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Short Communication

Impacts of Campus Green Spaces Exposure on Psychological Stress of College Students Based on Apple Watch Data Analysis

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Abstract

Current research has revealed significant benefits of green space exposure (GSE) on psychological stress. However, few studies have explained the cumulative effects of GSE and how these effects vary across different demographic groups, such as gender and education level. This research aims to evaluate the long-term effects of GSE on psychological stress and heart rate variability (HRV) while examining how these effects vary across different demographic groups, such as gender and education level, utilizing Apple Watch data to provide a more objective measure of these effects. In a 6-week experiment, 43 college students were required to engage in GSE at least three times a week, each lasting no less than 10 minutes, based on their schedules. During the experiment, participants wore the Apple Watch continuously to collect physiological data automatically. This study demonstrates a significant reduction in emotional disturbance and notable changes in HRV amplitude following GSE, with variations observed based on gender and education levels. These findings underscore the substantial psychological health benefits of GSE.

Keywords— Apple Watch, College student, Green space exposure, Heart rate variability (HRV), Nature prescription, Stress reduction

1 Introduction

Psychological stress refers to an individual's psychological state of tension, anxiety, or unease when faced with changes in internal or external environments [1]. This state typically arises when the individual perceives an inability to cope with or control these changes or challenges effectively. Mental health, or psychological health, is defined as the state that enables individuals to handle life stresses, recognize their abilities, engage productively in learning, work, and life, and contribute to society [2]. It is closely related to physical health and is a fundamental component of overall well-being. Recent studies have highlighted the growing concern regarding psychological stress and mental health issues among college students. The transition to higher education often coincides with significant psychological challenges, including depression, anxiety, and stress, which can adversely affect students' academic performance and overall well-being [3]. The prevalence of psychological stress problems in this population has increased substantially, with many students experiencing severe psychological distress without seeking adequate treatment [4]. Research further indicates that factors such as academic distress, financial stress, and inadequate coping skills exacerbate these issues, contributing to a high incidence of psychological disorders on college campuses [5, 6, 7, 8].

The restorative effects of green spaces on college students' psychological stress are supported by several theoretical frameworks. The Biophilia Hypothesis proposes that humans have an intrinsic affinity for nature, and this connection, when fostered through green spaces, can significantly improve psychological stress [9]. Attention Restoration Theory (ART) suggests that natural environments facilitate cognitive recovery by enabling effortless attention, which reduces mental fatigue [10, 11, 12]. Additionally, Stress Reduction Theory (SRT) posits that nature exposure induces a state of relaxation, mitigating stress and enhancing psychological well-being [13].

Dose-response studies on green space exposure (GSE) have consistently demonstrated a positive relationship between the extent of exposure and improvements in psychological outcomes. Longitudinal and cross-sectional surveys, as well as ecological studies utilizing GIS to measure environmental variables like the Normalized Difference Vegetation Index (NDVI), reveal that higher levels of GSE are associated with significant reductions in stress and enhancements in mood and well-being [14]. The research also identifies mediating factors such as physical activity, social cohesion, and reduced environmental stressors (e.g., noise), which help explain the mechanisms through which green space contributes to improved psychological stress [15]. Furthermore, individual variability in response to GSE suggests that specific populations may benefit more significantly, highlighting the importance of tailored approaches in environmental health interventions [16].

Observational research indicates that the effects of GSE may vary across demographic groups in terms of gender and education level. Studies have shown that men generally experience more significant reductions in cardiovascular and respiratory mortality rates with increased GSE compared to women, who show no significant associations [17]. Additionally, individuals with lower education levels tend to benefit more from GSE, particularly regarding mental health improvements and positive pregnancy outcomes [18, 19]. These findings underscore the importance of considering demographic differences when evaluating the impact of GSE on health outcomes.

Apple Watch, equipped with electronic sensors that measure physiological signals when placed on or near the skin, has proven to be a highly effective tool for monitoring and recording up to 58 data points related to fitness, health, and well-being. Among these, Heart Rate Variability (HRV) is a key metric, that serves as an indicator of changes in both physical and emotional states with high accuracy and feasibility [20]. The Apple Watch's capabilities make it particularly advantageous for psychological stress assessments, offering comprehensive and precise data collection at a finer temporal scale, which is more objective and persuasive than self-reported measures. Furthermore, its ability to automatically measure and record data non-intrusively enhances the reliability of research outcomes [21].

Several studies highlight GSE's importance in reducing student stress and promoting well-being, particularly in urban university settings. A nationwide study in China found that green spaces significantly alleviate uncertainty and life stress among students, emphasizing the mental health benefits of nature exposure in high-pressure environments like Shanghai [22]. Additionally, initiatives to create "green universities" have shown that enhancing the accessibility and attractiveness of campus green spaces can contribute to student well-being and sustainability efforts [23]. Given Shanghai's urban density and the academic stress faced by students, Shanghai Jiao Tong University provides an ideal setting to explore the cumulative effects of green space exposure on mental health.

Existing research on green space exposure has largely relied on observational studies or single, fixed-dose interventions, which do not adequately address the optimal frequency and duration of exposure needed to effectively reduce psychological stress [24, 25]. The evidence base does not clearly understand how different exposure patterns influence psychological outcomes, particularly in regular, short-term interactions with green spaces. This research aims to evaluate the long-term effects of GSE on psychological stress and heart rate variability (HRV), while examining how these effects vary across different demographic groups, such as gender and education level, utilizing Apple Watch data to provide a more objective measure of these effects.

2 Methods

This study used simple random sampling to recruit healthy students from the Minhang campus of Shanghai Jiao Tong University, Shanghai, China, between February 20 and March 3, 2024. Students were considered eligible if they were aged 18-29, were not on daily psychiatric medications, had no cardiovascular diseases, physical disabilities, or chronic underlying conditions, and had normal or corrected vision and normal hearing. Recruitment was conducted via physical posters, social media, BBS, and snowball sampling. Eligible participants were required to have been using an Apple Watch Series 4 or later for at least one year, running watchOS 9 or later. The study received ethical approval from the Human Research Ethics Committee of Shanghai Jiao Tong University (Approval No. H20240036I). It adhered to the principles of the Belmont Report and the Declaration of Helsinki, with informed consent obtained from all participants [26]. The minimum sample size was calculated to be 33 with a sampling rate of 0.25, a two-sided 95% confidence interval, a width of 0.3, and a margin of error of 0.15 based on previous studies [27, 28], but to account for potential dropouts, 50 participants were initially selected. Seven participants withdrew during the study, leaving a final sample of 43 (22 males and 21 females).

The psychological health of participants was assessed using the Profile of Mood States (POMS) Short Form [29], a validated self-report questionnaire designed to evaluate emotional disturbances across seven dimensions: tension, anger, fatigue, depression, vigor, confusion, and self-esteem. The short form used in this study, revised by Zhu Beili [30] in 1995, is tailored to Chinese college and high school students, providing standard scores with a reliability range of 0.62 to 0.82 (average r = 0.71) and high validity. Each item is rated on a 5-point Likert scale, and the Total Mood Disturbance (TMD) score is calculated by subtracting the sum of two positive mood dimensions from the sum of five negative mood dimensions, then adding a correction value of 100. A higher TMD score indicates a more negative emotional state, with thresholds defined as 288 for high, 287-207 for medium, and <208 for low emotional disturbance [30, 31].

Psychological stress occurs when perceived environmental demands exceed an individual's coping ability, leading to emotional, cognitive, behavioral, and biological responses [32]. Physiologically, stress manifests in fluctuations such as increased heart rate and cortisol levels [33]. Objective stress measurements often include indicators like heart rate, heart rate variability (HRV), and salivary cortisol levels [34]. HRV, which reflects autonomic nervous system activity, is particularly valuable as higher HRV indicates better stress resilience, while lower HRV correlates with higher psychological stress [35, 36]. In this study, the Apple Watch's built-in photoplethysmography

(PPG) sensor was used to monitor HRV. The device automatically records HRV data approximately every two hours, calculating the standard deviation of normal-to-normal intervals (SDNN), a key time-domain measure of HRV that evaluates overall heart rate variability over 24 hours. This method ensures participant comfort and safety during monitoring, providing reliable data on their physiological stress levels [37]. Participants were asked to wear their Apple Watch all day during the 6 weeks of the experiment, both pre- and post-GSE HRV data were automatically collected via the Apple Watch.

For the analysis of HRV, we utilized the cosinoRmixedeffects model, a statistical tool for fitting mixed-effects cosinor models that account for individual variability in cyclical data patterns [38]. This model focuses on key parameters: MESOR (Midline Estimating Statistic of Rhythm), which represents the average HRV level; amplitude, indicating the range of HRV oscillation; acrophase, marking the time of the peak HRV within a cycle; and peak time, the specific point when HRV reaches its maximum. Research shows lower MESOR and amplitude are associated with higher psychological stress and diminished resilience. At the same time, shifts in acrophase and peak time often indicate disruptions in circadian rhythms linked to mental health issues like anxiety and depression [35]. These HRV changes, automatically tracked by the Apple Watch, provide insight into how the autonomic nervous system responds to psychological stress before and after green space exposure, offering a detailed view of the body's stress responses.

The experimental site was selected at the Minhang Campus of Shanghai Jiao Tong University, situated in a subtropical monsoon climate zone. The study was conducted from March 4 to April 14, 2024, during the spring season when temperatures gradually rose. During this period, sunrise times ranged from 6:17 AM to 5:27 AM, and sunset times from 5:55 PM to 6:22 PM [39]. Participants were provided with a guidebook as shown in Figure 1 detailing 12 specific campus green spaces and walking trails to facilitate consistent GSE.

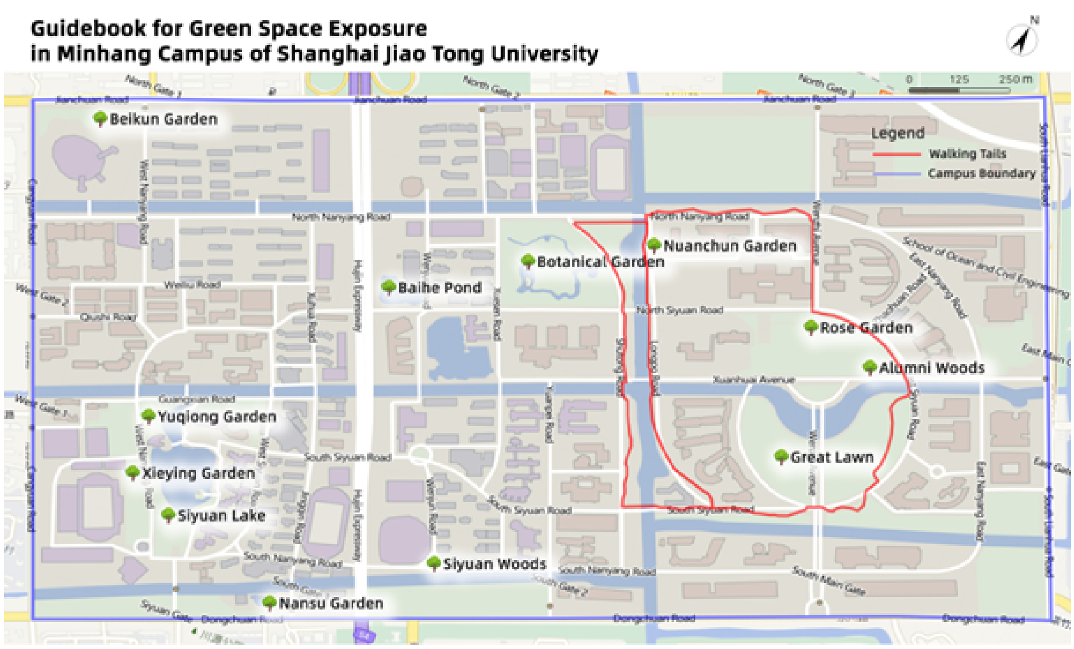

Figure 1.
Guidebook for GSE in Minhang campus of Shanghai Jiao Tong University

This study employed an innovative approach to assess participants' exposure to green spaces. The core tool used was the Apple Watch's fitness tracking application, which recorded participants' activities in real-time, allowing precise tracking of their movement patterns, time spent, and duration of exposure in green spaces. To ensure the completeness and accuracy of the data, participants were also asked to provide a detailed GSE log. This log required them to document the frequency and duration of each exposure session. By integrating real-time data from the Apple Watch with self-reported log entries, the study could comprehensively evaluate the dose of GSE. This combination of advanced technology and traditional logging methods enhanced the efficiency of data collection and the reliability of the study's findings.

3 Results

The study included a total of 43 participants, consisting of 22 males and 21 females, with an average age of 23.14 years. Among them, 51.16% were Master students. Over the 5-week intervention period, participants engaged in an average of 3.45 times GSEs per week, with each session lasting an average of 27.71 minutes. This resulted in an average weekly exposure dose of 95.64 minutes.

The POMS demonstrated high internal consistency, with Cronbach's alpha values of 0.82 pre-intervention and 0.84 post-intervention (Table 1). The intervention led to a notable decrease in the average Emotional Disturbance score by 14.49 points, indicating a positive impact on psychological stress. Due to the non-normality of the data, the Wilcoxon Signed-Rank Test was employed, revealing a significant difference in POMS scores post-intervention (V=723, p=0.003). The most significant changes were observed in the negative mood dimensions, while positive dimensions remained unchanged.

Table 1. Change in outcomes of the Wilcoxon signed-rank test scale before and after the intervention

POMS	TMD	Tension	Anger	Fatigue	Depression	Energy	Panic	Ego
V	723.000**	504.500**	624.000**	710.500***	414.000*	267.500	609.000***	375.500
p	0.003	0.002	0.004	0.001	0.047	0.056	0.001	0.647

* Significant at the level of 0.05
** Significant at the level of 0.01
*** Significant at the level of 0.001

3.1 Changes in HRV Before and After Green Space Exposure

This study examined the effects of GSE on HRV, focusing on key metrics such as MESOR, amplitude, and acrophase. A mixed-effects cosinor model was applied with HRV as the dependent variable and GSE status as the independent variable. Results showed that after GSE, the average MESOR remained nearly unchanged (53.88 before vs. 53.80 after, p=0.906). No significant changes were observed in acrophase or peak time. At the same time, the amplitude significantly decreased from 10.70 to 9.04 (p=0.036), indicating that GSE primarily influenced HRV amplitude, which may suggest physiological adaptation or stress response.

3.2 HRV and Gender Differences

Further analysis explored gender differences in HRV using a mixed-effects cosinor model. The results indicated significant gender differences in several HRV parameters. Women had lower average MESOR (50.06 vs. 57.49, p=0.034) and amplitude (8.28 vs. 10.41, p=0.002) compared to men, with a more advanced acrophase and earlier peak time. These findings highlight the importance of considering gender in HRV analysis, as it significantly affects physiological rhythms.

3.3 Impact of Green Space Exposure on HRV by Gender

A mixed-effects cosinor model was also used to assess the interaction between gender and GSE on HRV. Results indicated a significant interaction effect on HRV amplitude (p=0.028), with men showing a more pronounced decrease in amplitude post-exposure than women. However, no significant interaction effects were found for MESOR, acrophase, or peak time. These results suggest that gender moderates the physiological response to GSE, particularly in HRV amplitude.

3.4 Impact of Green Space Exposure on HRV by Education Level

The study further explored the interaction between GSE and education level on HRV using a mixed-effects cosinor model. The results indicated that individuals with a Ph.D. degree showed a significant change in HRV amplitude after GSE compared to those with a bachelor's degree (p=0.004), while other educational levels did not show significant differences. This suggests that higher education levels might be associated with different physiological responses to GSE, as indicated by changes in HRV amplitude. The interaction between GSE and education level could reflect varying stress perceptions and adaptation among individuals with different educational backgrounds.

3.5 Differences in HRV on Exposure vs. Non-Exposure Days

Lastly, the study assessed HRV differences between GSE days and non-exposure days using a mixed-effects cosinor model. The analysis revealed that the MESOR, amplitude, and peak time did not differ significantly between exposure and non-exposure days. However, there was a marginally significant difference in acrophase (p=0.056), suggesting a possible shift in physiological rhythms on exposure days. These findings indicate that while most HRV parameters remain stable regardless of exposure, there may be subtle changes in physiological responses associated with GSE timing. Further research with larger sample sizes may be needed to understand these effects fully.

4 Key Findings Summary

The study revealed a significant reduction in emotional disturbance scores following the intervention and notable changes in HRV amplitude in response to GSE. Variations in HRV were also observed based on gender and education levels, highlighting the differential impacts of GSE on physiological responses for different groups. Overall, the findings suggest that GSE has a substantial positive effect on psychological health.

Given these results, campus planners should prioritize integrating accessible and attractive green spaces into campus design, ensuring that these areas are available to all students regardless of their schedules or backgrounds. For example, creating walking paths, quiet zones, and diverse green areas could maximize the mental health benefits for the university population. For health professionals, the study highlights the importance of prescribing regular green space exposure as a preventive and therapeutic measure for managing stress and improving mental health. Tailoring GSE recommendations based on individual characteristics such as gender and education level may enhance the efficacy of these interventions. Developing "green prescriptions" could become a low-cost, widely accessible mental health strategy. Lastly, students should be encouraged to engage with green spaces regularly, understanding that even short periods of exposure can contribute to stress relief and overall well-being. Universities can promote initiatives such as outdoor study sessions, guided nature walks, and relaxation areas in green spaces to foster more frequent use.

This research is significant for several reasons. First, it provides insights into the long-term impact of GSE on psychological stress by examining the response-dose relationship. Second, it introduces an innovative assessment strategy using the Apple Watch for fine-scale biomarker data collection, enabling continuous, non-invasive physiological monitoring. This approach offers an alternative to traditional randomized controlled trials by employing a first-week blank control to mitigate individual differences. The cost-effective and accessible nature of these interventions, combined with the significant health benefits, highlights the untapped potential of nature in improving human well-being.

Statements and Declarations

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Conflicts of Interest

The authors declare that they have no conflicts of interest related to this work.

Ethical Considerations

This study was approved by the Shanghai Jiao Tong University Institutional Review Board for Human Research Protections (Approval No. H20240036I) and adhered to the principles of the Belmont Report and the Declaration of Helsinki. Informed consent was obtained from all participants.

Data Availability

The raw questionnaire data and Apple Watch physiological data are not publicly available due to ethical restrictions. However, the datasets analyzed during the current study are available from the corresponding author upon reasonable request.

Authors Contribution

Liyao Zou contributed to the conceptualization, study design, investigation, experimentation, data analysis, and manuscript writing. **Liqing Zhang** contributed to the conceptualization, study design, funding acquisition, supervision, review, and editing of the manuscript. All authors read and approved the final manuscript.

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