Article

The Relationship between Nature Deprivation and Individual Wellbeing across Urban Gradients under COVID-19

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Abstract: Shelter-in-place aimed at slowing COVID-19 transmission has altered nature accessibility patterns, creating quasi-experimental conditions to assess if retracted nature contact and perceived nature deprivation influences physical and emotional wellbeing. We measure through survey methods how pandemic mandates limiting personal movement and outdoor nature access effect self-assessed nature exposure, perceived nature deprivation, and subsequent flourishing as measured by the Harvard Flourishing Index. Results indicate that perceived nature deprivation strongly associates with neighborhood nature contact, time in nature and access to municipal nature during the pandemic, after controlling for shelter-in-place mandates, job status, household composition, and sociodemographic variables. Our hypothesis that individuals with strong perceived nature deprivation under COVID-19 leads to diminished wellbeing proved true. Interaction models of flourishing showed positive modification of nature affinity with age and qualitative modification of nature deprivation with race. Our results demonstrate the potential of local nature contact to support individual wellbeing in a background context of emotional distress and social isolation, important in guiding public health policies beyond pandemics.

Keywords: nature exposure, nature deprivation, health disparities, wellbeing, built environment, urban health interventions

1. Introduction

Evidence of nature's beneficial impact on physical [1-5], cognitive [6-9], and emotional health [10-13] is well-substantiated in scientific literature. Nearly all studies conclude that health outcomes improve with exposure to non-threatening outdoor nature; fewer studies examining indoor nature exposure mostly associate positively [14-17]. Variability of nature exposure differentiates one's experience in nature as well as response to nature contact, such that health outcomes are influenced by appropriate "dose" [18, 19], frequency of contact [20, 21], quality of nature exposure [22, 23], biodiversity level [24-27], aesthetic preference [28, 29] and urban greenspace proximity [30, 31]. Even with emerging awareness of these distinctions, Kuo [32] infers that cumulative exposure to green *in*

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toto—parcel size, nature type, vicinity, etc.— accounts for nature contact's beneficial imprint on health.

Studies of nature-health relationships often approach exposure additively. Intervention studies frequently contrast participant responses between non-natured built environments and nature-dense urban parks. Observational studies analyze proximity and expanse of residential greenspace in increasing increments using spatial measures such as Normalized Difference Vegetation Index (NDVI) or locational data such as GPS [33-38]. Epidemiological methods have identified a range of health improvements, e.g., lower morbidity and annual disease prevalence, fewer premature births. These studies nonetheless lack data on individual nature use and specific participant characteristics, making it difficult to learn which exposure factors most strongly impact outcome effects. A reverse scenario of nature deprivation or withdrawal from nature has rarely been empirically explored owing to scenario improbability, the ethics of withdrawing salutogenic stimuli in experiments involving humans, and from a pragmatic study design point, leakage within non-exposed groups. This paper associates changes to nature contact under COVID with individual wellbeing.

1.1 Nature deprivation

COVID-19's emergence in early 2020 occasioned urgent public health protocols led by shelter-in-place mandates and suspension of daily activity patterns including nature seeking throughout much of the world. The lengthy period of home confinement imposed in many U.S. states and municipalities, as well as concomitant restrictions on local nature access, has given rise to unfamiliar but opportune circumstances to expand qualitative public health research on changes to individual wellbeing related to modified nature contact. From a wellbeing perspective, many individuals go outdoors seeking physical activity, socialization, and emotional resilience derived from immersion in natural environments. Because immersion in nature has been shown to mitigate feelings of anxiety [39] and attention deficit [40] and promote self-efficacy [41, 42] and meaningfulness [43], habitual nature contact may provide an essential coping mechanism for many people during times of distress. Current shelter-in-place policies may be causing nature-dependent individuals to experience feelings of nature deprivation in situations where habitual nature-seeking behaviors might otherwise have assuaged a heightened pathogenesis brought on by health, financial, or emotional concerns stemming from the COVID-19 pandemic [44].

The extraordinary situation of a global health crisis, compulsory shelter-at-home policies, and changes in the supply of and demand for outdoor nature areas has shaped conditions for a natural experiment in which to study how alterations in established patterns of nature exposure may differentially affect individual wellbeing under a state of generalized societal adversity. While we do not presume that most individuals experienced total separation from nature under COVID-19, the overlay of restricted personal mobility and closure of public nature sites like state and national parks—what nature-seekers refer to as "the nature I desire"—irrefutably resulted in the contracted supply of nature and individual access to it. Furthermore, shelter-in-place and lockdown restrictions

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in many states and urban cities have created immediate and captive audiences for nature where it is circumstantially found. To this end, degree of restrictions on public nature areas such as green and blue space under municipal management may directly relate to wellbeing.

1.2 Background literature

Multiple studies indicate that exposure to nature amplifies beneficial physical, psychological, and emotional outcomes. Nature connectivity is core to the environmental psychology literature regarding pro-environmental attitudes and behaviors [45-48]. The many instruments which operationalize nature affinity share a common construct [49-50] rooted in positive affect, though their predictive power does not extend to the effects of nature withdrawal. Nature connectedness has been positively linked with psychological resilience and maintenance of positive mental health under challenge [51] and individual reliance on favorite places in nature for restoration [29]. However, only one study [52] formally analyzes nature connectivity as a potential modifier of nature contact to assess wellbeing and pro-environmental behaviors. Our study considers both nature connectivity and the lesser-explored feelings of nature deprivation under conditions where altered nature contact may be perceived to insufficiently support challenges to individual wellbeing. Although flourishing has empirically associated wellbeing with nature forms in prior studies [53-54], our study is also the first to apply the Harvard Flourishing Index as a formal psychometric construct to relate perceived nature deprivation to wellbeing [55].

Green exercise, i.e, physical activity performed outdoors, offers known remediation pathways for wellbeing improvements [56-59]. Many studies have considered the association of green space in one's immediate residential vicinity to health outcomes. As urbanization displaces traditional venues for nature contact, nearby greenspace increasingly becomes a key exposure criterion for health outcomes, with mental illness and emotional disorders strongly related to proximate green space [18, 60, 61]. Some researchers theorize that individuals with lower mobility—the elderly, children—and those of lower socioeconomic status (SES) concentrate their outdoor activities closer to home. Emotional health outcomes of nature exposure furthermore have been demonstrated to preferentially benefit residents of lower baseline nature, as is typical of low SES-areas [62-64]. Nature found in the immediate neighborhood vicinity thus takes on a larger predictive role to accommodate intentional outdoor nature-seeking in the absence of routinely accessible natural sites.

Loss of nature contact has been widely reported [65, 32, 66] and attributed to urban lifestyles, with ensuing disengagement from and disaffection for nature repercussive for human and planetary health. Researchers have measured baseline indicators of time in nature to conclude that absence of nature contact is the population norm, with the consequence of "nature deprivation" [67] as permanent removal of nature contact being vulnerability to a range of negative health outcomes. Shared concern for a phenomenon described as the "rarity of direct experience," [68] and characterized in the literature as nature deficiency [69] or nature impoverishment [23] has led to research on prescriptive nature re-engagement [70, 71] and nature-based health treatment [72], especially among children. Still, conceptualization of nature deficit disorder [73] remains a descriptive and not diagnostic condition, with formal study elusive given research bounds, though a few exceptions exist [74].

The term nature deprivation here denotes perceived nature deficiency, i.e., unmet personal need to access the nature one desires, rather than comparative resource inadequacy described in

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relative deprivation theory [75]. We draw attention to our use of this term in the emotional sense of withdrawal from habituated forms of nature exposure rather than as the area-level relative absence of green or blue space. To our knowledge, no study has examined the effects on wellbeing from diminished or withdrawn nature exposure, particularly where society-wide restrictions on personal mobility and on the accessibility of some types of nature-rich areas are responsible for nature separation. U.K. epidemiological studies of neighborhood deprivation account for nature density at local levels but not as a discrete exposure metric, nature being but one of many deprivation exposure metrics jointly examined in the British Household Panel Survey and therefore not separable for direct effect comparison.

In this study we hypothesize that changes to nature exposure at the indoor, neighborhood, and municipal levels will induce feelings of individual nature deprivation during the period of Covid-19 restrictions, controlling for age, gender, race, urbanicity, area-level poverty, and US geographic region. Second, we posit that individuals who feel deprived of nature will experience a loss of baseline flourishing after accounting for job status and household composition under the pandemic. While our exposure of interest consists of nature contact potentially modified by pandemic restrictions, we hypothesize that subjective nature affinity may underlie pre-established patterns of nature pursuit that will continue under sheltering. We additionally consider secondary objectives specific to restrictive policies existing at the time of survey-taking, given information available from our results. First, will municipal restrictions on publicly managed nature areas influence feelings of nature deprivation under shelter-in-place; second, will pre-existing patterns of nature exposure impact subsequent wellbeing when habitual nature contact is altered; and third, do sociodemographic variables modify relationships with self-defined nature affinity and self-expressed nature deprivation that predict individual flourishing during Covid-19-like conditions?

2. Materials and Methods

2.1 Survey Population

Our study population consisted of individuals originally recruited to participate in focus group interviews to explore formative experiences and origins of attitudes shaping nature-seeking behaviors as adults. Study participants were recruited through Facebook advertisements placed October 2019 in four regionally distinct metropolitan areas—Boston, Atlanta, San Francisco, and Phoenix—directing prospective participants to an on-line enrollment portal. Additional focus group recruitment occurred with the assistance of university faculty in the targeted metropolitan areas in the attempt to diversify the age, race, and gender of the study base. Survey research participants (n=625) already had already voluntarily enrolled and consented through electronic recruitment. We had no pre-existing data on study participants.

A new recruitment email for this study addressing exposure to nature under COVID-19 restrictions was sent to study participants via email addresses on file explaining survey study objectives and linking to a Qualtrics-distributed on-line survey instrument. Study participants were sent a reminder email at seven and 14 days to request survey completion. No contact was made with study participants after two attempts. A survey link specific to the enrollment ID of each originally enrolled participant allowed us to monitor response rates of the initial cohort at 37.6%; a second, non-specific survey link created for survey forwarding allowed us to track the

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snowball effect of the study design that provided 62.4% of our study population. Survey forwarding extended the initial four metropolitan areas to 36 U.S. states, Puerto Rico, and the District of Colombia.

734 participants returned the survey during the month the link was active. Survey-takers who omitted items were dropped from the study, resulting in a final sample size of 529 participants. This final study population resided in areas of population density (large urban areas and suburbs each represented 36% of respondents), were majority female (75%), white non-Hispanic (82%), and of slightly younger age (age 25-34 = 29%) although no age category was below 10.6%. Individuals who identified as black or Hispanic lived within zip codes of on-average lower normalized difference vegetation index (NDVI) levels and higher poverty rates. Nature affinity trended upward and rose with age, consistent with findings of higher nature connectedness at progressive age [76-78]. Table 1 provides a demographic breakdown of the final study population stratified by nature deprivation response discussed later in this paper. The Harvard T.H. Chan School of Public Health Institutional Review Board approved both the original focus group and survey studies.

Table 1: Characteristics of the survey study population (N (% total)). P-values indicate level of significance for a univariate test for differences in each variable across strata.

	Stratified by Perceptions of Nature Deprivation					
	Strongly disagree that feel deprived	Disagree on feeling deprived	Neither agree nor disagree that deprived	Agree that feel nature deprived	Strongly agree that feel deprived	p
N = 529	93	82	71	169	114	
Nature Affinity (%)						0.62
Low Affinity	15 (16.1)	10 (12.2)	9 (12.7)	18 (10.7)	11 (9.6)	
Medium Affinity	43 (46.2)	44 (53.7)	36 (50.7)	96 (56.8)	54 (47.4)	
High Affinity	35 (37.6)	28 (34.1)	26 (36.6)	55 (32.5)	49 (43.0)	
Job Status (%)						0.14
Work on-line/from home	38 (40.9)	39 (47.6)	29 (40.8)	86 (50.9)	59 (51.8)	
Lost job due to Covid	11 (11.8)	5 (6.1)	4 (5.6)	7 (4.1)	10 (8.8)	
Lost wages due to Covid	14 (15.1)	10 (12.2)	7 (9.9)	30 (17.8)	19 (16.7)	
Essential Worker	9 (9.7)	9 (11.0)	14 (19.7)	17 (10.1)	6 (5.3)	
Not working, e.g., retired	21 (22.6)	19 (23.2)	17 (23.9)	29 (17.2)	20 (17.5)	
Age (%)						0.003
18-24	11 (11.8)	8 (9.8)	5 (7.0)	16 (9.5)	17 (14.9)	
25-34	24 (25.8)	26 (31.7)	13 (18.3)	57 (33.7)	49 (43.0)	
35-44	8 (8.6)	5 (6.1)	10 (14.1)	19 (11.2)	16 (14.0)	
45-54	16 (17.2)	8 (9.8)	8 (11.3)	22 (13.0)	12 (10.5)	
55 ≥	34 (36.6)	35 (42.7)	35 (49.3)	55 (32.5)	20 (17.5)	
Gender (%)						0.004
Male	26 (28.0)	28 (34.1)	20 (28.2)	49 (29.0)	14 (12.3)	
Female	67 (72.0)	54 (65.9)	51 (71.8)	120 (71.0)	100 (87.7)	
Race (%)						0.004
White	82 (88.2)	75 (91.5)	57 (80.3)	144 (85.2)	83 (72.8)	
Non-white	11 (11.8)	7 (8.5)	14 (19.7)	25 (14.8)	31 (27.2)	
Urbanicity (%)						<0.001
Large city	19 (20.4)	20 (24.4)	27 (38.0)	62 (36.7)	57 (50.0)	
Suburb	37 (39.8)	30 (36.6)	24 (33.8)	71 (42.0)	33 (28.9)	
Small town	22 (23.7)	19 (23.2)	16 (22.5)	26 (15.4)	22 (19.3)	
Rural	15 (16.1)	13 (15.9)	4 (5.6)	10 (5.9)	2 (1.8)	

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Poverty (%)						0.17
Low	16 (17.2)	19 (23.2)	14 (19.7)	30 (17.8)	15 (13.2)	
Low-Medium	39 (41.9)	36 (43.9)	21 (29.6)	68 (40.2)	36 (31.6)	
Medium	26 (28.0)	15 (18.3)	20 (28.2)	49 (29.0)	38 (33.3)	
High	12 (12.9)	12 (14.6)	16 (22.5)	22 (13.0)	25 (21.9)	
Region (%)						0.21
Northeast	46 (49.5)	37 (45.1)	36 (50.7)	67 (39.6)	44 (38.6)	
Southeast	16 (17.2)	11 (13.4)	15 (21.1)	41 (24.3)	23 (20.2)	
Central	6 (6.5)	3 (3.7)	0 (0.0)	10 (5.9)	2 (1.8)	
Southwest	5 (5.4)	7 (8.5)	5 (7.0)	14 (8.3)	7 (6.1)	
West	20 (21.5)	24 (29.3)	15 (21.1)	37 (21.9)	38 (33.3)	
Household (%)						0.23
Live alone	12 (12.9)	11 (13.4)	12 (16.9)	35 (20.7)	28 (24.6)	
Live with spouse/partner	40 (43.0)	40 (48.8)	32 (45.1)	77 (45.6)	39 (34.2)	
Live with children < 18	17 (18.3)	11 (13.4)	7 (9.9)	17 (10.1)	11 (9.6)	
Live with roommate(s)	13 (14.0)	11 (13.4)	12 (16.9)	16 (9.5)	23 (20.2)	
Live with parents/family	11 (11.8)	9 (11.0)	8 (11.3)	24 (14.2)	13 (11.4)	

2.2 Outcome Measures

Our main outcomes of interest were individual feelings of nature deprivation, operationalized across five levels of agreement with the statement, "I feel nature deprived since coronavirus restrictions were imposed," and subsequent flourishing self-assessed through survey items comprising the Harvard Flourishing Index. Because nature exposure has been formally linked to sentiments of positive psychological functioning [26, 49], flourishing is a suitable outcome to measure the impact of nature deprivation under conditions of psychological challenge and adversity. The Harvard Flourishing Index, a lesser-known, validated measurement approach to human flourishing [79], highlights five central domains nearly universally apprised as vital elements of human wellbeing: happiness and life satisfaction, mental and physical health, meaning and purpose, character and virtue, and close social relationships and was selected over alternative subjective wellbeing indices for its optional sixth domain, financial and material stability, deemed highly relevant to COVID-19's implications of wage or job loss on individual wellbeing. Each of the flourishing questions was assessed on a 0-10 scale, with flourishing outcomes calculated on a continuous 0-90 scale.

We substituted resilience for happiness as a Flourishing Index measurement item due to potential temporal confounding as pandemic malaise. Happiness has previously been positively associated with nature exposure [53, 76, 80], though the COVID-19 Response Tracking Study conducted May 21-29, 2020 (n= 2,279 adults nationwide) and the General Social Survey reported the highest percentage of individuals since record-keeping began 1972 (23%) responding at the lowest level of happiness [81]. A third scale item, "My relationships are as satisfying as I would want them to be," similarly was measured in terms of resiliency as "I feel close to others in my community." Cronbach's alpha test of internal consistency was performed on the nine remaining items comprising the Flourishing Index, resulting in an alpha of 0.82, a high indicator of composite scale reliability.

We tested missingness through R statistical analysis but did not impute missing values; neither did we transform any outcome measures. We did not adjust for length of shelter-in-place

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restrictions due response homogeneity: 85.97% of respondents were under restriction for 4 weeks, 6.85% for 3-4 weeks, and 5.87% considered essential workers temporally unaffected by restrictions. A second covariate, mode of transportation, was dropped from analysis due to similar response homogeneity, with under 1% using public transit, a marker initially presumed to associate with accessing nature under COVID-19.

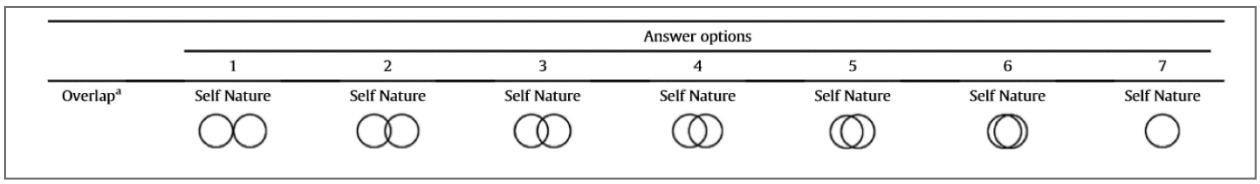
2.3 Exposure

Our exposure of interest was cumulative nature contact experienced by individuals during shelter-in-place restrictions at the time of survey-taking. We analyzed three levels of nature exposure—indoor, neighborhood, and municipal—under conditions of pandemic restrictions. We distinguished in situ, i.e., incidental, nature contact from intentional nature desired for outdoor activities [82]. Survey-takers most commonly cited intentional nature-based activities, e.g., hiking, kayaking, community gardening, as being missed due to pandemic restricted non-accessibility.

The term "outdoors" was explicitly defined for survey-takers as "time intentionally spent in or near nature: backyard, outdoor gardening, urban park, other urban/suburban greenspace, greenway for walking or biking, open woodlands, state or national park/forest/seashore, all forms of outdoor sport or recreation." Indoor nature exposure was represented by four measures: nature seen through window views, seasonal stage of nature experienced, having indoor plants, and having a pet. Neighborhood-level exposure consisted of summative nature contact dictated by local shelter-in-place policies (four categories: complete lockdown; can go outside but don't have no nature contact; can go outside, but preferred nature is inaccessible; no pandemic restrictions: normal outdoor access) and by a second item comparing amount of time spent outdoors in local nature under COVID-19 vis-à-vis pre-pandemic conditions (three categories: less, same, more). Municipal-level nature exposure concerned access to municipally-managed nature areas such as parks, conservation lands, and beaches (four categories: full access with social distancing required; reduced parking to limit park occupancy; non-vehicular foot or bicycle egress only into parks; and complete closure of nature areas to the public).

Frequency of time in nature prior to COVID-19 restrictions provided a baseline measure of nature exposure and was used as a variable to predict nature deprivation. Nature affinity was self-assessed through the single-item measure Inclusion of Nature in Self (INS) [83] addressing degree of connectedness with nature, where option (1) represents no overlap between nature and self, and option (7) represents oneness with nature (Figure 1). Because distribution of INS responses was positively skewed, scores were transformed from a seven-point continuous scale into a three-point categorical indicator by collapsing levels one through three as Low Nature Affinity, levels four and five as Medium Affinity, and levels six and seven as High Nature Affinity. Nature affinity was tested both as an independent variable as well as a modifier of sociodemographic variables to predict flourishing.

Figure 1: Inclusion of Nature in Self Scale (Schultz, 2000) used in survey to indicate self-expressed nature affinity



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We tested for collinearity between nature affinity and nature deprivation to ensure these two variables independently predict flourishing outcome values. A Spearman correlation test of the relationship between nature affinity and feeling nature deprived produced a non-significant -0.002 correlation.

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2.4 Covariates

Individual-level covariates assessed in this survey were age (18-24 = reference, 25-34, 35-44, 45-54, 55-64, 65-74, and ≥ 75), gender (male = reference, female, non-binary), urbanicity (large city = reference, suburbs, small town, and rural area), race (Non-Hispanic White = reference, Native American or Alaska Native, Black or African American, Hispanic or Latinx, Middle Eastern, Native Hawaiian or Pacific Islander, South or East Asian), and zip code in which the survey was taken. Decadal age was analyzed as a five-category covariate after merging the upper three categories—55-64, 65-74, and ≥ 75—into a single upper-tier category of over-55 age based on statistically similar modeling output. Race was analyzed dichotomously (Non-Hispanic white vs Non-white) due to the overrepresentation of white (81.94%) and underpowered seven non-white response categories. Gender was transformed into a dichotomous covariate due to only six (0.99%) responses from individuals identifying as non-binary, later treated as female.

Since we intentionally did not ask about income or education, respondent zip codes were cross-referenced with Zip Code Tabulation Area percent of population living under the poverty data from The Public Health Disparities Geocoding Project [84] to control for socio-economic variation which might relate to neighborhood-level nature exposure. Area-level poverty was categorized as low = reference [0.0-0.05%), low-medium [0.05-0.10%), medium [0.10-0.20%), and high [0.20-1.0] with ≥ 96 entries in each category. We also assessed current employment status (five categories: not working, e.g., retired = reference; working virtually or from home; working in a position deemed "essential;" some loss of wages due to coronavirus; and loss of job due to workplace closure) and household composition (five categories: live alone = reference; live with spouse or partner; live with parents; have children under the age of 18 living at home with me; share living space with roommates) as outcome-related predicters of flourishing since coronavirus measures were imposed.

2.5 Analytical Approach

We used bivariable and multivariable logistic regression analysis in this study to predict associations of levels of nature exposure to individual flourishing under shelter-in-place restrictions. Each nature exposure variable was examined through bivariate correlation to derive statistical significance at the individual test level and to screen as multi-degree of freedom test based on F-statistics and p-values. This determined which variables produced meaningful effect estimates of nature deprivation and flourishing. We conceptualized our model building behind the signal strength of individual exposure variables found to describe our principle outcome and, from those descriptions of bivariable significance and effect, constructed our final multivariable exposure models. Nature exposure factors associating significantly in bivariable modeling of flourishing were retained. Multi-degree of freedom tests showing no statistical significance resulted in the remaining exposure items being eliminated from the full multivariable models of nature deprivation. Bivariable models examining confounding by sociodemographic variables showed only age, race, and urbanicity to relate both to exposure factors and nature deprivation, though we accounted for all six sociodemographic variables, adding gender, area-level poverty, and region in this model. Measures of association are reported as unstandardized betas, 95% confidence intervals and p-values.

Extensive consideration was given to how moderation of our subjective variables by sociodemographic differences may associate with wellbeing under COVID-19 and the potential limitations this may impose on exposure variables. We assessed effect modification by factor levels

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of age, gender, race, urbanicity, area-level poverty, and region on categorical nature affinity and perceived nature deprivation. We also evaluated the statistical strength of interaction terms by using a generalized test score for linear regression models. All statistical analyses were performed in R version 3.6.3.

3. Results

3.1 Main findings: bivariate and multivariate models

Bivariable and multivariable regression of nature exposure consisting of indoor, neighborhood, and municipal level predictors showed consistent and often monotonic associations with individual nature deprivation under the pandemic, when controlling for sociodemographic factors of age, gender, race, urbanicity, area-level poverty, and region as well as baseline nature affinity. Table 2 shows medium and high levels of nature affinity strongly predicted higher perceived nature deprivation. Greater time spent in nature under COVID-19 restrictions vis-à-vis pre-pandemic had the most pronounced effect on reducing feelings of deprivation among all exposure variables (-1.07, 95% CI: (-1.32, -0.81), p = <0.001). Other exposure variables significantly associated with lower perceived nature deprivation were public nature parks and reserves remaining fully open under the pandemic as compared to restricted entry policies, attenuated COVID-19 sheltering policies, pet ownership, older age, and Western U.S residence. Female gender was the only sociodemographic variable to associate positively and significantly with nature deprivation.

Table 2: Linear regression analysis illustrating effect of bivariable predictors and fully-adjusted multivariable model of nature deprivation under COVID-19 shelter-in-place restrictions.

Outcome: Nature Deprivation (5-pt scale)	**Model 1: Bivariable**			**Model 2: Multivariable**		
Variable	beta	95% CI	F-test p	beta	95% CI	F-test p
Nature Affinity						
Low affinity = reference	---	---	0.34	---	---	0.001
Medium affinity	0.27	(-0.12, 0.66)		0.46	(0.11, 0.80)	
High affinity	0.29	(-0.12, 0.69)		0.69	(0.32, 1.06)	
Pre-pandemic time in nature						
Never or >monthly = reference	---	---	0.06	---	---	0.60
1-2x/month	-0.64	(-1.67, 0.39)		-0.38	(-1.25, 0.48)	
1-2x/week	-0.80	(-1.80, 0.21)		-0.53	(-1.41, 0.34)	
3-4x/week	-0.62	(-1.61, 0.38)		-0.49	(-1.37, 0.40)	
Daily	-0.99	(-1.99, 0.01)		-0.61	(-1.50, 0.29)	
Time in nature during pandemic						
Less time vs pre-pandemic = reference	---	---	<0.001	---	---	<0.001
Same time as pre-pandemic	-1.47	(-1.76, -1.19)		-0.98	(-1.28, -0.69)	
More time vs pre-pandemic	-1.51	(-1.74, -1.28)		-1.07	(-1.32, -0.81)	
Municipal restriction on nature areas						
Parks entirely shut to public = reference	---	---	<0.001	---	---	<0.001
Foot/bike access only	-0.38	(-0.80, 0.04)		-0.47	(-0.83, -0.10)	
Parking spaces limited but not closed	-0.39	(-0.77, -0.00)		-0.21	(-0.55, 0.13)	
Full access to nature areas	-1.33	(-1.72, -0.95)		-0.81	(-1.17, -0.45)	

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View from windows						
Buildings, urban view = reference	---	---	<0.001	---	---	0.18
Street trees	-0.39	(-0.93, 0.16)		-0.25	(-0.72, 0.22)	
Lawns, some garden	-0.66	(-1.20, -0.11)		-0.05	(-0.54, 0.44)	
Woodlands	-1.31	(-1.87, -0.74)		-0.34	(-0.87, 0.19)	
Water views	-0.68	(-1.37, -0.01)		-0.03	(-0.64, 0.58)	
Pandemic mobility restrictions						
Complete lockdown = reference	---	---	<0.001	---	---	<0.001
Go outside but no nature contact	-0.39	(-0.97, 0.18)		-0.58	(-1.160, -0.0)	
Go outside, preferred N inaccessible	-0.56	(-1.02, -0.10)		-0.36	(-0.80, 0.07)	
No restriction: normal outdoor access	-1.79	(-2.24, -1.33)		-0.87	(-1.33, -0.41)	
Pets						
Don't have pets = reference	---	---	0.001	---	---	0.01
Have pets	-0.39	(-0.63, -0.15)		-0.27	(-0.46, -0.07)	
Age						
18-24 = reference	---	---	0.003	---	---	0.17
25-34	0.13	(-0.29, 0.55)		-0.12	(-0.46, 0.23)	
35-44	0.17	(-0.34, 0.68)		-0.06	(-0.47, 0.36)	
45-54	-0.26	(-0.75, 0.23)		-0.26	(-0.67, 0.15)	
≥ 55	-0.40	(-0.81, 0.02)		-0.36	(-0.71, -0.01)	
Gender						
Male = reference	---	---	0.01	---	---	<0.001
Female	0.36	(0.09, 0.63)		0.40	(0.18, 0.62)	
Race						
White, Non-hispanic = reference	---	---	0.002	---	---	0.84
Non-white	0.50	(0.18, 0.82)		-0.03	(-0.30, 0.25)	
Urbanicity						
Large city = reference	---	---	<0.001	---	---	0.41
Suburb	-0.49	(-0.74, -0.19)		-0.10	(-0.36, 0.16)	
Small town	-0.57	(-0.90, -0.24)		-0.13	(-0.43, 0.16)	
Rural	-1.30	(-1.75, -0.85)		-0.37	(-0.80, 0.06)	
Poverty						0.93
Low = reference	---	---	0.15	---	---	
Low-Medium	0.03	(-0.31, 0.38)		-0.03	(-0.31, 0.25)	
Medium	0.30	(-0.07, 0.66)		0.02	(-0.29, 0.32)	
High	0.32	(-0.09, 0.73)		-0.08	(-0.44, 0.28)	
Region						
Northeast = reference	---	---	0.24	---	---	0.07
Southeast	0.30	(0.02, 0.63)		0.10	(-0.18, 0.37)	
Central	-0.16	(-0.79, 0.47)		-0.37	(-0.89, 0.14)	
Southwest	0.18	(-0.31, 0.66)		-0.02	(-0.41, 0.38)	
West	0.25	(-0.05, 0.55)		-0.30	(-0.57, -0.04)	

p-value significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1; ± 95% CI = 95% Confidence Interval

Model 2: Nature exposures and nature affinity predicting self-assessed nature deprivation, adjusted for age (in deciles), gender, race, urbanicity, area-level poverty and region.

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Table 3 assesses the relationship between nature deprivation and flourishing. Feeling nature deprived produced strong effect signals at high levels of significance in both bivariable and multivariable models. The item assessing perceived nature deprivation effectively asked survey-takers if their nature contact under quarantine met their needs. Survey-takers who strongly agreed with the statement, "I feel nature deprived under coronavirus restrictions," experienced a significant flourishing decline of 4.04 units (95% CI: (-7.33, -0.74), p = 0.02) relative to those who strongly disagreed with feeling nature deprived under a multivariable model. Individuals who agreed with feeling deprived lost 2.72 flourishing units at a marginal level of significance (95% CI: -5.68, 0.24, p = 0.07). Those who neither agreed nor disagreed with feeling nature deprived still experienced a non-significant loss of flourishing compared to those not feeling deprived of nature. Bivariable modeling of strongly feeling nature deprived similarly predicted high flourishing losses (-5.52, 95% CI: (-8.80, -2.25), p = <0.001), an effect exceeding all factors except job loss due to the pandemic (-7.54, 95% CI: (-11.62, -3.45), p = <0.001).

Table 3: Linear regression analysis of bivariable model and multivariable model of individual flourishing adjusted for age and urbanicity under COVID-19 shelter-in-place restrictions.

Outcome: Flourishing (90-point scale)	**Model 1: Bivariable**			**Model 2: Multivariable**		
Variable	beta	95% CI	F-test p	beta	95% CI	F-test p
Nature Affinity						
Low affinity = reference	---	---	0.03	---	---	0.06
Med affinity	0.33	(-2.99, 3.66)		-0.03	(-3.21, 3.15)	
High affinity	3.17	(-0.28, 6.62)		2.49	(-0.88, 5.87)	
Nature Deprivation						
Strongly disagree feel nature deprived	---	---	<0.001	---	---	0.03
Disagree that feel nature deprived	1.01	(-2.54, 4.57)		0.47	(-2.91, 3.86)	
Neither agree nor disagree	0.42	(-3.28, 4.12)		-0.49	(-4.09, 3.11)	
Agree that feel nature deprived	-3.24	(-6.27, -0.21)		-2.72	(-5.68, 0.24)	
Strongly agree feel nature deprived	-5.52	(-8.80, -2.25)		-4.04	(-7.33, -0.74)	
Job Status						
Work on-line/from home = reference	---	---		---	---	
Lost job due to COVID	-7.54	(-11.62, -3.45)	<0.001	-6.75	(-10.78, -2.72)	0.002
Lost wages due to COVID	-2.03	(-5.00, 0.95)		-3.42	(-6.36, -0.49)	
Essential worker	-0.51	(-3.96, 2.94)		-1.90	(-5.68, 1.61)	
Not working (retired, etc)	4.90	(2.21, 7.58)		1.10	(-1.90, 3.92)	
Household						
Live alone = reference	---	---	<0.001	---	---	0.005
Live with spouse/partner	6.20	(3.36, 9.03)		5.23	(2.52, 7.95)	
Live with children < 18	3.62	(-0.09, 7.35)		5.24	(1.22, 9.26)	
Live with roommate(s)	1.47	(-2.13, 5.06)		4.30	(0.60, 8.01)	
Live with parents/family	2.11	(-1.65, 5.86)		4.17	(0.19, 8.15)	
Age						
18-24 = reference	---	---	<0.001	---	---	<0.001
25-34	1.39	(-2.11, 4.88)		0.39	(-3.26, 4.04)	
35-44	1.38	(-2.88, 5.63)		0.55	(-4.24, 5.35)	
45-54	3.05	(-1.08, 7.17)		1.98	(-2.63, 6.58)	
≥ 55	9.19	(5.72, 12.66)		6.76	(2.63, 10.88)	
Gender						
Male = reference	---	---	0.67	---	---	0.94
Female	-0.52	(-2.89, 1.85)		-0.08	(-2.34, 2.18)	

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Race						
White, Non-hispanic = reference	---	---	0.75	---	---	0.19
Non-white	-0.45	(-3.24, 2.34)		1.79	(-0.92, 4.50)	
Urbanicity						
Large city = reference	---	---	0.13	---	---	0.61
Suburb	1.47	(-0.97, 3.82)		-1.10	(-3.66, 1.47)	
Small town	2.79	(-0.12, 5.70)		0.44	(-2.47, 3.36)	
Rural	3.86	(-0.13, 7.86)		0.81	(-3.24, 4.85)	
Poverty						
Low = reference	---	---	0.01	---	---	0.17
Low_Medium	2.43	(-0.53, 5.39)		2.45	(-0.92, 5.33)	
Medium	-0.04	(-3.09, 3.17)		1.26	(-1.95, 4.48)	
High	-2.49	(-6.01, 1.04)		-0.59	(-4.32, 3.14)	
Region						
Northeast = reference	---	---	0.25	---	---	0.52
Southeast	-0.31	(-2.49, 3.11)		1.12	(-1.59, 3.82)	
Central	-4.99	(-10.43, 0.44)		-3.45	(-8.65, 1.75)	
Southwest	-0.85	(-5.02, 3.33)		-1.21	(-5.10, 2.86)	
West	-1.90	(-4.49, 0.69)		-0.14	(-2.74, 2.47)	

p-value significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1; ± 95% CI = 95% Confidence Interval

Model 2: Nature affinity, self-assessed nature deprivation, job status and household composition during COVID, pre-pandemic frequency in nature predicting flourishing, adjusted for age (in deciles) gender, race, urbanicity, area-level poverty and region.

3.2 Main findings: interaction models

Our modification models showed affinity interacted positively with the 35-54 age range categories but negatively with the youngest (18-24) and oldest (over 55) categories in predicting flourishing. Nature deprivation modified race, with white non-Hispanic individuals experiencing negative effects on flourishing outcomes and non-white individuals showing positive effects on flourishing. Net interaction effects in Table 4 measures how affinity varies among individuals of a given age category, such that medium affinity among individuals age 25-34 = -2.78 (medium affinity) + 4.85 (interaction effect) = 2.07. No other potential modifier proved statistically significant in our models.

Table 4: Interaction of nature affinity, nature deprivation with sociodemographic variables to predict flourishing

Interaction	Net effect^	p-value	95% CI
Affinity			
Age 18-24 = reference			
Medium affinity: Age 18-24	-2.78	0.47	(-10.27, 4.71)
High affinity: Age 18-24	-10.40	0.01	(-18.53, -2.28)
Age 25-34			
Medium affinity: Age 25-34	2.07	0.30	(-3.03, 7.17)
High affinity: Age 25-34	3.80	0.004	(-1.69, 9.28)
Age 35-44			
Medium affinity: Age 35-44	7.61	0.09	(-1.59, 16.81)
High affinity: Age 35-44	10.62	0.001	(0.72, 20.50)
Age 45-54			

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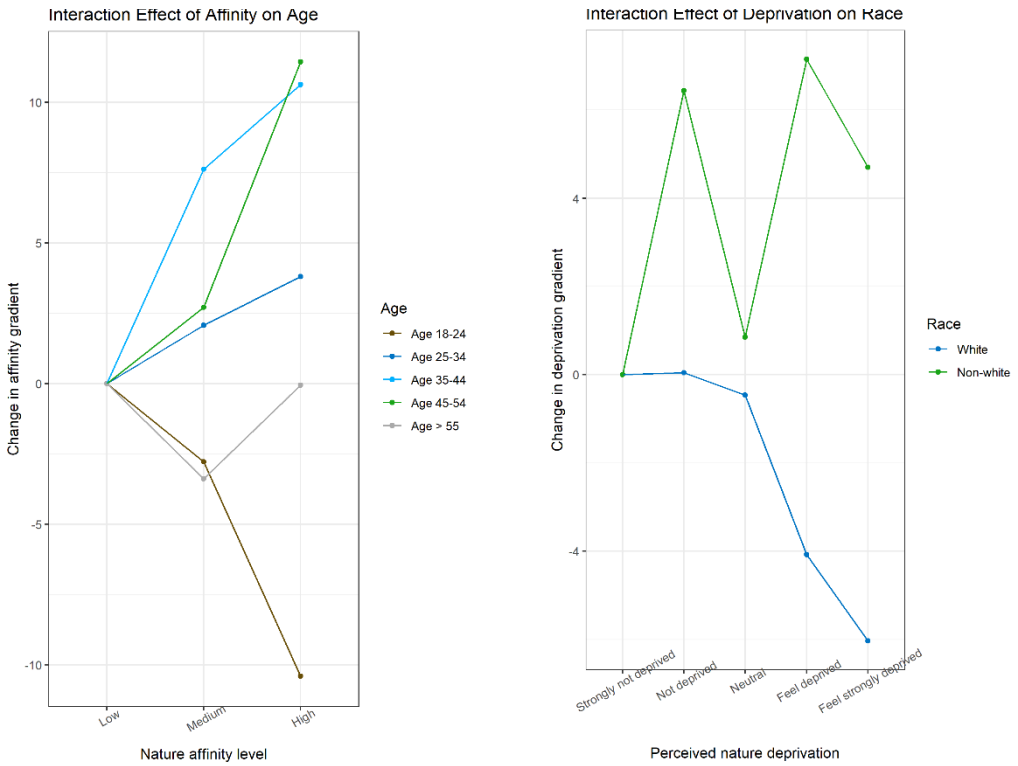
Medium affinity: Age 45-54	2.71	0.40	(-8.01, 13.43)
High affinity: Age 45-54	11.43	0.001	(0.58, 22.23)
Age 55 >			
Medium affinity: Age 55 >	-3.39	0.90	(-9.70, 2.94)
High affinity: Age 55 >	-0.06	0.05	(-6.42, 6.13)
Deprivation			
White Race = reference			
Don't feel nature deprived: White	0.05	0.98	(-3.58, 3.47)
Neutral: White	-0.46	0.82	(-4.33, 3.42)
Feel nature deprived: White	-4.08	0.01	(-7.24, -0.93)
Feel strongly nature deprived: White	-6.03	<0.001	(-9.60, -2.46)
Non-White Race			
Don't feel nature deprived: Non-white	6.44	0.26	(-4.84, 17.63)
Neutral: Non-white	0.85	0.79	(-8.35, 10.96)
Feel nature deprived: Non-white	7.15	0.01	(2.63, 19.83)
Feel strongly nature deprived: Non-white	4.70	0.01	(2.25, 19.21)

p-value significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1; ± 95% CI = 95% Confidence Interval

^Footnote: net effect measures the role of affinity among individuals in the indicated age category

Figure 2a and 2b: Interaction models of nature affinity and age (2a) and perceived nature deprivation and race (2b).



4. Discussion

Our main findings support both our hypotheses that 1) changes to nature exposure identified at the indoor, neighborhood, and municipal levels related to self-expressed nature deprivation under the COVID-19 pandemic, with those who spent the same or more time in nature during shelter-in-place feeling significantly less deprived after accounting for sociodemographic variables and severity of

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pandemic restrictions on personal mobility and public nature access; and 2) individuals who felt nature deprived during shelter-in-place restrictions experienced reduced flourishing at high statistical significance, controlling for job and household factors. These results are analyzed within strata of nature exposure and independently of background declines of flourishing during COVID-19 found in national online sampling [85].

4.1.1 Summary of results

Our survey data shows a slight overall decline but a large redistribution in the amount of time individuals spent outdoors under COVID-19, not unexpected given business closures and state and municipal limits on non-essential activity. 151 (23.3%) individuals spent much less time outdoors, 122 (18.8%) less time, 132 (20.4%) the same time, 147 (22.7%) more time, and 96 (14.8%) much more time. Declines in flourishing corresponded monotonically to individual feelings of nature deprivation since shelter-in-place began. We note that while some individuals experienced greater nature contact due to virtual or at-home work transition, job loss, or shuttered alternative activities, others were unable to access desired nature venues for context-specific outdoor activities. While we do not know how frequently those spending the same amount of time in nature went outdoors, individuals who reported feeling nature deprived or strongly nature deprived since sheltering began experienced a statistically significant drop in flourishing of 4.6% and 6.8%, respectively, as compared to those who strongly disagreed with feeling nature deprived. In comparison, pandemic-related wage loss and job loss were associated with a 5.5% and a 11.4% respective flourishing decline.

4.1.2 Neighborhood level nature contact

We found that neighborhood-level nature contact drove cumulative exposure under the pandemic, adding to previous evidence highlighting the relevance of neighborhood greenspace in health outcomes. COVID-19 shelter-at-home policies restricting personal mobility, destination availability, and openness of public spaces preclude or constrict choice of nature contact for many people, leaving incidental contact with indoor and neighborhood nature the de facto exposure. Intentional nature-seeking lapses to circumstantial contact with neighborhood-level tree-cover or greenspace availability under sheltering conditions. Interventions to re-introduce nature into urban areas should thus prioritize the greening of neighborhoods in ways that recognize highly localized, incidental contact with nature.

4.1.3 Subjective factors relating nature contact under pandemic circumstances

While objective variables summarily captured cumulative nature exposure measures, subjective nature affinity and perceptual aspects of nature contact affected by COVID-19 also impacted feeling nature deprived. The item "How have coronavirus restrictions where you currently live affected your interaction with nature?" revealed that individuals who went outside but found their preferred nature inaccessible felt sixty percent more deprived of nature (-0.36, 95% CI: (-0.80, 0.07), p=0.10) than those unaffected by lockdown. Likewise, feelings of nature deprivation rose commensurate with extent of restrictions imposed by local governments and nonprofit land trusts on natural areas considered high quality. "Given restrictions on personal mobility within your city or state, can you freely access nature areas such as parks, conservation

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land, beaches, etc?" Perceived deprivation declined 3.2-fold among individuals where municipal nature sites remained completely open to the public as compared to parks having limits or bans on vehicle access (-1.79, 95% CI: (-2.24, -1.33), p=<0.001). Stronger nature deprivation connected to closure or restricted park access in our study inversely mirrored greater levels of restoration experienced by participants in a previous study after visiting sites of higher environmental quality as compared with urban spaces [86]. Higher quality sites in that study were operationalized by protected/designated area status such as nature reserves, rural and coastal locations, the same as those affected by pandemic restrictions or closures here.

4.1.4 Effect modification by socio-demographics

Having expected nature affinity to be an informative qualitative indicator of feelings of nature deprivation, our tests for effect modification of sociodemographic variables on flourishing by the subjective variables of nature affinity and nature deprivation proved insignificant but for two exceptions. Interaction between nature affinity was observed only for age, with strongest effects and significance among individuals ages 25 through 45. Our significant finding that affinity and flourishing vary with age contrasts with no effect moderation between nature connectedness and age previously found but upheld negative findings for gender [53]. Nature deprivation interacted negatively with white race yet positively with non-white race in determining flourishing outcomes. While other outcome related variations may have differentially contributed to flourishing among white vs non-white individuals, we believe the qualitative interaction that switches directions by race in part owes to our grouping of non-white races into a single binary category to achieve statistical power.

4.2 Policy Implications

Research on restricted access to nature during a period of high global distress is unique and timely. Our survey data captured across regional, socio-demographic, and density spectra call attention to individual reliance on nature for wellbeing and the detriments of restricting nature contact when its need is most acute. Science demonstrates that nature exposure stimulates salutogenic response pathways counteractive to negative emotional impulses. This study adds to previous evidence that pre-existing patterns of nature-seeking influence behaviors which reduce feeling nature deprived and contribute to increased flourishing under shelter-in-place. Understanding if nature exposure serves as a positive coping mechanism to buffer negative affect may inform long-term preparedness for population-level, environmentally triggered health emergencies well beyond disease. These include heat- and climate-related confinement and indoor retreat from hazardous air pollution incidents. Shelter-in-place is already common in Chinese and Indian cities during high PM2.5 occurrences [87, 88]. These recurring episodes forecast the need for preventative wellbeing measures when indoor lockdown is required.

Public health policy recommendations pertinent to these research findings are four-fold: 1) decentralized and more equitable distributed urban greenspace, 2) demand management at public nature-based venues, 3) public health advisories on green exercise as an essential activity under specific sheltering conditions, and 4) investment in urban infrastructure to facilitate outdoor physical activity.

First, our study results show that shelter-in-place shifts the locus of urban nature contact from large parks to the neighborhood level. Theis shift results from closing or restricting large

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nature-based destinations, fear of taking public transit to reach distant greenspace, and displacement of recreational greenspace to accommodate large-scale COVID-19 testing sites like New York's Central Park or San Francisco's Golden Gate Park. The signal importance of neighborhood-level nature exposure which emerges reaffirms that urban landscapes must contain smaller, decentralized greenspaces accessible by walking.

Second, closure of public nature spaces diminishes wellbeing already eroded by indoor confinement, social isolation, and fear of disease transmission. Demand management and distributed access to public nature areas is preferable to total shuttering of nature spaces prone to transmit disease through overcrowding. Alphabetical assignment to certain days of the week or odd-even license plate park entry are already used by municipalities to regulate public access. Assisted reservation-based systems such as that used by the US National Forest and Park Services successfully manage public demand for nature and wilderness.

Third, public health guidance issued under San Francisco's shelter-in-place order explicitly lists engagement in "outdoor activity, such as walking, hiking, or running, provided maintenance of social distancing" as an exempted essential activity under COVID-19 [89]. Cities can promote green exercise as a safe, preventative health behavior given appropriate precautions.

Fourth, government investment in neighborhood pedestrian green infrastructure can help to address on-going health risks associated with physical inactivity and social isolation further exacerbated by shelter-in-place. Our results show that higher frequency of outdoor nature-seeking established prior to COVID-19 greatly helped preserve flourishing once pandemic restrictions were introduced. Subpopulations currently unable to engage in safe outdoor activity due to shortage of proximate urban infrastructure thus enter shelter-in-place conditions already disadvantaged in terms of beneficial green exercise pattern-forming.

4.3 Study Strengths and limitations

4.3.1 Strengths

This study provides preliminary evidence of how nature exposure influences feelings of nature deprivation that reduces wellbeing among individuals confronting the physical and emotional isolation of health restrictions. It reaffirms the potential for mitigating adverse emotional health outcomes through prudent access to outdoor nature. Taking advantage of the widespread behavioral changes brought on by the COVID-19 pandemic for study design purposes reduced or removed many confounders implicit in measuring cumulative nature exposure, e.g., socialization to mediate nature exposure benefits [49]. Our survey data collection from April 22 to mid-May 2020 measured wellbeing one-month into the pandemic but before large-scale urban protests around racial injustice broke out, with its potential confounding among respondents in large cities. Finally, our collection of individual-level exposure data in this study, e.g., windows views, differences in seasonality and landscape, and work patterns may inform further epidemiological study for assessing the accuracy of Normalized Difference Vegetation Index (NDVI) as an ecological-level proxy for nature exposure.

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4.3.2 Potential for reverse causality

The cross-sectional design of this study precludes us from drawing any conclusions other than associative. The severity of background circumstances for many individuals under the COVID-19 pandemic admittedly implies that our analysis of survey data may be subject to other unmeasured confounders not assessed here and which might surface in a survey repeated over a period of time. Implicit in any nature exposure research is the question of bidirectionality: do people choose to live in greener areas due to high nature affinity, or does vicinity of greenspace cultivate engagement? The potential for reverse causality therefore exists, particularly among individuals disinclined or unable to frequent outdoor nature for purposes of health or emotional restoration. The lack of temporal measures other than time spent in nature pre-pandemic as well as under restrictions cannot refute that potential. Moreover, nature deprivation is just one of many means by which individuals may feel dispossessed under the COVID-19 pandemic; social, financial, and emotional deprivation also accompany sheltering.

4.3.3 Limitations

We acknowledge several limitations in this study which prevent us from drawing stronger conclusions or from generalizing to sub-populations underrepresented in the study base we analyzed.

Self-selection into the original focus group study may have attracted individuals inclined to report stronger nature-seeking attitudes and behaviors as compared to a general population, thus over-representing perceived nature deprivation under COVID-19. Because our original study recruitment targeted four large metropolitan areas with higher population density and distance to large-scale outdoor nature, the impact of restricted municipal nature access may appear more acute within this study population than for the U.S. population as a whole. More fundamental limits to result generalizability stem from a predominantly white (82%) and female (75%) study base. Despite targeted efforts to diversify our original study enrollment to include more male and non-white respondents, the snowball nature of survey link forwarding may have compounded the original imbalance of study population demographics.

Under-representation of some racial and ethnic groups gave us insufficient statistical power to stratify further on race despite eight options posed in our survey. Race was further confounded by unsettling social stigmatization associating Asian-identifying individuals related to COVID-19's geographic origins in China. While we controlled for race and urbanicity at the individual level, we modeled SES at the zip code level. It is likely that there is some residual confounding by race and income, as black and Hispanic individuals of lower SES may have suffered stronger COVID-19-related losses of job or income while residing in nature-deficient urban neighborhoods. Analysis of an income variable matched to respondent zip code and de facto urban vegetation levels extracted from high-resolution NDVI data could reduce the confounding potential by SES in associating nature exposure and wellbeing.

5. Conclusion

Substantial evidence exists for enhanced human health outcomes in the presence of nature. This survey study has shown that under widespread emergency policies of shelter-in-place, feelings of nature deprivation link strongly to individual wellbeing outcomes. Higher levels of cumulative

nature exposure demonstrated lower nature deprivation scores as well as the reverse effect, that withdrawal of nature exposure and opportunities to pursue activity in nature compromise individual emotional health and wellbeing. Nature exposure was shown to offset reductions in nature exposure under quarantine for purposes of preventing human disease transmission. Lower nature deprivation resulted in higher flourishing. Policies that allow for the continuation and even increases in local nature contact should be part of public health strategies favoring shelter-in-place as precautionary under pandemics. Nature contact offers a means to proactively confront the emotional and physical health consequences corollary to social isolation and physical inactivity that COVID-19 has exposed.

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