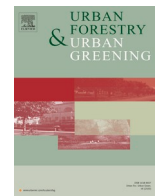




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Original article

## Perceived naturalness and wellbeing: Differential benefits for marginalized and privileged groups



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## A B S T R A C T

This quasi-experimental study investigated whether increased perceived naturalness of walking environments lead to immediate psychological wellbeing improvements, guided by a theory suggesting greater proportional benefits for marginalized groups (Mitchell & Popham, 2008). We focused on differential benefits for individuals of low socioeconomic status (SES) and people of color (POC). A sample of 475 undergraduates at a Midwestern U.S. university completed two self-directed 45-minute walks (self-rated on a 7-point scale of naturalness). Psychological wellbeing was measured pre- and post-walk using the Warwick-Edinburgh Mental Well-Being Scale (WEMWBS). Bayesian counterfactual simulations were used to estimate post-walk wellbeing across the naturalness levels with moderation by SES (Pell Grant recipient, low social class, first-generation students) and race/ethnicity.

Walks perceived as highly natural (levels 6 or 7) were associated with meaningfully higher post-walk wellbeing compared to more built walks (levels 1–5). Evidence of moderation by sociodemographic variables was mixed. At low perceived naturalness (levels 1–3), Pell Grant recipients (indicating low SES and eligibility for federal funding to attend college or university) had meaningfully lower post-walk wellbeing compared to non-recipients. This gap narrowed as perceived walk naturalness increased and became non-meaningful at level 4, consistent with an equigenic pattern. No meaningful moderation was observed for the other measures of SES. For race/ethnicity, results were not consistent with equigenesis as, at the highest level of perceived naturalness, gains potentially widened disparities, with non-POC deriving meaningfully greater wellbeing benefits than POC.

The findings indicate that higher perceived naturalness is associated with higher psychological wellbeing. While more natural spaces demonstrate potential to reduce certain SES disparities, the mixed results underscore that benefits are not universally equitable. This suggests that while naturalness should be prioritized, practitioners should consider inclusion, safety, and cultural relevance to promote gains across marginalized groups.

## 1. Introduction

The worsening mental health crisis in North America (Schafer et al., 2022; Terlizzi and Zablotzky, 2024; Wright et al., 2025) disproportionately affects marginalized community members who face structural

barriers such as limited access to healthcare, stigma surrounding mental illness, and socioeconomic disadvantage (Costa et al., 2014). These barriers intersect with urbanization and loss of natural space (i.e., unmaintained and maintained natural areas). Unequal access to natural space means that populations who might benefit most from its

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psychological and cognitive benefits often cannot realize these gains. Thus, communities already structurally marginalized in relation to healthcare and socioeconomic disadvantage may also experience unequal access to natural space, further exacerbating disparities in psychological health and wellbeing (Allison and Hibbler, 2004; Bratman et al., 2019; Finney, 2014; Keniger et al., 2013; Millennium Ecosystem Assessment, 2005; Pyle and Lefèvre, 2016; Rigolon, 2016; Rigolon et al., 2018; Schafer et al., 2022; Shanahan et al., 2015).

Evidence indicates that exposure to natural space can improve mood (Barton et al., 2011; Bratman et al., 2015a; Neill et al. 2019), enhance cognitive function (Berman et al., 2008; Bratman et al., 2015b), and reduce stress (Hunter et al., 2019; Yao et al., 2021). Recent findings, examining what is labelled the “equigenic effect,” have shown that benefits may be particularly pronounced for individuals experiencing higher baseline stress or disadvantage, potentially narrowing health inequities between low- and high-resourced populations (Mitchell and Popham, 2008; Ruijsbroek et al., 2017). However, evidence remains limited and mixed, particularly regarding the role of race and ethnicity, and most studies have not examined individual-level experiences or perceptions of natural space; rather relying on broader population data and objective measures of access such as spatial vegetation and satellite image-based approaches (e.g., NDVI), which do not account for actual use and have other limitations (Dzhambov et al., 2020; Jarvis et al., 2020; Rigolon et al., 2021; Tomasso et al., 2021).

In examination of broader questions of natural space’s benefits for all, prior research using interventions have primarily used walking methodology, often using a dichotomized approach that compares “natural” versus “built” routes. This binary framing may limit understanding of whether wellbeing benefits scale gradually across a spectrum of naturalness or emerge only at certain levels, patterns that might better reflect practical applicability and experience of real-world, urban environments (Berman et al., 2008; Brancato et al., 2022; Bratman et al., 2015b). Secondly, while socioeconomic status (SES) has been more frequently examined as a moderator of natural space’s effects, the role of race and ethnicity remains underexplored, despite evidence that people of color (POC) often report limited access, safety concerns, and social stigmas (Frumkin et al., 2017; Marselle et al., 2021; Rigolon et al., 2021; Wang et al., 2022). Advancing understanding of race and ethnicity as moderators, alongside further examination of SES in direct use studies (e.g., walking interventions), and variation in perceived naturalness, is critical for designing interventions that are culturally responsive, appropriately targeted, and effective. Without this specificity, well-intentioned interventions might overlook structural inequities or misalign with community needs and best practices, potentially perpetuating the very disparities planners and policymakers aim to mitigate (LoTempio et al., 2023; Sax et al., 2022).

The current study seeks to address these concerns. First, we examine how the gradients of perceived naturalness relate to wellbeing, moving beyond binary comparisons of that may obscure the nuanced ways environmental qualities influence lived experiences and outcomes (Cox et al., 2017; Labib et al., 2020; Helbich, 2019). This approach connects back to Attention Restoration Theory, which emphasizes that restoration or recovery from natural space is influenced by individuals’ subjective appraisal of various qualities or elements of the space (Kaplan and Kaplan, 1989; Ulrich, 1983). Second, we analyze differential benefits across sociodemographic groups, providing a basis for testing the equigenesis hypothesis (i.e., whether benefits are disproportionately greater for marginalized populations) (Mitchell and Popham, 2008). This allows us to examine whether wellbeing benefits are distributed equitably, across naturalness levels and group identities.

To explore these considerations, we collected primary data in an aim to address two research questions: (1) Are psychological wellbeing benefits associated with different levels of perceived naturalness in a walk-based study? and (2) Do race/ethnicity and/or SES moderate the psychological wellbeing benefits across a gradient of perceived naturalness in a walk-based study?

## 2. Methods

### 2.1. Study design

To answer these questions, the study employed a quasi-experimental design with two hypotheses:

- H1: Higher levels of perceived naturalness on walks is associated with higher self-ratings of psychological wellbeing.
- H2: The association between perceived naturalness of a walk and psychological wellbeing is stronger for marginalized community members than those of more advantaged groups.

Fig. 1 illustrates the hypothesized relationship between exposure to natural spaces (ranging from “very built” (1) to “very natural” (7)) and post-walk psychological wellbeing levels (Hypothesis 1). The diagram, adapted from Hartig et al. (2014), further considers effect modifiers (blue box), which captures the potentially moderating role of structural, sociocultural, and contextual factors.

In our study, we examined SES and race/ethnicity in moderation analyses to determine the change in level of wellbeing for groups of differing race/ethnicity and SES (Hypothesis 2). Three measures are used as proxies of low SES: Pell Grant receipt (i.e., obtaining a U.S. federal student grant limited to undergraduate students with the most exceptional financial need), first-generation student status (i.e., first in their immediate family to pursue post-secondary education), and those self-identifying as belonging to low or working social classes of origin.

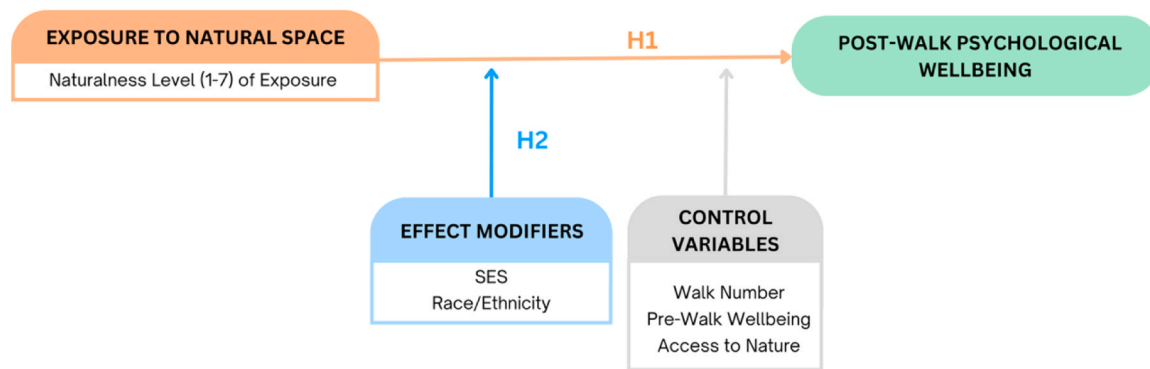
In our moderation analyses, we controlled for variables (gray box) such as baseline wellbeing scores, walk number, and access to nature. Access to nature was included in the model, as it may be associated with wellbeing by shaping perceptions of natural space and affecting factors involved in walk route selection (Korpela et al., 2014).

To assess hypotheses, we used a quasi-experimental design in which participants were instructed to complete a 45-minute self-directed walk twice. The walk duration aligns with recommendations by Meredith et al. (2020), who reported that walks in natural spaces lasting between 31 and 50 min are optimal for psychological benefits. Participants initially completed a screening survey to collect demographic and baseline information. Within one week of this screening, they undertook Walk 1, which included surveys completed at the start (pre-walk survey) and end of the walk (post-walk survey) hosted by Qualtrics. Participants then scheduled their second walk to take place between 2 and 10 days after Walk 1, following the same route. This interval protocol was designed for ease and flexibility for the participants; however, each walk was treated as an independent observation within our counterfactual analysis framework as later discussed. The pre- and post-test process was repeated for Walk 2.

Participants were instructed to walk alone, without pets, and refrain from phone use. Adherence to these instructions was monitored with survey questions on protocol compliance and any deviations.

### 2.2. Participants

Undergraduate students (n = 475) from a university in the Midwestern United States were recruited via email using a randomized list of domestic students (i.e., U.S. permanent residents) from the university’s registrar. Participants were recruited during both summer 2020 and autumn 2020 recruitment periods through email invitations, which were distributed approximately once per week or every other week over the course of one month. Instructions indicated that participants would take two chosen walks in their neighborhood or local area; however, participants could choose to walk outside of their immediate local area if they preferred. Due to the COVID-19 lockdowns in 2020, students were unable to live on campus; most returned to their hometowns or other permanent residences. This presented a unique study situation, with unstandardized walking routes. The quasi-experimental design helped



**Fig. 1.** Visual Representation of the Hypotheses. Note: Post-walk psychological wellbeing is modelled conditional on the baseline of the pre-walk psychological wellbeing score.

ensure a more applied, real-world approach while still allowing us to test the fundamental hypothesis. Participation of students representing marginalized backgrounds was more heavily incentivized (1 in 250 chance vs. 1 in 2500 chance in the advantaged group to win \$20–30 gift cards).

For purposes of analyses here, we included participants who completed at least one set of pre- and post-walk surveys, ensuring pre-walk scores served as reliable baselines for wellbeing change. Partial responses were excluded to reduce bias associated with lower study engagement.

Institutional Review Board approval was received for each iteration of the study from the first university's review board (Protocols: 2020E0035, 2020E0207, 2020E0608, 2020E0660, 2020E0974), and approval from the second university's board was received as well (BREB Protocol: H23–01900).

### 2.3. Measures

Participants completed walks in environments of varying perceived naturalness. Psychological wellbeing was measured using the Warwick-Edinburgh Mental Well-Being Scale (WEMWBS; Stewart-Brown and Janmohamed, 2008). After each walk, participants rated the naturalness of the setting. Key sociodemographic moderators included race, ethnicity, and SES (e.g., Pell Grant status, first-generation status, and self-reported social class). Control variables (e.g., access to nature, walk number, and pre-walk wellbeing; Appendix Table 1) were measured to account for other influences on wellbeing.

**Psychological Wellbeing.** The 14-item WEMWBS scale was used to measure psychological wellbeing, adapted to be in the present tense. WEMWBS includes subjective wellbeing and psychological qualities of wellbeing, with items relating to hedonic and eudaimonic domains. A final WEMWBS score out of 70 was calculated using a summation of each of the 14 items' 1–5 score. WEMWBS was selected as a psychometrically robust alternative to the Ryff Psychological Wellbeing Scale (Ryff and Keyes, 1995), which, when piloted in this population, demonstrated weak internal consistency for two of the six domains. Both stress and spirituality failed to hold under factor analysis, perhaps due to inconsistency in interpretation by students. As an alternative, we selected the life satisfaction and meaning-based WEMWBS scale and assessed its reliability and instrument biases by reviewing existing scholarly validation studies. Tennant et al. (2007) found high test-retest reliability with an intra-class correlation coefficient of 0.83, indicating that the scale's performance remained stable over a one-week period. This suggests short-term retesting, as in our quasi-experiment, is unlikely to introduce significant measurement bias.

**Perceived Walk Naturalness.** Participants were asked to report the level of naturalness of their walk on a 7-point scale ranging from "Very Built" to "Very Natural," where built refers to an area with noticeable

human activity or influence. Perceived naturalness, rather than objective measures, was emphasized to capture the participant's lived experience of their walk environment, consistent with prior studies demonstrating the importance of perception in moderating wellbeing benefits derived (Beil and Hanes, 2013; Cox et al., 2017; Herzog, 1989; Kaplan, 1985).

**Race and Ethnicity.** Race and ethnicity were measured using a multiselect question to accommodate mixed-race individuals. Participants were asked whether they identified as Hispanic, Latino, or of Spanish origin, an ethnicity question specific to the U.S. Census. Then, racial identity was assessed with answers "White", "Black or African American", "Native American or Alaska Native", "Asian", "Native Hawaiian or Pacific Islander", and "Some other Race". Participants who selected any race besides or in addition to "White" were determined to be POC (Table 1). In our analysis, POC was encoded as a binary variable, with only participants exclusively identifying as "White" (i.e., non-POC) serving as the reference category. This approach allowed for broad examination between racially advantaged non-POC individuals and marginalized POC in the Midwestern setting of our study, through a comparison group framework (Krieger, 2012; Krieger et al., 1999) that aligns with current nature-health equity research (Rigolon et al., 2021; Wang et al., 2024).

**Socioeconomic Status.** Socioeconomic status was assessed using multiple indicators including first-generation college status, Pell Grant receipt, and social class. Pell grants are non-repayable stipends that the U.S. federal government only awards to undergraduate students who display exceptional financial need with maximum awards up to \$7395 in the 2025–2026 academic year (U.S. Department of Education, 2025). Eligibility and award size vary depending on family income, assets, and enrollment status, meaning students from various self-identified social class backgrounds may still qualify for partial Pell support. Pell Grant status captures formal financial aid eligibility, while our self-reported class measure reflected self-perceived economic origin as either lower, working, middle, upper-middle, and upper classes. Due to imbalances in our respondents from each class, particularly the higher number of respondents identifying as middle class, we aggregated categories for analysis as a three-level ordinal scale: lower and working class grouped into a "lower class" category, middle class remained unchanged, and upper-middle and upper class were grouped as "higher class" category.

**Access to Nature.** Access to nature where one lives (e.g., physical access, distance, opening hours, etc.) was self-reported by participants on a 4-point scale from 1, "great difficulty with access" to 4 "very easy access." This measure reflects perceived accessibility rather than objective distance metrics, due to accessibility needs and past literature positioning perceptions of access as shaping behavior and wellbeing outcomes (Rigolon, 2016).

**Table 1**  
Demographics and descriptive statistics of the intervention study sample (N = 475).

Characteristic	N = 475
<b>Outcome Variable, Mean ± SD</b>	
Post-Walk Wellbeing	50.67 ± 10.22
<b>Natural Space Exposure Variable, median (IQR)</b>	
Perceived Walk Naturalness Rating	3 (3)
<b>Walk-Specific Variables</b>	
Pre-Walk Wellbeing, mean ± SD	44.25 ± 10.29
Access to Nature, median (IQR)	3 (2)
<b>Race and Ethnicity, n (%)*</b>	
People of Color (POC)	182 (38.4)
Hispanic, Latinx, Spanish Origin	40 (8.5)
White	338 (71.3)
Black or African American	49 (10.3)
Asian	96 (20.3)
Native American, Alaska Native, Native Hawai'ian, Pacific Islander	7 (1.5)
Other	17 (3.6)
<b>First-Generation Student, n (%)</b>	105 (22.1)
Is Both First Generation and POC, n (%)	76 (16.0)
<b>Pell Grant Recipient</b>	119 (25.1)
Has Both Pell Grant and is First Generation, n (%)	49 (10.3)
Has Both Pell Grant and is POC, n (%)	74 (15.6)
<b>Socioeconomic Class of Origin, n (%)</b>	
Lower Class	117 (24.6)
Middle Class	201 (42.3)
Higher Class	157 (33.1)
Both Lower Class and POC	84 (17.7)
Both Middle Class and POC	138 (29.1)
Both Higher Class and POC	78 (16.4)
<b>Age, median (IQR)</b>	21 (3)
<b>Years in State, median (IQR)</b>	20 (9)
<b>Gender, n (%)</b>	
Women	346 (72.8)
Men	121 (25.5)
Other	8 (1.7)
<b>Urbanity of Community of Origin, n (%)</b>	
Urban	47 (9.9)
Suburban	308 (64.8)
Small Town/Village	60 (12.6)
Rural (Non-Agricultural)	23 (4.8)
Rural (Farming/Agricultural)	37 (7.8)

\* Sums to greater than 100, multiple options allowed

## 2.4. Analysis methods

We analyzed 781 walks from 475 unique participants over two collection periods (summer and autumn 2020). Each participant was invited to complete two walks, but not all completed both. To maximize the use of available data and preserve statistical power, we treated each walk as an independent observation, allowing us to include participants who completed only one walk, without compromising data quality or introducing bias from missing responses. Preliminary analyses indicated that walk order (e.g., first vs. second walk) did not significantly affect wellbeing outcomes. Additionally, baseline wellbeing was comparable between participants one completed one or both walks. Together, these tests support the validity of treating each walk independently.

### 2.4.1. Bayesian approach

To analyze our participants' walk effects on psychological wellbeing and moderation effects of sociodemographic variables, we used two approaches. First, we fit a Bayesian ordinal regression model. This model provided the estimated parameter values, through the posterior distribution, that were used to calculate the estimated counterfactual predictions. As a result, understanding the regression model structure is essential for interpreting the simulated outcomes and their relevance. We then generated counterfactual predictions of mean post-walk wellbeing outcomes across the full range of perceived walk naturalness levels from very built (1) to very natural (7), simulating scenarios as if each participant experienced every walk condition. The Bayesian ordinal regression model was not used to test primary study hypotheses

directly, as the counterfactuals could offer more interpretable and policy-relevant insight (Höfler, 2005; Morgan and Winship, 2014; Weisberg and Gopnik, 2013). Instead, the Bayesian ordinal regression served as the framework for the counterfactual simulations, which estimated the potential causal effect of perceived walk naturalness by holding all participant characteristics constant and varying only the level of environmental naturalness, modeling what would happen if the same individuals experienced walks of differing perceived naturalness levels.

### 2.4.2. Bayesian ordinal regression model foundations

The Bayesian ordinal regression model, shown below, included key predictors and interaction terms (Appendix Table 1). A random effect variable (1|id) was included to capture both between-subject differences in baseline wellbeing and within-subject correlation across repeated walks. By including the random effect we retain statistical power, reduce the risk of inflating Type 1 error, and improve post-walk wellbeing estimates (McElreath, 2020). We used the mo() function from the "brms" package R to model the ordinal walk-specific and sociodemographic variables as monotonic effects, allowing us to account for ordered levels that may be unequally spaced but are assumed to follow a consistently increasing or decreasing trend.

**2.4.2.1. Full Model (only.post) Model Formula.** Post-Walk WEMWBS =  $\beta_0 + \beta_1$  Perceived Walk Naturalness +  $\beta_2$  Walk-Specific Variables +  $\beta_3$  Sociodemographic Variables +  $\beta_4$  (Perceived Walk Naturalness x Sociodemographic Variables) + (1|id)

Rather than estimating a single "best fit" point estimate for each model parameter, the Bayesian framework treats the parameters as distributions, capturing the range of plausible values for each variable, given both prior information and the data itself (McElreath, 2020). This flexibility is particularly important for our data due to the added complexity from the interactions between self-rated walk naturalness levels and marginalized identities. To support estimation and prevent overfitting, particularly in a model with multiple predictors and interaction terms, we included prior distributions of the parameters. These priors help regularize the estimates by constraining the range of plausible values for each of the parameter distributions. Specifically, we specified a weakly regularizing prior, which helped to prevent overfitting without strongly influencing the results (McElreath, 2020).

### 2.4.3. Counterfactual analyses

Using the Bayesian counterfactual framework for each of seven perceived walk naturalness conditions, we predicted the most likely wellbeing score for each of the participants as if they were going on a walk in that condition. These counterfactual simulations directly integrated posterior uncertainty, aligning with real-world variability, by extracting the most probable post-walk wellbeing score from the posterior predictive samples (Gelman et al., 2013). This approach offered key advantages over a more frequentist-based approach by avoiding rigid assumptions and instead regularizing parameter estimates to balance flexibility and overfitting (Lemoine, 2019). Ultimately, by incorporating uncertainty and modeling potential outcome beyond the observed data, this approach allowed to estimate potential causal effects, providing unique insights on the perceived naturalness of a walk potentially shaping wellbeing outcomes.

#### Hypothesis 1

For each level of walk naturalness, we found the mean and standard error of the participants' simulated WEMWBS scores. We compared across all the levels of perceived naturalness from very built (1) to very natural (7) to determine if each of these different walk environments produced meaningful wellbeing changes. If the margin of error (MOE) of the mean of one of the perceived walk naturalness levels overlapped with the MOE of another, the difference in wellbeing score between the two would not be meaningful. These simulations provided estimates of

wellbeing scores changing under different perceived walk naturalness conditions, accounting for uncertainty and random effects, and answering hypothesis one of whether perceived walk naturalness affects self-reported wellbeing.

Hypothesis 2

We analyzed the impact of the different walk conditions (1–7) by comparing the mean predictions between groups of students. As with Hypothesis 1, we compared predicted wellbeing at each of the perceived naturalness levels, stratified by sociodemographic group (POC, class, first-generation student, Pell Grant recipient). We examined if the MOE of one group overlapped the MOE of the other at each of the rated naturalness levels to assess whether between-group differences were likely meaningful. Additionally, we compared differences across perceived naturalness (e.g. very built (1) and very natural (7)) to evaluate whether any meaningful between-group differences emerged or diminished.

2.4.4. R functions and details

We conducted our analyses using R 4.4.2 and built our models using the brms package, which facilitates Bayesian regression modeling via Stan. Model fit and performance checks were conducted using the posterior and performance packages as well as a custom function bayes\_R2\_mz to compare mean Bayesian R<sup>2</sup> values. We incorporated prior sensitivity checks using the prior sense package. Data wrangling and visualizations were handled with tidyverse and ggplot2 respectively.

3. Results

3.1. Descriptive statistics

Ninety-five of the 5000 students contacted during summer 2020 participated in at least one walk (57 of these participants completed both walks). In the autumn 2020 period, 380 of a new pool of 20,000 students contacted participated in at least one walk (249 of these participants completed both walks). After applying a series of exclusion criteria, the analytical sample consisted of a total of 475 participants, 306 of those completing both walks. Specifically, observations were removed for participants who (a) did not complete both pre- and post-surveys associated with a single walk, (b) deviated from the first walk route they chose, or (c) exhibited potentially biased responses identified through multiple sensitivity analyses of situational distractions (e.g., mobile phone use, environmental noise, unanticipated social interactions) as well as inattention (i.e., failing to respond appropriately to an embedded negative item within the WEMWBS series). Therefore, the final dataset included 781 walk observations, comprising two sets of pre- and post-walk surveys from 306 participants, and one set of pre- and post-walk surveys from the remaining 169 participants (out of the total 475).

Participants were a median age of 21 years old, with a median of 20 years spent in the same state as the university (Table 1). They were

mostly white (71.3%), women (72.8%), from suburban areas (64.8%), and middle or upper-middle class (73.5%). Most participants selected walks that were built-leaning, with a median of 3 out of 7 in perceived walk naturalness scoring of all walks and “Moderately Built” as the most commonly selected category. Reported access to natural space had a median rating of 3, corresponding to the “easy access” category, which was selected by 36.8% of participants. Both pre- and post-walk wellbeing follow a relatively normal distribution.

Although, our primary analyses use the counterfactual simulations—estimations of each participant’s wellbeing under every walk condition—we examined the observed distribution of walk naturalness ratings across sociodemographic groups (Table 2) to provide context about participation patterns. As shown, the distributions of perceived walk naturalness were broadly similar across race and ethnicity, Pell grant status, first-generation status, and social class, indicating that no group was strongly over- or under-represented at any level of perceived walk naturalness. These observed distributions provide descriptive context for understanding participation patterns; and, the main analyses are simulations that do not depend on the observed walk participation.

3.2. H1 findings: wellbeing scores and perceived walk naturalness

Based on our Bayesian counterfactuals simulations, we found that the mean post-walk wellbeing score was a 51.0 (MOE: 50.6, 51.3) for a walk with a perceived naturalness level of 1 (most built) and a 52.9 (MOE: 52.6, 53.2) for a walk with a perceived naturalness level of 7 (most natural) (Fig. 2). Because the margin of errors for these results do not overlap, we can conclude that this is a meaningful difference in post-walk wellbeing scores. In fact, walks with a perceived naturalness of 6 (moderately natural) or 7 (very natural) were associated with statistically higher post-walk wellbeing compared to walks of perceived naturalness levels of 1 (very built) through 5 (slightly natural) (Fig. 2).

To assess whether the relationship was gradual or reflected a threshold pattern, we examined the simulated mean wellbeing scores across adjacent levels of perceived naturalness. Wellbeing scores gradually increased across levels 1 through 5, with a comparatively larger increase (approximately 1.21 points) between levels 5 and 6, and then again a gradual change to level 7. This pattern loosely suggests that the wellbeing benefits associated with natural space may reflect a threshold effect at higher levels of perceived naturalness, rather than a strictly graded increase across all levels.

These results provided statistically meaningful support for H1, as very natural and moderately natural walks were associated with greater post-walk wellbeing than walks that were very built to slightly natural.

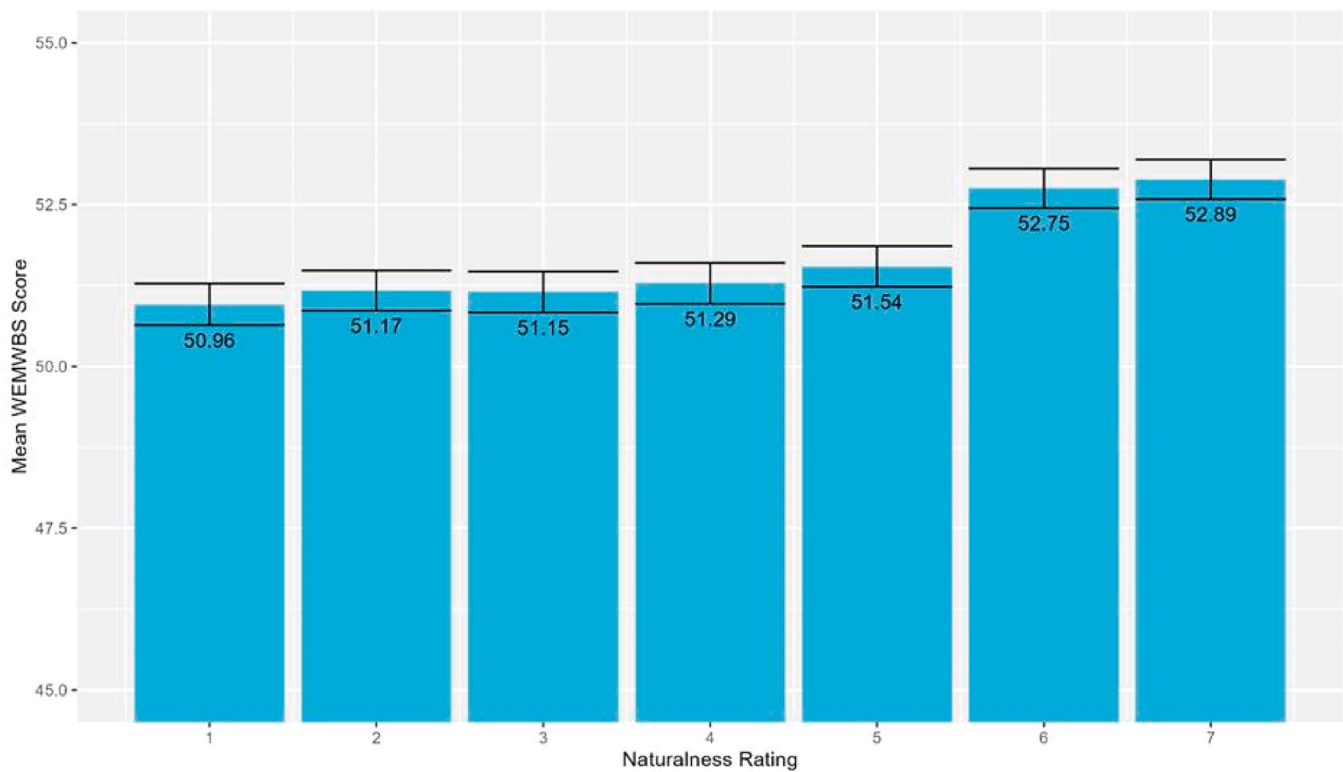
3.3. H2 findings: interactions between perceived walk naturalness and sociodemographic variables

Using our Bayesian counterfactuals, we isolated marginalized groups to analyze differences in perceived walk naturalness’ associations with psychological wellbeing across marginalized participants.

Table 2

Distribution of walk naturalness ratings by sociodemographic group. Values represent the percentage of participants in each naturalness category.

Variable	Group	Very Built (%)	Moderately Built (%)	Slightly Built (%)	Equal (%)	Slightly Natural (%)	Moderately Natural (%)	Very Natural (%)
POC status	Non-POC	9.1	28.5	18.7	15.2	8.3	16.2	4
	POC	9.0	24.7	15.3	20	10	15	6
Pell Grant	Non-Recipient	9.7	27.1	16.9	15.6	9.2	16.9	4.5
	Recipient	7.1	26.6	19	21.7	8.2	12	5.4
First-Generation	Non-First-Gen	10.0	29.5	17.7	15.1	8.2	14.9	4.7
	First-Gen	5.9	18.2	16.5	24.1	11.8	18.8	4.7
Class	Lower	7.1	20.2	23.5	18.6	13.1	11.5	6
	Middle	9.3	23.7	14.4	18.6	6.9	21.3	5.7
	Higher	10.2	35.8	17	14	8.7	11.7	2.6



**Fig. 2.** Mean Bayesian Counterfactual Post-Walk Scores by Perceived Walk Naturalness. Mean post-walk wellbeing measured on a scale from 14 to 70. Perceived walk naturalness on a scale from 1 to 7.

### 3.3.1. People of color

When examining POC participant scores, we found that with walks of a naturalness rating of 1 (most built), the mean WEMWBS score for participants of color is 51.2 (MOE: 50.7, 51.7), which is not meaningfully different from non-POC participants, whose mean WEMWBS score is a 50.8 (MOE: 50.4, 51.2) (Fig. 3). At the other extreme, POC participants had a mean WEMWBS score of 52.2 (MOE: 51.7, 52.7) at a walk naturalness rating of 7, which was only visually meaningful compared to non-POC participants at this level's threshold, with non-POC participants having a mean WEMWBS score of 53.3 (MOE: 53.0, 53.7) (Fig. 3). This was the only level at which scores meaningfully differed between POC and non-POC, suggesting that non-POC derived meaningfully greater wellbeing benefits than POC from very natural walks (level 7). This pattern suggests that the relationship between perceived naturalness and wellbeing for POC may not be equalizing, meaning that naturalness exposure, rather than reducing wellbeing disparities, might widen them.

### 3.3.2. Class

Examining the effect of social class (measured using three categories), we found that participants in the lower class had mean post-walk WEMWBS scores of 50.1 (MOE: 49.5, 50.7) and 52.0 (MOE: 51.4, 52.6) at a perceived walk naturalness of 1 and 7, respectively (Fig. 4). Those who self-reported as middle class had mean post-walk WEMWBS scores of 51.7 (MOE: 51.1, 52.2) and 53.7 (MOE: 53.2, 54.2) at a perceived walk naturalness of 1 and 7 respectively (Fig. 4). Finally, those who self-reported as higher class had mean WEMWBS scores of 50.6 (MOE: 50.1, 51.2) and 52.5 (MOE: 52.0, 53.0) at walk naturalness ratings of 1 and 7 respectively (Fig. 4).

No meaningful difference in post-walk wellbeing emerged for those of lower classes compared to those of higher classes for any level of perceived naturalness, suggesting no evidence of an equigenic effect for lower class participants.

However, differences between middle and higher class participants

varied by naturalness level. At lower levels (1–2), the contrasts were not meaningfully different (Fig. 4). From moderate (3–5) to higher (6–7) levels of perceived naturalness, differences became meaningful, with middle class participants showing higher post-walk wellbeing than higher class participants. Across all groups, post-walk wellbeing increased with larger increments observed at higher levels of perceived naturalness, consistent with the overall pattern of association between naturalness and wellbeing. The overall pattern indicates that differences between middle and higher class participants are primarily evident at moderate to higher levels of perceived naturalness, and further investigation is needed to understand the underlying factors.

### 3.3.3. Pell grant recipients

In our Bayesian counterfactual models, those of who received a Pell Grant, a measure of low-SES, showed a meaningful increase in post-walk wellbeing scores as perceived walk naturalness increased. For the most built walk, Pell Grant recipients had a meaningful lower mean post-walk wellbeing score, 49.9 (MOE: 49.3, 50.5), than non-recipients, who scored a mean of 51.3 (MOE: 50.9, 51.7) (Fig. 5). This result displays a meaningful wellbeing gap at the most built end of the naturalness rating scale (perceived walk naturalness level 1), Pell Grant recipients derived less wellbeing benefits from the walk compared to those not receiving a Pell Grant. This gap persisted through perceived naturalness levels 2 and 3, however, as the perceived naturalness increased, it narrowed (Fig. 5). By walk naturalness ratings of 4 (i.e., equally built and natural), the difference between post-walk wellbeing became statistically non-meaningful and remained at higher levels. At the most natural walk level, Pell Grant recipients scored a mean post-walk wellbeing of 53.0 (MOE: 52.4, 53.6) and non-recipients scored a mean post-walk wellbeing of 52.8 (MOE: 52.5, 53.2), a non-meaningful difference (Fig. 5). In partial support of H2, the convergence of post-walk wellbeing scores with increasing perceived naturalness for this SES group is in an equigenic manner, suggesting that walking in places perceived as more natural can reduce wellbeing gaps for those who receive a Pell Grant.

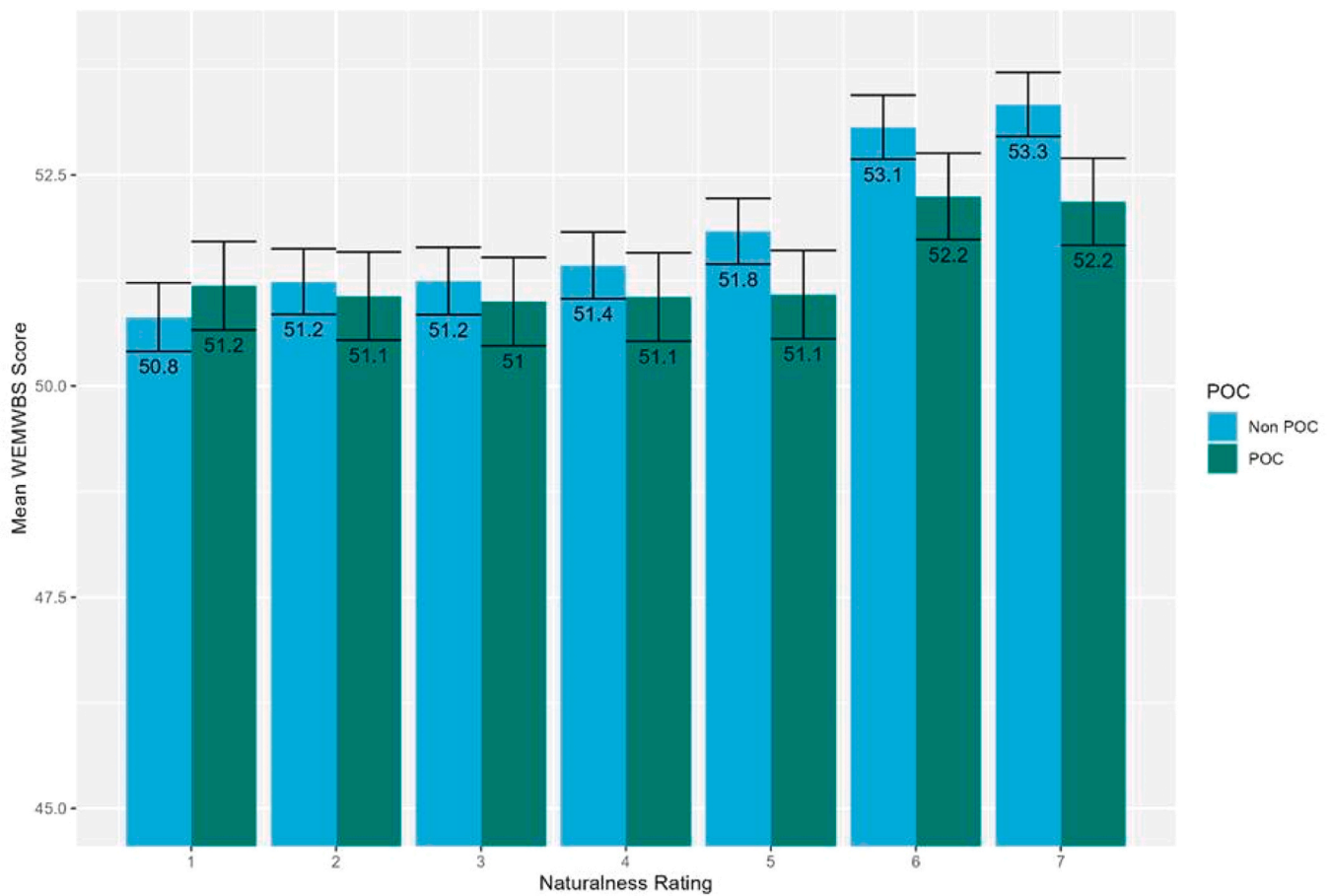


Fig. 3. Mean Bayesian Counterfactual Post-Walk Scores for POC and Non-POC.

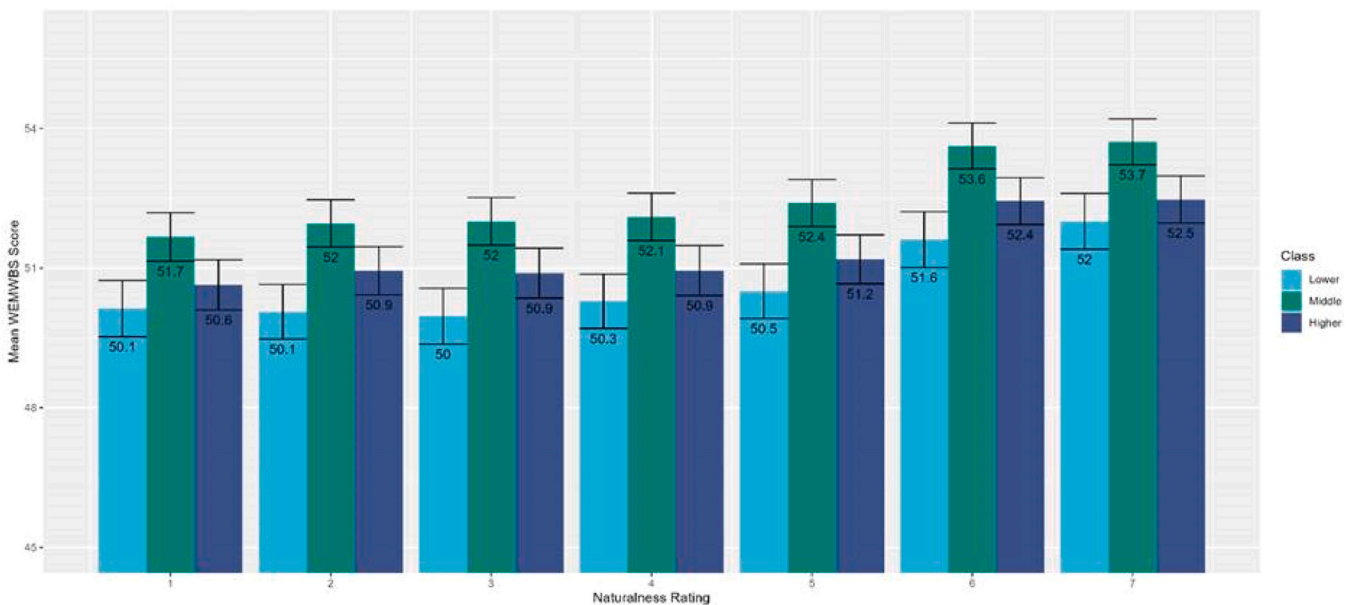


Fig. 4. Mean Bayesian Counterfactual Scores for Class.

### 3.3.4. First-generation students

We also studied first-generation students who, similarly to POC and those self-reporting as lower classes, meaningfully benefitted from walks perceived as the most natural. However, these benefits were not sufficient to narrow the gaps in wellbeing levels of advantaged and

marginalized peers. At a perceived walk naturalness level of 1, first-generation students had a mean post-walk WEMWBS score of 50.9 (MOE: 50.2, 51.5) and advantaged students had a mean of 51.0 (MOE: 50.6, 51.4) (Fig. 6). At a walk naturalness level of 7, first-generation students scored a mean post-walk wellbeing of 52.3 (MOE: 51.7, 53.0)

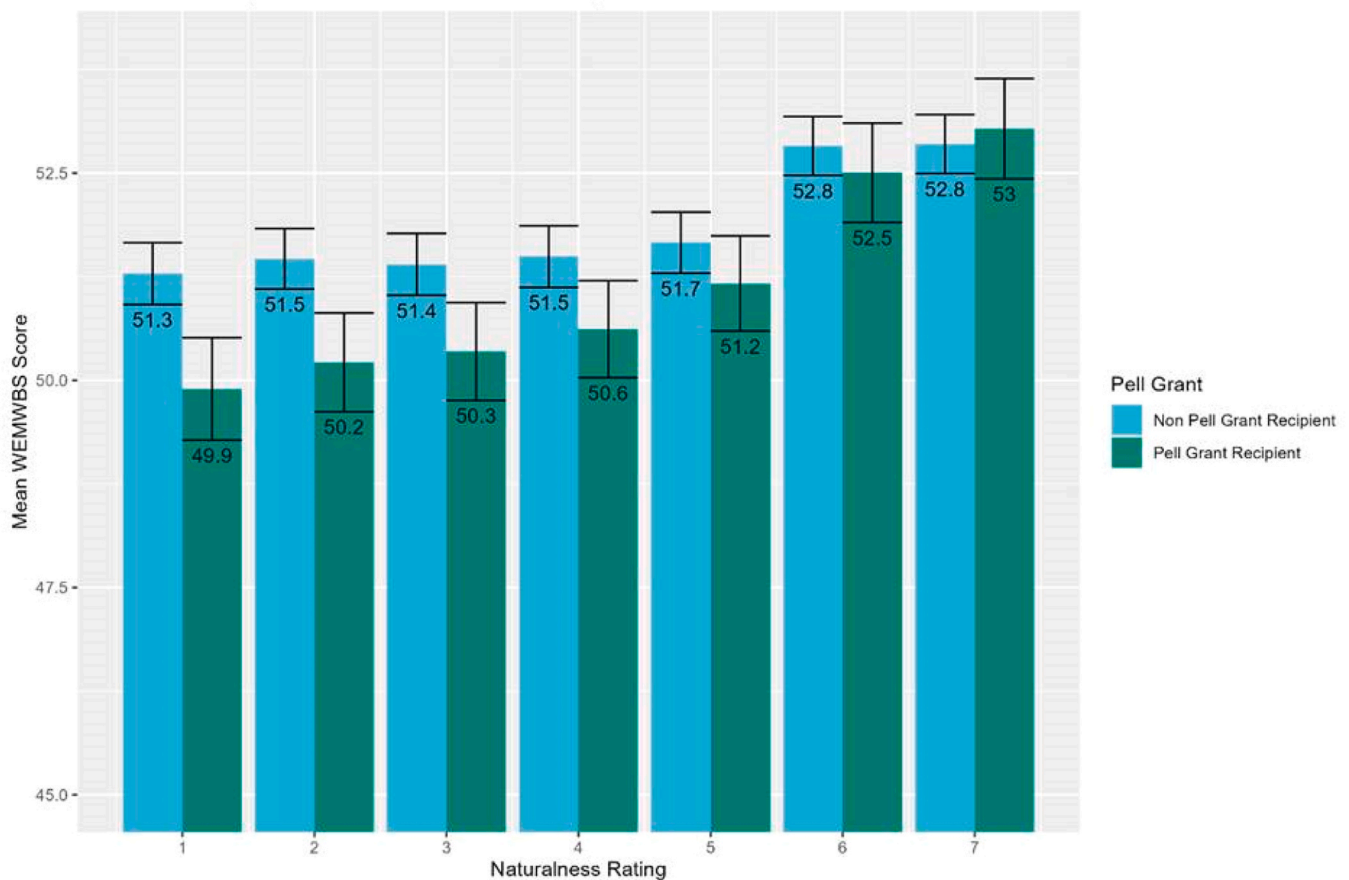


Fig. 5. Mean Bayesian Counterfactual Scores for Pell and Non-Pell Grant Recipients.

and advantaged students scored a mean post-walk wellbeing of 53.0 (MOE: 51.7, 53.4) (Fig. 6). The MOE overlapped for first-generation and non-first generation students at each level of perceived naturalness, indicating a non-meaningful difference in post-walk wellbeing. These results suggest that while more natural walks may have a possible threshold effect in terms of benefits on wellbeing for first-generation students, the effect does not appear equigenic, leaving H2 unsupported.

#### 4. Discussion

This quasi-experimental study examined if the perceived naturalness of walks was associated with psychological wellbeing, and whether these effects differ across race/ethnicity and SES indicators. Using Bayesian counterfactual simulations, we estimated whether walks perceived as more natural would be associated with greater psychological wellbeing, and if these effects would be higher among marginalized groups, examining the equigenic hypothesis (Mitchell and Popham, 2008). Because our analytic approach estimates each participant's wellbeing under all levels of perceived naturalness, the observed differences are best interpreted as reflecting heterogeneity in response to naturalness, rather than differences driven by the distribution of observed exposures.

Our models indicated that walks perceived as more natural were associated with greater post-walk wellbeing than more built walks, supporting our first hypothesis. Importantly, this effect was consistent even after accounting for pre-walk wellbeing and other covariates, suggesting that the perceived naturalness of the walk itself contributes to these benefits. However, the average wellbeing scores increased overall, from 44.3 pre-walk to 50.7 post-walk, indicating that walking in any setting, regardless of perceived naturalness, was associated with meaningful improvements. This general improvement aligns with

broader evidence that physical activity and being in natural space can enhance wellbeing (White et al., 2019), potentially via mood regulation, psychophysiological benefits, and cognitive pathways (Bratman et al., 2019; Bardhan et al., 2023; Kuo et al., 2015). These findings also align with a broad body of literature linking exposure to nature with improved mental health outcomes (Bratman et al., 2019; Bardhan et al., 2023; Kuo, 2015) and certain factors within our WEMWBS measure around stress reduction ideas and attention restoration, such as feeling relaxed and ready to tackle problems (Kaplan, and Kaplan, 1989; Ulrich, 1983).

Our findings regarding Pell Grant recipients provided partial support for Mitchell & Popham's equigenic effect (our second hypothesis). Greater reported naturalness was associated with higher wellbeing among Pell Grant recipients, who started at lower levels of wellbeing than their peers in built environments but reached comparable levels in spaces perceived as most natural. Our results align with prior work suggesting that exposure to natural spaces may buffer against the mental health impacts of social and economic disadvantage (Markevych et al., 2017; Shanahan et al., 2016). Students from low-income backgrounds typically experience higher levels of financial strain, academic pressure, and social stressors in higher education (Moore et al., 2021), which might make particularly responsive to the restorative effects, aligning with past work (Mitchell and Popham, 2008; Mitchell et al., 2015; Pearce et al., 2018; Ulrich, 1983; Wang et al., 2022; Wells and Evans, 2003). Our insights support the idea that even small increases in naturalness in low-income areas can promote health equity, particularly where access to restorative spaces is limited (Byrne and Wolch, 2009; Boone et al., 2009; Park and Pellow, 2011; Rigolon et al., 2019).

Another notable finding emerged with middle class participants appearing to derive greater wellbeing benefits from more natural spaces than those from lower and higher classes. While this pattern is not equigenic, as those from middle class are not necessarily structurally

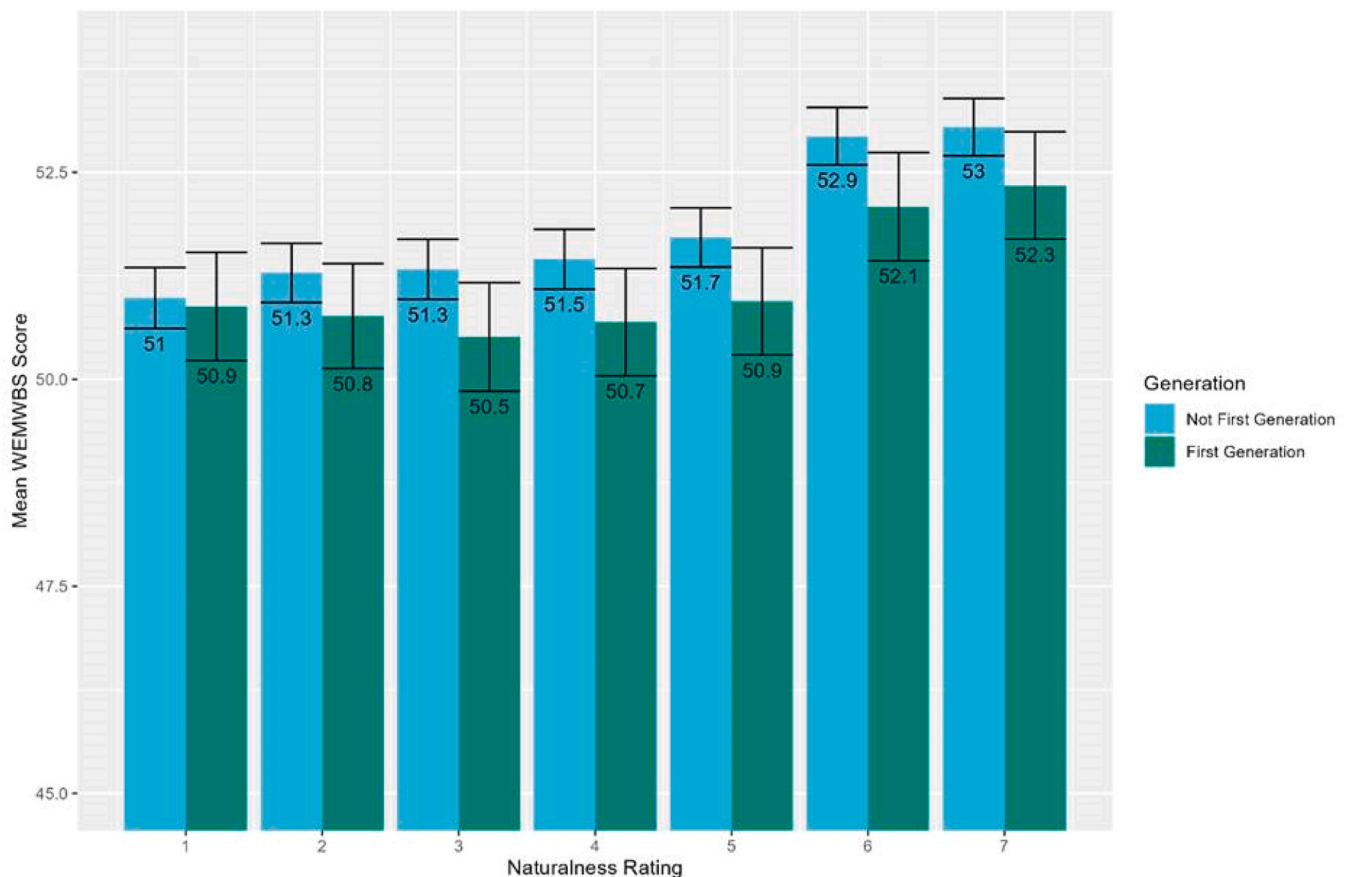


Fig. 6. Mean Bayesian Counterfactual Scores for First Generation Students.

disadvantaged (Koo, 2016) or limited in access to natural space, it does suggest that perceived social positioning may shape how individuals respond to natural space. One explanation that might account for this could be with the mismatch of subjective and objective indicators of SES. Among the 119 Pell Grant recipients in our sample, 26 identified as lower class, 43 as working class, 44 as middle class, and 6 as upper middle class, with none identifying as upper class. Since the Pell Grant is provided at a scaled amount based on financial need, those of middle and higher classes seem to be benefitting as well; therefore, this is a discrepancy indicating that the objective, need-based indicator of low-SES (Pell Grant receipt) and subjective self-reported social class did not fully align.

The higher level of benefits observed among middle class participants may reflect the inclusion of structurally disadvantaged Pell Grant recipients within this category. These individuals may still perceive themselves as middle class due to education level, occupation, or cultural identity, a pattern well-documented in subjective social status literature (Kraus et al., 2011). The apparent middle class advantage may be capturing the wellbeing gains of disadvantaged individuals situated within that group, rather than reflecting a uniform middle class effect, consistent with theories of stress recovery and differential susceptibility or resource substitution theories (Belsky, 2013; Ulrich, 1983). Further research, particularly on access to natural space and urbanity in relation to the middle class and outcomes, is warranted to evaluate the moderation of these effects.

The nuanced equigenic patterns we observed—where some marginalized individuals did not experience the expected benefits—provided novel evidence at the individual level that naturalness may help reduce wellbeing disparities. While not all measures showed the effect, our results demonstrated the value of objective indicators like Pell Grant receipt for economic hardship. Overall, blanket policy or planning

solutions may inadvertently perpetuate disparities unless paired with efforts to address structural and perceptual barriers (Rigolon and Németh, 2018; Triguero-Mas et al., 2017a).

#### 4.1. Limitations

There are several limitations to the present study design. First, the quasi-experimental design involved participant self-selection of walking conditions rather than random assignment, which may introduce selection bias and unmeasured confounding (Pearl, 2009). Conducted in uncontrolled, real-world settings, external factors such as noise, social interactions, or personal notifications could have influenced wellbeing outcomes. To mitigate these effects, sensitivity analyses were performed considering attention, weather, and disturbances. Weather was not significantly related to outcomes in preliminary sensitive analyses and left out of final models. Additionally, participants who self-reported distractions (we did not have an objective measure of these distractions) or failed attention checks were excluded from analyses to ensure data quality. However, unmeasured confounders (e.g., day of the week, time of the day, tree canopy, noise, construction) may still exist, limiting causal inferences.

Using a randomized controlled trial could address some of these limitations by better isolating causal effects and controlling for confounding variables, though the ecological validity of our study might decrease (Dzhambov et al., 2020; Triguero-Mas et al., 2017b). Future studies may consider exploring other potential moderators in this manner. While we simulated our outcomes, implementing them experimentally would yield additional evidence (Höfler, 2005). Though, it has been noted that Bayesian methods are especially helpful in situations like ours with studies shaped by limitations of pandemics as in the COVID-19 era, or other phenomenon that cause imperfect conditions, as

well as for studies involving quasi-experimental designs more generally (Höfler, 2005; Weisberg and Gopnik, 2013).

Second, the use of self-reported measures, particularly of perceived naturalness levels of the walk, WEMWBS, and social class, also raises concerns about measurement accuracy and potential response bias. Participants may have unintentionally misinterpreted questions or responded in ways they perceived as socially desirable, leading to inaccurate assessments of the wellbeing benefits they derived from the walk and the actual walk experience (Dzhambov et al., 2020). Moreover, the current study did not include a control variable to account for individual differences in perception of naturalness, so this measurement was based solely on participants' subjective ratings (Cerv et al., 2023). Previous research has shown that individual perception of naturalness influences benefits that are gleaned like improvements in attention or cortisol (Beil and Hanes, 2013; Cox et al., 2017; Herzog, 1989; Kaplan, 1985). Differences in perceived naturalness could reflect underlying contextual inequities, such as disparities in access to natural spaces, experience or knowledge, or stigmas and traumas (Dietsch et al., 2021; Korpela et al., 2014). Future research might integrate physiological or behavioral indicators of wellbeing such as EEG or skin conductance to help objectively measure wellbeing outcomes, as well as a possible control variable or visual benchmark to guide "naturalness" ratings, all of which may reduce the presence of bias in the results (McDonnell and Strayer, 2024).

A third limitation concerns the measurement of sociodemographic variables. The study relied on proxy indicators of SES (e.g., social class, Pell Grant receipt, first-generation status) and collapsed race and ethnicity into a binary POC variable. These proxies may not fully capture the multidimensional nature of SES, nor its intersections with race and other variables, which include income, neighborhood disadvantage, and intergenerational factors (Braveman et al., 2005), potentially obscuring subgroup differences in post-walk wellbeing. Similarly, aggregating POC groups may mask distinct structural barriers, experiences, and cultural connections to nature across racial and ethnic groups.

Finally, regarding generalizability, the sample consisted of undergraduate students from a Midwestern U.S. university, and is relatively homogeneous in age, SES, race, ethnicity, hometown rurality, and education. Thus, our sample likely does not fully capture the diverse experiences, stressors, and structural barriers faced by broader populations, particularly marginalized groups (Twohig-Bennett and Jones, 2018). Generalizability could be improved by recruiting beyond university settings, using probability or community-based sampling with stratified oversamples of under-represented groups, and including multiple sampling locations spanning diverse contexts.

## Appendix

**Table 1**  
Operationalization and Measurement of Variables for Bayesian Counterfactual Models

Variables	Definitions	Types of Measures and Range
<u>Outcome variable</u>		
<u>Post-Walk Wellbeing</u>	Post-walk wellbeing score measured by WEMWBS	Ordinal (14–70)
<u>Natural space exposure variable</u>		
<u>Perceived Walk Naturalness</u>	Participant-assessed walk naturalness rating (very built to very natural; 7-point bipolar Likert scale)	Ordinal (1–7)
<u>Walk-specific</u>		
<u>Walk Number</u>	Walk 1 or walk 2	Binary (1, 2)
<u>Pre-Walk Wellbeing</u>	Pre-walk wellbeing score measured by WEMWBS	Ordinal (14–70)
<u>Access to Nature</u>	Participant's access to nature (great difficulty with access to very easy access; 4-point bipolar Likert scale)	Ordinal (1–4)
<u>Sociodemographic variables</u>		

(continued on next page)

## 5. Conclusions

This study contributes to the understanding how natural environments affect psychological wellbeing by examining individual-level differences, from an equigenic lens. Most clear of our findings, we found support for the equigenic effect when using an objective measure of economic disadvantage (Pell Grant status), demonstrating that natural space may help reduce class-based wellbeing disparities. Consistent with prior research, our results indicate that naturalness is associated with higher wellbeing compared to built space. However, these benefits are not uniform across marginalized groups. The results offer only partial support for the equigenic effect, perhaps highlighting that intersecting factors like safety, access, culture, and belonging influence who benefits most. Effective interventions must prioritize equity-focused, context-specific, co-created approaches that pair naturalness enhancing efforts with community-identified needs, particularly amid current mental health challenges (Global Burden of Disease Study, 2019, 2022).

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## CRediT authorship contribution statement

**Everly Jazi:** Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Alia M. Dietsch:** Methodology, Data curation. **Matilda van den Bosch:** Writing – review & editing, Methodology. **Margarita Triguero-Mas:** Writing – review & editing, Methodology. **Michael J. Meitner:** Writing – review & editing, Methodology, Formal analysis. **Curtis Atkisson:** Methodology, Investigation, Formal analysis. **Annmarie Thomson:** Writing – review & editing, Visualization, Formal analysis. **Keunhyun Park:** Writing – review & editing, Supervision, Methodology, Investigation, Formal analysis.

## Declaration of Competing Interest

The authors have no conflicts of interest to disclose.

Table 1 (continued)

Variables	Definitions	Types of Measures and Range
<i>Race and Ethnicity</i>	Whether a participant has a race or ethnicity selected besides and beyond white (i.e., someone might be white and another ethnicity, and therefore are included as a person of color)	Binary (No, Yes)
<i>First Generation</i>	Whether a participant is a first-generation student	Binary (No, Yes)
<i>Pell Grant</i>	Whether a participant is a Pell Grant recipient	Binary (No, Yes)
<i>Social Class</i>	A participant's self-reported socioeconomic class (lower class, middle class, higher class)	Ordinal (1–3)
<i>Random effect</i> (1 id)	Respondent ID as a random effect	Levels n = 475

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