Journal Pre-proof

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PII: S0013-9351(24)02139-X

DOI: https://doi.org/10.1016/j.envres.2024.120232

Reference: YENRS 120232

To appear in: *Environmental Research*

Received Date: 8 July 2024

Revised Date: 22 October 2024

Accepted Date: 23 October 2024

Please cite this article as: Shen, H., Flouri, E., Cheng, Y., Li, Y., Wei, G.-X., Greenspace Use and Anxiety in Young Adults: The Role of Interoception, *Environmental Research*, https://doi.org/10.1016/j.envres.2024.120232.

Greenspace Use and Anxiety in Young Adults: The Role of Interoception

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Abstract

Objective: Greenspace is linked to the prevention and management of anxiety, but the underlying mechanisms remain unclear. This study aims to evaluate the association between greenspace use and anxiety in Chinese young adults, focusing on the mediating role of interoception.

Methods: This population-based study was conducted between September and October 2023 in four local universities in China. A total of 27,755 young adults were included. Greenspace use was assessed by self-report, anxiety by the Generalized Anxiety Disorder (GAD) assessment, and interoception by the Body Perception Questionnaire (BPQ). Generalized linear mixed models (GLMMs) and mediation models were utilized to analyze associations.

Results: The mean age of participants was 19.39 ± 1.64 years, with 10,944 (39.4%) being female. A total of 10,273 (37.01%) participants suffered from anxiety. GLMMs indicated that compared to their counterparts who did not visit green spaces at all in the past four weeks, those who visited once or twice, once a week, or several times a week had lower odds of anxiety. A lower level of interoception was associated with reduced odds of anxiety. Furthermore, interoception mediated much of the association between greenspace use and anxiety. These associations were robust in a series of sensitivity analyses.

Conclusions: These results suggest the crucial role of green spaces on interoception and anxiety and point to the importance of promoting student well-being through interaction with greenspace and nature. Further research is needed to better understand how interoception mediates the connection of greenspace and other aspects of the built environment with anxiety.

Keywords: greenspace use, anxiety, interoception, young adults

1 Introduction

Anxiety is a common mental health disorder among adolescents and young adults. More than 30% of young adults experience anxiety with 8.3% suffering from severe anxiety (Merikangas et al., 2010). Anxiety has a range of negative outcomes on mental and physical health, psychosocial function and academic performance, and has even been implicated in suicidal thoughts and suicide attempts (Cohen et al., 2015; Lepp et al., 2014). Adolescent anxiety also imposes economic burdens on families and societies (Xin et al., 2022). Consequently, preventing and managing anxiety in adolescents and young adults is of critical importance.

Some recent research has suggested that the built environment, and particularly greenspace, can be associated with both prevention and management of anxiety (Borgi et al., 2023; Bray et al., 2022; Liu et al., 2023). Greenspace refers to natural vegetation such as grass, plants, or trees and built green environments such as parks (Heo et al., 2021). Empirical evidence has demonstrated that the availability of greenspace is inversely correlated with anxiety levels in young people (de la Osa et al., 2024; Reece et al., 2021; Ryan et al., 2024). It appears, however, that the use of greenspace is probably a more critical factor than its proximity (Elliott et al., 2020). For example, one study indicated that the visit frequency to greenspace mediated the associations between residents of the greenest and well-being (White et al., 2021).

The influence of greenspace use on anxiety received particular attention during the COVID-19 pandemic (Borgi et al., 2023). For example, one study assessed greenspace use by asking monthly frequency of visits to greenspaces (including parks and gardens) during COVID-19 and found a decline in greenspace use, which correlated with increased anxiety (Lemyre et al., 2024), although another reported no association between greenspace use and anxiety (Heo et al., 2021). These inconsistent results may be because during COVID-19 people experienced dramatic disruptions and were exposed to several risk factors for mental health problems (Borgi et al., 2023), such as social isolation, academic or work-related pressure, and uncertainty about the future. These factors likely heightened anxiety levels and may have complicated the

relationship between greenspace use and anxiety during this period. Now that COVID-19 no longer represents a "global health emergency", it is important to explore the association between greenspace use and anxiety in adolescents and young adults. In China, the prevalence of anxiety among adolescents and young adults is high, especially after COVID-19, with recent studies showing rates of anxiety for Chinese adolescents between 7% and 46.7% (Zhou et al., 2023). Understanding how greenspace use may contribute to reducing anxiety in this population could provide insights for developing mental health interventions in the post-pandemic era.

The mechanisms by which greenspace can alleviate anxiety are several, including improved air quality, increased physical activity, enhanced social contact, and better immune-metabolic function (Bird et al., 2018; Bray et al., 2022; Hartig et al., 2014). Furthermore, greenspace may also be linked to anxiety because it modulates interoception, the integration of multisensory inputs, and the interpretation of the body's reactions to the environment (Ruotolo et al., 2024). The process by which the brain senses, interprets, and integrates signals originating from within the body is known as interoception (Khalsa et al., 2018), which coordinates homeostatic and behavioral responses, playing a crucial role in physical and mental health (Hubner et al., 2022; Nord and Gar, 2022). The three-dimensional model of interoception by Garfinkel and Critchley divides interoception into three key components: interoceptive accuracy, interoceptive sensibility, and interoceptive awareness (Garfinkel and Critchley, 2013). Interoceptive accuracy refers to the objective ability to accurately detect internal bodily signals, such as perceiving one's heartbeat. Interoceptive sensibility involves the subjective perception and beliefs about the body's physical state, often measured by self-report tools. Lastly, interoceptive awareness relates to meta-cognitive awareness of one's interoceptive abilities (Garfinkel and Critchley, 2013). In this study, we chose interoception sensibility as the focus because it can be measured using self-report questionnaires, and is therefore appropriate for very large-scale investigations. The most commonly used self-report measures of interoception are the Multidimensional Assessment of Interoceptive Awareness (MAIA) (Mehling et al., 2012) and the Body Perception Questionnaire (BPQ) (Cabrera et al., 2018).

These two measures assess distinct constructures: the MAIA is designed to capture an adaptive interoceptive style, with high scores considered adaptive, whereas the BPQ relates to anxiety-induced hypervigilance and somatization, assessing the dispositional tendency to pay attention to aversive physical symptoms, with high scores considered maladaptive (Trevisan et al., 2021; Vig et al., 2022a). The evidence for the relationship between anxiety and the MAIA is mixed. One study found that anxiety was positively associated with two subscales of the MAIA, namely Noticing and Body Listening, but negatively related to other subscales (Suzuki et al., 2021). Another study also showed positive correlations between anxiety and the Noticing subscale (Vabba et al., 2023). On the other hand, positive associations have been reported between anxiety and the BPQ (Poli et al., 2021; Vig et al., 2022b). These results suggest that paying too much attention to bodily sensations may exacerbate anxiety and hypochondriasis (Hoehn-Saric and McLeod, 2000; Khalsa et al., 2018).

Arguably, greenspace may possess qualities that modulate bodily self-experiences favorably (Ebisch, 2020). For instance, compared to conventional mindfulness training, training in green settings enhances mindful sensory experiences (Lymeus, 2019). A recent study found that interoception fostered connections with nature, thus improving well-being and pro-environmental behaviors (Branham, 2024). Butterfield and Martin highlighted that one of the mechanisms of a 'therapeutic garden' lies in its capacity to engage individuals in a multisensory experience with nature, encompassing the integration of vision, sound, touch, and smell (Butterfield and Martin, 2016). Engaging in greenspace may alleviate distractions associated with painful sensations, reduce hypersensitivity to uncomfortable bodily sensations, and improve the ability to regulate physical sensations (Branham, 2024). Thus, our representation of the environment may be formed by the integration of different types of bodily sensations. A recent study has indeed indicated that adaptive interoception is beneficial for emotional experiences when viewing images of natural environments (Ruotolo et al., 2024). Importantly, a link between greenspace and interoception may be particularly salient for anxiety, a disorder strongly linked to interoception.

Taken together, these findings suggest that the impact of greenspace on anxiety

may depend on the capacity to interpret the body's responses to environmental stimuli. Interoception may serve as a mechanism mediating the relationship between greenspace use and anxiety. To date, no study has explicitly examined this relationship among young adults. Therefore, we conducted a large population-based study to evaluate associations between greenspace use and anxiety in young adults in China, as well as the possible mediating role of interoception in this relationship. As hypersensitive bodily sensations are considered maladaptive and are associated with heightened anxiety (Hoehn-Saric and McLeod, 2000; Khalsa et al., 2018), we focused on maladaptive bodily sensations and utilized BPQ to measure interoception. We hypothesized that individuals who visited greenspace in the past month, regardless of frequency, would exhibit lower levels of interoception and anxiety compared to those who did not visit greenspace at all. Additionally, we hypothesized that interoception would mediate the relationship between greenspace use and anxiety.

2 Methods

2.1 Participants

This study employed a cluster sampling method and it selected young adults in China from four geographically dispersed universities located in Dalian, Fuzhou, Kaifeng, and Zhengzhou during September and October 2023. A total of 28,335 young adults were enrolled in the four universities, and all of them consented to participate. After informed consent was obtained, participants completed an online questionnaire survey. We utilized three separate lie-detection questions to ensure the validity of participant responses. Each question instructed participants to choose a specific answer: 'Always', 'Often', or 'Never'. Questionnaires with more than one incorrect response to these lie-detection questions were considered invalid, resulting in 167 invalid responses. Additionally, 413 questionnaires containing responses that deviated more than three standard deviations from the mean were also excluded as outliers. The online format of the survey required participants to complete all questions before submission, ensuring no missing values. After these adjustments, a total of 27,755 (Mean age: 19.39 ± 1.64,

39.4% female) valid questionnaires remained, resulting in a response rate of 97.95%.

2.2 Measures

Outcome

Anxiety was measured by the Generalized Anxiety Disorder-7 (GAD-7) assessment, a widely used evaluation tool that can effectively determine anxiety symptoms in a short time. GAD-7 includes seven items related to anxiety with scores ranging from 0 to 3 points. The measure provides a 0-21 severity score (0–4, normal; 5–9, mild anxiety symptoms; 10–14, moderate anxiety symptoms; and 15–21, severe anxiety symptoms) (Spitzer et al., 2006). Study participants were categorized into the non-anxiety group (normal) and the anxiety group (mild, moderate, and severe symptoms) (Liao et al., 2022).

Exposure

Based on previous studies (Lemyre et al., 2024; Ricciardi et al., 2023), greenspace use was assessed using a single-item screening measure: "*How often have you interacted with green spaces (such as parks, forests, meadows) in the past 4 weeks?"* Participants were asked to choose from the following options: Not at all in the past 4 weeks; One or two times in the past 4 weeks; Once a week; or Several times a week.

Mediator

Interoception was measured by the Body Perception Questionnaire-Very Short Form (BPQ-VSF), which indexes individual sensitivity to bodily sensations. The BPQ-VSF incorporates 12 statements about various bodily sensations (e.g., stomach and gut pains, facial twitches, dry mouth, urge to urinate). Participants rated their awareness of each sensation on a five-point scale from 'never' (1) to 'always' (5). Scores on the questionnaire range from 12 to 60, with higher values indicating greater sensitivity to bodily sensations (Wang et al., 2020).

Confounders

Several potential confounders were considered in the present study, including age (years), sex (male, female), grade (freshman, sophomore, junior, senior), body mass index (BMI; underweight, BMI < 18.5 kg/m^2; normal, 18.5 kg/ m^2 ≤ BMI < 24.0 kg/

m^2; overweight, 24.0 kg/ m^2 ≤ BMI < 28.0 kg/ m^2; obese, BMI ≥ 28.0 kg/ m^2) (Liu et al., 2023), physical activity level (low, moderate, high), cigarette smoking (yes or no), alcohol drinking (yes or no), number of siblings (0 vs ≥1), parental education level (the highest level of education completed by either parent: primary school and below, middle school, high school, college and above), and type of home district (main urban area, suburban area, town center, town-rural interface, and rural area).

2.3 Statistical analyses

Firstly, differences in exposure and confounders between the non-anxiety and anxiety groups were compared. For continuous variables, the mean and standard deviation (SD) were reported, and the analysis involved t-tests. Categorical data were presented as group size (%), and differences were evaluated via chi-square tests. These analyses were conducted in SPSS. Secondly, the region-based cluster random sampling method used in this study means that non-independence among individuals within the same cluster cannot be excluded (Sashegyi et al., 2000). To address this, generalized linear mixed models (GLMMs) were employed, treating regions as a random effect to account for the lack of independence among individuals. Two separate models were constructed: one with greenspace use and the other with interoception as predictors of anxiety. The intraclass correlation coefficient (ICC) was calculated to assess the proportion of variance in anxiety attributable to differences between regions. Odds ratios (ORs), and 95% confidence intervals (CIs) for these associations were estimated. This model was implemented in R using the lme4 package.

Additionally, analyses were conducted to explore the role of interoception in the relationship between greenspace use and anxiety using the Baron and Kenny approach (James et al., 2006). To account for the effect of different regions, GLMM was utilized in R using the lme4 package. The first GLMM was employed to examine the relationship between greenspace use and interoception. Then, two separate GLMMs were constructed to assess the mediation role of interoception: the first model included greenspace use as the sole predictor of anxiety, and the second model included both greenspace use and interoception to assess their combined effect on anxiety. This approach allowed for the examination of whether greenspace use predicted anxiety and

if the presence of interoception as a mediator weakened this relationship. Subsequently, a Sobel test was conducted to evaluate the significance of the indirect effects (Al Nima et al., 2013).

To ensure the robustness of the present findings, several sensitivity analyses were conducted. First, the sensitivity of the results to the inclusion of confounders was assessed by comparing models that incorporated a comprehensive set of confounders (adjusted models) with those that did not (crude models). All confounders including age, sex, grade, BMI, physical activity, smoking, drinking, number of siblings, parental education, and family domicile were incorporated into the models in one go in the GLMM. Second, according to GAD-7, we categorized anxiety into subtypes—normal (0-4), mild (5-9), moderate (10-14), and severe (15-21) —to examine how the association between greenspace use and anxiety may vary across different levels of symptom severity. Third, we tested whether confounders modified the associations between greenspace use and anxiety. Fourth, we compared models that included outliers with those that excluded them.

3 Results

3.1 Descriptive Statistics

Of the 27,755 participants, 10273 (37.01%) had at least some anxiety (Table 1). The mean age of the participants was 19.39 ± 1.64 years, and 10,944 (39.4%) were female. Compared with participants without anxiety, those with anxiety were older ($t = 10.49$, $p < 0.001$), had lower physical activity levels ($\chi^2 = 96.20$, $p < 0.001$), were less likely to have siblings ($\chi^2 = 4.30$, $p = 0.04$), were less likely to live in main urban areas ($\chi^2 = 43.84$, $p < 0.001$), were less likely to engage in greenspace visits frequently ($\chi^2 = 508.06$, $p < 0.001$), and had a higher score on interoception ($t = 97.50$, $p < 0.001$). No significant differences were found by sex ($\chi^2 = 0.04$, $p = 0.85$), grade ($\chi^2 = 7.52$, $p = 0.07$), BMI ($\chi^2 = 1.04$, $p = 0.79$), cigarette use ($\chi^2 = 2.62$, $p = 0.011$, alcohol use ($\chi^2 = 0.74$, $p = 0.39$), or level of parental education ($\chi^2 = 3.72$, $p = 0.45$).

3.2 Associations of greenspace use and interoception with anxiety

As shown in Table 2, more frequent visits to green spaces were associated with lower odds of anxiety symptoms. Specifically, compared to participants who did not visit green spaces at all in the past four weeks, those who visited one or two times during that period had an OR of 0.69 (95% CI: 0.64, 0.75), those visiting once a week had an OR of 0.52 (95% CI: 0.47, 0.57), and those visiting several times a week had an OR of 0.42 (95% CI: 0.39, 0.46). All these associations were statistically significant ($p < 0.001$, ICC = 0.02), and the random effect of region was not significant (z = 1.18, $p = 0.24$). The predicting role of greenspace use on anxiety remained significant after adjusting for age, sex, grade, BMI, physical activity, smoking, drinking, number of siblings, parental education, and family domicile ($p < 0.001$, ICC = 0.03), while the effect of region was not significant (z = 1.19, $p = 0.24$). Furthermore, a higher level of interoception was significantly associated with greater odds of anxiety symptoms (OR = 1.18, 95% CI: 1.17, 1.18, $p < 0.001$, ICC = 0.02), an association that remained significant even after adjusting for confounders (OR = 1.18, 95% CI: 1.17, 1.18, $p < 0.001$, ICC = 0.03). The random effect of region was not significant ($p > 0.05$).

We then split the anxiety group into mild, moderate, and severe groups. The results showed that in the adjusted models, more frequent greenspace use was significantly associated with lower odds of mild anxiety ($p < 0.05$), moderate anxiety ($p < 0.001$), and severe anxiety ($p < 0.001$) (Table S1). We also analyzed the associations (reported in the main analysis) between greenspace use and anxiety stratified by age, sex, grade, BMI, physical activity, smoking, drinking, number of siblings, parental education, and family domicile. The results showed that none of these confounders moderated the associations observed (all $p > 0.05$) (Table S2). Finally, the results showed that the associations remained significant when including the outliers (all $p < 0.001$) (Table S3).

3.3 The mediating role of interoception

To account for the random effect of region, GLMM was used to examine the associations between greenspace use and interoception while controlling for all the potential confounders. The results indicated that more frequent visits to greenspace were associated with lower levels of interoception (all $p < 0.001$, ICC = 0.03). To formally test for mediation, GLMM results showed that after controlling for

confounders, greenspace use was negatively associated with anxiety (all $p < 0.001$, ICC = 0.03). When interoception was also controlled, the effect of greenspace use was attenuated somewhat but was still significant (all $p < 0.001$, ICC = 0.03) (Table 3). A Sobel test confirmed that interoception significantly mediated the association between greenspace use and anxiety (all $p < 0.001$). Specifically, compared to participants who did not visit greenspaces at all over the past four weeks, those who visited greenspaces one or two times ($z = -4.62$, $p < 0.001$), once a week ($z = -7.81$, $p < 0.001$), and several times a week ($z = -10.12$, $p < 0.001$) exhibited lower anxiety, mediated by decreased interoception.

4 Discussion

In this large study of Chinese young adults, we investigated the association of greenspace use with anxiety, with a particular focus on the mediating role of interoception. The results showed that frequent greenspace use and lower levels of interoception were associated with reduced odds of anxiety in our sample of young adults. To our knowledge, this study is one of the few to investigate the link between greenspace use and anxiety in emerging adulthood in China, and it is the first to uncover the potential mediating mechanism of interoception in this association.

Our study indicated that frequent visits to greenspace are associated with a decreased likelihood of anxiety, consistent with findings from previous research. For example, a study examining the link between greenspace use and mental health in four European countries found that frequent visits were positively correlated with higher mental health scores, both across and within the individual countries studied (van den Berg et al., 2016). Another study revealed recently that individuals who visit green spaces more frequently exhibit lower levels of stress, anxiety, and depression compared to those who visit less often. Additionally, both the frequency of greenspace use and the presence of green views from home windows were inversely related to anxiety (Soga et al., 2021). Our study not only confirmed the beneficial impact of greenspace on anxiety but also included a sample size that was 7- and 13-fold larger, providing greater statistical power to detect associations.

The most intriguing result was that interoception mediated much of the association between greenspace use and anxiety. The BPQ (Body Perception Questionnaire) used in this study is a unidimensional measure of an individual's sensitivity to anxiety-related bodily sensations, particularly those associated with discomfort or distress (Toda et al., 2020). Young adults often face numerous challenges from study, work, and social roles, leading to stress that may result in somatization and hypersensitivity to bodily sensations (Krygsman et al., 2023). Importantly, two recent studies have indicated that higher levels of residential surrounding greenspace are associated with a lower risk of somatization (Madzia et al., 2019; Toda et al., 2020). Our study built on this previous work on anxiety and interoception and on greenspace and interoception to suggest a mechanism linking these paths. We think that the reduction in interoception (and subsequently anxiety) through greenspace use suggested by our study is due to two reasons. First, according to Attention Restoration Theory (ART), high-intensity stimulation and stress in urban lifestyles lead to attention fatigue, whereas natural environments provide relaxed attention restoration (Kaplan and Kaplan, 1989). Similarly, natural environments also help individuals divert their attention away from maladaptive bodily sensations to external stimuli (visual, auditory, and other). By reducing hyperawareness of uncomfortable bodily sensations and alleviating the distress associated with these sensations, individuals may experience a greater sense of physiological regulation in natural settings (Branham, 2024). This improved regulation can enhance their self-efficacy in managing bodily sensations, serving as a protective factor against anxiety (Ruotolo et al., 2023). Second, green spaces promote physical activity, such as walking and running (Bray et al., 2022), in turn enhancing the regulation and control of the brain over the bodily consciousness (Skrinar, 1986), thus decreasing “noise” in body signals and identifying internal sensations more adaptively (da Silva Machado et al., 2019). These adaptive changes in bodily awareness not only diminish excessive vigilance and hypersensitivity to minor bodily fluctuations but also help reduce the tendency to overreact to these sensations, thereby alleviating anxiety symptoms.

Our findings have important implications. They provide policymakers and

universities with evidence promoting student well-being through interaction with greenspace and nature. For example, initiatives like the ‘whole university approach’ advocate for the development of mentally healthy universities. This framework emphasizes the importance of the social and natural environments in enhancing young adults’ well-being (Lemyre et al., 2024). Universities might consider adopting structured programs, such as outdoor exercise programs, or "green breaks," which encourage individuals to engage actively with nature. Furthermore, given the mediating role of interoception in the relationship between greenspace use and anxiety, future interventions could benefit from incorporating strategies that regulate interoception alongside greenspace exposure. For instance, research has shown that mindfulness training conducted in natural settings is more effective compared to conventional indoor practice (Lymeus, 2019).

At the same time, we must acknowledge some important study limitations. First, we only asked about the frequency of greenspace visits in the last month but not the types of green spaces visited, their quality, the duration of visits, as well as the activities (e.g., walking, running, interacting with others) carried out in those spaces. Second, blue space, defined as all visible surface water like rivers, ponds, lakes, and oceans (Völker and Kistemann, 2011), has also been shown to have a strong association with anxiety levels (Bray et al., 2022) and should be considered in future investigations. Third, other objective factors, such as the greenspace/bluespace availability, environmental issues (e.g. noise, air pollution), and environmental qualities can significantly influence anxiety levels (Lan et al., 2022; Liu et al., 2023). Fourth, while the current study primarily relied on cross-sectional data, longitudinal studies are needed to gain a more comprehensive understanding of the temporal relationships between greenspace use, interoception, and anxiety. Future studies should both include follow-ups and consider Structural Equation Modeling (SEM) to explore the interplay between these environmental factors and anxiety to better capture their combined effects over time. Fifth, as highlighted by the three-dimensional model of interoception, interoception comprises multiple dimensions and measures. In this study, we focused solely on interoceptive sensibility, assessed using the BPQ, which targets dysfunctional

attention to bodily sensations. To obtain a deeper insight into interoception and its role in the relationship between greenspace use, interoception, and anxiety, future research should include a broader range of assessments that capture all facets of interoception.

5 Conclusion

This study showed the mediating role of interoception between greenspace use and anxiety levels among young adults. These findings may provide policymakers and healthcare authorities with tools to enhance mental well-being in the young adult population. Further research is needed to better understand the role of interoception. If the links we identified are causal they suggest that green environments may help regulate bodily sensations, thereby improving emotional states. Recently, a randomized controlled trial found that in depressed patients a single 60-minute walk in nature significantly decreased negative affect compared to walking in an urban setting (Watkins-Martin et al., 2022). Our findings could help guide the design of similar trials testing the role of greenspace exposure in reducing anxiety via reducing interoception.

Glossary

Greenspace: natural vegetation such as grass, plants, or trees, and built green environments such as parks.

Greenspace use/visit: the frequency of interaction with green spaces (such as parks, forests, and meadows)

Interoception: the extent to which the brain senses, interprets, and integrates signals originating from within the body.

Acknowledgments

The authors wish to extend their sincere gratitude to the universities in China that provided the essential data for this study.

Author contributions

Haoran Shen: Formal analysis, Writing - Original Draft, Visualization. Eirini Flouri:

Writing – Review, Methodology. Yang Cheng: Conceptualization, Investigation. Youfa Li: Resources, Funding acquisition, validation. Gao-Xia Wei: Conceptualization, Writing – Review, Supervision, Funding acquisition.

Funding Sources

This work is supported by STI 2030—Major Projects 2021ZD0200500 and the National Natural Science Foundation of China: 32471133.

Reference

Al Nima, A., et al., 2013. Anxiety, Affect, Self-Esteem, and Stress: Mediation and Moderation Effects on Depression. Plos One. 8.

Bird, W., et al., Unifying mechanisms: nature deficiency, chronic stress, and inflammation. In: M. van den Bosch, et al., Eds.), Oxford Textbook of Nature and Public Health: The role of nature in improving the health of a population. Oxford University Press, 2018, pp. 0.

Borgi, M., et al., 2023. Reduction in the use of green spaces during the COVID-19 pandemic and its impact on mental health. Health & Place. 83.

Branham, L., 2024. Embodied earth kinship: interoceptive awareness and relational attachment personal factors predict nature connectedness in a structural model of nature connection. Frontiers in Psychology. 15.

Bray, I., et al., 2022. Exploring the role of exposure to green and blue spaces in preventing anxiety and depression among young people aged 14-24 years living in urban settings: A systematic review and conceptual framework. Environmental Research. 214.

Butterfield, A., Martin, D., 2016. Affective sanctuaries: understanding Maggie's as therapeutic landscapes. Landscape Research. 41**,** 695-706.

Cabrera, A., et al., 2018. Assessing body awareness and autonomic reactivity: Factor structure and psychometric properties of the Body Perception Questionnaire-Short Form (BPQ-SF). Int J Methods Psychiatr Res. 27**,** e1596.

Cohen, B. E., et al., 2015. State of the Art Review: Depression, Stress, Anxiety, and Cardiovascular Disease. American Journal of Hypertension. 28**,** 1295-1302.

da Silva Machado, D. G., et al., 2019. Short-Term Psychological and Physiological Effects of Varying the Volume of High-Intensity Interval Training in Healthy Men. Percept Mot Skills. 126**,** 119-142.

de la Osa, N., et al., 2024. Long-term exposure to greenspace and anxiety from preschool and primary school children. Journal of Environmental Psychology. 93.

Ebisch, S. J. H., 2020. The Self and Its Nature: A Psychopathological Perspective on the Risk-Reducing Effects of Environmental Green Space for Psychosis. Frontiers in Psychology. 11.

Elliott, L. R., et al., 2020. Research Note: Residential distance and recreational visits to coastal and inland blue spaces in eighteen countries. Landscape and Urban Planning. 198.

Garfinkel, S. N., Critchley, H. D., 2013. Interoception, emotion and brain: new insights link internal

physiology to social behaviour. Commentary on: "Anterior insular cortex mediates bodily sensibility and social anxiety" by Terasawa et al. (2012). Social Cognitive and Affective Neuroscience. 8, 231-234.

Hartig, T., et al., Nature and Health. In: J. E. Fielding, (Ed.), Annual Review of Public Health, Vol 35, 2014, pp. 207-+.

Heo, S., et al., 2021. Impact of Changed Use of Greenspace during COVID-19 Pandemic on Depression and Anxiety. International Journal of Environmental Research and Public Health. 18.

Hoehn-Saric, R., McLeod, D. R., 2000. Anxiety and arousal: physiological changes and their perception. Journal of Affective Disorders. 61, 217-224.

Hubner, A. M., et al., 2022. Interindividual differences in interoception modulate behavior and brain responses in emotional inference. NeuroImage. 261, 119524-119524.

James, L. R., et al., 2006. A tale of two methods. Organizational Research Methods. 9, 233-244.

Kaplan, R. S.-W., Kaplan, S., The Experience of Nature: A Psychological Perspective. 1989.

Khalsa, S. S., et al., 2018. Interoception and Mental Health: A Roadmap. Biological Psychiatry-Cognitive Neuroscience and Neuroimaging. 3, 501-513.

Krygsman, A., et al., 2023. Anxiety symptoms before and during the COVID-19 pandemic: A longitudinal examination of Canadian young adults. Journal of Anxiety Disorders. 99.

Lan, Y., et al., 2022. Daily space-time activities, multiple environmental exposures, and anxiety symptoms: A cross-sectional mobile phone-based sensing study. Science of the Total Environment. 834.

Lemyre, A., et al., 2024. Mental wellbeing among higher education students in England during the pandemic: A longitudinal study of COVID-19 experiences, social connectedness and greenspace use. British Educational Research Journal.

Lepp, A., et al., 2014. The relationship between cell phone use, academic performance, anxiety, and Satisfaction with Life in college students. Computers in Human Behavior. 31, 343-350.

Liu, Y. Y., et al., 2023. Does awareness of diabetic status increase risk of depressive or anxious symptoms? Findings from the China Multi-Ethnic cohort (CMEC) study. Journal of Affective Disorders. 320, 218-229.

Lymeus, F., 2019. Mindfulness training supported by a restorative natural setting: Integrating individual and environmental approaches to the management of adaptive resources.

Madzia, J., et al., 2019. Residential Greenspace Association with Childhood Behavioral Outcomes. Journal of Pediatrics. 207, 233-240.

Mehling, W. E., et al., 2012. The Multidimensional Assessment of Interoceptive Awareness (MAIA). Plos One. 7.

Merikangas, K. R., et al., 2010. Lifetime Prevalence of Mental Disorders in U.S. Adolescents: Results from the National Comorbidity Survey Replication-Adolescent Supplement (NCS-A). Journal of the American Academy of Child and Adolescent Psychiatry. 49, 980-989.

Nord, C. L., Gar, S. N., 2022. Interoceptive pathways to understand and treat mental health conditions. Trends in Cognitive Sciences. 26, 499-513.

Poli, A., et al., 2021. Item Reduction, Psychometric and Biometric Properties of the Italian Version of the Body Perception Questionnaire-Short Form (BPQ-SF): The BPQ-22. International Journal of Environmental Research and Public Health. 18.

Reece, R., et al., 2021. Exposure to green space and prevention of anxiety and depression among

young people in urban settings: a global scoping review. Journal of Public Mental Health. 20**,** 94-104.

Ricciardi, E., et al., 2023. Perceived Social Support Mediates the Relationship between Use of Greenspace and Geriatric Depression: A Cross-Sectional Study in a Sample of South-Italian Older Adults. International journal of environmental research and public health. 20.

Ruotolo, F., et al., 2024. Well-being and multisensory urban parks at different ages: The role of interoception and audiovisual perception. Journal of Environmental Psychology. 93.

Ruotolo, F., et al., 2023. Psychological Reactions during and after a Lockdown: Self-Efficacy as a Protective Factor of Mental Health. International journal of environmental research and public health. 20.

Ryan, S. C., et al., 2024. Advancing Understanding on Greenspace and Mental Health in Young People. Geohealth. 8.

Sashegyi, A. I., et al., 2000. Application of a generalized random effects regression model for cluster-correlated longitudinal data to a school-based smoking prevention trial. American Journal of Epidemiology. 152**,** 1192-1200.

Skrinar, G. S., Bullen, B. A., Cheek, J. M., McArthur, J. W., & Vaughan, L. K, 1986. Effects of Endurance Training on Body-Consciousness in Women. Perceptual and Motor Skills. 62(2), 483–490.

Soga, M., et al., 2021. A room with a green view: the importance of nearby nature for mental health during the COVID-19 pandemic. Ecol Appl. 31**,** e2248.

Spitzer, R. L., et al., 2006. A brief measure for assessing generalized anxiety disorder -: The GAD-7. Archives of Internal Medicine. 166**,** 1092-1097.

Suzuki, N., et al., 2021. Effects of Interoceptive Sensibility on Mental Health during the Coronavirus Disease 2019 Pandemic. International Journal of Environmental Research and Public Health. 18.

Toda, M. T., et al., 2020. Residential Surrounding Greenspace and Mental Health in Three Spanish Areas. International Journal of Environmental Research and Public Health. 17.

Trevisan, D. A., et al., 2021. Adaptive and Maladaptive Bodily Awareness: Distinguishing Interoceptive Sensibility and Interoceptive Attention from Anxiety-Induced Somatization in Autism and Alexithymia. Autism Research. 14**,** 240-247.

Vabba, A., et al., 2023. A longitudinal study of interoception changes in the times of COVID-19: Effects on psychophysiological health and well-being. Heliyon. 9.

van den Berg, M., et al., 2016. Visiting green space is associated with mental health and vitality: A cross-sectional study in four european cities. Health & Place. 38**,** 8-15.

Vig, L., et al., 2022a. Questionnaires of interoception do not assess the same construct. Plos One. 17.

Völker, S., Kistemann, T., 2011. The impact of blue space on human health and well-being - Salutogenetic health effects of inland surface waters: a review. Int J Hyg Environ Health. 214**,** 449-60.

Wang, N., et al., 2020. Factor Structure and Psychometric Properties of the Body Perception Questionnaire-Short Form (BPQ-SF) Among Chinese College Students. Front Psychol. 11**,** 1355.

Watkins-Martin, K., et al., 2022. The effects of walking in nature on negative and positive affect in adult psychiatric outpatients with major depressive disorder: A randomized-controlled

study. Journal of Affective Disorders. 318**,** 291-298.

White, M. P., et al., 2021. Associations between green/blue spaces and mental health across 18 countries. Scientific Reports. 11.

Xin, S., et al., 2022. Changes of social anxiety in Chinese adolescents during 2002-2020: An increasing trend and its relationship with social change. Children and Youth Services Review. 142.

Zhou, K., et al., 2023. Prevalence of and factors influencing depression and anxiety among Chinese adolescents: a protocol for a systematic review. Bmj Open. 13.

Tables

Table 1 Characteristics of Study Participants by Anxiety Status

Characteristics	Participants, No. (%) (N = 27,755)			
	With anxiety (n=10,273)	Without anxiety (n=17,482)	t/χ^2	*p* value
City			77.53	< 0.001
Zhengzhou	3113 (30.3)	5140 (29.4)		
Kaifeng	2214 (21.6)	3248 (18.6)		
Dalian	1975 (19.2)	4053 (23.2)		
Fuzhou	2971 (28.9)	5041 (28.8)		
Age	19.53 ± 1.74	19.31 ± 1.58	10.49	< 0.001
Sex			0.04	0.85
Female	4044 (39.3)	6900 (39.5)		
Male	6229 (60.6)	10582 (60.5)		
Grade			7.52	0.07
Freshman	4129 (40.2)	7029 (40.2)		
Sophomore	2815 (27.4)	4989 (28.5)		
Junior	2307 (22.5)	3711 (21.2)		
Senior	1022 (9.9)	1753 (10.0)		
BMI			1.04	0.79
Underweight	2061 (18.0)	3571 (18.6)		
Normal	5945 (55.8)	10145 (56.2)		
Overweight	1478 (12.3)	2487 (12.4)		
Obese	789 (5.6)	1279 (5.5)		
Physical Activity Level			96.20	< 0.001
Low	3606 (35.1)	5152 (29.5)		
Moderate	5099 (49.6)	9508 (54.1)		
High	1568 (15.3)	2822 (16.1)		
Cigarette Smoking			2.62	0.11
No	9939 (96.7)	16974 (97.1)		
Yes	334 (3.3)	508 (2.9)		
Alcohol Drinking			0.74	0.39
No	9979 (97.1)	16950 (97.0)		
Yes	294 (2.9)	532 (3.0)		
Number of Siblings			4.30	0.04
0	3204 (31.2)	5245 (30.0)		
≥1	7069 (68.8)	12237 (70.0)		
Parental Education Level			3.72	0.45
Primary school and below	2056 (20.0)	3658 (20.9)		
Middle school	3701 (36.0)	6231 (35.6)		
High school	3003 (29.3)	5017 (28.7)		
College and above	1513 (14.7)	2576 (14.7)		
Family Domicile			43.84	< 0.001
Main urban area	4172 (40.6)	7747 (44.3)		
Suburban area	1910 (18.6)	2960 (16.9)		
Town center	854 (8.3)	1414 (8.1)		
Town-rural interface	978 (9.5)	1447 (8.3)		
Rural area	2359 (23.0)	3914 (22.4)		
Greenspace Use			508.06	< 0.001
Not at all in the past 4 weeks	1508 (14.7)	1498 (8.6)		

One or two times in the past 4 weeks	4055 (39.5)	5804 (33.2)		
Once a week	1953 (19.0)	3746 (21.4)		
Several times a week	2755 (26.8)	6434 (36.8)		
Interoception	25.94 ± 9.18	16.76 ± 5.68	97.50	< 0.001

Table 2 Associations of Greenspace Use and Interoception with Anxiety

Variables	Crude Model		Adjusted Model	
	OR [95%CI]	*p* value	OR [95%CI]	*p* value
Greenspace Use				
Not at all in the past 4 weeks	Ref.		Ref.	
One or two times in the past 4 weeks	0.69 [0.64, 0.75]	< 0.001	0.71 [0.65, 0.77]	< 0.001
Once a week	0.52 [0.47, 0.57]	< 0.001	0.54 [0.49, 0.59]	< 0.001
Several times a week	0.42 [0.39. 0.46]	< 0.001	0.45 [0.41, 0.49]	< 0.001
Interoception	1.18 [1.17, 1.18]	< 0.001	1.18 [1.17, 1.18]	< 0.001

Abbreviations: OR: Odds ratio; CI: Confidence interval.

Table 3 Association Between Greenspace Use, Interoception, and Anxiety

Variables	Model 1		Model 2	
	OR [95%CI]	*p* value	OR [95%CI]	*p* value
Greenspace Use				
Not at all in the past 4 weeks	Ref.		Ref.	
One or two times in the past 4 weeks	0.71 [0.65, 0.77]	< 0.001	0.78 [0.71, 0.86]	< 0.001
Once a week	0.54 [0.49, 0.59]	< 0.001	0.63 [0.56, 0.70]	< 0.001
Several times a week	0.45 [0.41, 0.49]	< 0.001	0.57 [0.51, 0.63]	< 0.001
Interoception			1.18 [1.17, 1.18]	< 0.001

***Notes*:** Model 1 analyzed the direct relationship between the frequency of greenspace use and anxiety levels after controlling for confounders.

Model 2 incorporated interoception to evaluate its mediating effect on the relationship between greenspace use and anxiety after controlling for confounders.

Highlights

- Frequent greenspace use alleviates anxiety in young adults;
- Greenspace use decreases hypersensitive bodily sensations;
- Interoception is a key mediator in the link between greenspace use and anxiety;
- Incorporating greenspaces in university design can promote mental well-being.

Declaration of interests

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

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: