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'The Elephant in the Room' – does actual or perceived biodiversity elicit restorative responses in a virtual park?

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ABSTRACT

Previous studies suggested that urban green spaces with rich fauna and flora (i.e. rich biodiversity) improved well-being, in the form of reduced stress and better mood. However, few studies manipulated the biodiversity experimentally and controlled for potential confounders. In the current study, an online experiment tested the hypothesis that more biodiverse green spaces will elicit greater well-being. Over 1600 participants from the UK and China reported their mood before and after virtually exploring the same urban park but with lower or higher macro-biodiversity (plants, birds and mammals). All participants also rated their perceived biodiversity (i.e. how many kinds of plants and animals they guessed to be present). The results showed that all park variations produced improved mood, especially in stressed participants. This counters the initial expectations that maximum biodiversity correlates with higher well-being. Instead, participants who *perceived* higher biodiversity reported greater mood improvements than those who perceived low biodiversity. However, the perceived biodiversity overestimated the *actual* biodiversity. Interestingly, these findings were consistent in both UK and China samples. This indicates that well-being benefits and stress recovery can occur in parks with low and high biodiversity. However, greater well-being effects can be gained if park visitors perceive and notice more biodiversity.

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Introduction

Biodiversity (the variety and abundance of living species in a given geographical region) is going through a global crisis ushered in by climate change, overexploitation of natural resources and habitat loss (Fisher *et al.* 2023). Cities and their green infrastructure – i.e. networks of natural and artificial ecosystems within and around the city (Tzoulas *et al.* 2007) – have become unexpected sanctuaries for many bird and plant species (Aronson *et al.* 2014, Spotswood *et al.* 2021). In time, with appropriate management, cities could be turned into favourable habitats, providing a haven for species while their natural habitats keep shrinking due to e.g. the intensification of agriculture (Tilman *et al.* 2017). The development of Nature-based solutions – i.e. 'actions to protect, sustainably manage and restore natural or modified ecosystems, that address societal challenges [. . .]' (Cohen-Shacham *et al.* 2016) – has the potential to increase the biodiversity in urban environments, since these solutions must also enhance biodiversity as part of their outputs (European Commission *et al.* 2020).

Biodiverse environments, including those found in urban settings, have many ecosystem services to offer, not least those related to human health (Fisher *et al.* 2023). For instance, physical health may benefit from contact with a biodiverse microbiota in the soil as this can positively change the biota of skin (Grönroos *et al.* 2019, Robinson and Barrable 2023) and gut (Liddicoat *et al.* 2020), both important in supporting the immune system. In general, biodiversity is also capable of reducing exposure to harmful environmental factors, e.g. air pollutants and excessive heat (Marselle *et al.* 2021), which are especially present in large cities. For example, research has shown that the amount of cooling provided by urban trees is determined by the species traits (e.g. leaf shape), which can enhance/reduce the tree's evapotranspiration (Gunawardena *et al.* 2017) and shading (Cameron *et al.* 2014, Speak *et al.* 2020).

Another large body of research investigated the benefits of urban green spaces on mental health (Frumkin *et al.* 2017). Urban environments that host relatively high biodiversity, such as parks, gardens and arboretums have been seen as providers of psychological well-being (Markevych *et al.* 2017). As a quality of these landscapes, biodiversity can be linked to at least two psycho-evolutionary theories proposing that natural-looking landscapes (including urban green spaces) can support well-being (Cracknell *et al.*

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2017). The Attention Restoration Theory (Kaplan 1995) suggests green spaces provide 'soft-fascinating' content (i.e. engaging but low-stimuli), allowing the brain to replenish its cognitive capacity ('Directed attention') and thus improving cognitive processes (e.g. memory). For example, a group of university staff who watched a video of a nature trail showed improved long-term memory and task accuracy compared with their baseline values and compared to a control group who watched a video of a busy city street (Pilotti *et al.* 2015). The Stress Reduction Theory (Ulrich *et al.* 1991) postulates that views of 'unthreatening nature' with a moderate degree of visual complexity (common in urban green spaces) enhance relaxation processes and reduce stress. This reduction in stress was observed both physiologically (e.g. reduced blood pressure; Lanki *et al.* 2017) and psychologically (e.g. improved mood; Kondo *et al.* 2020). In particular, Positive Affect (positive emotions and their cognitive, physiological and behavioural expressions) seems to improve from contact with natural environments (McMahan and Estes 2015). In summary, a higher number of species in a given location (higher biodiversity) could increase the chances of being exposed to either 'fascinating content' or moderate 'visual complexity', in turn leading to well-being improvements.

In a recent framework looking at the multiple pathways that may link biodiversity and human health (Marselle *et al.* 2021), the contact with biodiversity has been conceptualised as the sum of 'exposure' (duration and frequency of interaction) and 'experience' (qualities of the experience, e.g. intentionality of the interaction, the direct/indirect physical proximity with biodiversity). Direct interactions (being physically present with biodiversity), such as birdwatching and berry picking, have been shown to be one of the reasons that attract visitors to city parks (Palliwoda *et al.* 2017). Direct interactions generally have a greater potential to provide well-being compared to indirect interactions (not being physically present in nature, e.g. watching a documentary) (Browning *et al.* 2020). Nonetheless, researchers have successfully observed improvements in well-being even when their participants came in contact with biodiversity indirectly through pictures (Brown *et al.* 2013), slideshows (Johansson *et al.* 2014) and videos (Wolf *et al.* 2017).

Unresolved research questions on biodiversity and well-being

Early studies (Fuller *et al.* 2007) hypothesised the relationship between biodiversity and mental well-being followed a linear trend (i.e. the greater the biodiversity the better the mental well-being). Over the years, the general research question revolved around this hypothesis (Lovell *et al.* 2014), but results varied. Some were supportive of this positive relationship, finding reduced anxiety and increased Positive Affect (Cox *et al.* 2017, Wolf *et al.* 2017) and better quality of life (Rantakokko *et al.* 2018). Other studies instead found no relationship between biodiversity and stress (e.g. Grahn and Stigsdotter 2010), or biodiversity and general mental health (e.g. van den Bosch *et al.* 2015). The interest in gaining an understanding of these relationships is still growing (Hedin *et al.* 2022); however, the experimental evidence linking biodiversity and mental well-being remains limited, with only a handful of experiments controlling for biodiversity (Marselle *et al.* 2019, Hedin *et al.* 2022).

Further, some of the existing experiments seem to suggest that the biodiversity/mental health relationship could be non-linear, i.e. a certain degree of biodiversity is beneficial, but too much or too little is not. For example, Johansson *et al.* (2014) showed their participants slideshows of broadleaf forests at high, intermediate and low levels of biodiversity. The participants' emotional well-being was significantly higher after watching the intermediate forests, compared with the other two. In another experiment (Lindemann-Matthies and Matthies 2018), participants showed reduced blood pressure and better stress recovery when relaxing in front of a meadow with medium plant diversity (32 species) than when in front of a less diverse (0, 1 and 16 species) or much more diverse (64 species) meadows. Similarly, an experiment that used videos at different levels of biodiversity showed that participants relaxed more (i.e. reduced anxiety and slower heart rate) after seeing a video with some biodiversity compared to videos with little and high biodiversity (Schebella *et al.* 2020). If the biodiversity/well-being relationship is non-linear, this could explain why high biodiversity is sometimes associated with reduced well-being (Dallimer *et al.* 2012).

Often, improved well-being is associated with *perceived* biodiversity (i.e. how biodiverse a place is perceived to be), irrespectively of the *actual* biodiversity (i.e. biodiversity objectively measured) (Dallimer *et al.* 2012). Recent research showed that perceiving a higher number of species in urban parks in Portugal (Gonçalves *et al.* 2021) and Singapore (Nghiem *et al.* 2021) resulted in higher Attention Restoration, but the actual park biodiversity had little effect. Similarly, a survey study from a natural park in Ontario (Reining *et al.* 2021) showed that perceiving a higher number of species had strong associations with well-being, while the type of ecosystem (and their different species richness) did not show a significant difference (i.e. all examined ecosystems were restorative).

Perceptions of biodiversity represent a complex construct, which includes both the processing of the sensorial information of biodiversity (Botzat *et al.* 2016) and a subjective experiential component. Examples of sensorial stimuli are flower colours (Elsadek and Liu 2020, Zhang *et al.* 2023) and birdsong (Fisher *et al.* 2021), which have been shown to improve self-reported well-being. The subjective component, as suggested by qualitative research (Austen *et al.* 2021), goes beyond the sensorial aspects to include past experience (familiarity with species, memories of interaction) and knowledge about biodiversity (e.g. species behaviour and its ecological value). Finally, perceptions of biodiversity can also increase over time, for example, as a result of targeted education (Lindemann-Matthies 2002). This complexity could explain why, often, public perceptions of biodiversity were poorly correlated with measured biodiversity (Lindemann-Matthies and Bose 2008, Dallimer *et al.* 2012, Shwartz *et al.* 2014).

In a previous experiment (Farris *et al.* 2024), there was some indication that *noticing* biodiversity could be a key element in enhancing well-being. While holding the level of biodiversity and the perceived biodiversity constant, those participants who reported noticing some elements of biodiversity (i.e. flowers, birds, trees) showed higher Positive Affect while recovering from a stressor than participants who did not notice or did not share what they had seen. Other studies (Passmore and Holder 2017, Passmore *et al.* 2022) showed that mindfully noticing nature and the emotions evoked by it can increase Positive Affect, in particular low-arousal Positive Affect such as relaxation (McEwan *et al.* 2021).

The present study

Considering this summary of the existing literature, the present study aimed to 1) contribute to the limited experimental evidence that has linked well-being and biodiversity; 2) compare the effect of perceived biodiversity and actual biodiversity on the same stress recovery process but at different baselines of stress; 3) explore the effect of noticing biodiversity on well-being. The experiments focused on answering the following questions:

(1) Does higher park biodiversity improve well-being more than lower (but not total lack of) biodiversity?
(2) Does the perceived biodiversity elicit more well-being than actual biodiversity?
(3) Does noticing individual elements of biodiversity elicit well-being?
(4) Is there any difference between non-stressed and stressed participants?

The last research question allowed a comparison between those who, theoretically, should receive more benefits from green spaces (and biodiversity) because they need to recover from stress (Ulrich *et al.* 1991), and the effect of green space (and biodiversity) under normal circumstances (lower stress).

Materials and methods

To address the research questions, a total of four experiments were developed. Experiment 1 measured the participants' emotional well-being before and after a virtual tour of an urban park. Experiment 2 replicated Experiment 1 but introduced a stressor task before the virtual tour. Experiments 3 and 4 replicated experiments 1 and 2 (respectively) with a different group of participants in a different language (Chinese). This was attempted to broaden the scope of the research, as most of the evidence available about biodiversity and well-being was based in Western countries (see Marselle *et al.* 2019, Hedin *et al.* 2022). The following sections will provide more details about the virtual tour, the participants, the experimental procedures and the measures used.

Treatment setup and virtual park development

The main reason for developing a virtual park was to compare different levels of species richness while keeping the context as constant as possible. Eight different versions of the same virtual park were developed (Table 1). These park variations were used as treatments to expose the participant to different levels of biodiversity while accounting for the effect of flower colours. Flower colours can influence Positive Affect (Elsadek and Liu 2020, Zhang *et al.* 2023) but are also one of the most intuitive species traits used to distinguish one species from another (Hoyle *et al.* 2018). Therefore, it was necessary to control for the diversity of the flower colours which may overlap and be confounded with

Table 1. Summary of the characteristics selected for the virtual park variations.

Treatment	Species count	Experiments 1 and 3	Experiments 2 and 4
High biodiversity and high colour diversity (HBHC)	28 (12 herbs or shrubs, 10 trees, 4 birds, 2 mammals)	Blue, pink, purple, white	Red, orange, yellow, white
High biodiversity and low colour diversity (HBLC)	28 (12 herbs or shrubs, 10 trees, 4 birds, 2 mammals)	Blue, white	Orange, white
Low biodiversity and high colour diversity (LBHC)	15 (10 trees, 3 herbs or shrubs, 2 birds)	Blue, pink, purple, white	Red, orange, yellow, white
Low biodiversity and low colour diversity (LBLC)	15 (10 trees, 3 herbs or shrubs, 2 birds)	Blue, white	Orange, white

biodiversity. Biodiversity was manipulated by introducing digital models of flowering plants, small domestic mammals and birds. This was done to make biodiversity as noticeable as possible, attempting to make the comparison between actual and perceived biodiversity clearer. This produced one low biodiversity treatment (3 plants, 2 birds) and one high biodiversity treatment (12 plants, 2 mammals, 4 birds). All versions of the park included 10 species of trees, mown lawns, benches, rubbish bins and some human models. Species and abundance of trees did not vary. This was intentional to control the visual impact of trees, which is known to change the character of the landscape (Jorgensen *et al.* 2002, Zhao *et al.* 2017). The effect of the flower colours was controlled by limiting the number of colours to 2 (lower colour diversity) and 4 (higher colour diversity). To maximise the affective response to the planting, warm colours were used in experiments 1 and 3 (i.e. without the stress induction) and cool colours were used in experiments 2 and 4 where participants received a stress induction. This choice was based on previous research which showed a relaxing effect of cool flower colours and an uplifting effect of warm flower colours (Zhang *et al.* 2023). Sample images of the planting are included in the supporting information (S2).

The park was created in Google SketchUp and Lumion Pro (ver. 12), had a size of 100 × 100 m and featured a paved path where each participant could 'walk' by clicking on arrow-shaped buttons placed on it. Thirty 360-degree photos of the park were linked together with Marzipano (http://www.marzipano.net.), creating a virtual tour experience similar to Google's 'Street View'. Just like Google's experience, the tours were developed to be visualised on a bidimensional screen. The participant could change the point of view by clicking and dragging on the image. The planting was arranged in repeating blocks so that the participant could move freely in any direction while remaining exposed to the same plants. No audio background was included in any of the tours to avoid confounding stimuli. The participants could explore the park for 150 seconds, which accounted for the time needed to load the photos (dependent on the internet connection) and to read the instructions on how to move around the park. Short exposures to virtual nature have been successfully used in the past to induce measurable changes in mood (e.g. Wolf *et al.* 2017, Douglas and Evans 2022) and reduce the potential for participant dropout (e.g. due to boredom).

Participant recruitment and ethics approval

Participants were first recruited via social networks (Twitter and Facebook) and two Europe-based survey exchange platforms (SurveyCircle.com and Surveyswap.com). The recruitment was then repeated with a Chinese audience, distributing the survey, translated into Mandarin, on WeChat. Data collection took place between April and December 2022. All participants took part in the same online procedure from their own devices. The study and the procedure were reviewed and approved by the Department of Landscape Architecture Ethics Committee (Approval Ref. 039698).

Measures

Assessing mental well-being involves appraising one's psychological, cognitive and emotional quality of life (Linton *et al.* 2016). Considering the fast-paced online data collection of this study, the appraisal of well-being focused on the affective states (i.e. emotional well-being), as these provide a proxy for in-the-moment stress response and mood regulation (Gross *et al.* 2019). Although mental well-being cannot be solely determined by individual positive events (e.g. a break in the park), short-term proxies are useful to investigate which elements of the environment can improve well-being (Zhang *et al.* 2023). The affective states were measured with two subscales, Joviality and Serenity, from the Positive and Negative Affect Schedule Extended (PANAS-X; Watson and Clark 1994) and the Negative Affect subscale from the International short form of the same schedule (I-PANAS-SF; Thompson 2007). Combined, these scales formed a questionnaire with 16 items (8 Joviality, 3 Serenity, 5 Negative Affect), each one indicating how much the participant felt a certain emotion on a 5-point Likert scale. Theoretical work concerning the Affective regulation (Posner *et al.* 2005, Panksepp 2010, Richardson *et al.* 2016) has suggested that two dimensions of Positive Affect exist; one is more related to enjoyment and attraction (high arousal) while the other involves relaxation and contentment (low arousal; McManus *et al.* 2019). Therefore, the Joviality and Serenity scales were selected to measure these two dimensions of the Positive Affect. For the Chinese version of the survey, the PANAS-X subscales and the other measures detailed below were translated into Mandarin by one of the authors and translated back to English with the help of an independent academic. In the Chinese translation two items from the Serenity scale were redundant, 'relaxed' (平静的) and 'calm' (平静的); therefore, only the item 'calm' (平静的) was included in the questionnaire.

Perceptions of biodiversity and colour diversity were measured on a 4-point Likert scale (Cameron *et al.* 2020). Participants were asked to guess 'How many types of plants/trees/animals' were in the park they explored. Possible answers were as follows: 'none', 'a few', 'quite a bit', and 'lots'.

The participants were asked to state their age group, gender, ethnicity and educational level to ensure a balanced, randomised distribution among the experimental groups. Additional checks asked if this was the first time they had experienced a virtual tour, what device they were using and if they had any difficulties in perceiving colours (e.g. colour blindness).

Along with their demographics, the participant reported their nature connectedness via the one-item Inclusion of Nature in Self scale (Schultz 2002). This is a single-item scale, measured on a 7-point Likert scale. Nature connectedness measures one's affective affiliation with nature (Mayer and Frantz 2004) and could play a role in the relationship between biodiversity and well-being.

Finally, the participants were asked to comment about anything they had noticed or liked during their virtual tour. Applying content analysis (Neuendorf 2017) to these comments produced binary variables which were used in the statistical analysis.

Stressor

In restorative research, the use of psychophysiological stressors is justified to briefly simulate the effect of a stressful urban environment, which will alter the baseline parameters, allowing the recovery process to be clearly observed (Ulrich *et al.* 1991, van den Berg *et al.* 2003). Being this an online study, it could not involve physical stressors, such as the 'cold pressor task' (i.e. immersion of an arm into icy water) (Schwabe and Schächinger 2018). Instead, a moderate stress induction was attempted by playing the sound of a fire alarm; this aimed to increase Negative Affect momentarily. Hearing a fire alarm test is a regular experience in the UK, where weekly testing is compulsory in most buildings. These tests expose people to a very loud sound for tens of seconds (depending on the system and its testing procedure). In this study, the stressor was set at −19 LUFS (i.e. Loudness units relative to full scale) sound intensity via loudness normalisation. This value is quieter than the current standard value for most of the music streaming platforms. This protected the participants' hearing from excessive volume and also standardised the effect of the sound loudness across all participants. As required by the ethics review, the information sheet forewarned the participants they could be hearing an annoying noise (i.e. the stressor).

Experimental procedures

All the experimental procedures were delivered on Qualtrics (Provo, UT, US). After reading the information sheet and providing consent, the participants were instructed to wear headphones and avoid distractions for the duration of the study. The participants were initially randomised into one of the experimental procedures (Figure 1), two without a stress induction (Experiments 1 and 3) and two which included a stressor task (Experiments 2 and 4) and then to 1 out of the 4 park variations (as described below). For both randomisations, the 'evenly present elements' function by Qualtrics was used.

In Experiments 1 and 3, the participants first reported their baseline affective states and then were randomly assigned one of the warmly coloured virtual tours to explore for about 150 s. After that, they reported their affective states a second time and their perceptions about the biodiversity they had observed. Space was provided for further comments and participants were shown a debrief.

In Experiments 2 and 4, the participants received the stress induction immediately after baseline measurement. This was the sound of a fire alarm, which lasted 15 s. After that, they immediately reported their post-stressor affective states. Following, each participant was randomly assigned one of the cool-coloured parks to explore for 150 s. After the tour, the participants reported their affective states one last time and reported their perceptions of biodiversity. Finally, they were provided space for comments and debriefing.

Statistical analysis

The statistical analysis was carried out using SPSS (version 28) for Windows. Responses which met the following criteria were excluded from the analysis: 1) Incomplete responses; 2) multiple responses identified by the same IP address and demographic information; 3) responses where the Affective scores were the same for all items at all stages of the procedure (e.g. all 5).

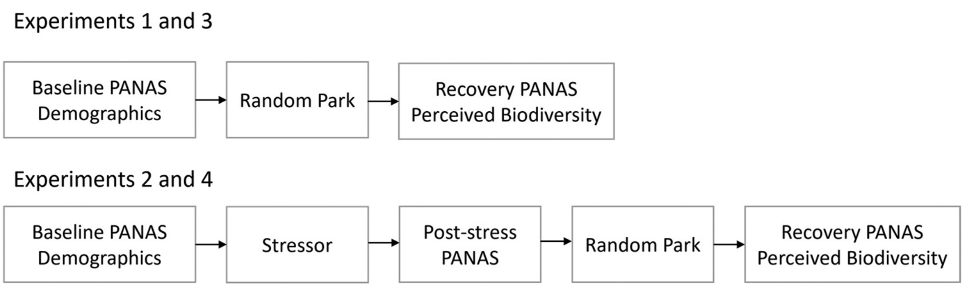

Figure 1. Flowcharts illustrating the experimental procedures. Note: nature connectedness was assessed as part of the demographics.

The distribution of demographics among the treatment groups was explored with histograms and cross-tabulations. Changes in the Affective states were analysed via repeated measures analysis of variance (RM-ANOVA), using the park treatment as the between-subject variable and the procedure's stages (baseline, stressor, park) as the within-subject variable. An interaction term between the stage of the procedure and the Park treatment was included to compare the affective response at the park stage between the groups. The Greenhouse-Gausser correction was applied to the probability values (p-values), as the assumption of sphericity was usually violated by the model. The Bonferroni correction was applied to any post hoc tests involving multiple comparisons.

Since only 2.7% of the perceptions of biodiversity fell into the lowest category (i.e. 'none'), perceived biodiversity was recoded into three categories (low, medium, and high) by collapsing the two lower categories ('none' and 'a few') together. Similarly, nature connectedness was also recoded into three categories as follows: low (scores 1 to 3), medium (scores 4 and 5), and high (scores 6 and 7).

The Affective scores (Joviality, Serenity, Negative Affect) were calculated by averaging the items of each subscale. In parallel with the park treatment, ratings of perceptions of biodiversity and nature connectedness were used as between-subjects variables. Dummy variables generated via content analysis were also used as between-subject variables, exploring the effect of specific elements on the affective response.

Required sample sizes for this analysis (Mixed repeated measure design) were calculated using G*Power (Faul *et al.* 2007), aiming to achieve a power of beta = 0.8 at the significance threshold of alpha = 0.05. A small effect size (Cohen's d = 0.15) was assumed based on previous meta-analyses (McMahan and Estes 2015, Browning *et al.* 2020).

Results

Descriptive data (experiments 1 to 4)

After applying the exclusion criteria, 940 responses from the English survey and 774 responses from the Chinese survey were included in the analysis. Over 350 participants were involved in each experiment (Table 2). The majority of English-speaking participants were female, while males were prevalent among the Chinese-speaking participants.

Table 3 reports the distribution of nature connectedness, perceived biodiversity and the perceived biodiversity in relation to the actual biodiversity presented in the virtual park.

Finally, a reliability test revealed satisfactory values (Cronbach alpha > 0.85) for the Joviality and Negative Affect scales in all four experiments. The Serenity scale was again reliable in the English survey (Cronbach alpha > 0.85) but less reliable in the Chinese (Cronbach alpha = 0.6). Means and standard deviations of all the affective scores are reported in the supporting information (S1, Tables S4–8).

Experiment 1

Effect of virtual park biodiversity on the affective response

Exposure to the park environments improved the well-being parameters (affective scores), but there were no statistical differences based on the level of biodiversity present (Table 4). Overall, the Joviality

Table 2. Distribution of demographics across the four experiments.

Measure	Experiment 1 N = 463	Experiment 2 N = 477	Experiment 3 N = 379	Experiment 4 N = 395
Gender				
Male	32%	37.90%	66.8%	64.6%
Female	66.1%	59.1%	30.9%	32.2%
Non-binary/third gender	1.5%	2.3%	0.3%	0.5%
Prefer not to say	0.4%	0.6%	2.1%	2.8%
Age category				
18–24	38.4%	30.2%	3.7%	4.3%
25–34	30.7%	34.2%	18.7%	18.7%
35–44	11.2%	14.9%	28.2%	27.1%
45–54	7.6%	7.8%	34.8%	32.4%
55–64	5.4%	6.1%	12.7%	14.4%
65+	6.70%	6.90%	1.8%	3.1%
Ethnicity				
White	68.5%	73.4%	2.4%	1%
Mixed/Multiple ethnic groups	4.3%	4.6%	0%	0.5%
Asian	18.1%	14.9%	97.1%	97.2%
Black/African/Caribbean	3.9%	4.4%	0.3%	0%
Other ethnic group (self-described)	4.8%	2.5%	0.3%	1.3%
Education				
High school, GCSE or equivalent	9.3%	10.1%	36.4%	38.7%
Bachelor or equivalent	44.5%	41.9%	52.2%	50.4%
Masters or equivalent	36.7%	37.9%	5.5%	5.6%
Doctoral or equivalent	7.1%	8%	1.1%	1%
Other (self-described)	2.2%	1.9%	4%	3.8%

Table 3. Distribution of nature-related variables across the four experiments. Key for the treatment acronyms: H = high, L = low, B = biodiversity, C = colour diversity.

Measure	Experiment 1	Experiment 2	Experiment 3	Experiment 4
Nature connectedness				
Low	23.1%	22.2%	5%	6.8%
Medium	51%	41.9%	26.4%	24.6%
High	25.9%	35.8%	68.6%	68.6%
Perceived biodiversity				
low	10.4%	7.8%	28.8%	34.9%
medium	29.2%	33.1%	40.9%	38%
high	60.5%	59.1%	30.3%	27.1%
	HBHC	**HBLC**	**LBHC**	**LBLC**
Perceived biodiversity by park variation – all experiments pooled together				
Low	20.4%	18.7%	17.4%	20.9%
Medium	29.6%	35.7%	35.4%	39.0%
High	50.0%	45.6%	47.2%	40.1%

Table 4. Experiment 1. Summary of the RM-ANOVA comparing the effect of park treatment on the three affective states.

		Experiment 1	
Affect	Component	F	*p*-value
Joviality	Park (Between-subjects)	1.354	0.256
	Stage of the procedure (Within-subjects)	18.776	<0.001
Serenity	Park (Between-subjects)	0.747	0.525
	Stage of the procedure (Within-subjects)	9.559	0.002
Negative Affect	Park (Between-subjects)	0.487	0.691
	Stage of the procedure (Within-subjects)	82.615	<0.001

and Serenity scores increased slightly after the park, while the Negative Affect score was reduced.

Effect of perceived biodiversity on the affective response

There were significant interactions between levels of perceived biodiversity and the stage of the procedure for Joviality ($F = 11.01$, $p = 0.001$) and Serenity ($F = 3.098$, $p = 0.046$). Post hoc comparisons showed that participants perceiving medium/high biodiversity showed significantly higher Joviality and Serenity after touring the park than those who perceived low biodiversity (Figure 2, left). Joviality and Serenity scores were reduced after the park, compared with baseline, for those who perceived low biodiversity. Negative affect decreased after park exposure, but the decrease was significantly greater ($F = 6.654$, $p = 0.001$) for those that perceived biodiversity levels as medium or high compared to low (Figure 2, right).

Experiment 2

Effect of virtual park biodiversity on the affective response

All park experiences restored affective scores after the stressor (i.e. stage was significant, Table 5), but as in Experiment 1 there was no effect due to the level of biodiversity present. Overall, the Joviality and Serenity scores decreased after the stressor and then increased after the park; the Negative Affect followed an opposite trend, increasing after the stressor and decreasing after the park.

Effect of perceived biodiversity on the affective response

There were significant interactions between levels of perceived biodiversity and the different stages of the procedure for both Joviality ($F = 3.674$, $p = 0.007$) and Serenity ($F = 2.363$, $p = 0.055$). Post hoc tests, however, showed significant improvements in these emotions when participants perceived the park biodiversity to be medium or high (Figure 3, left and middle). Negative Affect decreased on park exposure after the stressor, but post hoc tests did not suggest significant differences based on perceptions of biodiversity.

Experiment 3

Effect of virtual park biodiversity on the affective response

Scores for Joviality and Serenity after the park exposure did not differ significantly from the baseline at any of the levels of biodiversity. In contrast, Negative Affect was instead significantly reduced (Table 6), but at both levels of biodiversity – i.e. no significant effect based on the level of biodiversity viewed.

Effect of perceived biodiversity on the affective response

There were significant differences between the Joviality scores associated with the three levels of perceived biodiversity ($F = 5.872$, $p = 0.003$). Post-hoc comparisons showed that participants who

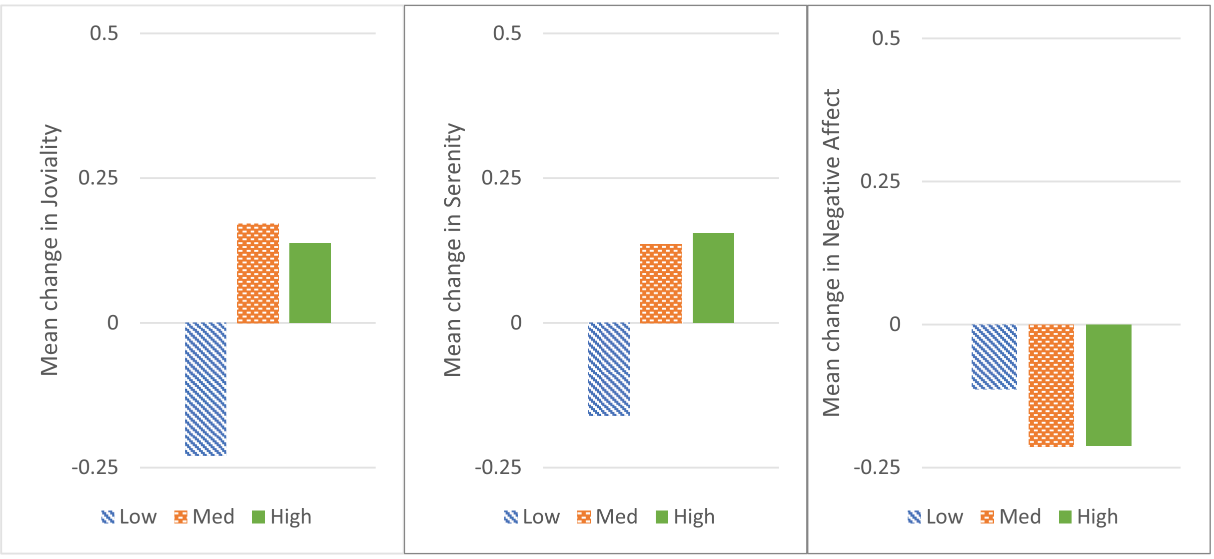

Figure 2. Experiment 1. Changes, after touring the park, in the joviality (left), serenity (centre) and negative affect (right) scores by perceived biodiversity.

had perceived high biodiversity increased Joviality whereas those who perceived medium or low levels decreased slightly compared to baseline levels (Figure 4). Changes were significantly different between perception levels. Serenity stayed level for perceptions of medium biodiversity, but decreased for both low and high perception levels compared to baseline ($F = 3.52$, $p = 0.03$); differences compared to the medium being significant ($p = 0.048$). The effect of perceived biodiversity on the Negative Affect was not significant ($F = 0.36$, $p = 0.69$).

Experiment 4

Effect of virtual park biodiversity on the affective response

Exposure to the park environments restored positive emotions after the stressor, but the level of biodiversity had no significant effects on Joviality, Serenity and Negative Affect scores. Joviality and Serenity were reduced by the stressor and then increased again after the park tour. The Negative Affect also changed, increasing after the stressor and decreasing after the park (Table 7).

Effect of perceived biodiversity on the affective response

Higher perceived biodiversity was associated with greater restoration of Joviality and Serenity, after the stressor (Figure 5) (e.g. for joviality H vs L, $p = 0.001$; M vs L, $p = 0.002$). Negative Affect decreased after the park exposure, but the perception of biodiversity did not show a significant effect ($F = 0.885$, $p = 0.156$).

Noticing individual features of the parks (experiments 1 to 4)

Content analysis of the comments showed participants in Experiments 1 and 2 (i.e. English-speaking) mostly noticed the presence of birds ($N = 58$), small domestic mammals ($N = 146$) and trees ($N = 60$). Fewer noticed or appreciated the flowers ($N = 48$). A series of exploratory RM-ANOVAs revealed that participants in Experiment 1 (i.e. unstressed) who noticed the mammals and birds reported overall lower Negative Affect ($F = 4.402$, $p = 0.045$) than other participants. Participants assigned to Experiment 1 who noticed the birds showed increased Serenity after the park experience ($F = 5.291$, $p = 0.006$). Noticing mammals and birds had an effect also on Experiment 2 participants (stressed)

Table 5. Experiment 2. Summary of the RM-ANOVA comparing the effect of park treatment on the three affective states.

		Experiment 2	
Affect	Component	F	*p*-value
Joviality	Park (Between-subjects)	2.663	0.047
	Stage of the procedure (Within-subjects)	109.1	<0.001
Serenity	Park (Between-subjects)	0.332	0.802
	Stage of the procedure (Within-subjects)	195.1	<0.001
Negative Affect	Park (Between-subjects)	0.724	0.538
	Stage of the procedure (Within-subjects)	118.4	<0.001

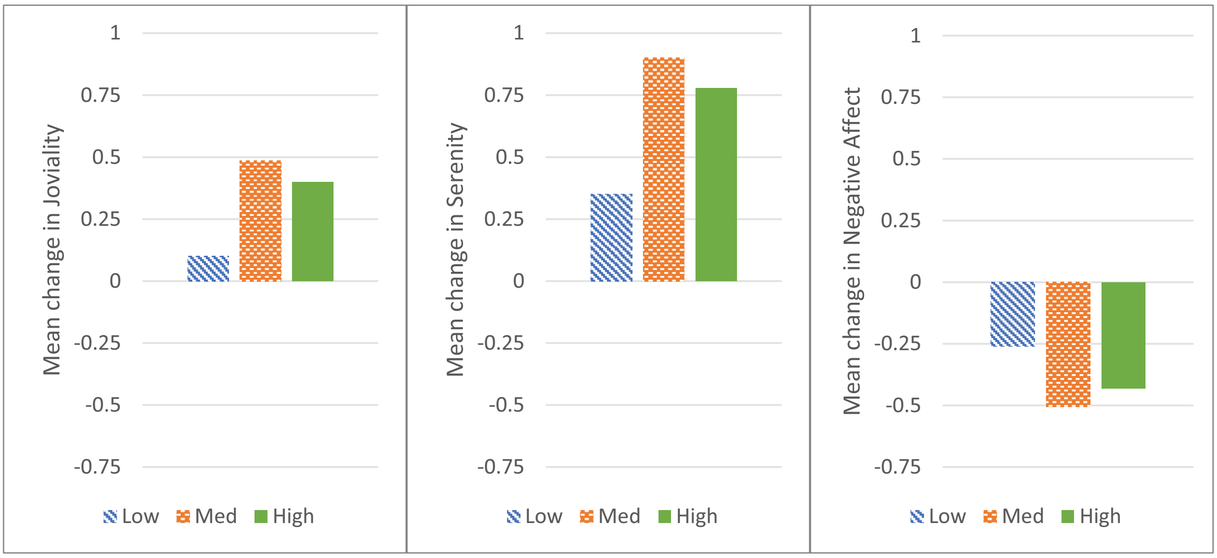

Figure 3. Experiment 2. Changes, from after receiving the stressor to after exploring the park, in the joviality (left), serenity (centre) and negative affect (right) scores by perceived biodiversity.

who reported lower overall Negative Affect (F = 4.023, $p = 0.045$) than other participants. In both Experiments 1 and 2, participants who noticed the trees reported lower overall Negative Affect scores than those who did not mention the trees (Experiment 1, F = 5.0, $p = 0.026$; Experiment 2, F = 5.827, $p = 0.016$). Additionally, participants in Experiment 2 who noticed the trees showed a much higher increase in Serenity after the park compared with the others (F = 5.291, $p = 0.006$). The analysis did not show a statistically significant difference between participants who mentioned the flowers and those who didn't.

Participants in Experiments 3 and 4 (i.e. Chinese-speaking) primarily noticed the flowers ($N = 115$) and the 'grasses' (草地) ($N = 44$). Only a few mentioned the mammals ($N = 16$) or the birds ($N = 11$). The participants who noticed the flowers showed overall higher Joviality than the others in both Experiment 3 (F = 5.885, $p = 0.016$) and 4 (F = 12.01, $p = 0.001$). Additionally, participants in Experiment 4 reported higher Serenity (F = 6.912, $p = 0.009$) and higher Joviality scores when they noticed the grasses (F = 6.761, $p = 0.001$). Noticing these elements did not show any differences in Negative Affect.

Discussion

Virtual parks improved emotional well-being

Overall, this research supports the notion that green spaces, in this case parks, can improve emotional well-being. All virtual park variations improved the affective states compared to the baseline, increasing Joviality and Serenity and reducing the Negative Affect. For those participants who received a minor stress induction, virtually exploring the parks also improved the affective states compared with the post-stressor levels. Despite their differences (see below), the results showed that both English-speaking and Chinese-speaking participants had similar responses to the parks. These results agree with other studies which have used simulated parks to elicit well-being improvements. Videos of urban and natural parks shown to Australian participants resulted in lower Negative Affect and higher Positive Affect compared with an urban control (McAllister *et al.* 2017). More recently, researchers measured levels of happiness, calm and anger in response to images of three park types: parks with green vegetation, parks with colourful (artificial) amenities and sculptures and squares with pleasant architecture but no vegetation. Green parks elicited higher happiness

Table 6. Experiment 3. Summary of the RM-ANOVA comparing the effect of park treatment on the three affective states.

		Experiment 3	
Affect	Component	F	*p*-value
Joviality	Park (Between-subjects)	1.907	0.128
	Stage of the procedure (Within-subjects)	0.140	0.709
Serenity	Park (Between-subjects)	0.357	0.784
	Stage of the procedure (Within-subjects)	1.077	0.3
Negative Affect	Park (Between-subjects)	0.335	0.800
	Stage of the procedure (Within-subjects)	41.949	<0.001

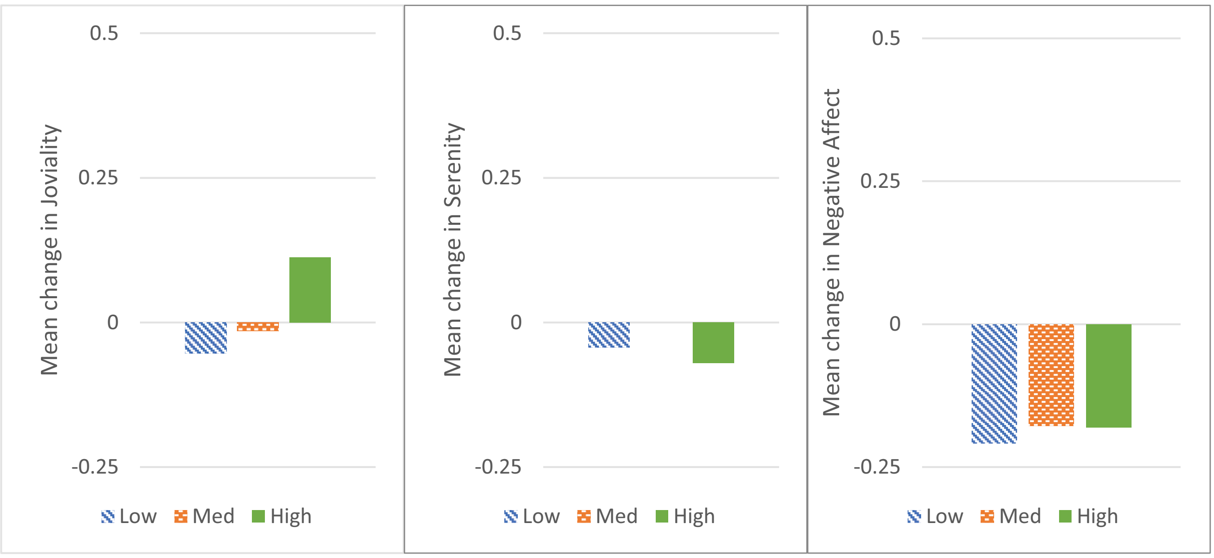

Figure 4. Experiment 3. Changes, after touring the park, in the joviality (left), serenity (centre) and negative affect (right) scores by perceived biodiversity.

and calm and lower anger than both colourful and non-vegetated parks (Rapuano *et al.* 2022). In China, videos of urban parks produced stress recovery and decreased anxiety in participants who were previously stressed (Wang *et al.* 2016). In the current study, Chinese-speaking participants reported reduced Negative Affect after virtually visiting the park, however, their Joviality and Serenity improved significantly only for those who received the stress induction (i.e. had higher levels of stress). This suggests that contact with green spaces (and their biodiversity) could have different benefits for stressed and unstressed individuals. Even if the exposure to the park was short and limited to visual (online) stimulation (Elsadek *et al.* 2020), stressed individuals seemed happier and more relaxed.

Actual biodiversity was not associated with better or worse emotional well-being

The analysis showed that parks at different levels of biodiversity did not produce different responses. These results contradict the expectations for the first research question (i.e. more biodiversity elicits better well-being) because both higher and lower biodiversity performed similarly. To make these results more robust, the diversity of flower colours, which may overlap with plant biodiversity (Hoyle *et al.* 2018), was controlled. Exposure to biodiversity was also made consistent throughout the tour by working with identical planting blocks, which showed the same plant species and abundance.

Previous studies have reported similar neutral effects of actual biodiversity. For example, Van Den Berg *et al.* (2014) relaxed pre-stressed participants by showing them a video featuring three green spaces (which had different biodiversity levels) or an urban control; they observed a significant mood improvement comparing the green spaces with the control, but no differences comparing the three green spaces. Similarly, Douglas and Evans (2022) did not observe significant differences in attention restoration and cognitive improvement after exposing their participants to videos with 8 or 2 species of birds singing. In contrast, *in-situ* studies of urban parks in the UK, have correlated higher biodiversity with increased Positive Affect (Cameron *et al.* 2020) and higher attention restoration (Wood *et al.* 2018). These differences could be explained by the different types of contact with biodiversity, *direct* vs *indirect* (i.e. video-based). Although media-based studies provide access to

Table 7. Experiment 4. Summary of the RM-ANOVA comparing the effect of park treatment on the three affective states.

		Experiment 4	
Affect	Component	F	*p*-value
Joviality	Park (Between-subjects)	0.404	0.75
	Stage of the procedure (Within-subjects)	28.58	<0.001
Serenity	Park (Between-subjects)	1.516	0.21
	Stage of the procedure (Within-subjects)	17.42	<0.001
Negative affect	Park (Between-subjects)	0.101	0.959
	Stage of the procedure (Within-subjects)	36.64	<0.001

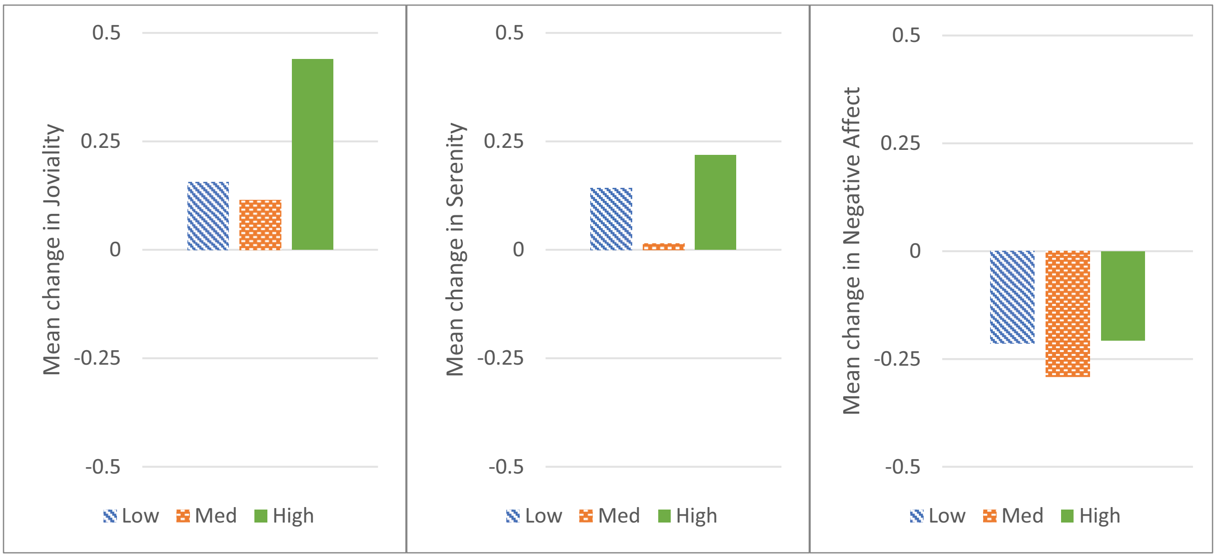

Figure 5. Experiment 4. Changes, from after receiving the stressor to after exploring the park, in the joviality (left), serenity (centre) and negative affect (right) scores by perceived biodiversity.

a wider population and allow better control of the experimental conditions (e.g. the same exposure, the same weather, the same park), *in-situ* measurements of well-being are likely to reflect a richer experience, which can include multi-sensory stimulation and engagement with biodiversity, in turn producing stronger feelings, especially for the Positive Affect (Browning *et al.* 2020).

Ultimately, even if there was no direct effect of the park biodiversity level on emotional well-being, there was no indication that increasing the number of plant species could be detrimental to the affective states. This finding provides evidence against the notion that high plant biodiversity may produce negative outcomes on wellbeing (Dallimer *et al.* 2012). Such contrast may reflect a comparison between designed and semi-natural green spaces (as in Dallimer et al.), in which denser, untamed vegetation may have prompted feelings of unsafety (Jorgensen *et al.* 2007). Instead, the virtual park was designed to feel unthreatening, being not crowded and without large animals (e.g. dogs). Although not conclusive, this evidence has value for the development of nature-based solutions. Since enhancing biodiversity is important to maintain the functionality of other ecosystem services (Fisher *et al.* 2021), appropriately designing biodiversity could minimise the risk of negative well-being outcomes.

Higher perceived biodiversity predicted higher positive affect

Although actual biodiversity showed a neutral effect on emotional well-being, this varied significantly across the levels of perceived biodiversity (i.e. the number of species people estimated in the park). A few nuances were found, depending on the stress condition and the language group. English-speaking participants who perceived a medium or a high level of biodiversity showed a higher increase in Joviality and Serenity, and a greater reduction in Negative Affect, than those who perceived the park as not biodiverse. Perceiving low biodiversity was also associated with reduced Joviality and Serenity, but only in unstressed participants. Unstressed participants may have experienced boredom due to the perceived low biodiversity, while their stressed counterparts felt uplifted. This again suggests that stress levels may play a role in the recovery process, in this case making a boring park able to induce joy and calm. Chinese-speaking participants who perceived High biodiversity reported only increased Positive Affect (Joviality and Serenity) compared to those who perceived low or medium biodiversity. These results are in line with previous studies that have found a positive effect on mental well-being more associated with perceived biodiversity than actual biodiversity (Gonçalves *et al.* 2021, Reining *et al.* 2021).

Interestingly, despite the parks' biodiversity being designed to be obvious, featuring attractive flamboyant flowers and non-threatening, endearing animals, all park variations received similar ratings of perceived biodiversity. Both the parks with 15 species (low biodiversity) and those with 28 species (high biodiversity) were perceived as 'high' in biodiversity (i.e. having 'a lot' of species) by roughly 60% of the English-speaking participants (Supporting information, Tables 8 and 9). This inaccurate estimation of the species richness from the public is not unprecedented (Lindemann-Matthies and Bose 2008) and has sometimes been defined as the 'people-biodiversity paradox' (Shwartz *et al.* 2014, Pett *et al.* 2016). Members of the public would prefer and feel better in spaces that they believe are very biodiverse but they would be unable to recognise the actual biodiversity of that space. Under this perspective, the results from our experiments are in line with Dallimer *et al.* (2012), whose participants reported higher well-being when perceiving a place as biodiverse, irrespectively of its actual biodiversity.

There are a few possible explanations about why the participants may have perceived all parks as similar in biodiversity. The vegetation structure, which included a low-density tree layer and three levels of height for the flowering plants (creeping, knee-high and waist-high), was kept consistent. The vegetation coverage has been cited as an important predictor of perceived biodiversity (Schebella *et al.* 2019), therefore the regular presence of the same trees and planting blocks across the park variations could have prompted similar perceptions. Another possible explanation is that perceptions of biodiversity could also be non-linear. Hypothetically, it may be easier to correctly perceive biodiversity when it is at the extremes (i.e. too little or too abundant) than when it is at any levels in between.

Finally, noticing the animals and the trees seemed to reduce Negative Affect and increase Serenity for some English-speaking participants. Noticing flowers instead had no effect, contrary to the expectations generated by a previous version of this experiment (Farris *et al.* 2024). In that study, a group of English-speaking participants who noticed the presence of flowers showed improved Positive Affect compared to the rest of the participants, even when the level of perceived biodiversity was accounted for. For Chinese-speaking participants, noticing flowers and grasses (草地) was instead associated with improved Joviality and Serenity, but only if the participants were stressed. In general, the results of these experiments support the findings of Passmore and Holder (2017), whose intervention showed that noticing nature can increase Positive Affect.

Cross-cultural findings

The analysis of the comments showed that the two language groups noticed different features. This could be due to the screen size of the device used to explore the park. The two groups also differed in the device used to take part in the study, as one group used mostly mobile devices (Chinese-speaking) while the other favoured laptops or larger screens (English-speaking). On a desktop/laptop, animals would have been much more noticeable than on a mobile screen.

The composition of the two language groups differed in many ways. Demographically, in terms of gender (Female English-speaking = 65%, Female Chinese-speaking = 35%), average age (Chinese-speaking participants were on average 10 years older than English-speaking participants) and Education Level. Nature connectedness was also different, with 50% of the Chinese-speaking sample reporting high Nature connectedness, compared with 30% of the English-speaking sample. This may suggest a different conceptualisation of the Inclusion of Nature in Self in the Chinese context, although this scale has been argued to be reliable in cross-cultural comparisons (Liu *et al.* 2023). Chinese-speaking participants also reported a weaker effect of the stressor alarm compared with the English-speaking respondents, which could be explained by their age and reduced sensitivity to that particular sound.

Despite these differences, both groups showed comparable improvements after their virtual tour of the park. This supports the notion proposed in previous studies that benefits provided by parks, including perceiving biodiversity, can go beyond geographical and cultural boundaries (Wood *et al.* 2018). For instance, in their analysis of psychological and physiological responses to different parks, Elsadek *et al.* (2019) found that Japanese and Canadian students were statistically similar. Sentiment analysis from a vast social network dataset (Huai and Van De Voorde 2022) showed that park users in Brussels (Belgium) and Shanghai (China) substantially agreed on what park features were positive. Perceived benefits provided by parks, such as ‘happiness’ and ‘relaxation’, were also argued to be the same in Turkey and the UK (Özgüner 2011), despite how the park was used is different in the two cultures.

Limitations

Despite the robust control exerted over the data collection and analysis, a few factors limit the generalisation of these findings. As in most online studies, the participants could not be supervised during the experiment. Although it was possible to remove some outliers using metadata (e.g. excessive completion time), it is impossible to establish to what extent the participants engaged with the procedure.

Moreover, this experiment focused on short-term improvement of well-being following exposure to virtual green space and the interaction with the parks’ biodiversity was only indirect and limited to visual stimulations. Although indirect interactions are easier to control and can reach larger audiences, it is possible that without the physical presence the effect of biodiversity may have been underestimated.

Finally, it is not clear what features were driving the perceptions of biodiversity. These seemed unrelated to the actual species number. Some hints from the comments suggested that noticing some features of the park’s biodiversity could be beneficial for well-being, but these were not consistent.

Conclusion

In summary, this experiment provided cross-cultural evidence of the beneficial effect of viewing a virtual park on mental well-being. Despite the demographic differences in the two language samples, the analyses showed similar responses, such as the significant improvement of the affective states when perceiving higher biodiversity and more evident improvement when recovering from a stressful event. This contributes to the previous notions that parks can be important providers of mental well-being, especially for those who are stressed. Although the level of biodiversity *per se* did not show a significant effect on well-being, we found no evidence that high park biodiversity could be detrimental. On a cautionary note, although the results of this study have been based on virtual reality, there is no intention to suggest that virtual nature alone could suffice as a provider of mental well-being. Instead, these results provide evidence that increasing biodiversity in real parks can improve well-being, provided that it is perceived.

Implication for practice

The implications for landscape management and design are multiple. This is compelling evidence that managing green spaces to increase biodiversity can be promoted without reducing the well-being provisioning. More biodiverse parks are more resilient against climate change and provide more ecosystem services. More importantly, designers of green spaces could aim to increase the perceived biodiversity, which has shown the potential to improve the well-being provided. Helping people to notice, perhaps through guided walks, signage and educational activities might help increase their perception and noticing of biodiversity and therefore offer more well-being benefits. The role of managers in sustaining and enhancing park landscapes for biodiversity is not to be underestimated, given the potential benefits for long-term well-being.

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