Objective Measures of Emotion During Virtual Walks through Urban Environments

Amir H. Elamin[1], Fatima S. Mahmoud[2], and Khalid A. Osman[3]
[1]Department of Civil Engineering, University of Khartoum, Khartoum, Sudan
[2]Department of Electrical Engineering, Sudan University of Science and Technology, Khartoum, Sudan
[3]Department of Computer Science, Nile Valley University, Atbara, Sudan

Abstract: Previous research has demonstrated variations in affective responses to environments through subjective verbal reports. This study employed objective measures to explore emotional responses. Participants virtually walked through six distinct areas of urban Paris using Google Maps' Street View tool, with areas chosen based on their median real estate prices—information concealed from the participants. Emotional responses were assessed via startle reflex modulation, heart rate, and skin conductance. Results showed a strong correlation between real estate prices and subjective pleasantness ratings. Startle reflex amplitudes differed significantly between the areas with the lowest and highest median real estate prices, while heart rate and skin conductance did not vary across conditions. These findings suggest that environmental interactions evoke measurable emotional responses, engaging motivational and emotional brain circuits. This aligns with the evolutionary theory of environmental preference. The implications are discussed within the context of environmental psychology and aesthetics.
Keywords: startle reflex modulation; urban environments; emotion and motivation; affective appraisal; environmental preference

1. Introduction:

Why do we prefer some environments, built and natural, over others? Why do we respond with certain emotions to places, even if we do not have any prior experience with them? Some scholars attributed aesthetic responses to environments solely to learning experiences. Accumulating evidence from environmental psychology and aesthetics though suggests an evolutionary interpretation of preference. The finding that young children prefer depictions of savannah landscapes was interpreted as evidence for a phylogenetically developed system of preference. Appleton's Prospect and Refuge theory is another strand of evidence suggesting that places offering an overview of the landscape as well as a site from which one can see without being seen would be preferred which has been validated empirically to some degree. Kaplan *et al.* studied preference for different environmental scenes and finally postulated four predictor variables, namely mystery, complexity, coherence and legibility to account for preference judgments. According to their theoretical framework those variables can be understood in terms of information gathering. Scenes high in mystery and complexity both promise a gain in information while coherence and legibility assures its comprehension. They link this information processing approach to an evolutionary perspective of preference by stating that human survival depends on constantly updating ones cognitive maps of the environment which would be served by a natural preference for places that offer new information while enabling its easy comprehension. With respect to the roles of cognition and affect in creating preferences they claim that automatic cognitive processes such as the identification of content and the extraction of potential informational gains would integrate into an affective code resulting in avoidance or approach behavior. This sort of automatic habitat selection seems reasonable to be innate to some degree; after all, it is not unprecedented in humans as many animals show this innate pattern of habitat selection. Russell and collaborators investigated affective responses to environments and showed that affective appraisal of environments could reliably be reduced to the two dimensions valence and arousal by factor-analysing subjects' ratings of landscapes on bipolar adjective pairs. The valence dimension of affect has been conceptualized as a behavioural tendency ranging from approach/appetitive to withdrawal/defines thus fitting neatly with Kaplan and Kaplan *et al.* who proposed a role of affect in guiding interaction with the environment. Affect was in these studies defined as "emotion expressed in language". By definition, verbally reported affective appraisal could occur with no inner emotional feeling. It has also been pointed out that subjects could rate a set of landscape depictions as being differently pleasant while the ongoing emotional state during this task could be steady boredom . Most scholars agree that emotions consist of several components usually termed behavioural, physiological and mental which do not necessarily covary. Behavioural and language dimensions of arousal and valence are presumed to be roughly coupled .

Opposed to verbal measures of emotion, psychophysiological approaches to environmental psychology have been an exception thus far. A number of studies used indicators of autonomic arousal to study the effects of environmental stressors or the restorative qualities of places . No reported study employed the startle modulation paradigm to study affective evaluation of environments. The present study examines if environmental scenes can alter not only verbally reported emotion, but also its physiological components by measuring the modulation of the eye-blink component of the startle reflex. Our expectation was that an attractive environment results in a reduction of the startle reflex whereas an unattractive environment enhances it. Furthermore, we recorded ongoing changes in skin conductance level (SCL) and heart rate (HR) to define states of arousal related while being exposed to different environments. Lang and associates extensively demonstrated the modulation of the startle reflex to a sudden acoustic probe (white noise delivered through headphones) by ongoing emotional states. Emotional states have mostly been elicited using pictures as lead stimuli although some studies demonstrated startle reflex modulation using more complex stimuli such as music , film-clips , odors and food . Pleasant states diminish the startle response while it is enhanced in an aversive state. According to Lang and colleagues emotions are organized around the two strategic dimensions valence and arousal. Internal and environmental stimuli induce an affective state along these dimensions which guides subsequent behavior within a particular environment by priming according reflexes. More concretely, this implies that a place that makes us feel uneasy would automatically enhance defensive reflexes such as startle or flight in response to sudden stimuli while a place that makes us feel comfortable and safe would foster an appetitive behavioural repertoire including procreation and nurturance while the exact reason for this emotion might be outside awareness which seems in accordance with subjective experience. The present study makes use of the StreetView tool of Google Maps, an interactive internet mapping service. StreetView is a novel feature of Google Maps which allows for 360° panoramic views on the street level. Subjects can look around at whatever they are interested in by making use of the 360° panoramic feature thus allowing for an experience more alike being at the actual place than photographs or VR models could.

Furthermore, we draw on an external criterion–the median real estate price of a given urban area–as an indicator of valence. Average real estate price is thought to be influenced in part by the affective evaluation of a neighbourhood by the city's inhabitants. The exact mechanisms determining a neighborhood's real estate price are certainly more complex, involving aesthetic, social, infrastructural and other variables. Nevertheless, these variables might be partially accessible through StreetView, as subjects can not only view physical features like building exteriors but also environmental aspects such as signs of deterioration, the type of people present in the scene *etc.* which might serve as indicators for latent social and infrastructural characteristics. Thus we hypothesize that the more expensive areas do not only cause higher ratings of pleasantness but also an attenuated startle reactivity as indicated by the eye-blink EMG.

2. Method

2.1. Study Participants

The initial sample comprised 20 volunteers, all university students, with a balanced gender representation of 8 men and 12 women, aged between 17 and 28 years (mean age = 22.15, SD = 2.39). All participants were right-handed and had normal or corrected-to-normal vision. They reported no history of neurological or psychological disorders, ensuring a homogeneous and reliable sample for physiological measurements. Furthermore, none of the participants had any known familiarity with the selected districts in Paris, thus minimizing potential biases related to personal experiences or preconceptions. Data from four participants were excluded due to artifacts distorting their recordings, resulting in a final sample size of 16 participants.

2.2. Lead Stimuli (Urban Environments)

Paris was selected as the representative urban environment due to the availability of detailed real estate price data published by the city's Chamber of Notaries. Median real estate prices per square meter for each quartie (sub-unit within districts) were sourced based on sales from the second trimester of 2009. Six quarties were chosen to represent a spectrum of real estate prices:

Charonne (20th district): €4,750/m²
Porte Saint-Denis (10th district): €5,650/m²
Croulebarbe (13th district): €7,040/m²
La Muette (16th district): €7,600/m²

Notre-Dame-des-Champs (6th district): €9,000/m²
St.-Thomas-d'Aquin (7th district): €12,090/m²
The selected routes comprised small streets with one or two lanes, featuring only daytime scenes. Routes were created using Google Maps' route finder tool and adjusted to ensure uniformity in length, street characteristics, and environmental conditions across all routes. Minor fluctuations in the real estate prices over time were negligible, as the study treated price as an ordinal variable.

2.3. Startle Response Measurement

The startle probes consisted of 50 ms bursts of acoustic white noise at 105 dB sound pressure level, delivered binaurally through professional-grade headphones to ensure clear stimulation. Sound levels were calibrated using a mobile measuring device (Voltcraft) and amplified with a headphone preamplifier (Behringer MicroAMP HA400).

Six audio tracks were designed, each containing five startle probes spaced at varying intervals (minimum inter-stimulus interval: 40 seconds) following an initial baseline probe. Electromyography (EMG) was recorded using a NeXus-10 wireless system, capturing activity from the musculus orbicularis oculi of the left eye. Adhesive pregelled electrodes were placed below the lower eyelid and at the outer corner of the eye, with a ground electrode positioned on the right cheek. The EMG signal was sampled at 2,048 Hz and processed using a 20–500 Hz bandpass filter. Signals were then transformed into amplitudes using the Root Mean Square (RMS) method for statistical analysis.

2.4. Skin Conductance and Heart Rate

Skin conductance (SC) and heart rate (HR) were recorded using the NeXus-10 system. SC data were collected at 32 samples per second using a two-finger sensor attached to the middle and ring fingers of the left hand, capable of detecting minute changes in microsiemens.

HR was measured via photoplethysmography using a blood volume pulse sensor attached to the left index finger. This method employed near-infrared light to track pulse variations. Both SC and HR signals were analyzed using the BioTrace+ software to extract baseline and stimulus-related measurements.

2.5. Procedure

Participants were seated comfortably in front of a computer screen and instructed to navigate six predefined routes through Paris using a mouse. Routes were standardized to 0.7 km in length and featured similar street widths, daylight conditions, and moderately cloudy weather. Participants were guided to imagine they had recently moved to the city for work and were exploring their new neighborhood.

During the trial phase, participants practiced navigating at an approximate pace to complete each route within five minutes. Upon reaching the endpoint, they were instructed to return along the same route. Startle probes were introduced during the trial to familiarize participants with the stimulation. Each route was presented in a randomized and counterbalanced order, with five startle probes delivered per route.

After completing each route, participants rated their experience using the Self-Assessment Manikin (SAM) on dimensions of pleasure and arousal, along with a 28-item questionnaire assessing perceptions of the environment.

2.6. Analysis

2.6.1. Data Pre-Processing

Raw EMG signals were processed to extract amplitudes using the RMS method. Responses occurring between 100–200 ms post-startle probe were selected for analysis. Trials with distorted or missing signals were excluded, resulting in 0.007% missing values. SC and HR data were analyzed for baseline (first 15 seconds) and stimulus phases (30 seconds–5 minutes) to calculate percentage changes in autonomic responses.

2.6.2. Statistical Analysis

Repeated-measures ANOVAs were conducted on physiological data (startle reflex, SC, HR) with AREA as the within-subject factor. Rank correlations between real estate price and physiological responses were also calculated. Behavioral data, including SAM ratings, were similarly analyzed using ANOVAs, with additional rank correlations linking valence ratings, real estate price, and startle amplitu**des.**

3. Results

3.1. Physiological Data

3.1.1. Startle Modulation

The main effect of AREA on startle modulation was not significant, $F(5.75) = 1.33$; n.s. partial eta2 = 0.082. However, simple contrasts performed on the six conditions using the highest price category as baseline reached significance for the comparison highest versus the lowest price category [$F(1.15) = 5.63$; $p < 0.05$] partial eta2 = 0.27. None of the other comparisons approached significance. Correlation between MEANSTARTLE and real estate price (PRICE) revealed a strong linear relationship (−0.771; $p < 0.05$).

3.1.2. Autonomic Arousal

The main effects of AREA on SC [F(5.85) = 1.082, n.s]. and HR [F(5.85) = 1.739 n.s.] were not significant. Thus, indicators of autonomic arousal were not systematically affected by any area.

Paralleling the physiological results, the main effect of AREA on verbally stated arousal (SAMAROUSAL) was not significant, F(5.95) = 0.762; n.s. The main effect for verbally stated valence (SAMVALENCE) though was significant, F(5.95) = 5.664; $p < 0.001$ partial eta2 = 0.23. Polynomial contrasts showed a significant linear component when the conditions were arranged in ascending order with respect to their price, F(1.19) = 35.18; $p < 0.0001$, partial eta2 = 0.649. Correlation between SAMVALENCE and PRICE were even higher than between MEANSTARTLE and PRICE, 0.941; $p < 0.01$.

Correlation between MEANSTARTLE and SAMVALENCE was moderately high but not significant (0.698; n.s.). All reported p-values of correlations are one-tailed.

4. Discussion

The present study demonstrated verbally reported and physiological emotional responses to virtual walks through six urban environments varying in median real estate price. Regarding objective startle reflex measures the contrast highest versus lowest price category representing the conditions with the hypothesized maximum difference in affective valence revealed a strong effect and reached significance. Startle data correlated significantly with real estate price, which was in turn significantly correlated with ratings of valence, suggesting that real estate price was indeed a valid approximation of the affective quality of the presented areas. Simultaneous recordings of heart rate and skin conductance revealed no significant findings with respect to influences of different urban environments on these measures. It can be concluded that evaluation of urban environments does indeed have a strong affective component, detectable through a basic biological and phylogenetically old mechanism. This appears to be in line with the notion of an evolutionary developed system of preference for environments. An alternative attentional account of the startle modulation observed here cannot be completely ruled out although it seems unlikely as both verbal and physiological measures were not differentially affected by the urban areas, which might be expected had they engaged attention in different ways. The present study thus provides support for the hypothesis of affect guiding interaction with the environment by priming reflexes and behavior which match current affective states. Two issues remain open for future investigation: Firstly, the concrete variables causing the affective response are not elucidated in this study. Several of the above-mentioned theories of environmental preference could potentially explain why some urban scenes resulted in more positive effect than others. Was it a particular combination of mystery, complexity, coherence and legibility displayed by the scenery, a prevalence of prospect and refugee elements, or did our subjects infer social characteristics of the areas from certain visual cues? Possibly more than one theory can explain the observed differences in affective responses, leaving open the question to which degree they contributed respectively. Secondly, it remains unclear whether the variables influencing verbally stated affective appraisal are the same as those determining changes in physiological state. Albeit verbal and physiological measures were roughly correlated in this study they actually could have been evoked by different sets of stimulus properties which incidentally co-occurred within any area. For instance, variables concerned with the informational content could have been effective in producing verbally reported liking while the perceived danger of being attacked inferred through the analysis of the social makeup could have mainly contributed to the alteration in physiology. In fact, the second highest real estate price area (area five) highlights potential differences between subjective rating and objective startle response (see Figures 1 and 2). While it was rated to be the second most pleasant area, startle modulation indicated that it evoked less positive affect than the much cheaper areas three and four (this pattern is identical for males and females suggesting that it is not caused by outliers or incidental fluctuations in the startle data). One explanation for this irregularity might be that area five is centrally located, while areas three and four lie rather in the periphery. The high real estate price of area four might thus be due to infrastructural variables which could have caused the positive verbal rating while leaving startle reflex modulation unaffected, possibly because thorough cognitive analysis of the scene is a prerequisite for their appreciation.

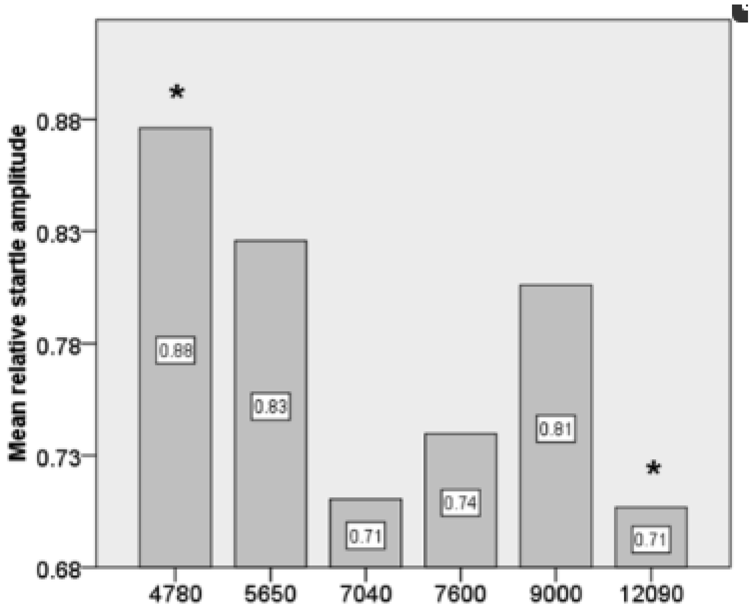

Figure 1. Mean relative startle amplitudes for all six areas with different median real estate prices per m^2. All means are calculated relative to their corresponding baselines. The lowest startle amplitude in the highest price condition differs significantly from the highest startle amplitude in the lowest price condition. This reflects the most positive emotional and motivational state while walking through the most expensive urban environment. Note that the second most expensive urban environment is associated with a higher startle amplitude than two cheaper urban environments.

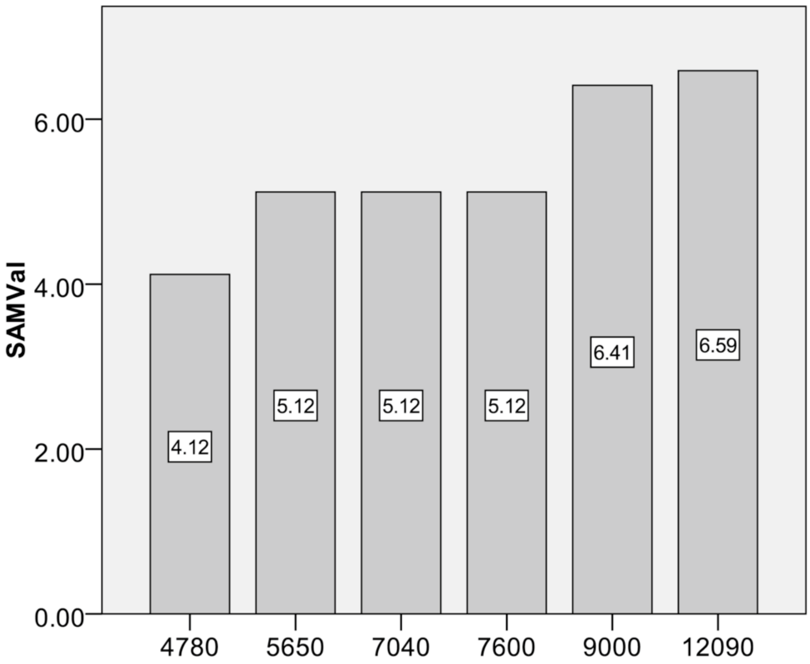

Figure 2. Subjective rating of pleasantness related to the six urban environments. Note, the higher the price the higher the subjective preference.

Interestingly, a recent startle reflex modulation study about degree of anger displayed in facial expressions revealed a similar non-linear relationship between facial expression intensity and startle reflex modulation . Although in their study, self-reported degree of anger in facial expressions gradually increased with true increasing anger in facial expressions, eye blink amplitudes actually matched this pattern only for the neutral and the 100% angry facial expression. Our results show a strikingly similar pattern. Final interpretations are difficult, especially with facial expressions, because they mean communicating an emotion rather than actually eliciting one.

As far as we know, the Streetview tool (Google Inc.) has not been deployed in experimental psychological research to date. Compared to photographic or virtual stimulus material it can provide experimental subjects in the laboratory setting with an experience similar to being at an actual place without having to actually take them there. Subjects' responses can then be related to demographic data such as crime statistics, social characteristics of the area's inhabitants or real estate price as done in the present study.

In terms of a better understanding of emotion as such, our study may be seen as highlighting possible discrepancies between basic unconscious emotion and subjective preference.

References

1. Lyons, E. Demographic correlates of landscape preference. *Environ. Behav.* **1983**, *15*, 487–511.
2. Balling, J.D.; Falk, J.H. Development of visual preference for natural environments. *Environ. Behav.* **1982**, *14*, 5–28
3. Appleton, J. *The Experience of Landscape*; John Wiley: London, UK, 1975.
4. Stamps, A.E. Some findings on prospect and refuge: I. *Percept. Motor Skills* **2008**, *106*, 147–162]
5. Stamps, A.E. Some findings on prospect and refugee theory: II. *Percept. Motor Skills* **2008**, *107*, 141–158.
6. Woodcock, D.M. A Functionalist Approach to Environmental Preference. Ph.D. Dissertation, University of Michigan, Ann Arbor, MI, USA, 1982
7. Kaplan, S.; Kaplan, R.; Wendt, J.S. Rated preference and complexity for natural and urban visual material. *Percept. Psychophys.* **1972**, *12*, 354–356.
8. Kaplan, R. The analysis of perception via preference—A strategy for studying how the environment is experienced. *Landsc. Plann.* **1985**, *12*, 161–176.
9. Kaplan, S. Aesthetics, affect, and cognition - environmental preference from an evolutionary perspective. *Environ. Behav.* **1987**, *19*, 3–32.
10. Ruso, B.; Renninger, L.; Atzwanger, K. Human habitat preferences: A generative territory for evolutionary aesthetics research. In *Evolutionary Aesthetics*; Voland, E., Grammer, K., Eds.; Springer-Verlag: Berlin, Germany, 2003; pp. 279–294.
11. Russell, J.A. A circumplex model of affect. *J. Perso. Soc. Psychol.* **1980**, *39*, 1161–1178.
12. Russell, J.A.; Mehrabian, A. Approach-avoidance and affiliation as functions of emotion-eliciting quality of an environment. *Environ. Behav.* **1978**, *10*, 355–387.
13. Russell, J.A.; Pratt, G. Description of the affective quality attributed to environments. *J. Perso. Soc. Psychol.* **1980**, *38*, 311–322.
14. Russell, J.A.; Ward, L.M.; Pratt, G. Affective quality attributed to environments—A factor analytic study. *Environ. Behav.* **1981**, *13*, 259–288.
15. Snodgrass, J.; Russell, J.A.; Ward, L.M. Planning, mood, and place-liking. *J. Environ. Psychol.* **1988**, *8*, 209–222.
16. Russell, J.A.; Snodgrass, J. Emotion and the environment. In *Handbook of Environmental Psychology*; Stokols, D., Altman, I., Eds.; Wiley: New York, NY, USA, 1987; pp. 245–281.
17. Lang, P.J.; Bradley, M.M.; Cuthbert, B.N. Emotion, attention, and the startle reflex. *Psychol. Rev.* **1990**, *97*, 377–395.
18. de Kort, Y.A.W.; Meijnders, A.L.; Sponselee, A.A.G.; Ijsselsteijn, W.A. What's wrong with virtual trees? Restoring from stress in a mediated environment. *J. Environ. Psychol.* **2006**, *26*, 309–320.
19. Hartig, T.; Evans, G.W.; Jamner, L.D.; Davis, D.S.; Garling, T. Tracking restoration in natural and urban field settings. *J. Environ. Psychol.* **2003**, *23*, 109–123.
20. Ulrich, R.S. Natural *versus* urban scenes—Some psychophysiological effects. *Environ. Behav.* **1981**, *13*, 523–556.
21. Bradley, M.M.; Lang, P.J. Measuring emotion—The self-assessment mannequin and the semantic differential. *J. Behav. Ther. Exp. Psychiatry* **1994**, *25*, 49–59.
22. Lang, P.J. The emotion probe—Studies of motivation and attention. *Am. Psychol.* **1995**, *50*, 372–385.
23. Vrana, S.R.; Spence, E.L.; Lang, P.J. The startle probe response—A new measure of emotion. *J. Abnorm. Psychol.* **1988**, *97*, 487–491.
24. Roy, M.; Mailhot, J.P.; Gosselin, N.; Paquette, S.; Peretz, I. Modulation of the startle reflex by pleasant and unpleasant music. *Int. J. Psychophysiol.* **2009**, *71*, 37–42.
25. Kaviani, H.; Gray, J.A.; Checkley, S.A.; Kumari, V.; Wilson, G.D. Modulation of the acoustic startle reflex by emotionally-toned film-clips. *Int. J. Psychophysiol.* **1999**, *32*, 47–54.

26. Kaviani, H.; Wilson, G.D.; Checkley, S.A.; Kumari, V.; Gray, J.A. Modulation of the human acoustic startle reflex by pleasant and unpleasant odors. *J. Psychophysiol.* **1998**, *12*, 353–361.
27. Walla, P.; Richter, M.; Färber, S.; Leodolter, U.; Bauer, H. Food evoked changes in humans: Startle response modulation and event-related potentials (ERPs). *J. Psychophysiol.* **2010**, *24*, 25–32.
28. Chambre des Notaires de Paris. Le marché immobilier en Ile de France. Available online: (accessed on 5 April 2009).
29. Hanyu, K. Visual properties and affective appraisals in residential areas in daylight. *J. Environ. Psychol.* **2000**, *20*, 273–284.
30. Dunning, J.P.; Auriemmo, A.; Castille, C.; Hajcak, G. In the face of anger: Startle modulation to graded facial expressions. *Psychophysiology* **2010**, *47*, 874–878.