Approximately 65–80% of survey respondents participated in green exercise over the study period. The proportion of green exercisers increase during the first few survey waves; however, the proportion decreases modestly

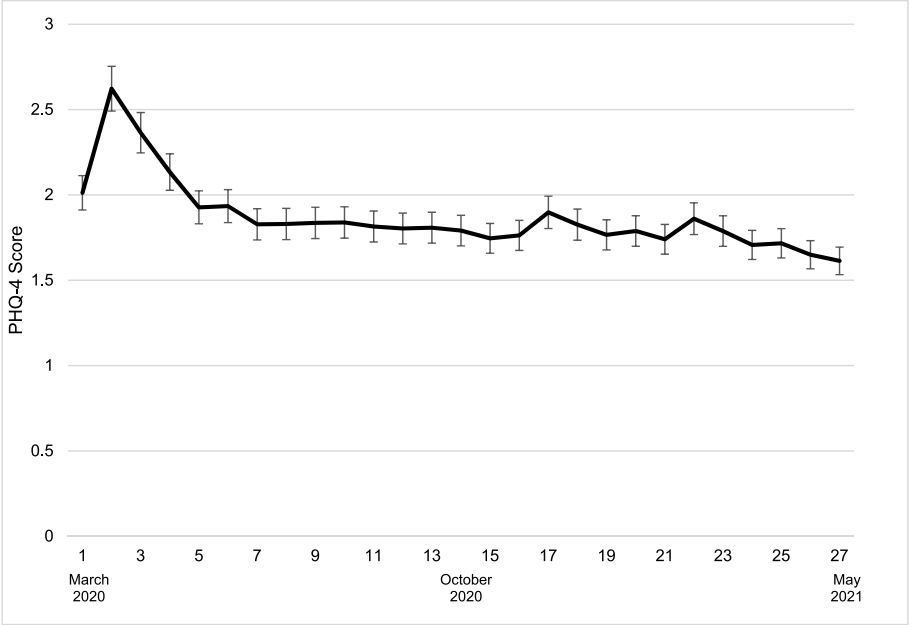

Fig. 1. Patient Health Questionnaire-4 (PHQ-4)[a,b] scores among 8253 respondents, over 27 survey waves, March 10, 2020–May 26, 2021.
[a]PHQ-4 scale range from 0 to 12
[b]5% error bars shown

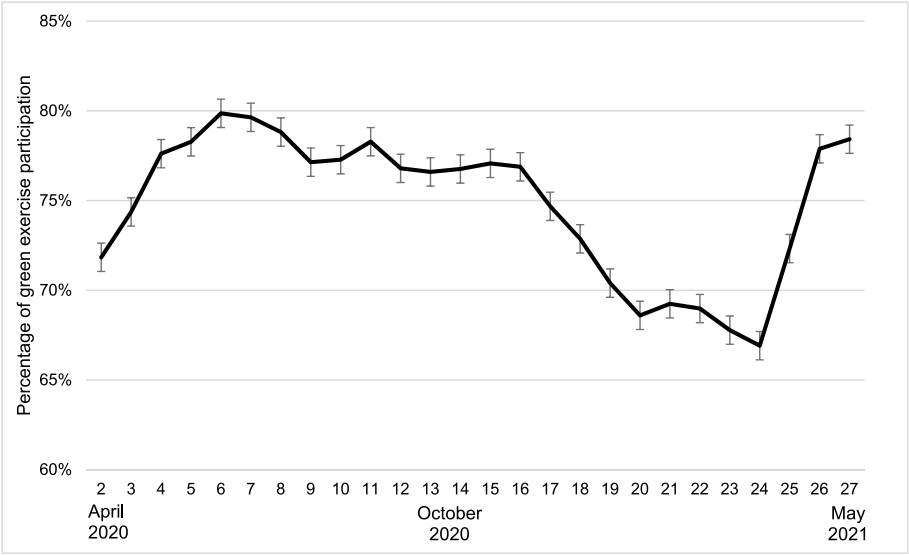

Fig. 2. Percentage of individuals participating in green exercise[a] among 8253 respondents, survey waves 2–27, March 10, 2020–May 26, 2021.
[a]5% error bars shown.

during waves 17–24, which correspond with the winter season.

Fig. 3 shows the spatial-temporal variation in state lockdown policies across the US. Alabama and Missouri enacted policies for less than 30 days whereas California and New Mexico implemented mandates for more than five months (Fig. 3). Lockdown enactment dates also differed in that California implemented its policy mid-March, whereas other policies (i.e., South Carolina, Missouri, Alabama) began lockdown mandates in early April (Fig. 3).

Fig. 4 shows the average PHQ-4 scores among individuals who did and did not participate in green exercise by lockdown status. During lockdown, participants show higher PHQ-4 scores when compared to non-lockdown in both exercise groups. Across both lockdown and non-lockdown periods, respondents participating in green exercise show lower PHQ-4 scores (less severe mental health symptoms) (Fig. 4). For example, during lockdown, participants who reported engaging in green exercise show PHQ-4 scores of 1.99, on average, compared to 2.61 among those who did not report green exercise (Fig. 4).

Table 2 shows linear regression results predicting PHQ-4 scores as a function of green exercise controlling for lockdown policies. We find that green exercise corresponds with a modest reduction in mental health symptoms (Coeff = −0.10, 95% CI = −0.13, −0.06, $p < 0.001$) (Table 2).

Table 3 provides stratified results for the relation between green exercise and mental health symptoms by lockdown status. Our findings indicate a slightly greater decline in mental health symptoms following green exercise during lockdown when compared to no lockdown (Coeff for During Lockdown = −0.10, 95% CI = −0.16, −0.05, $p < 0.001$; No lockdown = −0.09, 95% CI = −0.13,-0.05, $p < 0.001$) (Table 3).

Fig. 3. Timeline of lockdown policy enactment in 43[a] of the 50 US states during the study period, March 10, 2020–May 26, 2021
[a]Seven states that did not enact lockdown policies (AR, IA, ND, NE, SD, UT, WY) not included in figure.

Using an interaction term (lockdown* green exercise), we also find that the relation between green exercise and mental health differs by lockdown status. We report a greater decline in PHQ-4 scores when participating in green exercise during lockdown, as opposed to no lockdown; however, our findings do not reach conventional levels of statistical detection ($p < 0.1$) (Table 3).

Lastly, our results remain robust to analysis in a restricted sample of individuals who reported engaging in any form of physical activity. We find that green exercise, as opposed to indoor exercise, corresponds with a decrease in PHQ-4 scores during lockdown (Coeff for green exercise $= -0.09$, 95% CI $= -0.15, -0.03$, $p < 0.05$) (Table 4). This result suggests that physical activity in general cannot explain observed inverse associations between green exercise and mental health symptoms (Table 4).

4. Discussion

Lockdown policies significantly restricted population movement to prevent the transmission of COVID-19. The psychological fallout from the pandemic prompted a greater need for protective factors associated with mental health. Exposure to the outdoors in the form of green exercise may alleviate depression and anxiety symptoms. We find that green exercise corresponded with a modest decrease in mental health symptoms during the COVID-19 pandemic. Moreover, results show a modestly greater protective association between green exercise and mental health during lockdown as opposed to non-lockdown periods; however, results of the interaction model, testing effect modification, do not reach conventional levels of statistical significance.

Theories of Stress Reduction and Attention Restoration offer plausible explanations for these results. The COVID-19 pandemic led to

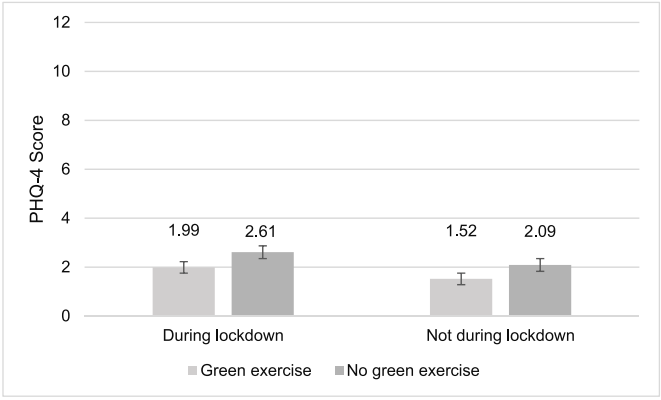

Fig. 4. Average PHQ-4 scores[a] among 8253 respondents who did and did not participate in green exercise by lockdown status, over 27 waves, March 10, 2020–May 26, 2021.
[a]5% error bars shown.

Table 2
Linear fixed effects regression results predicting PHQ-4 score as a function of green exercise among 8253 respondents, over 27 survey waves, March 10, 2020–May 26, 2021.

Covariates[a]	Coefficient	95% CI[b]
Green exercise		
Yes	−0.10****	(-0.13,-0.06)
No (ref)	–	–
Household Income		
<25k	0.07	(-0.12,0.27)
25-50k	−0.01	(-0.18,0.16)
50-100k	−0.04	(-0.16,0.09)
100k+ (ref)	–	–
Employment Status		
Unemployed	−0.06	(-0.16,0.05)
Employed (ref)	–	–
Lockdown		
Yes	0.51****	(0.46,0.56)
No (ref)	–	–
N	8253	

*p < 0.1, **p < 0.05; ***p < 0.01; ****p < 0.001.
[a] Time invariant individual fixed effects included but not shown.
[b] Robust standard errors.

decreased physical activity and elevated levels of stress in the population, owing to fear of virus contraction and uncertainty (Amini et al., 2021; Puccinelli et al., 2021; Zheng et al., 2020). SRT and ART suggest that, under these conditions, contact with nature can replenish adaptive psychological resources (Kaplan & Kaplan, 1989; Ulrich Simons et al., 1991). Lockdown policies may exacerbate mobility constraints and mental health symptoms, such that population needs for restoration exceed those of non-lockdown periods. We speculate that contact with nature, particularly during lockdowns, may result in improved mood and reduced psychophysiological stress (e.g., blood pressure, heart rate) (Kondo et al., 2018). Similarly, exposure to nature may restore mental fatigue by allowing the mind to practice effortless, involuntary attention on natural features such as clouds, trees, or sunsets (Kaplan & Kaplan, 1989).

Past work finds mixed evidence of the additive or synergistic effects of green exercise. A 2010 review supports that physical activity in the presence of nature shows positive associations with mood and self-esteem (Barton & Pretty, 2010). However, this meta-analysis "[did] not assess the separate contributions of nature and physical activity on mental health" (p. 3948). As such, the benefits of physical exercise in general may have explained findings. Our results – particularly comparing outdoor exercise to indoor exercise – add to the evidence base that green exercise contributes independently to mental health,

Table 4
Linear fixed effects regression results predicting PHQ-4 score as a function of the green exercise (as opposed to indoor exercise) during lockdown, among UAS respondents, over 27 survey waves, March 10, 2020–May 26, 2021.

Covariates[a]	Coefficient	95% CI[b]
Green exercise		
Green exercise	−0.09**	(-0.15,-0.03)
Indoor exercise (ref)	–	–
Household Income		
<25k	−0.02	(-0.30,0.26)
25-50k	−0.06	(-0.31,0.18)
50-100k	−0.01	(-0.18,0.17)
100k+ (ref)		
Employment Status		
Unemployed	−0.04	(-0.20,0.13)
Employed (ref)	–	–
N	6635	

*p < 0.1, **p < 0.05; ***p < 0.01; ****p < 0.001.
[a] Time invariant individual fixed effects included but not shown.
[b] Robust standard errors.

Table 3
Linear fixed effects regression results predicting PHQ-4 score as a function of green exercise stratified by lockdown status and the interaction of green exercise and state lockdown policies among UAS respondents, over 27 survey waves, March 10, 2020–May 26, 2021.

Covariates[a]	Lockdown		Non-Lockdown		Lockdown Compared to Non-Lockdown	
	Coefficient	95% CI[b]	Coefficient	95% CI[b]	Coefficient	95% CI[b]
Green exercise						
Yes	−0.10****	(-0.16, −0.05)	−0.09****	(-0.13,-0.05)	–	–
No (ref)	–	–	–	–	–	–
Lockdown*Green exercise						
During lockdown	–	–	–	–	−0.07*	(-0.13,1.00E-3)
No lockdown (ref)	–	–	–	–	–	–
Household Income						
<25k	−0.06	(-0.35,0.22)	0.20	(-0.10,0.50)	0.08	(-0.12,0.27)
25-50k	−0.13	(-0.38,0.12)	0.16	(-0.09,0.41)	−0.13	(-0.18,0.16)
50-100k	0.01	(-0.16,0.18)	−0.02	(-0.21,0.16)	−0.04	(-0.16,0.09)
100k+ (ref)	–	–	–	–	–	–
Employment Status						
Unemployed	−0.01	(-0.18,0.15)	−0.07	(-0.20,0.06)	−0.06	(-0.16,0.05)
Employed (ref)	–	–	–	–	–	–
N	6822		5474		8253	

*p < 0.1, **p < 0.05; ***p < 0.01; ****p < 0.001.
[a] Time invariant individual fixed effects included but not shown.
[b] Robust standard errors.

strengthening the conclusions of Barton and Pretty (2010).

In contrast to our findings, a recent meta-analysis comparing effects of outdoor and indoor exercise finds limited support for the proposed additive effects of green exercise (Lahart et al., 2019). Lahart et al. (2019) find that exercise in the presence, versus absence, of nature shows stronger associations with enjoyment, but not with emotions or biomarkers (e.g., cortisol) associated with mental and physical health. The authors suggest that findings from their meta-analysis may suffer from imprecision and bias due to small sample sizes and differences in outcome measures for mood (Lahart et al., 2019). In addition, only three of the studies included in this meta-analysis used longitudinal study designs.

In comparison to past work (e.g., summarized in Barton & Pretty, 2010; Lahart et al., 2019), our study examined mental health symptoms using a repeat, clinically valid measure, rather than emotional or psychosocial (e.g., self-esteem) correlates. Moreover, we longitudinally assessed, in a large, nationally representative panel of adults in the US., within-individual associations between changes in green exercise and mental health symptoms over a relatively longer period of time. Our study also evaluated differences in associations with mental health during state lockdown policies. This departs from the current literature in that societal restrictions appear to have played a role in the relation between green exercise and mental health.

The study's strengths include use of longitudinal data on a nationally representative panel of respondents from all 50 states in the US. These data allow for measuring within-individual changes in green exercise and mental health over time. Our fixed effects analysis controls for time-invariant characteristics, such as propensity to exercise or genetic disposition to mental disorder, that may correspond with the exposure or outcome. Models further adjusted for time-varying sociodemographic characteristics, including household income or employment status, as these factors may influence both frequency of physical activity and mental health.

Our study has limitations. UAS provides state-level geographic resolution for each respondent which does not allow for examination of proximal greenspace (e.g., distance to nearest park) or the extent of residential nature exposure. Fine-grained data at the census tract or smaller levels of analysis may provide greater detail as to whether green exercise in areas with varied levels of greenspace differentially relates to mental health outcomes.

The UAS question on green exercise, moreover, does not differentiate between walking, hiking, or other forms of outdoor exercise. This limits any interpretation of whether certain types of green exercise exert a greater salutary benefit on depression and anxiety symptoms. Data limitations also do not allow us to measure frequency, duration, or intensity of green exercise as these may change mental health symptomology. Further research would benefit from such data granularity, as these factors may also influence anxiety and depression. We also note that evaluation of clinic-based data may provide more rigorous measurements for psychiatric diagnoses and mental health symptomology than currently provided by our data.

In addition, survey questions regarding green exercise and mental health symptoms have differences in recall periods. The UAS inquiries about green exercise in the past week, whereas questions on mental health symptoms have a two week recall period. This may result in reverse causality as enhanced mental health (two weeks prior) may precede greater participation in green exercise (one week prior). Access to data that provides more fine-grained temporal resolution or identical recall periods for green exercise and mental health symptoms may provide further evidence for temporal order. Moreover, although theories of restorative environments (ART, SRT) guide our research questions, data limitations preclude us from conducting tests of restoration hypotheses (e.g., acute stress reduction following nature exposure). Experimental studies in laboratory (e.g., Ulrich Simons et al., 1991) and field (e.g., Hartig et al., 2003) settings provide compelling evidence that contact with nature promotes psychophysiological stress recovery, which may explain our findings. Finally, study designs that randomize exposure to green exercise may reduce bias resulting from self-selection processes that reflect reverse causality (i.e., as healthier individuals may 'select' into green exercise with greater frequency) (Lahart et al., 2019).

Age-related differences may also exist. Stratification of our results, through exploratory analyses, indicates that older age groups (55–64 and 65+) show decreases in mental health symptoms as a function of green exercise during lockdown (Appendix Table A1). Lastly, our study population does not include youth under the age of 18. Green exercise as a recommended behavioral intervention may hold particular relevance for this population as previous literature reports that adolescents experienced greater adverse mental health during stay-at-home orders (Rogers et al., 2021). We encourage future research that investigates the relation between green exercise and mental health symptoms during lockdown among this population.

State lockdown policies have exacerbated anxiety and depression symptoms among adults in the US (Das et al., 2022). We find that physical activity, particularly green exercise, may buffer stress and tension experienced during lockdown. Media messaging targeting outdoor activities may endorse beneficial coping mechanisms, while also alleviating mental health symptoms. Additionally, media can serve as a platform for behavioral interventions directed at increasing green exercise, at the population-level. Previous mass media campaigns for physical activity have preceded a reduction in sedentary behavior (Stead et al., 2019). One systematic review and meta-analysis finds that mass media campaigns specifically increase (moderate intensity) outdoor walking (Abioye et al., 2013). Studies also report that media messaging precedes changes in physical activity throughout the course of campaigns (Stead et al., 2019). Promotion of green exercise, in particular, may influence population level health during stress-inducing periods.

Author statement

Abhery Das: conceptualization; methodology; formal analysis; writing – original draft; writing – review and editing. Sam Gailey: conceptualization; methodology; validation; writing-review and editing; supervision.

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Ethics approval

The University of California, Irvine, institutional review board deemed this study exempt owing to the use of publicly available, deidentified data.

Data availability

The dataset used for the analysis and the statistical code is available from the corresponding author.

Declaration of competing interest

The authors of this paper do not report any financial disclosures.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvp.2022.101848.

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