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Neural signatures of older adults as indicators of the age-friendliness of the built environment

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ABSTRACT

The frequency and time older adults spend in the outdoor built environment depends on the age-friendliness of the outdoor environment features. An age-friendly environment can reverse the speed of decline in the functional capacity of older adults. Most of the existing studies that assessed the age-friendliness of the built environment employed subjective rating scales that rarely consider the cognitive processing capacity of older adults. The present study used electroencephalography (EEG), Global Positioning System (GPS), and a subjective rating scale to investigate how the older adult brains response to different environmental features or situations at specific locations. The results from an experiment with four older adults indicate that age-friendly, stress-inducing, and adverse features of the outdoor built environment construct different neural signatures for cognitive processing. These suggest the feasibility of using cognitive responses from older adults to continuously diagnosis the built environment and will be essential in determining what and when age-friendly interventions are needed in a timely manner. This study will pave the way towards automation and digitisation of built environment assessment.

Keywords: age-friendly cities and communities, built environment, electroencephalogram (EEG), older adults, wearable sensing.

INTRODUCTION

The global population is ageing, with an increasing number of older adults (people aged 65 or above) experiencing a decline in functional capacity (United Nations, 2019). Mobility in the built environment is becoming more complex and can be cognitively demanding and emotionally stressful to its residents, especially older adults (Tilley et al., 2017). Research has shown that older adults residing in areas with environmental barriers, such as poor sidewalk conditions, path obstructions, inadequate street lighting, and poor traffic calming devices, are at greater risk of reporting a decline in functional capacity (Twardzik et al., 2019). Appropriate interventions such as designing an age-friendly built environment can directly influence older adults' activity levels, general health, overall satisfaction with life, and may reverse the speed of decline in the functional capacity of older adults (WHO, 2007). An increasing number of researchers have studied how the built environment affects older adults' physical activity (Hawkesworth et al., 2018; Menec et al., 2016; Tsai et al., 2016). However, the knowledge about how the built environment affects the ageing brain—cognitive-emotional states of older adults—is still in its infancy.

Neuroimaging literature indicates that various environments may be associated with characteristic patterns of brain activity (Chen et al., 2018; Tilley et al., 2017). Therefore, the present study is proposing that features that constitute the built environment are external stimuli that construct different neural signatures (distinct brainwaves) for cognitive processing. That is age-friendly built environment features, and stress-inducing or adverse built environment features reflect a distinct neural signature. The hypothesis is that older adults will exhibit negative emotions when exposed to stress-inducing or adverse environment features such as untidy alley. The present study pilots an investigation into the feasibility of using the neural signatures of older adults to assess the age-friendliness of the built environment. The neural responses are aligned with Global Positioning System (GPS) coordinates to provide more insight into the environmental feature or situation that stimulated a particular response. The significance of the results will set the foundation towards adapting the built environment to compensate for the deteriorating changes in older adults' functional capacity.

PREVIOUS RESEARCH WORKS

Existing methods that have been used to assess the age-friendliness of the built environment include questionnaire surveys completed by older adults and visual audits completed by trained auditors (Wong et al., 2017; Inclusive Design for Getting Outdoors, 2010). These methods are subjective, time-consuming, cost and labour intensive. Furthermore, the progress in urban big data and urban informatics over recent years has spurred emerging research methods that harness urban data to understand the built environment. The emerging studies have used accelerometer data (Hawkesworth et al., 2018), pedometer data (Menec et al., 2016), and Global Positioning System (GPS) data (Tsai et al., 2016) to assess the physical environmental features. These cutting-edge methods have significantly advanced the frontiers of the relationship between the physical environment and physical activity among older adults. Although these methods adopted objectively generated user data, answers to the fundamental question of how the older adult response to stress-inducing or adverse environment features has not been adequately answered. The dynamic nature of human-physical system interactions may influence what a person perceives as an adverse environmental feature. Therefore, using data such as the EEG can provide a more human-centred assessment of the built environment that takes into consideration the individual older adult's interaction. With current advances in non-intrusive wearables EEG sensors, EEG data can be collected continuously while older adults experience the built environment. Such data can be integrated with GPS data to facilitate a timely, cost-effective, and continuous assessment of the built environment.

EXPERIMENT DESIGN AND METHOD

An approximate 570 m walking path—between Hung Hom and Homatin, Kowloon, Hong Kong—was carefully selected, which covers diverse urban scenarios as shown in Figure 1. This path was selected because it consists of various features that can stimulate distinguishing human experiences, as described in Table 1. Six older adults took part in the experiment. However, only the data from four participants (2 male, 2 female; average age = 70 years, range = 65-75 years) were considered for analysis due to corrupt signal data. All the participants scored more than 22 points on the Cantonese version of the Mini-Mental State Examination (Chiu et al., 1994; Lao et al., 2019), which means they are not cognitively impaired. Each participant walked on the path at a self-directed pace while equipped with wearable electroencephalography (EEG) headset and a clip-to-belt type GPS sensor. The brain electrical activity was recorded non-invasively from the scalp using a wearable EMOTIV EPOC+ 14 channel mobile EEG headset.

The older adults took a second walk on the path (without wearing sensors), and each participant was required to describe their emotions and experience at each segment regarding how the segment influences their well-being or the functioning of the segment (subjective response from the older adults). The two-dimensional emotional circumplex space model with emotional states plotted according to Russell (1980), Barrett and Russell (1998), and Scherer (2005) was be adapted to represent the emotional status of the participants. Figure 2 shows the representation of emotional states. The walking path and data collection procedures were reviewed and approved by the Human Subjects Ethics Sub-committee of The Hong Kong Polytechnic University (Reference Number: HSEARS20190826002).

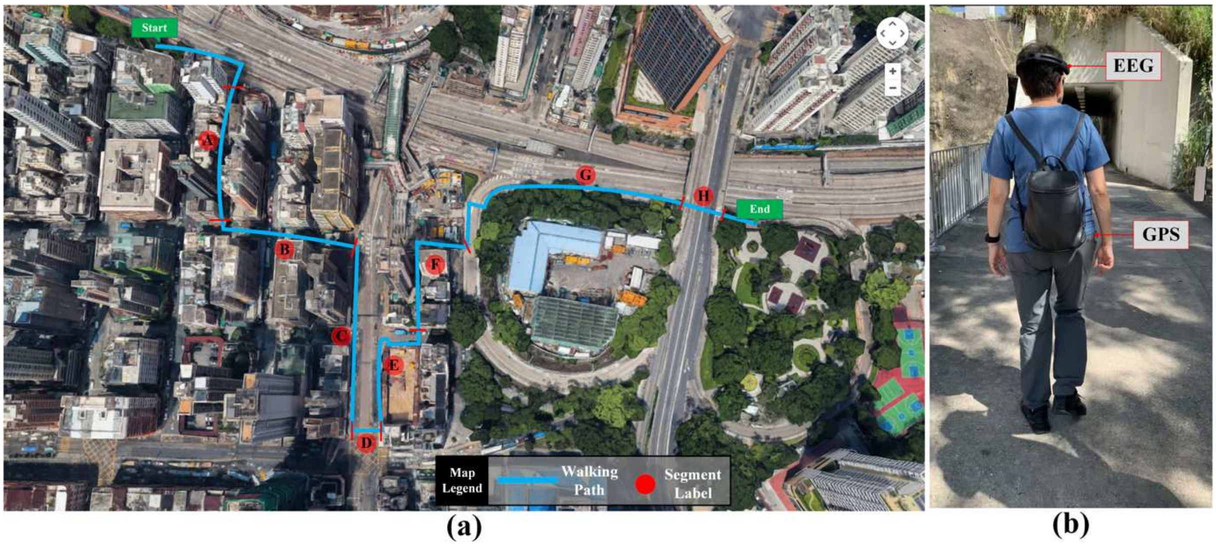


Figure 1. Experiment overviews: (a) Map of the walking path with segment; (b) Older adult equipped with EEG sensor and GPS

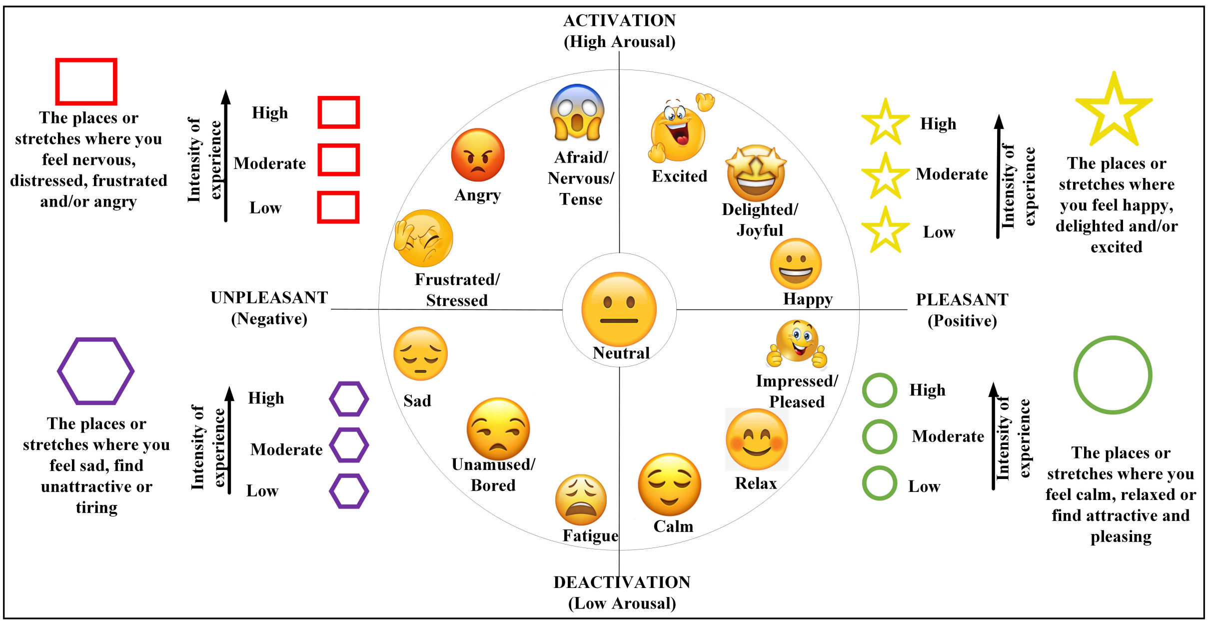


Figure 2. Emoticon representation of two-dimensional emotional circumplex space model

Adapted from Russell (1980), Barrett and Russell (1998), and Scherer (2005)

Table 1. Description of the walking route

Segment	Environment feature	Feature description	Surrounding features
A	Alley	Untidy alley	People, Shops, Flower shops, Restaurant, Stray dogs, Unattractive building
B	Wide Street with shops	Footpath between shops with rest benches	People, Shops, Flower shops, Bench, Restaurant
C	Footpath beside bus stop, gas station, car wash, and high traffic road	Footpath beside bus stop, gas station, car wash, and high traffic road	People, Gas station, Car wash, Bus stop, Moving vehicles
D	Crosswalk with traffic light	Crosswalk with high pedestrian and vehicle traffic	People, Vehicles, Traffic light, Buildings
E	Footpath beside construction site and high traffic road	Footpath between on-going construction and high vehicle traffic road	People, Construction site, Hoarding, Moving vehicles
F	Alley	Alley with playground view	People, Flower shop, Buildings, Street playground
G	Footpath through green space	Footpath along a carriageway with high traffic	People, Trees, Street garden, Carriageway, Bus stop, Buildings, Moving vehicles
H	Subway	Subway beneath carriageway	People, Graffiti

DATA ANALYSIS METHOD

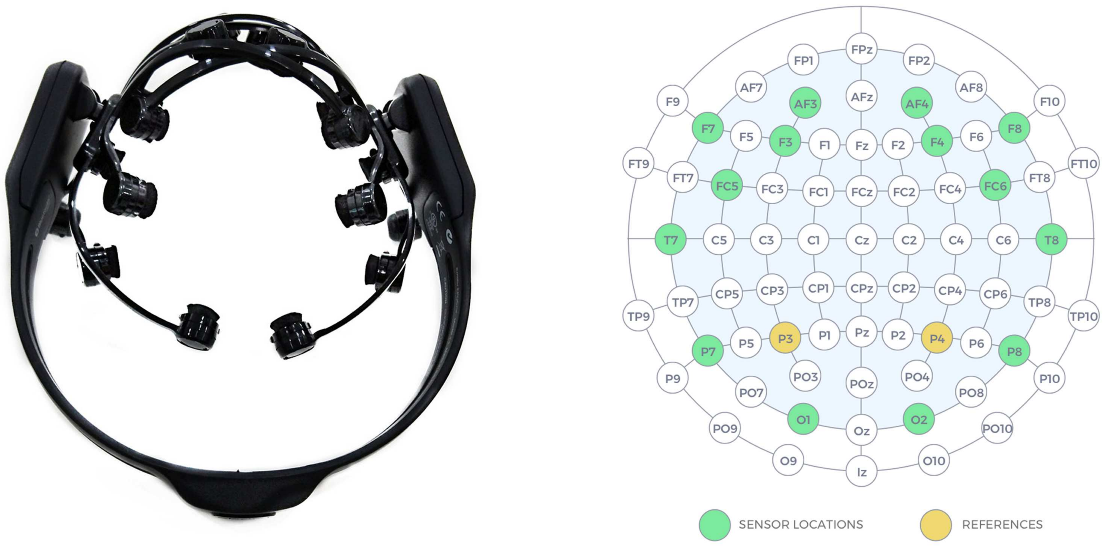
EEG signals were pre-processed internally from the Emotiv EPOC+ system. Analogue signals were high-pass filtered with a 0.16Hz cut-off, preamplified, low-pass filtered with a 43Hz cut-off, and sampled at 2048 Hz. Digital signals are notch-filtered at 50/60Hz and downsampled to 128Hz. In this study, the EEG data was time-domain interpolated using Fast Fourier Transform (FFT) to account for missing samples due to connectivity issues (Saitis and Kalimeri, 2018). The band power in each of the interested frequency bands—alpha (α) (8-13Hz) and beta (β) (13-30Hz)—is calculated for each of the nine interested channels (F4, F3, FC6, F8, P8, AF3, AF4) in the frontal cortex and parietal cortex of the brain as shown in Figure 3.

Based on the EEG frequency band powers, the indices of valence, arousal, and dominance are computed to quantify the cognitive-emotional state of the older adults during the walking course (Ramirez and Vamvakousis, 2012; Xing et al., 2019). Valence measures the level of happiness (equation 1). The valence level ranges from unpleasant (negative) to pleasant (positive). Arousal measures the level of excitement (equation 2). The arousal level ranges from not aroused (low arousal) to excited (high arousal). Dominance measures the level of control (equation 3). The dominance level ranges from submissive (without control) to dominant (in control).

$$Valence = \frac{\alpha(F4)}{\beta(F4)} - \frac{\alpha(F3)}{\beta(F3)} \quad (1)$$

$$Arousal = \frac{\alpha(AF3 + AF4 + F3 + F4)}{\beta(AF3 + AF4 + F3 + F4)} \quad (2)$$

$$Dominance = \frac{\beta(FC6)}{\alpha(FC6)} + \frac{\beta(F8)}{\alpha(F8)} + \frac{\beta(P8)}{\alpha(P8)} \quad (3)$$



(a) **(b)**

Figure 3. (a) Emotiv EPOC+ 14 channel EEG device; (b) 14 electrode channels corresponding to the international 10-20 position system

Source: Emotiv (2019)

RESULTS

The results of the experiment are depicted in Figures 4-11 and Table 2. Each result was computed based on the average valence, arousal, and dominance values from all the participants. In path segment A, the valence index is negative, the arousal index is relatively high, and the dominance index is relatively low. This means that the features within this segment induced a state of nervousness and stress among the older participant. The older adults reported feelings of nervousness, stress, boredom, and sadness from the subjective response. In path segment B, the valence index is positive at the beginning of the segment and is negative during the rest of the segment at a relatively low level. The arousal index is relatively high at the beginning of the segment and low during the rest of the segment, and the dominance index is relatively high. The older adults affective state changed from happiness to sadness in path segment B. This could be because of the funeral flowers in path segment B. Three of the participants reported the feeling of sadness, and one participant reported feeling relaxed.

In path segment C, the valence index is negative, the arousal index is relatively low, and the dominance index is relatively high. This implies that the presence of gas stations, car wash, bus stops, and moving vehicles within segment C induced feelings of sadness, boredom, and stress. From the subjective response, the participants reported feelings of stress, relaxation, neutral and happiness. In path segment D, the valence index is negative at the beginning of the segment and changed to almost zero during the rest of the segment. The arousal index is relatively low, and the dominance index is relatively high. This means the older adults were bored while waiting for the traffic signal and calm while crossing the road. From the subjective response, two participants reported feeling relaxed, one participant reported feeling calm, and another reported feeling neutral.

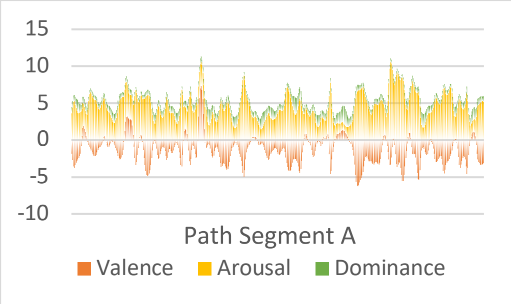


Figure 4. Path segment A

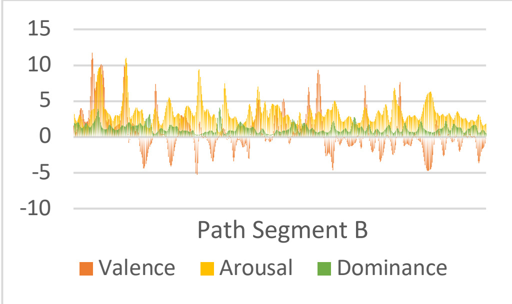


Figure 5. Path segment B

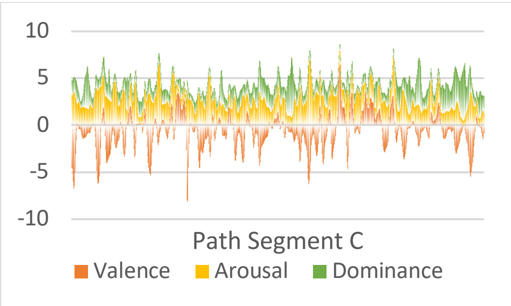


Figure 6. Path segment C

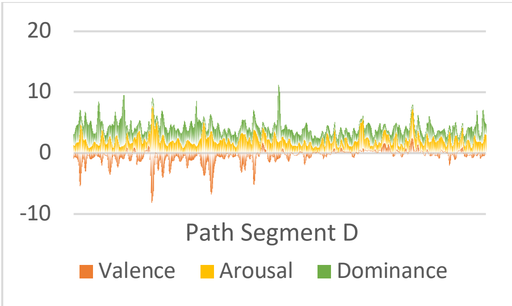


Figure 7. Path segment D

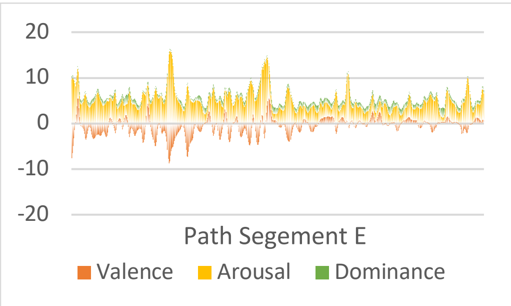


Figure 8. Path segment E

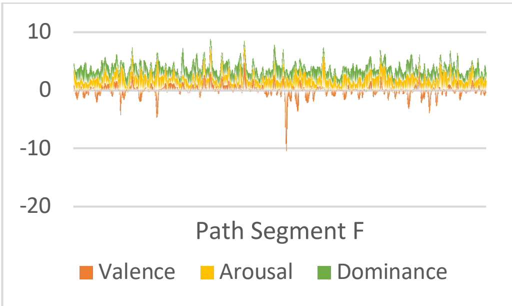


Figure 9. Path segment F

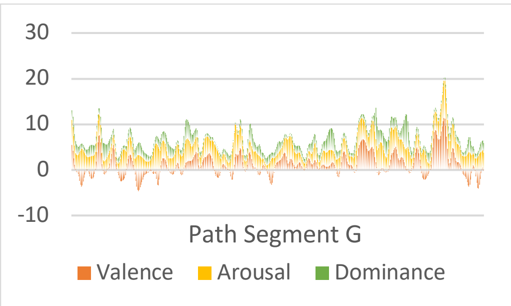


Figure 10. Path segment G

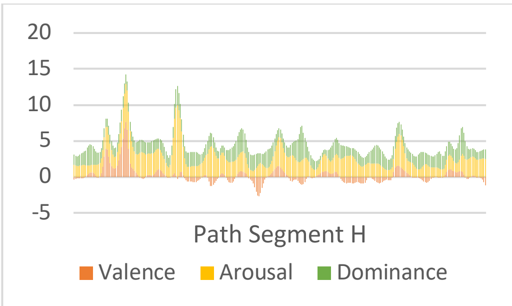


Figure 11. Path segment H

Table 2. Comparison of response

Segment	Self-rating Response for each Participant				Average EEG Response
	1	2	3	4	
A	Afraid (Moderate)	Frustrated (High)	Bored (Low)	Sad (Moderate)	V=Negative A=High D=Low
B	Relax (Moderate)	Sad (High)	Sad (Low)	Sad (Moderate)	V=Positive A= High D= High
C	Relax (Moderate)	Neutral	Frustrated (Low)	Happy (Moderate)	V=Negative A= Low D= High
D	Relax (Moderate)	Neutral	Relax (High)	Calm (Low)	V=Negative A= Low D= High
E	Relax (Moderate)	Frustrated (Low)	Relax (Moderate)	Happy (Low)	V= Negative A= High D= Low
F	Sad (Low)	Frustrated (Moderate)	Relax (Moderate)	Calm (Moderate)	V= Positive A= High D= High
G	Relax (Moderate)	Relax (Moderate)	Relax (High)	Relax (High)	V= Positive A= Low D= High
H	Calm (Moderate)	Neutral	Calm (High)	Bored (Moderate)	V= Positive A= Low D= High

V=Valence; A=Arousal; D=Dominance

In path segment E, the valence index is negative and relatively high at the beginning of the segment and gradually changed to zero. The arousal index is relatively high, and the dominance index is relatively low for the entire segment. The older adults were stressed and angry while walking close to the construction site and a bit of excitement while at the end of segment E. Based on the subjective response, two participants reported feeling relaxed, one participant reported feeling stressed, and another participant reported feeling happy. In path segment F, the valence index is relatively low (both positive and negative), the arousal index is relatively low, and the dominance index is relatively high. The features within segment F induced feelings of sadness, fatigue, calmness, and relaxation. From the subjective response, participants reported feeling sad, stressed, relaxed, and calmed. In path segment G, the valence index is low at the beginning and high towards the end (predominantly positive), arousal is relatively low, and dominance is relatively high. The path through the green space induced states of relaxation and excitement. All the participants reported feeling relaxed in the subjective report. In path segment H, the valence index is relatively positive, arousal is relatively low, and dominance is relatively high. The subway induced a feeling of fatigue and calmness among older adults. Two participants reported feeling calm, one reported feeling bored, and another reported feeling neutral.

Kernel density estimate was computed to visualise older adults' cognitive interaction on the path. Intense interactions were observed in segment A and around segment C, D, E, and F, as shown in Figure 12.

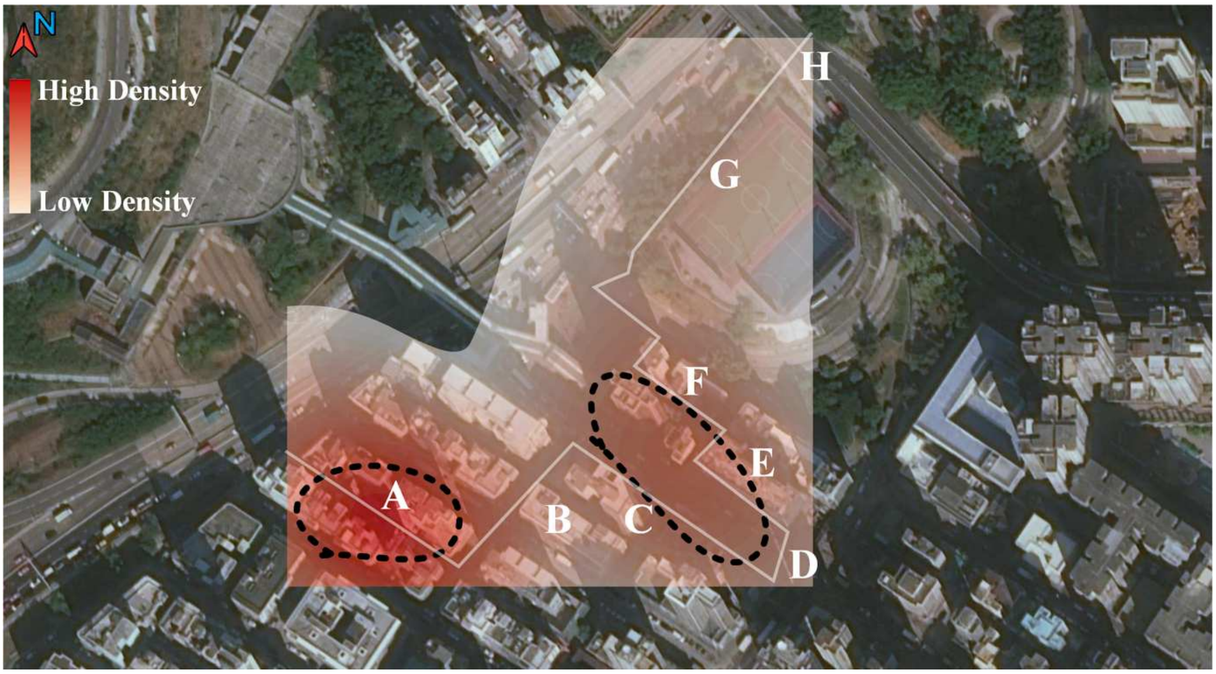


Figure 12. Density distribution of older adults' cognitive interaction on the path

DISCUSSIONS AND LIMITATIONS

The results demonstrate that features that constitute the built environment are external stimuli that construct different neural signatures for cognitive processing. That is, built environment features that the older adults perceived to be age-friendly (e.g., green spaces and crosswalk with traffic) and features that are stress-inducing (e.g., unattractive buildings and free-ranging urban dogs) reflect a distinct neural signature that can be reliably captured non-invasively using wearable EEG sensors. Moreover, this study shows the feasibility of older adult-centric sensing using wearable EEG sensors, which can let older adults participate in the evaluation of the outdoor built environment. If crowdsource EEG data are collected from older adults, a specific location can be evaluated using the proposed method. The method can be used to determine the age-friendliness—stress-inducing features—of the outdoor walking environment and will serve as a proactive approach to managing the age-friendliness of the outdoor built environment.

The findings of the study further suggest that the older adults' emotions may be affected by multiple built environment characteristics, including building shapes, building textures, visual complexity, and richness of the built environment, and many other isovist parameters. For example, the difference in compactness and visibility in segments A (alley) and G (footpath through green space) resulted in different neural signatures—positive emotions for segment G with low compactness and greater visibility and negative emotions for segment A with high compactness and lower visibility. This study will pave the way towards automation and digitisation of built environment assessment. Detecting the real-time index of an individual's emotional state can be useful in providing appropriate and real-time interventions in a smart built environment. Examples include a personalised recommendation system of route planning and labelling of age-friendly routes and streets. This information can be integrated and visualised on maps and smartphone applications. The elderly-centric sensing approach can be harness in designing adaptable built environment (e.g., buildings that can change textures, colours, and shapes to compensate for an individual's emotions).

The older adults' cognitive responses collected from the EEG sensor are related to the subjective responses of the older adults at some segments. The differences in response in some segments may be due to the following:

- Individual differences such as physical characteristics, previous experiences, social and psychological factors are beyond control. This may cause older adults to express different emotions with the same segment or perceive a segment differently. Crowdsource EEG data supplemented with other modalities such as heart rate variability and skin conductivity can be used to reduce human variability. The normalisation of individual response using baseline measurement can also minimise the variability in response.

- The subjectivity of the rating scale. For example, a subject may rate the mere presence of a gas station as stressful with a high-intensity rating, although the gas station did not distress the older adult. In this case, an EEG sensor may not capture any variation in the subject's emotional state, thus affecting the correlation and validation of the results. Future studies should be aware of the inherent limitations of the subjective rating and should be cautious when interpreting the results from a subjective rating scale.

- The number of participants in this study limited an in-depth analysis of the relationships between an individual's emotion and built environment characteristics. Although this pilot study revealed promising results, reporting the findings should be considered with caution. Additionally, the walking activity affected the stability and functioning of the EEG sensor during the experiment. With more advances in wearable technologies, it is hoped that future EEG sensors will be more stable "in the wild."

CONCLUSION

This study aimed to understand the age-friendliness of the outdoor environment by monitoring the cognitive-emotional states of older adults while they experienced the outdoor environment. This study investigated the feasibility of using the neural response of the older adults to detect age-friendly, stress-inducing, or adverse features in the outdoor environment. A pilot study was conducted in the outdoor environment with four older adults, and their neural responses were collected using a wearable EEG sensor. The indices of valence, arousal, and dominance were computed to quantify the cognitive-emotional state of the older adults for each segment of the path. The results demonstrate that the older adults' cognitive response correlates with the presence of age-friendly, stress-inducing, and adverse features of the outdoor environment. Also, potential associations exist between EEG measures and subjective self-assessment reports. However, more participants will be recruited in future studies to determine if this correlation in the response is statically significant.

ACKNOWLEDGEMENTS

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