Neurophysiological Effects of Architectural Styles in Virtual Reality

Disclaimer: This report is based on simulated data.

This work contains around 1763 words.

Introduction

The discipline of neuroarchitecture seeks to bridge the subjective experience of space with objective neural measures (Higuera-Trujillo et al., 2021). With the advent of virtual reality (Valtchanov & Ellard, 2015) and portable neuroimaging techniques (Neale, 2019), it is now possible to assess the physiological effects of architectural aesthetics. Understanding how different styles affect well-being can inform evidence-based urban planning.

Nature's restorative effects on attention and stress are well-documented (Ohly et al., 2016; Stigsdotter, 2019; Ulrich, 2023). Urban environments demand direct attention, increasing stress. Exposure to nature reduces stress (Valtchanov, 2010), even in surrogate forms like nature posters. Stress reduction theory (SRT; Ulrich, 2023) and attention restoration theory (ART; Ohly et al., 2016) explain these effects, linking nature with indirect attention. EEG studies associate alpha waves (9-13 Hz) with relaxation and beta waves (13-27 Hz) with alertness (Neale et al., 2019).

Brutalism, characterized by raw concrete and stark forms, is polarizing (Reynolds, 2017; Hanley, 2019; Erdogan, et al., 2010). Studies link alpha waves (relaxation) with neoclassicism and beta waves (alertness) with brutalism (Ellard, 2020), suggesting brutalism may not be conducive to well-being. This study compares responses to natural and built environments, focusing on brutalism.

We expect to replicate the results where nature reduces stress in relation to urban environments (Neale et al., 2019), and that brutalism is considered less pleasant (Ellard, 2020). If we discover that this is the case, it could have serious consequences for the future of public brutalist buildings everywhere. However, it may also promote better urbanism by providing evidence for universal design principles. This shift would make urbanism more evidence-based, moving away from "designerly ways of knowing" (Higuera-Trujillo et al., 2021).

However, optimizing design for the majority risks homogenizing culture. Neuroarchitecture assumes universal aesthetics, ignoring social factors like personal preference. If a universal aesthetic is found, how should we handle existing cities or people who prefer non-optimal designs? Moreover, philosophical debates around nature and culture complicate this issue. Studies often present overly positive views of nature, despite mixed evidence (e.g., Valtchanov & Ellard, 2010).

Do different architectural styles trigger different physiological responses? We measure this with electroencephalogram (EEG) data. More natural styles are expected to elicit higher alpha waves, while urban/artificial styles are linked to beta waves. We aim to replicate findings suggesting brutalism has fewer restorative properties than other styles (Ellard, 2020). Our null hypothesis is that there's no difference in alpha and beta waves between styles. This is also considered with the mediating effect of familiarity and style preference. To ensure validity, we compare self-reported preferences with measured responses. Based on existing research, we expect brutalism to be less inviting than neoclassicism, with preference playing a key role in neural activation patterns.

Method

Participants

Participants were recruited via posters distributed in local neighborhoods, university bulletin boards, and social media channels related to architecture. The final convenience sample comprised 123 individuals (60 males, ages 20-64, mean = 32.5, SD = 6.8). Inclusion criteria required normal or corrected-to-normal vision and no history of neurological disorders. Although we attempted to standardize the sample, recruiting from a local gallery and architecture-related social media pages may have introduced a bias toward individuals with an interest in architectural aesthetics.

Materials

VR The VR system employed was a Meta Quest 3, with resolution of 2064x2208 pixels per eye, refresh rate of 120Hz and horizontal field of view of 110 degrees and vertical of 96 degrees. Interpupillary distance (IPD) was adjusted per participant. Participants remained seated to control for VR-induced nausea (also known as simulation sickness).

VR environments were developed using Unity (Universal Rendering Pipeline) to ensure consistent lighting and shading across all conditions. The environments were ran on-device through sideloading, reducing possible latency issues.

EEG EEG data were acquired using a Muse headband connected to Mind Monitor software. Data collection focused on the alpha (9–13 Hz) and beta (13–27 Hz) frequency bands. Data processing included artifact removal, bandpass filtering, and the computation of root mean square (RMS) values to account for the oscillatory nature of the EEG signal. Data for each of the 32 electrodes and 30 seconds of recording was averaged, resulting in distribution of data for each frequency band (alpha, beta) for each level/category.

Stimuli Six conditions were examined: neoclassical, modern, high-tech, brutalist, biophilic brutalist, and park. Each condition was represented by a single

VR environment designed by professional 3D artists and architects. To minimize familiarity effects, environments were entirely fictional yet inspired by real-world architectural features. Visual characteristics, including brightness, contrast, and saturation, were standardized across conditions.

Questionnaire Following the VR exposure, participants completed a tablet-based questionnaire which included items to test for preference (5-point Likert scale), familiarity (5-point Likert scale), simulation sickness (yes/no) and demographic data (age, gender, VR experience). The questionnaire was designed to complement the EEG data, offering subjective insights into the participants' experience, and serve as cross-validation for the physiological measurements as well as the image quality measurements.

Procedure

Upon arrival, participants provided informed consent and were briefed on the study's general purpose without revealing the specific focus on brutalism. Participants were fitted with the Muse EEG headband then seated in a rotating chair in a controlled environment with standardized ambient noise

Participants first underwent a calibration task to familiarize themselves with the VR setup. Each VR environment was presented for 90 seconds with a 10-second warning prior to fading transitions. The order of environment presentation was randomized.

After completing the VR sessions, participants were given a 30-second period to adjust before completing the post-exposure questionnaire. Participants were instructed to remove the headset in case of nausea or any other discomfort.

Results

Preprocessed data was acquired from a real EEG dataset (FACED). Details of preprocessing can be found in the original paper. For the purposes of the ANOVA, data was randomly sampled and assigned to the simulated experimental conditions. Analyses can be found in the GitHub repository. Preference and familiarity data was randomly generated and assigned to participants.

ANOVA

An analysis of variance (ANOVA) was conducted to examine the effect of architectural style on the EEG signals. Results were not statistically significant for both alpha waves ($F(5, 732) = 0.56$, $p = 0.731$, eta-squared $= 0.004$) and beta ($F(5, 732) = 0.58$, $p = 0.715$, eta-squared $= 0.004$) waves. A similar result is acquired when considering the differences between means of alpha and beta frequencies for each condition ($F(5, 732) = 0.4$, $p = 0.531$, eta-squared $= 0.0026$).

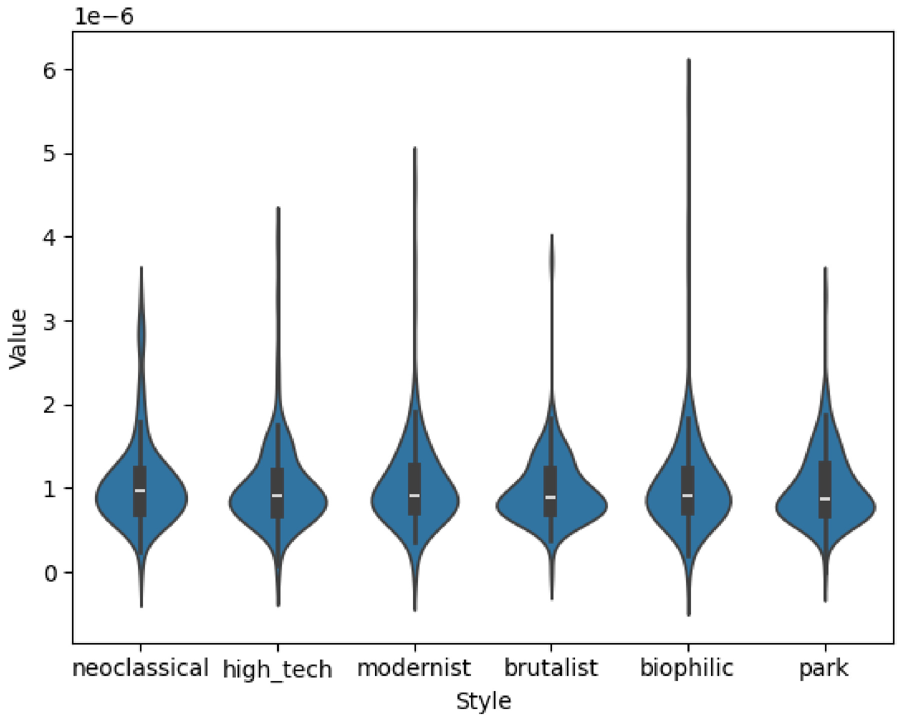

Figure 1. Violin plot of alpha frequency band activations per architecture style condition.

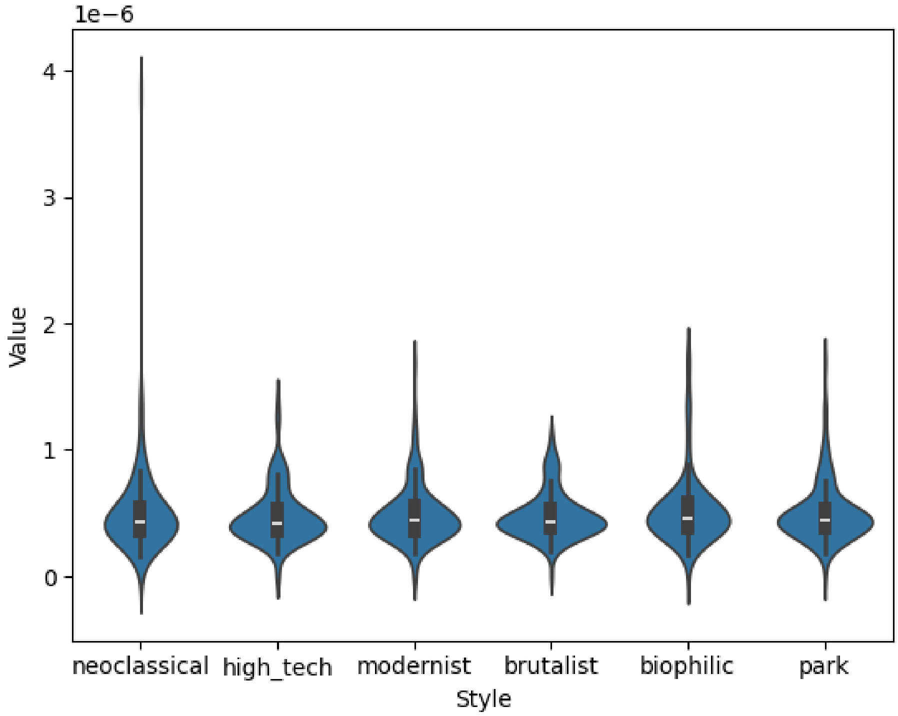

Figure 2. Violin plot of beta frequency band activations per architecture style condition.

ANCOVA

To control for preference and familiarity are known important effects in this phenomenon (Ng, 2020). To investigate this, an analysis of covariance (ANCOVA) was conducted to examine the effect of architectural style on the dependent variable while controlling for preference and familiarity (as self-reported in the questionnaire). Again, the results indicated that style did not have a statistically significant effect on alpha waves, $F(5, 731) = 0.58$, $p = .713$, eta-squared $= .004$. Similarly, preference was not a significant covariate, $F(1, 731) = 0.07$, $p = .788$, eta-squared $< .001$, nor was familiarity, with $F(1, 731) = 2.70$, $p = .101$, eta-squared $= .004$. Similar results were obtained for the beta waves ($F(5, 731) = 0.438$, $p = .613$, eta-squared $= .005$ and $F(1, 731) = 1.88$, $p = .313$, eta-squared $= .001$, respectively).

Discussion

Results did not support the hypothesis that architectural style differentially impact neurophysiological responses. We do not discard the null hypothesis that affirms that there is no difference between alpha and beta waves between different architectural styles. Previous findings linking natural settings with relaxation (Ellard, 2020; Valtchanov, Barton & Ellard, 2010) were not replicated.

The literature indicates that more natural conditions would display higher alpha frequencies and lower beta frequencies, which would, in turn, indicate restoration of attention and stress (Ulrich, 2023; Ohly, 2016). Although the literature suggests that this effect is strongly influenced by familiarity (Ellard, 2020) and preference (Cook & Furnham, 2013), familiarity and preference did not significantly mediate effects.

As current findings contradict much of the existing evidence, more research is needed. These results suggest that the intuitions surrounding the restorative qualities of natural spaces and the perception of brutalism as urban—therefore depleting attention and increasing stress—require further exploration.

Limitations

The sample consisted of 123 participants recruited through local channels and architecture-related social media, which may limit generalizability. The convenience sampling method could have introduced selection bias, particularly by overrepresenting individuals with a pre-existing interest in architecture. The use of a Muse EEG device, while convenient, is rudimentary in comparison with more sophisticated systems. Additionally, the presence of the VR headset might have introduced interference, although this was consistent across all conditions. Despite efforts to standardize VR environments, subtle differences in lighting, color, and design quality may have influenced results. Including multiple stimuli per condition and different artists' designs could improve reliability. The scales for aesthetic preference and simulation sickness used were not validated. Unlike other studies (Taylor, 2006), greyscale images were not used to avoid breaking VR immersion. We also did not control for immersive tendencies (Valtchanov, Barton & Ellard, 2010). Finally, we did not investigate the fractal-dimensional and frequency analysis of the visual stimuli, which have been found to be important in the restorative effects of nature (Taylor et al. 2005, Taylor, 2006).

Follow up research

Future studies could allow participants to move freely, offering more insight into their preferences. Another approach would be a simpler version of the experiment using static images or photos instead of VR. Using fMRI as an alternative would allow automatic control of movement and take advantage of built-in image display capabilities in MRI machines. Testing with artificially generated environments containing specific characteristics of interest could help isolate the relevant factors. Image frequency could also be subtly manipulated with post-processing filters.

Conclusion

The results of this study suggest that there is no clear evidence linking brutalist architecture to less favorable neurophysiological and subjective responses compared to more natural or biophilic environments. This challenges some existing theories about the restorative effects of nature and the aesthetic value of certain architectural styles. However, given the limitations of the study—such as sample bias, methodological constraints in EEG recording, and the use of simulated data—caution is needed in drawing definitive conclusions.

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