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Engaging the Brain: The Impact of Natural versus Urban Scenes Using Novel EEG Methods in an Experimental Setting

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Abstract

Background
Researchers in environmental psychology have consistently shown the restorative potential of natural – over urban - settings using video/photographic experiments in laboratory settings applying subjectively rated scales. But few studies have employed objective indicators of emotional response. This study investigates the use of electroencephalography (EEG) as a method to understand how the brain engages with natural versus (*vs*) urban settings – in tandem with subjective preferences.

Methods
Using Emotiv EPOC, a commercial and low-cost EEG recorder, participants (n=20) viewed a series of urban *vs* landscape scenes with proven reliability in restorative environments research. The equipment provided continuous recordings from 5 channels, labelled Excitement; Frustration; Engagement; Long Term (LT) Excitement (or arousal) and Meditation. Participants also rated the image set subjectively for valence (pleasure-displeasure), arousal (calm-excitement), attractiveness and willingness to visit the scene.

Results
Landscape scenes were consistently rated more positively on the preference scales (i.e. attractiveness, willingness to visit and valance ratings) (p<0001). Data reduction of the EEG output revealed two components: *Arousal* which correlated with urban scenes and *Interest* which correlated with landscape scenes ($p<0.01$). Latent class analysis was carried out to explore clusters – or sub groups – in the data and to identify significant emotional discriminators between the two sets of images. A two-cluster model produced the best fit, with image scene, and three of the EEG emotional parameters (i.e. excitement, LT excitement, and meditation) significantly discriminating between the two clusters ($p<0.05$). Landscape scenes were associated with greater levels of meditation and lower arousal (i.e. excitement) and the urban scenes with higher arousal.

Conclusion
It has been shown that EEG data in an experimental setting is sensitive to detecting emotional change from viewing different environmental settings, furthering the evidence base for a restorative effect of natural settings. We have established a novel method for measuring environment-mind interactions – a tool we have subsequently developed to establish the mood-enhancing benefits of walking in urban green space [1].

Keywords: restorative environments, landscape, urban, electroencephalography (EEG), preference

BACKGROUND

Laboratory studies comparing photo sets and/or videos of urban versus (*vs*) natural scenes have proved robust in detecting the perceived restorativeness of natural settings, reviewed in [2]. It is posited that the psychological benefit of natural settings operates via attention restoration mechanisms [3]. Soft fascination (intriguing environmental stimuli) promotes involuntary attention, enabling cognitive recovery from fatigue and is typically present in natural settings. By contrast, hard fascination (demanding stimulation) grabs attention dramatically increasing cognitive load and is typically present in urban settings. Consistently, over 20 years, results have shown increased positive affect, reduced arousal, and stress and fatigue recovery from viewing natural settings, using a range of outcome measures that include attention tests and self-report psychological scales. However, only a handful of studies have employed EEG identifying tranquility as an outcome of viewing natural settings [4], significantly higher alpha [5] and greater relaxation [6]. Recently Korean researchers utilized functional magnetic resonance imaging (fMRI) to investigate brain activation patterns in 30 participants viewing nature vs urban scenes [7]. The urban scenes showed enhanced activity in the amygdala, which is linked to impulsivity, anxiety and increased stress. By contrast, the natural scenes promoted activity in the anterior cingulate and the insula – where increased activity is associated with heightened empathy and altruistic behavior. Consistency in type of scene explored in laboratory experiments has been very variable; it's reported that only 35% of all experimental studies have contrasted urban *vs* natural scenes [2] and the formatting of image sets - using consistent landscape types – and the proportion of natural:built scene has only recently been systematically refined [8].

AIMS

Our study aimed to explore if electroencephalography (EEG) technology could, firstly, detect emotional change to the experience of landscape *vs* urban scenes and, secondly, further build the evidence base for restorative effect of natural environments. Based on earlier research we posited that natural scenes will be rated more positively than urban scenes (hypothesis 1). We further posited that natural scenes will be associated with EEG output indicating restorative health effects (i.e. increased meditation and lower arousal parameters) as compared to urban scenes (hypothesis 2).

METHOD

Participants:
20 students from Edinburgh University were recruited to participate, and ethical scrutiny and approval for the study was provided by the School Ethics Committee.

The mean age of participants was 30 (ranging from 22 to 62) with 8 males, and 12 females.

Development of the photoset:
We identified 2 core environments from a previous study by [8] each with a set of photographs known to have sensitivity to subjective restorative preferences: 'green' scenes' (fields, forests, parkland) and 'built' (or 'grey') scenes (i.e. buildings, roads, walls etc.) without people or animals (two factors known to affect preference). A set of 15 photographs were selected from the earlier study [8] including 'green', 'grey' (urban only) and combinations of 'grey-with-green' images (urban environments with varying degrees of vegetation (see an example set in Fig 1). The image set was selected to provide a diversity of environments perceived in a pseudo-random order.

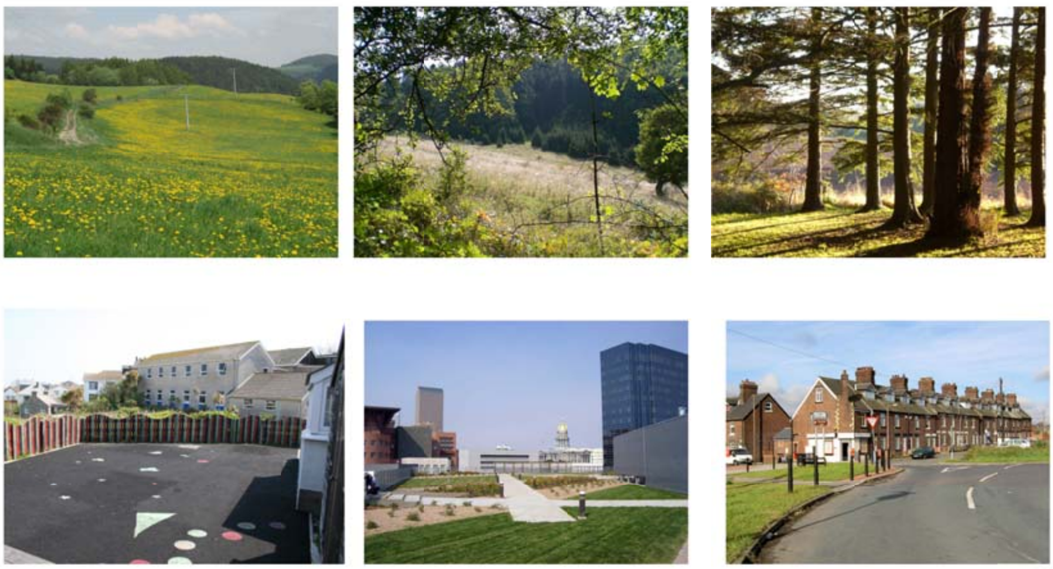


Fig 1: the reduced photo set with 'green' scenes (top) vs 'grey' scenes (bottom)

Procedure:
On arriving at the test lab participants provided informed consent. They were seated approximately 60 cm in front of a 42' Toshiba flat-screen monitor with the centre at eye-level, replicating [8], which was connected to a Toshiba satellite pro p200 (A). They were fitted with an EPOC EEG headset linked to a MacBookPro (B). The two computers were connected through an ad-hoc network, to synchronise the display of stimuli (A) and the data collection (B).

The participants were then asked to watch a series of 15 images, appearing for 20 seconds after a 20 second interval, while their emotional response to the stimuli was captured by their EEG. Afterwards, participants were asked to review the 15 slides and rate them on four dimensions (see below) and conducted three practice trials, prior to a random presentation of the full photo set. Each slide was presented for 20 seconds. Subjective responses were provided on a paper questionnaire; the EEG output was directly recorded by the computer. Finally, participants filled a debrief questionnaire providing demographic data.

Outcome measures

(1) Subjective preferences:

We selected 4 subjective questions to capture emotional and behavioural responses to scene replicating [8]. These rated (1) the aesthetic quality of the scene ("How attractive do you find this scene?") and (2) potential behaviour ("How willing would you be to visit this scene?"), with both items ranked from Not at all (1) to Extremely (10). The two remaining items were designed to tap into two dimensions of core affect i.e. valence (i.e. pleasure-displeasure) and arousal [9]: "How does this photo make you feel?" with two response scales, Very Sad (1) to Very Happy (10) (i.e. valence), and Calm (1) to Excited (10) (i.e. arousal).

(2) EEG outcome measures.

We used an Emotiv EPOC EEG headset for our study [1] [10] [11] which also provides software to analyse raw EEG data (emotiv.com). In brief, the headset captures 12 channels of EEG from frontal (AF3, AF4, F3, F4, F7, F8), fronto-central (FC5, FC6), occipital (O1, O2), parietal (P8) and temporal sites (T7, T8) capturing four main independent bands: *Delta* (0.5-4Hz) - indicating deep sleep, restfulness, and conversely excitement or agitation when delta waves are suppressed; *Theta* (4-8Hz) - indicating deep meditative states, daydreaming and automatic tasks; *Alpha* (8-15Hz) - indicating relaxed alertness, restful and meditative states; *Beta* (15-30Hz) - indicating wakefulness, alertness, mental engagement and conscious processing of information. Our study used "Affectiv Suite" emotion-detection software that interprets the EEG oscillations of the various bands into 5 emotional parameters: excitement (i.e. arousal of short duration – several seconds), Long-Term (LT) excitement (i.e. arousal of longer duration – several minutes), frustration (disappointment or cognitive load), engagement (i.e alertness), and meditation. For a full summary of the device and software, together with a review of studies validating the equipment, see Aspinall et al, 2013.

RESULTS

1. Subjective Preferences:

Significant differences were found between urban *vs* landscape scenes on 3 of the subjectively ranked questions (attractiveness, willingness to visit, valence, i.e. landscape slides were perceived as significantly more attractive, eliciting greater willingness to visit the scene and greater valence ($p<0.001$), see Table 1. Arousal did not significantly vary between the two image sets.

Table 1: Subjective preferences for urban *vs* landscape scenes

Subjective preference	**Urban Images Mean (SD)**	**Landscape Images Mean (SD)**	**Urban vs Landscape differences (Mann-Whitney U test)**
Attractiveness	3.93 (2.06)	8.22 (1.14)	$p<0.000$
Willingness to visit (WTV)	3.60 (2.41)	8.09 (1.54)	$p<0.000$
Valence	4.52 (1.86)	7.52 (1.39)	$p=0.000$
Arousal	5.03 (1.96)	4.27 (2.16	$p=0.065$

Note: A higher score on Attractiveness, Willingness to Visit (WTV) and Valence indicates a more positive outcome; a higher score on Arousal indicates greater excitement.

The data reported is for the reduced photo set applied in the exploratory analysis (reported below).

2. *The EEG data*

(a) Data reduction

To simplify the photographic analysis we created a binary variable categorizing the urban and landscape slides into two groups, using a set of 6 slides, significantly different in both their content and preference ratings (3 urban vs 3 landscape) (as reported in Table 1 and illustrated in Fig 1).

To simplify the EEG data we carried out a factor analysis (oblique rotation) which showed the 5 emotional channels belong to two basic groups. One group consists of excitement (short term and LT) with meditation as a correlated opposite (negative loading on same factor) which we labeled *Arousal*; the other group consists of engagement with frustration as a correlated opposite (negative loading again) which we labeled *Interest.*

(b) Exploring relationships between the images and the EEG data

Bi-variate correlations showed statistically significant and strong correlations between the *Arousal* factor and the urban images and between the *Interest* factor and the landscape scenes (at $p<0.01$). A surprising finding was the correlation between engagement and frustration in the *Interest* factor; this is contrary to restorative theory which posits that engagement (in the form of fascination) with natural scenes demands our attention effortlessly (i.e. without frustration). A further examination of the bivariate correlations showed frustration was the only variable to significantly correlate with all other emotional parameters – suggesting it therefore lacks uniqueness and shares similar attributes to the other emotional parameters. Frustration is also an unusual emotional term to use while looking at a landscape scene with no prescribed visual problem to solve. We therefore chose to run the subsequent analysis with frustration removed from the data.

(c) Latent Class Analysis (LCA)

Following methods outlined in [12] latent class analysis (LCA) was carried out using version 4.0 of Latent Gold [13]. This is a form of regression analysis which can handle non-parametric data and which identifies clusters or sub-groups (latent classes) in a data set. In an exploratory analysis, such as this, with no precedents on which to anticipate the cluster number, we estimated four latent class models, (from 1 to 4 clusters) and entered the binary image variable, and the average responses of each of the 4 four emotional parameters to each image (i.e. excitement, LT excitement, meditation, and engagement). We used the criterion of the minimum Bayesian Information Criterion (BIC) to determine cluster number [14]; the BIC values for the first 1 to 4 clusters were 956, 914, 928 945 respectively indicating a 2 cluster solution the best fit to the data.

(d) Latent Class profiles

Table 2 below shows the significance of each variable in its capacity to discriminate between the 2 clusters. The R squared value indicates how much of a variable is explained by the cluster model. The p values show that image (landscape *vs* urban), excitement (short term and LT) and meditation are all significant discriminators between the two clusters. Engagement is not a significant discriminator.

Table 2: Parameters discriminating between clusters

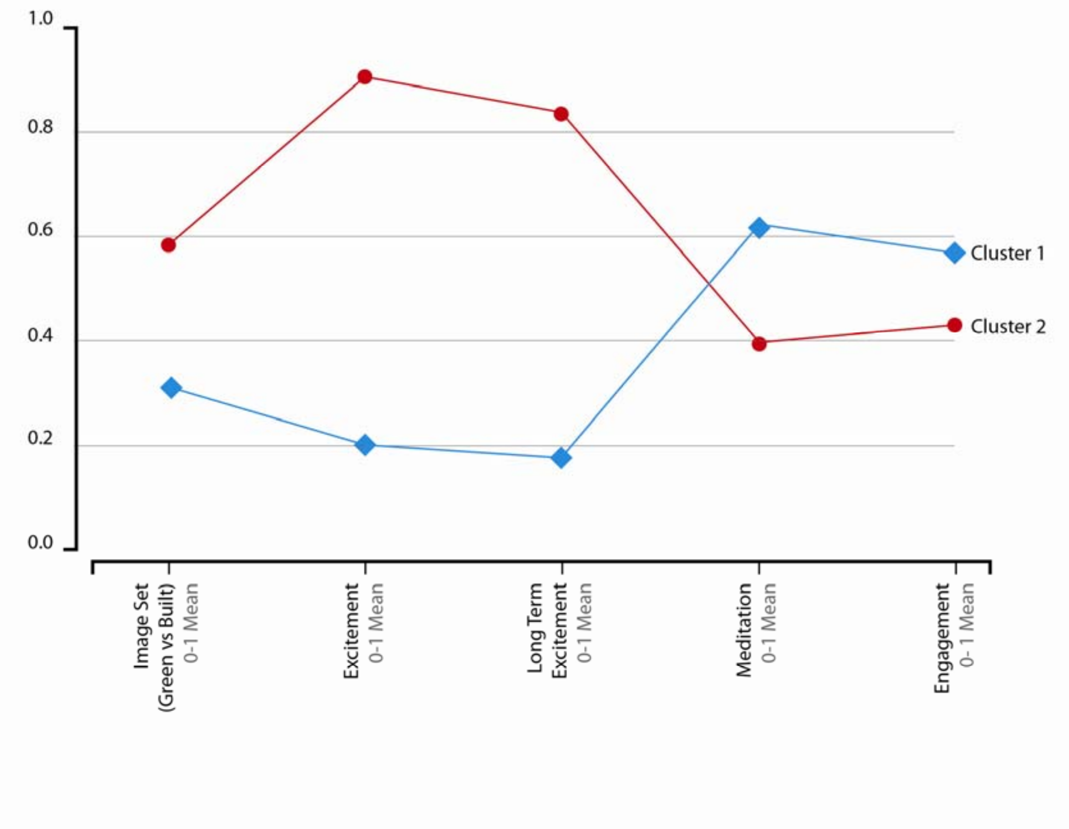
	Cluster1	**Cluster2**	**Wald**	**p-value**	**R^2**
Photoset (urban vs landscape)	-0.5600	0.5600	4.3366	0.037	0.0731
Excitement	-1.5713	1.5713	6.1048	0.014	0.7303
LT excitement	-1.0133	1.0133	10.7455	0.0010	0.6906
Meditation	0.2931	-0.2931	6.5220	0.011	0.1176
Engagement	0.1062	-0.1062	1.7491	0.19	0.0285

The cluster profile is shown in Table 3. The table presents mean item-response probabilities for the photoset and each of EEG emotional parameters. These indicate the probability of reporting a value above the median value within a class. Table 3 shows that the clusters are of approximately the same size i.e. 56% of participant cases are in cluster 1; 44% in cluster 2. The profile shows the landscape images predominantly appear in Cluster 1 (69%) whereas the urban images predominate in cluster 2 (58%). Exploring the means, Cluster 1 (landscape) is associated with lower excitement (short term and LT), higher engagement and increased meditation; Cluster 2 (urban) with higher excitement (short term and LT), lower meditation and lower engagement. This pattern is clearly shown in Fig 2 below, illustrating the cluster profile for the landscape (cluster 1) and urban (cluster 2) images.

Table 3: profile of the two clusters

	Cluster1	**Cluster2**
Cluster Size	0.5572	0.4428
Indicators		
Photoset (imagebin2)		
1 Landscape	0.6886	0.4191
2 Urban	0.3114	0.5809
Mean	1.3114	1.5809
EEG output	**Mean**	**Mean**
Excitement	1.7966	4.6184
LT excitement	1.7037	4.3531
Meditation	3.4721	2.5797
Engagement	3.2595	2.7082

Fig 2: EEG emotion profile for landscape (cluster 1) and urban (cluster 2) images



DISCUSSION

The subjective data indicates that natural scenes are rated more positively than urban scenes (as predicted by hypothesis 1), replicating findings by others on the same image set [8]. Our EEG analysis indicates that meditation and excitement (a factor group we have interpreted as arousal) can significantly predict image scene with lower arousal and higher levels of meditation associated with the landscape scenes (as predicted by hypothesis 2). This confirms restorative theory indicating a positive psychological effect of natural scenes.

Our data flags some interesting issues around the interpretation of frustration and engagement. Firstly, considering engagement; in the current study we found natural scenes – viewed in a laboratory setting - promoted stronger engagement; whereas using mobile EEG in our urban walking study [12] we found evidence of lower engagement in a green space setting. In our earlier paper we associated engagement with directed attention (i.e. the urban scene dramatically demanded greater cognitive attention to cross roads/negotiate traffic etc.). We suggest, firstly, the context of the study might explain this differing outcome i.e. sitting in a safe (rather dull) laboratory setting promoted higher levels of engagement with the landscape scenes as opposed to the 'grey' urban images. Secondly, given the foreground features in the landscape slides (see Fig 1), this might have engaged greater levels of curiosity, while, the 'urban' images did not include dynamic aspects, such as pedestrian and vehicular traffic, urban sounds and other sensory information that are usually anticipated in urban environments. We conclude the context of the study and content of the images explains the higher levels of engagement with landscape settings in this experimental study.

Considering frustration, we found this negatively correlated with engagement (i.e. higher levels of engagement were associated with higher levels of frustration - contrary to a restorative effect of natural settings), and subsequently removed it from the data analysis. The software developer, Emotiv, confirms frustration is a complex parameter and highly sensitive to the context in which it is measured. For instance, in a gaming context, it is not unusual for engagement to correlate with frustration in a situation where players are subjected to levels of increasing difficulty and frequently have their gameplay sabotaged. EPOC has suggested an alternative name for this state in this context might be Inherent Stress, and Disappointment. In respect to this study, disappointment may also apply i.e. there was simply insufficient interest in a 'grey' urban scene to promote fascination.

In summary, we have demonstrated that a commercial and low-cost EEG technology, such as Emotiv EPOC, is sensitive to detecting emotional change to different environmental settings, mirroring subjective preferences, and consistent with restorative theory. In this experiment, we have used the emotions detections from a "black-box" software kit, but demonstrated these measures are consistent with self-reported measures [15] and afford further research. We have subsequently developed mobile EEG to establish the mood-enhancing benefits of walking in urban green space [1]. The data shown here confirms the findings of our earlier paper indicating changes in EEG emotive channels as people move from urban to landscape environments.

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