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NEUROCOGNITIVE IMPACTS OF SALUTOGENIC LANDSCAPE DESIGN IN NEIGHBOURHOOD PARKS: AN EEG STUDY ON COGNITIVE RESTORATION

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Abstract

This study examines how park users engage with different spaces, focusing on their experiences in environments enriched by salutogenic and restorative landscape attributes. Investigating the neurocognitive responses to park effects, an electroencephalography (EEG) experiment (n=20, within-subject) was conducted to measure mental performance during exposure to various salutogenic landscape attributes in Taman Aman, Petaling Jaya (TAPJ), and Taman Rekreasi Indah, Shah Alam (TTSA). The analysis includes six primary parameters: Attention, Engagement, Excitement, Interest, Relaxation, and Stress. Statistical analysis (paired t-test with Holm-Bonferroni correction) were conducted to assess significant differences between the EEG metrics across locations. The findings indicate that exposure to salutogenic landscapes resulted in a reduction in mental fatigue, with higher Relaxation and lower Stress at TTSA than TAPJ ($t = -7.94$, $p < .001$; $t = 5.87$, $p < .001$), higher Excitement at TAPJ ($t = 3.46$, $p = .003$), higher Attention and Interest at TTSA ($t = -3.30$, $p = .004$; $t = -2.23$, $p = .038$), and non-significant differences for Engagement ($p = .226$). These findings enhance our understanding of the relationship between spatial design and cognitive recovery in urban green spaces, providing valuable insights for landscape architects and urban planners in designing healthier, more restorative urban environments.

Keywords: Neighbourhood Park, Neurocognitive, Psychological impact, Salutogenic design

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INTRODUCTION

Urban residents face heightened stress risks due to a hectic lifestyle and other contributing urban stressors. Research on the relationship between psychological well-being and urban design has increased in recent years. Scholars have long debated the impact of urban life on stress, considering factors like overcrowding, poor environmental quality, traffic, and work-life balance (Ward Thompson *et al.*, 2016). These challenges adversely affect people's health, particularly their mental well-being. Urban green spaces, especially neighbourhood parks, have received a lot of attention in recent years for their ability to improve people's well-being and promote positive human behaviour in the living environment (Shobri *et al.*, 2021). While research shows that parks promote social and recreational activities for physical well-being, there is still a gap in identifying how spatial design effects mental performance, particularly in terms of reducing mental fatigue. Parks with salutogenic and cognitively restorative attributes can promote mental recovery, yet the neurocognitive evidence in real settings remained limited. Little is known about the association between the human mind and the environment (Akpınar, 2021), specifically how our brain (cognitive) corresponds with the environment they experienced.

Urban green spaces have an important function in mental health and cognitive restoration (Olszewska-Guizzo *et al.*, 2022). It is crucial to understand how landscape components contribute to cognitive and psychological well-being. Salutogenic design principles, based on Antonovsky's (1996) Sense of Coherence (SOC) theory emphasise an environment that promotes psychological resilience and mental well-being. However, there is a lack of actual neuropsychological evidence to support these ideas. This study uses EEG-based neurocognitive analysis to assess the cognitive and psychological effects of salutogenic neighbourhood parks. Most studies on the restorative potential of green spaces use self-reported data rather than objective neuropsychological markers. The use of EEG performance metrics offers a more scientifically grounded approach to investigating how different landscape design attributes influence cognition, stress and relaxation. Therefore, this study aims to investigate the EEG-based mental performance metrics across various salutogenic landscape attributes in neighbourhood parks, and identify which attributes are associated with increased relaxation and reduced stress.

LITERATURE REVIEW

The Impact of Landscape Design on Neurocognitive Function

Landscape design could have an important role in supporting cognitive restoration, which includes reducing mental fatigue and improving cognitive functioning. According to the Attention Restoration Theory (Kaplan, 1995), exposure to natural environments can improve attention and cognitive restoration.

Researchers discovered that recognising this relationship assists urban designers in improving environmental quality and indirectly encouraging positive behaviours (Ward Thompson *et al.*, 2016). Many scholars observed that people living environment influences their emotions and psychological well-being (Xingrui & Ibrahim, 2024). Studies from throughout the world shows that applying neuro-based design is viable. In Edinburgh, a mobile EEG study found that walking from urban busy streets to green spaces promoted restorative neural processes and improved happiness (Aspinall *et al.*, 2015). A study in Finland observed that nature stimuli increase Alpha activity and physiological restoration (Grassini *et al.*, 2022). In Japan, contemplative gardens and forest therapy sessions increased cognitive function and mood, served as model for therapeutic garden for hospital and parks (Hiramasu *et al.*, 2022). Experimental research indicates that time spent in natural settings offers both perceived and actual benefits, such as reducing cognitive fatigue and improving mood. The Attention Restoration Theory (Kaplan, 1995) and the Stress Reduction Theory (Ulrich, 1991) propose that natural environments can replenish cognitive resources depleted by daily activities. Neuroimaging studies with EEG and functional magnetic resonance imaging (fMRI) (Yen *et al.*, 2023; Grassini *et al.*, 2022) demonstrated increased alpha brainwave and reduce amygdala activity in natural setting, indicating a relaxed but attentive state that is important for mental restoration.

Salutogenesis and Salutogenic Design

The term salutogenesis was first coined by sociologist Aaron Antonovsky in 1979 whose research focused on stress, health, and well-being. His research examined ways to improve or provide health benefits (Bauer *et al.*, 2020). Antonovsky presented the scientific community with the salutogenic phrase and idea of Sense of Coherence (SOC). He defines the SOC as a person's reflection of life in response to stressful situations (Mittelmark, 2016). The concept of salutogenesis then expanded to the design fields. Alan Dilani (2008) introduced Psychosocially Supportive Design, which incorporates SOC theory into architecture to improve the healthcare facilities design. Golembiewski (2012) takes this a step further by incorporating neurological components into architectural design for mental health care, with a focus on cognitive recovery through rehabilitation approaches. Maikov (2016) has extended these principles to landscapes using the Emotional Character Line Method (ECLM) to create therapeutic garden spaces. Each space combines visual, sensory, environmental, cultural and social components to promote mental health and mental resilience in a variety of settings.

METHODOLOGY

This study employed a quantitative approach using EEG field experiments at selected neighbourhood parks. The details regarding the selection of study sites and attributes, as well as the EEG experimental protocol, are as follows:

Salutogenic Design Attributes: Experimental Stimulus

The salutogenic design attributes were based on the basis of the salutogenic and cognitive landscape stimuli that derived from the conceptual model we had developed in our previous research (Syed *et al.*, 2023; Thani *et al.*, 2022)). Figure 1 shows the details of the salutogenic and cognitive design attributes.

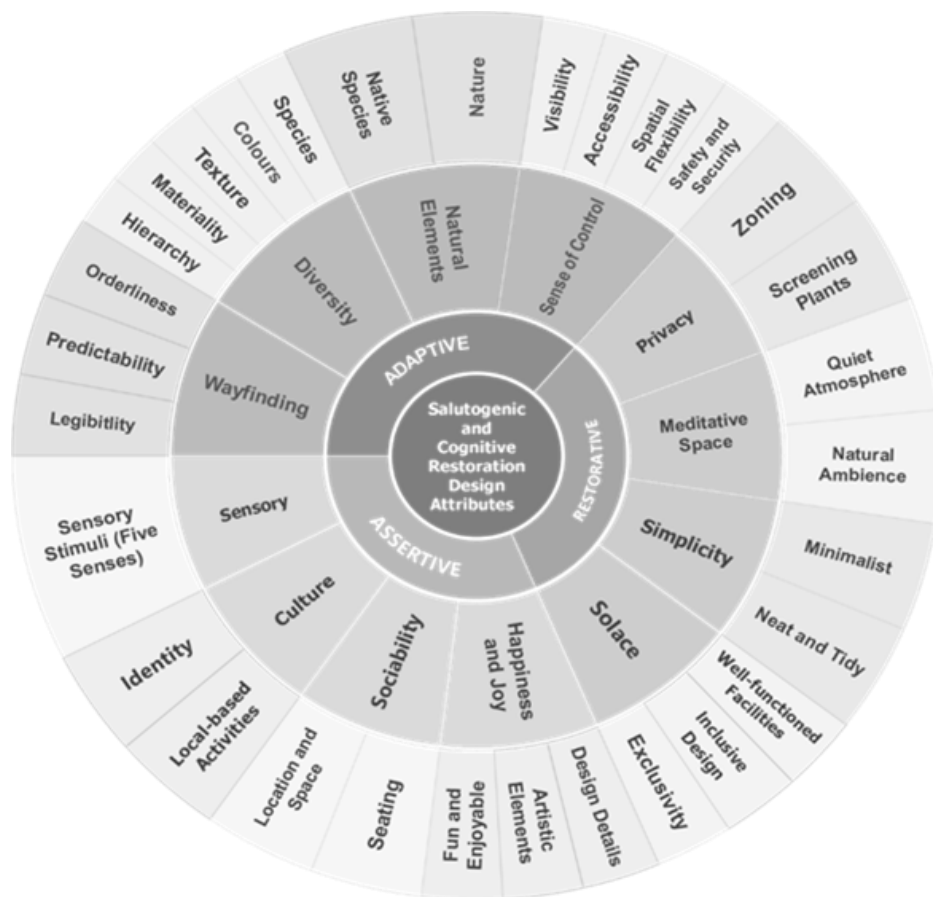


Figure 13: Salutogenic and Cognitive Design Attributes

Source: Authors (2022, 2023)

Each of the salutogenic design attributes are briefly defined as follows:

Adaptive stimuli

Stimuli that trigger involuntary attention, enhancing focus and environmental awareness, promoting a sense of control and increasing user concentration.

Restorative stimuli

Stimuli that promote relaxation through open space, waterbodies, vistas, minimal elements, and lush greenery.

Assertive Stimuli

Stimuli that promote sense of welcoming and belonging through sensory, cultural, tactile, and vibrant landscape elements.

Study Sites

Two neighbourhood parks, Taman Aman in Petaling Jaya (TAPJ) and Taman Rekreasi Indah (Tasik Tengah) in Shah Alam (TTSA), were selected for this study. These parks are located in urban residential areas and primarily serve as green spaces for local residents. Based on our previous research on salutogenic and cognitive attributes (Thani *et al.*, 2022), result from the site assessments indicates that TAPJ and TTSA possessed excellent salutogenic and cognitive restorative stimuli, which are important variables to be assessed in EEG field experiment. Figures 2 and 3 show the selected locations for EEG experimental study at both neighbourhood parks.

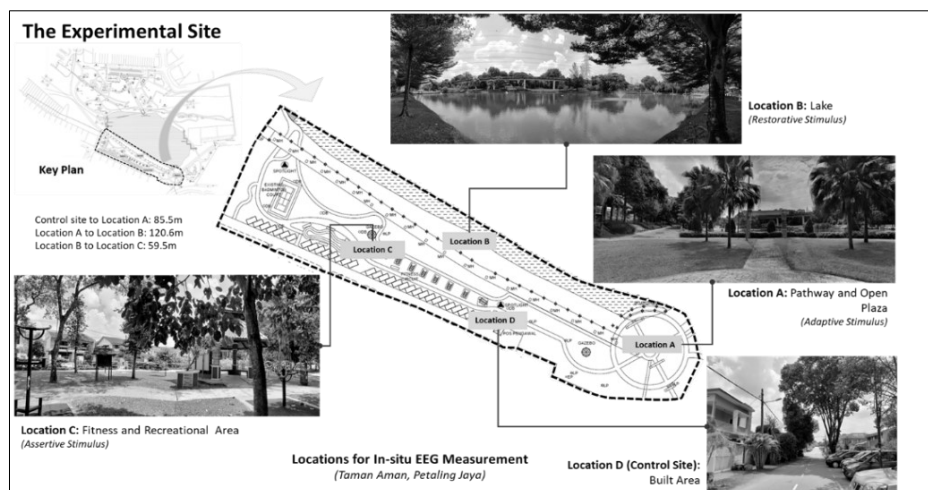


Figure 2: Selected locations at Taman Aman for EEG field experiments
Source: Authors (2025)

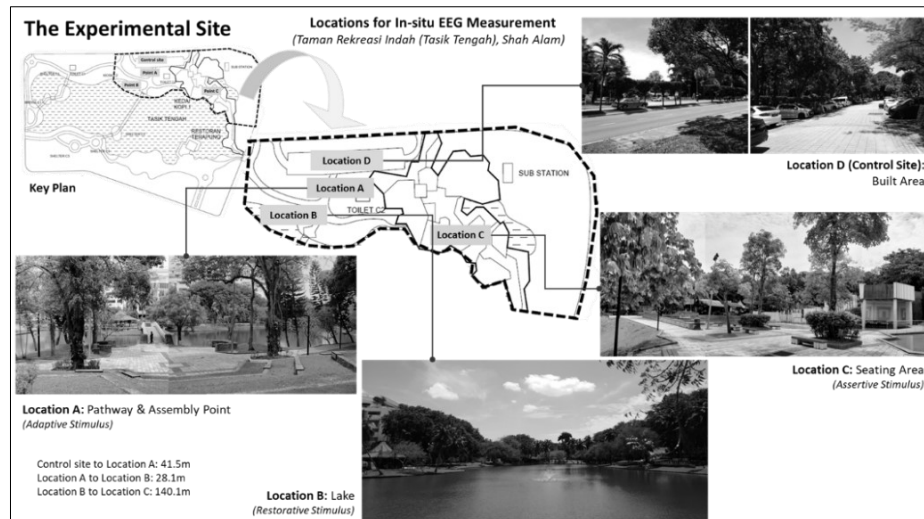


Figure 3: Selected locations at Taman Rekreasi Indah for EEG field experiments
Source: Authors (2025)

Subjects

The convenience sampling method was used to recruit participants for this study. Recruitment involved forwarding a request for voluntary participation to park users at both sites. A total of 20 subjects, aged 20 to 33 years, were recruited, ensuring gender balance ($n=10$ males and $n=10$ females). This study followed Declaration of Helsinki and obtained ethical approval from Universiti Malaya Research Centre (UMREC) prior to the commencement of data collection involving human subjects. The participant's anonymity, safety, and confidentiality were guaranteed, and participant's consent were obtained before experiment.

Experimental Protocol

A day prior to the experimental schedule, participants were notified via text message. They were instructed to follow certain instructions, such as getting sufficient sleep and rest, avoiding physically demanding activities, refraining from applying hair wax or spray, and not taking any medications the day before the experiment.

During the day of experiments, participants received detailed information about the study's procedures, and written consent was obtained. The EEG device was calibrated and installed on each participant's head. Participants were asked to close and open their eyes alternately for two minutes to obtain the baseline data. Next, they were instructed to walk to the experimental location, sit on a chair facing the selected landscape scene for three minutes, followed by

closing their eyes for two minutes before moving to another sit-and-view location. Once the recording for all scenes was completed and the device was removed, participants received a token of appreciation and were dismissed. The overall duration of experiment was approximately 30 to 45 minutes per participant. Figure 4 shows the EEG headset and a participant wearing the equipment during experiment.

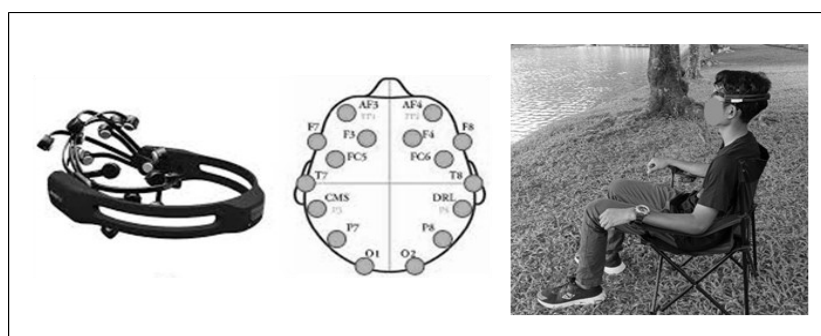


Figure 4: EEG Emotiv EPOC+ device (left), 14 electrodes (middle) and participant wearing the device during field experiment
 Source: Authors (2023)

EEG Data Acquisition and Analysis

The brainwave data were collected using the Emotiv EPOC+ EEG device. This non-invasive device offers the benefit of 14 electrodes data acquisition, corresponding to the international 10–20 position system (Wehrman *et al.*, 2021). During the experiment, the brainwaves were captured by connecting the headset with the software via USB Bluetooth to the laptop. Figure 5 shows the EEG signal of mental performance captured during experiment.

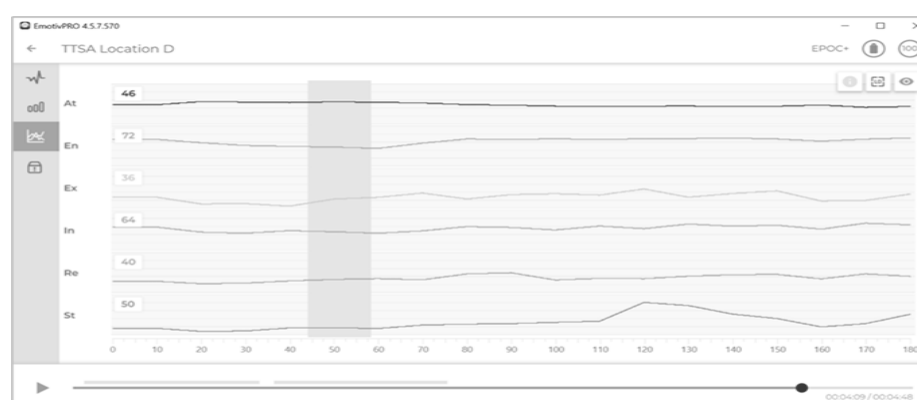


Figure 5: EEG mental performance signal captured during field experiments
 Source: Authors (2025)

For data analysis, the EEG signal processing was conducted through EmotivPRO software. After data cleaning and artifact removal, the mental performance analysis pipeline was selected to generate the mean value of mental performance for each parameter. In this analysis pipeline, the EEG signal for mental performance metrics data were converted to CSV file and averaged to get the mean value of each parameter (*Performance Metric Reports |EmotivPRO Analyzer*, 2024). The extracted mean values then exported to SPSS v27 for further statistical analysis. The key parameters measured is shown in Table 1.

Table 11: Key parameters of Mental Performance Metric

Performance Metric Parameters	Indicator
Interest (In)	Measure a stimulus's attraction or displeasure.
Excitement (Ex)	Measure the intensity of reaction or stimuli.
Engagement (En)	Measure person's level of engagement during a task.
Attention (At)	Measure prolonged concentration on a single job.
Relaxation (Re)	Measure relaxation after intense focus.
Stress (St)	Measure mental tension during a task.

Source: www.emotiv.com (2025)

RESULTS AND DISCUSSION

Mental Performance Distribution Across Locations

The EEG mental performance is varied from location to location and reflects the different characteristics of the landscape attributes in each park. The distribution of mental performance at both parks is shown in Figure 6.

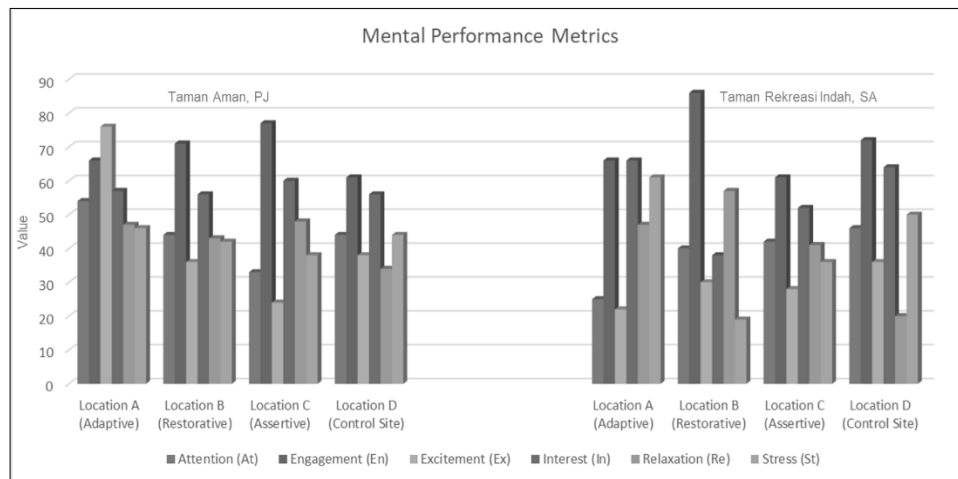


Figure 6: Distribution of EEG mental performance across locations at TAPJ and TTSA

Source: Authors (2025)

For Attention (At), the highest attention was measured at TAPJ Location A (*adaptive* stimuli) with 54 values, followed by TTSA Location C (*assertive* stimuli) with 42 values. This suggests that structured landscapes, particularly adaptive spaces, promote mental engagement and concentration, supporting the Attention Restoration Theory (ART) by Kaplan (1995). For Engagement (En), the highest value was found at Location A at both TAPJ and TTSA (*adaptive* stimuli) with 66 values. These results suggested that Engagement (En) is associated with cognitive and sensory stimulation, which is prominent in environment that have clear direction, visibility and implying visual susceptibility (Attar, 2022; Darfler *et al.*, 2022). TAPJ showed highest levels of Excitement (Ex) at Location A with 76 values. In TTSA, the Excitement (Ex) levels averagely lower than in TAPJ with only 36 values.

Overall, the mental performance showed higher levels of excitement in TAPJ than TTSA. The possible reason could be influenced by the availability of more recreational and leisure facilities in TAPJ than in TTSA. A study by Farooq *et al.* (2020) observed that structured pathways, diverse vegetation and interactive elements contribute to emotional attachment. For Interest (In), the highest values (52) were recorded at TTSA Location C, emphasising the influence of semi-structured landscapes that encourage exploration and curiosity. TTSA Location B had the highest relaxation scores, emphasising the idea that restorative landscapes with lush greenery, picturesque vista, shade and water elements promote mental relaxation. The lowest stress levels were found at TTSA Location B. Consistent with paired t-tests ($n = 20$, Holm-Bonferroni), Relaxation was higher and Stress lower at TTSA than TAPJ ($t = -7.94$, $p < .001$; $t = 5.87$, $p < .001$), Excitement higher at TAPJ ($t = 3.46$, $p = .003$), Attention higher at TTSA ($t = -3.30$, $p = .004$), and Engagement non-significant ($p = .226$) (refer Table 2).

Table 2: Statistical summary of EEG mental performance metrics

Metric	TAPJ Mean $\pm$ SD	TTSA Mean $\pm$ SD	Mean Diff (TAPJ – TTSA)	t(df=19)	p (Holm)	Cohen's dz
Attention	55.2 $\pm$ 4.8	61.8 $\pm$ 6.5	-6.5	-3.30	0.011	-0.738
Engagement	58.9 $\pm$ 8.3	56.5 $\pm$ 5.1	2.4	1.25	0.226	0.280
Excitement	59.0 $\pm$ 6.2	53.2 $\pm$ 5.3	5.7	3.46	0.011	0.774
Interest	57.2 $\pm$ 4.9	61.3 $\pm$ 5.4	-4.1	-2.23	0.076	-0.499
Relaxation	48.6 $\pm$ 5.1	64.5 $\pm$ 6.5	-15.9	-7.94	<.001	-1.776
Stress	66.3 $\pm$ 7.1	53.6 $\pm$ 8.0	12.6	5.87	<.001	1.313

Note: Mean difference is TAPJ minus TTSA; negative values indicate higher scores at TTSA. Holm–Bonferroni correction applied across six mental performance metrics.

This confirms that natural, restorative environments with minimal urban interventions significantly reduce stress responses (Wang *et al.*, 2020). These findings are consistent with Attention Restoration Theory (Kaplan, 1995) and Stress Recovery Theory (Ulrich, 1983), both of which emphasise the

restorative and cognitive benefits of green spaces, particularly in urban environments.

Mental Performance and Salutogenic Landscape Attributes

The results show how different landscape typologies influence mental performance by highlighting the neurocognitive impacts on cognitive engagement, relaxation and stress recovery. Table 3 tabulate the relationship between mental performance and salutogenic landscape attributes.

Table 3: Relationship between mental performance and salutogenic landscape attributes

Salutogenic Attributes	Location (Highest Value)	Mental Performance Findings	Landscape Typologies
<i>Adaptive</i>	TAPJ Location A / TTSA Location C	High attention and excitement, suggesting cognitive stimulation.	An open space surrounded by plants, walkways, and promenade. Outdoor cafeteria
<i>Restorative</i>	TTSA Location B/ TAPJ Location C	Lowest stress, highest relaxation, optimal for mental restoration.	A lake surrounded by greenery Outdoor gym, promenade
<i>Assertive</i>	TTSA & TAPJ Location C	High engagement and interest, balancing interaction and relaxation.	Social and recreational spaces
Control Site	TTSA & TAPJ Location D	Average EEG responses, lacking distinctive restorative or stimulating features.	Parking spaces and roadside

The findings shows that *adaptive* landscapes provide a dynamic interaction between built and natural elements that stimulate cognitive functions and improve mental focus (Browning *et al.*, 2020). A study by Darfler *et al.* (2022) noticed that presence of clear spatial layout, structured pathways and visual focal points has been associated with increased sustained attention and mental alert. In addition, interactive spaces such as outdoor cafeterias in TTSA provide multisensory stimulation that promotes higher neural activity, thus increasing engagement and cognitive alertness (Akpinar *et al.*, 2021). These findings are consistent with Attention Restoration Theory (Kaplan, 1995), which posits that structured environmental elements increase attention by providing directed cognitive engagement. Based on the findings, it was observed that the areas with restorative landscapes like lake and lush greenery recorded the highest relaxation and lowest stress in the EEG mental performance readings. *Restorative* landscapes, characterised by dense vegetation, water elements and open natural vistas facilitate psychophysiological recovery from stress (Wu *et al.*, 2022). The presence of blue spaces (such as lakes and water bodies) is associated with enhanced relaxation and lower cortisol levels, an important biomarker of stress

(Ward Thompson *et al.*, 2016). *Assertive* landscapes integrate elements that encourage active participation and social interaction like outdoor gym in TAPJ and outdoor cafe in TTSA. The presence of recreational spaces such as outdoor fitness area and interactive plazas stimulates sensorimotor and cognitive functions and promotes engagement without inducing excessive stress (Zeng *et al.*, 2021). These landscapes provide a transitional balance between cognitive arousal and relaxation that supports emotional resilience and sustained mental well-being. These findings are consistent with Cognitive Load Theory (Sweller, 2011), which suggests that environments with moderate cognitive demands optimise mental engagement and minimise cognitive overload, that will help in reducing mental fatigue. Control sites are characterized by low landscape diversity and minimal natural elements, which result in reduced cognitive and emotional engagement. Research has shown that urban hardscapes devoid of greenery fail to facilitate cognitive restoration or emotional relief, leading to increased mental fatigue and stress accumulation (Browning *et al.*, 2020).

CONCLUSION

This study highlights the significant impact of landscape attributes on neurocognitive function, mental well-being and stress recovery. By categorising landscapes into *adaptive*, *restorative* and *assertive* based on salutogenic attributes, the findings provide a structured framework for designing urban environments that support mental health. *Adaptive* landscapes attributes enhance cognitive engagement and alertness through structured design, clear wayfinding, and dynamic visual elements. *Restorative* attributes promote relaxation and stress reduction by incorporating open spaces, water features and minimal interventions to create tranquil environments that facilitate mental restoration. *Assertive* landscapes strike a balance between engagement and relaxation by integrating sensory stimulation, cultural elements, and social spaces, fostering a sense of belonging and emotional resilience. In contrast, control sites lacking these beneficial elements show minimal cognitive or emotional benefits, emphasising the importance of deliberate urban landscape design. Future research should focus on longitudinal EEG studies to assess neurocognitive changes over time and further explore how different landscapes influence mental well-being. By incorporating EEG-based restorative attributes into park design guidelines, local authorities can incorporate these findings into practical health promotion strategy in relation to urban design and landscape planning.

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ETHICAL STATEMENT

The authors adhere to the ethical procedures from Declaration of Helsinki and Universiti Malaya Research Ethics Committee (UMREC) (Ref. No: UM.TNC2/UMREC_1109) before commencing the data collection.

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