Research Article

Neuro-Urbanism: Measurement of the Street Enclosure and its Influence on Human Physiology Through Wearable Sensors

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Abstract

This study explores the neurophysiological impact of visual qualities in Shanghai's chosen urban spaces, specifically focusing on the perception of street's visual quality. This metric has been defined by changes in physical space of intersection vs. in street, visibility of the sky, continuity of the wall, and ratio of sections. These variables contribute to the "enclosure rating", a dimensionless number that can determine the perception of urban street intersectional space by occupants. We measured the changes in average heart rate of 15 participants at the selected intersections using a customized wearable sensor kit. We compared the participants' heart rate towards the intersectional space and towards street and ask participants to complete a comfort-related post-evaluation. Analysis of the data show that subjects who look at enclosed views of streets experienced a lower heart rate than those who look at intersections.

Keywords: Environmental Psychology, Neurophysiology, Street Intersections, Urban Environment, Wearable Technology.

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Araştırma Makalesi

Nöro-Şehircilik: Sokak Çevresinin İnsan Fizyolojisi Üzerindeki Etkisinin Giyilebilir Sensörler Aracılığıyla Ölçümü

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Özet

Bu çalışma, Şangay'ın seçilmiş kentsel alanlarındaki görsel niteliklerin nörofizyolojik etkisini araştırmakta, özellikle caddenin görsel kalitesinin algılanmasına odaklanmaktadır. Bu metrik, kavşağın fiziksel alanındaki ve sokaktaki değişiklikler, gökyüzünün görünürlüğü, duvarın sürekliliği ve kesitlerin oranı ile tanımlanmıştır. Bu değişkenler, kentsel cadde kavşak alanının yolcular tarafından algılanışını belirleyebilen boyutsuz bir sayı olan "çevreleme derecesine" katkıda bulunmaktadır. Özelleştirilmiş bir giyilebilir sensör kiti kullanarak seçilen kavşaklarda 15 katılımcının ortalama kalp atış hızındaki değişiklikleri ölçtük. Katılımcıların kavşak alanına ve sokağa yönelik kalp atış hızlarını karşılaştırdık ve katılımcılardan konforla ilgili bir son değerlendirmeyi tamamlamalarını istedik. Verilerin analizi, sokakların kapalı görünümlerine bakan deneklerin, kavşaklara bakanlara göre daha düşük bir kalp atış hızı yaşadığını göstermektedir.

Anahtar Kelimeler: Çevresel Psikoloji, Giyilebilir Teknoloji, Kentsel Çevre, Nörofizyoloji, Sokak Kavşakları.

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INTRODUCTION

Street intersections play a critical role in defining our urban experience. Their visual features identified by architecture and urban design principles (Lynch, 1960; Meenar and Mandarano, 2021, p. 1-12) impact our navigational (Dalton, 2003, p. 1-14; Hillier and Lida, 2005) and aesthetic preferences (Galindo and Corraliza, 2000, p.13-27; Chatterjee, 2010, p.53-62) as well as our cognition (Hillier, 2007, p. 1-20) and well-being (Gehl, 2006, p. 63). Along with streetscape design, where experience is defined more through movement related to wayfinding (Emo, 2012), intersections also act as anchors or nodes determining more stationary human behaviours. There are several features that determine the quality of the experience at the intersection and how we behave in these places. Many of these parameters are qualitative, relying on questionnaires and appraisals, based on measurements, and evaluations assessed through disciplines such as environmental psychology. However, an approach based on quantified data and measurements is less common for streets (Ewing and Handy, 2009, p. 65-84; Blecic et al., 2017, p.1-19) and relatively rare for street intersections.

With this study, we attempt to quantify, analyse and relate human neurophysiological response defining experience at street intersections. Visiospatial cognition and experience in urbanism have recently been investigated in areas such as healthy cognitive aging (Cassarino and Setti, 2015, p.167-182), as well as in pedestrian navigation patterns based on urban activities (Natapov and Fisher-Gewirtzman, 2016, p. 60-70). However, the limitations of analysis methods make it difficult to objectively determine how the spatial attributes of an urban space affect user subjective experiences.(Morello and Ratti, 2009, p. 837-853)

During recent years, along with the development of information technology, computer-aided methods have been introduced, tapping into big data and looking at its uses in urbanism and design. Some of these researchers look at social media feeds or shared online websites, such as research on preferred routes in a city based on happiness (Quercia et al., 2014). However, making sense out of big data relies on the additional collection of various environmental information, focusing on correlations.

There has been substantial research on wearable sensor technology and their use in urban design studies. Recent advances in wearable health monitoring systems enabled the development of many wearable human health monitoring devices that provide continuous measurements while users are on the move within a built environment (Lou et al., 2020, p. 1-43). Mobile measurements in urban built environments can also assess environmental quality in addition to personal measurements (Mamun and Yuce, 2019, p. 7771-7788). There have been several studies investigating the neurophysiological feedback of the urban built environment experience looking into autonomic nervous system response and urban experiential design features such as depth and visual entropy (Li et al., 2016, p. 218-236); thermal comfort, zoning characteristics, and visual complexity (similar to entropy) (Benita and Tunçer, 2019, p. 1-14) and visual features such as landscape, sky and colours (Zhang et al., 2021, p.1-20). Adding to emerging studies, there is a potential to develop streamlined methods to deliver a significant assessment framework that can work in real time by providing feedback at street intersections using mobile body and environment sensors, along with AI-based scene analysis.

Investigating the contradicting scales and the activity of the street in the area allowed the start of a study on the role of the enclosure of street space in the perceived comfort by pedestrians. This study aims at the following:

1. Determine and assess variables that physically contribute to the extent of obstruction in street-level spaces.
2. Measurement of the variation in the heart rate of pedestrians reacting to changes in the building environment.
3. Examine the correlation between perceived comfort and human neurophysiological response.

MATERIALS AND METHODS

Overview

In the study, two different data collection techniques were used: self-report questionnaires and heart rate measurement with wearable sensors. Although self-report questionnaires provide information on human response and perceived emotions, they are subjective and open to judgment. Therefore, the use of wearable sensors that monitor physiological responses such as heart rate increases objectivity and therefore the reliability of the study. Furthermore, the wearable sensors allowed the heart rate response to be measured on different streets and at different degrees of occlusion.

Human emotional behaviour results from activation in unique neural pathways of the central nervous system (CNS) (Russell, 1980, p. 1161-1178; Posner et al., 2005, p. 715-734). Along with the CNS, autonomic nervous system (ANS) activity is an important component of the emotional response. ANS responses, including changes in heart rate, can be modulated directly or indirectly by visual and auditory projections to the medial prefrontal cortex and thalamus, bypassing the amygdala in the limbic cortex (Kreibig, 2010, p. 394-421). These emotional correlates can be measured directly or indirectly using noninvasive sensor technologies. We can measure CNS and ANS responses using neuroscientific methods that focus on the brain and nervous system.

Experimental Design

In this study, the term "enclosed" refers to the limits to which the landscape, walls, and other elements of buildings surround streets and public spaces (Augst and Pape, 2022). The enclosure of the street shapes the interaction of pedestrians in urban spaces. Interaction in urban built environments and the level of activity on the streets are widely used to measure comfort. (Alkhresheh, 2007). Previous research has shown that well-coiled streets tend to give users a more secure impression, and thus provide more opportunities for physical activity. In the meantime, large-scale, wide-range, nonclosed spaces create a feeling of inactivity (Arnold, 1980). Using the concepts and definitions mentioned above, we understand the physiological and emotional reactions of pedestrians to buildings.

The enclosure rating is a nondimensional value that quantifies the perimeter of a street (Tang & Long, 2019, p.1-18). Three physical indicators (visibility of sky, continuity of wall, and ratio of section) are used to determine the extent of street closure. Since each variable's measurement has different units, it is necessary to normalize them as seen in Equation (1):

$$z_i = \frac{a_i - \min(a_i)}{\max(a_i) - \min(a_i)} \tag{1}$$

Here, refers to the visibility of the sky / continuity of walls / ratio of section. When these three variables are normalized, they are summarized as an enclosure rating. as seen in Equation (2):

$$\text{Enclosure Index} = \sum_i \beta_i a_i \qquad (2)$$

Here, is equal to the total of normalized values of visibility of the sky / continuity of walls / ratio of section; value is the weight of parameters and is the normalized value of visibility of the sky, continuity of wall, and ratio of section.

The study focuses on the visual properties of the street that affect pedestrians. The visibility of the sky, the continuity of the walls, along with the section ratio, are physical aspects of the buildings, which contribute to the perception of enclosure by pedestrians.

Visibility of Sky refers to the amount of sky visible to pedestrians (Figure 1). The canopies and buildings surrounding trees that determine the amount of visible sky for pedestrians. The more the sky is seen, the more daylight enters the streets. Daylight stimulates visual awareness and improves pleasant and attractive environments. (Dover and Massengale, 2013, p. 416). The continuity of the wall is the ratio of the length of a solid wall to the length of an opening or transparent window of a store. This shows the porosity of the streets. A complete and continuous façade of the building creates a lively and flow-free street within the available enclosure (Ewing and Handy, 2009, p. 65-84; Ewing et al., 2016, p. 5-15). The ratio of Section (Figure 2) is the rate of the width of a road and the height of a building (in average). This might affect the perception of the scale of pedestrians and, therefore, their level of comfort. (Alkhresheh, 2007). Together, these values establish the enclosure rating.

The experience of the streets is based on the physical, physiological, and psychological comfort of pedestrians in the environment (Gehl, 2013, p. 63). Self-evaluations provide information on human responses and emotions, but they are open and subject to bias. Because of this, sensors that monitor physiological responses (such as heart rate) offer objective and reliable measures. Furthermore, sensors have allowed one to observe the heart rate reaction in different streets and at different enclosure levels.

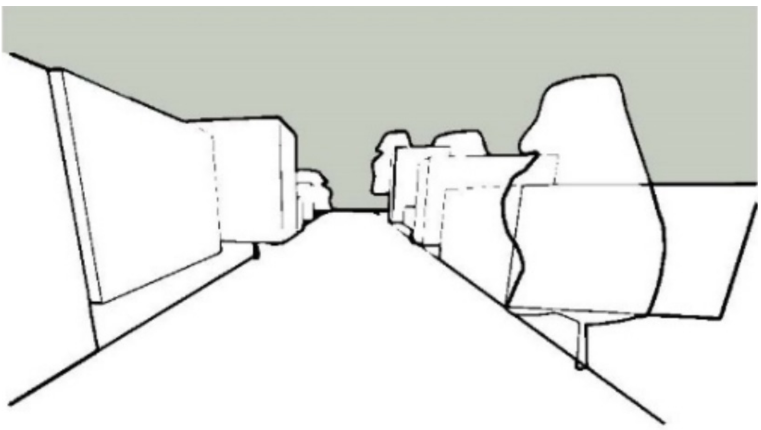

Figure.1- Visibility of Sky diagram

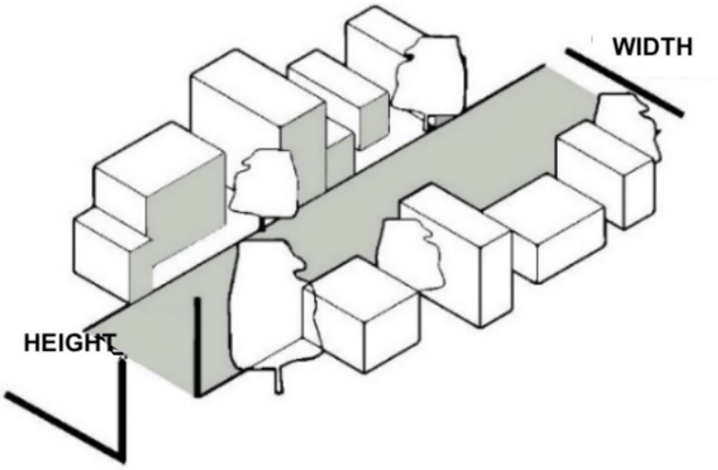

Figure.2- Ratio of Section diagram

Participants

We recruited participants among college students aged 19 to 28 years, through a short-term promotion in selected chat groups. We seek the following criteria in participants: Ability to communicate in English (reading and writing); No experience and training in architecture, urban planning, landscape, or interiors, or any design program related to the built environment-related design program; in good neurological and psychological health without any prior conditions; and normal vision (prescription glasses and contact lenses are allowed). Based on these criteria, we selected 15 adults to participate in this pilot study (Female to male ratio is 3:2; average age is 23). Due to COVID-19 related health protocols and lockdown measures, it was difficult to reach the desired number of participants. The participants are identified in 3 different countries in terms of their nationalities and native languages. They are given a printed questionnaire during the pre-experiment phase, which took an average of 5 minutes to complete. The questionnaire included 14 points of inquiry regarding their profile details, some of which are listed above, their current emotional state and stress levels, familiarity with the experiment area, whether or not they eat, drink any alcohol or caffeine-containing drinks, along with their age and major (Dixon-Woods et al., 2005, p. 45-53).

Stimuli

Figure 3 shows the Jingan area in Shanghai, a retail and commercial zone. The main street in the neighbourhood is close to a park and also to some single-lane streets. Many locals, tourists, and tourists enjoy the shops, cafes, and restaurants along the streets. The human scale with low-rise historic buildings, relatively narrow streets, and urban green creates a relaxing environment. Developed during the late nineteenth and early twentieth centuries, the area is known for its heritage European planning and architecture, and the region meets the criteria for its high urban vitality and excellent opportunities for social interaction (Dover and Massengale, 2013, p. 416). The six-way intersection chosen for the experiment has a distinct small park in the residual area surrounded and defined by the roads that join from different directions. The characteristic of the area is residential, with businesses on the first floor located in all except one direction facing that small park.

Figure.3- Map of the study site

Methods and Equipment

To measure different visual properties of the urban built environment, we have adopted a four-step method focusing on equipment, protocols to collect data, and analysis methods to achieve the results (Figure 4).

Visibility of Sky

- Equipment: Camera, Photoshop, and Tensorflow to process extracted images in the Pyramid Scene Parsing Network (PSPNet) (Zhao et al., 2017).
- Protocol: Take two photos of the view of pedestrians towards the intersections and towards the street of interest.
- Analysis: Images evaluated using PSPNet. The machine learning (ML) based algorithm performs semantic segmentation of the image, detecting the outline of objects (such as buildings, people, roads, trees). Using ML, the toolkit segments images into objects blocked as colours. Colour segments are identified, and percentages are automatically calculated (Figure 5)

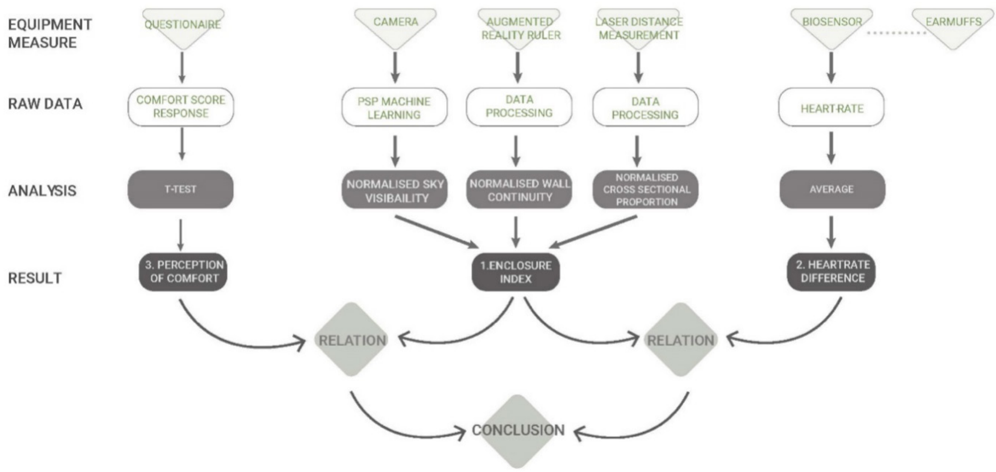

Figure.4- Methodology Diagram

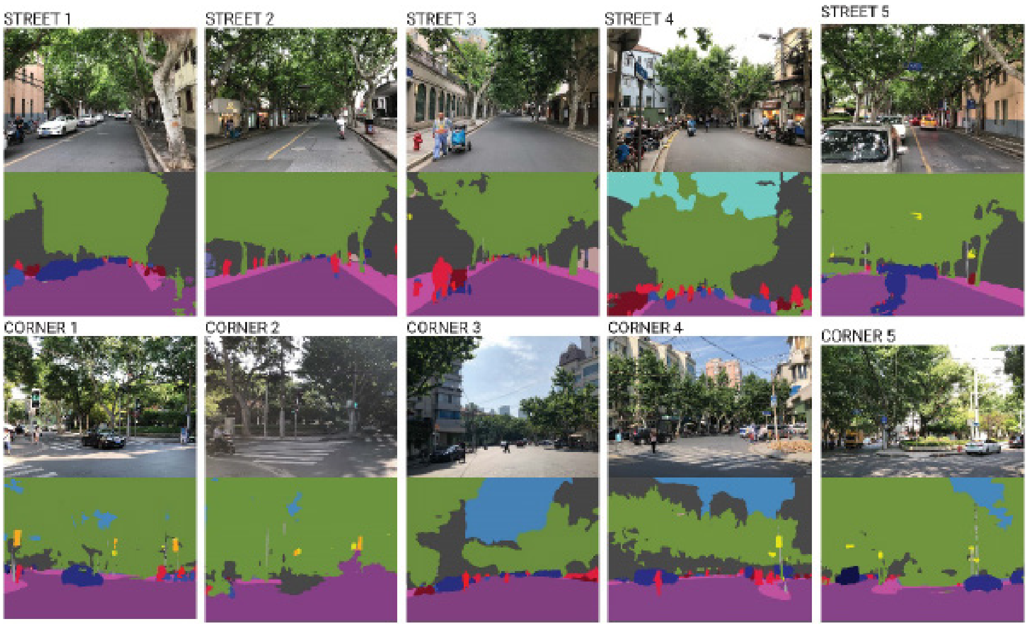

Figure.5- The framework to calculate the percentage of sky visibility using ML based PSPNet.

Continuity of Wall

- Equipment: A mobile app named Ruler (working in phone or tablet, Augmented Reality applications that measure the window width and openings) (Figure 6)
- Protocol: Measure the total length of the opening (such as the gap between doors and buildings) and transparent materials (such as store windows) along the façades on the street. Both sides were subjected to measurements.
- Analysis: The total length of the opening was divided into 100 meters.

Ratio of Section

- Equipment: Laser measurement device (Figure 6)
- Protocol: The height of all buildings on the 100-m street has been measured. The width of the road is measured.
- Analysis: The height of the buildings and the width of the road are average. On average, the height of the building and the width of the road are divided.

Figure.6- AR based measuring app and laser measurement device

Procedure

15 participants received a prequestionnaire and were randomly assigned to the space of the streets, as shown in Figure 7. The participants then carried a custom sensor kit (Figure 8), and heart rate was measured in seconds using four conditions using wearable biosensors.
1. looking intersection (urban noise and open space),

2. looking at the intersection of the street while wearing noise cancelation headphones (open, no noise),
3. looking at an enclosed street (loud and noisy and enclosed),
4. looking at the enclosed street with headphones (open, no sound).

After the experiment, the participants completed the self-evaluation. The higher they rank in the overall comfort rating; the more street comfort is assumed. This subjective questionnaire is used to attribute negative or positive emotions to the average heart beat rates of the heart (Figure 9).

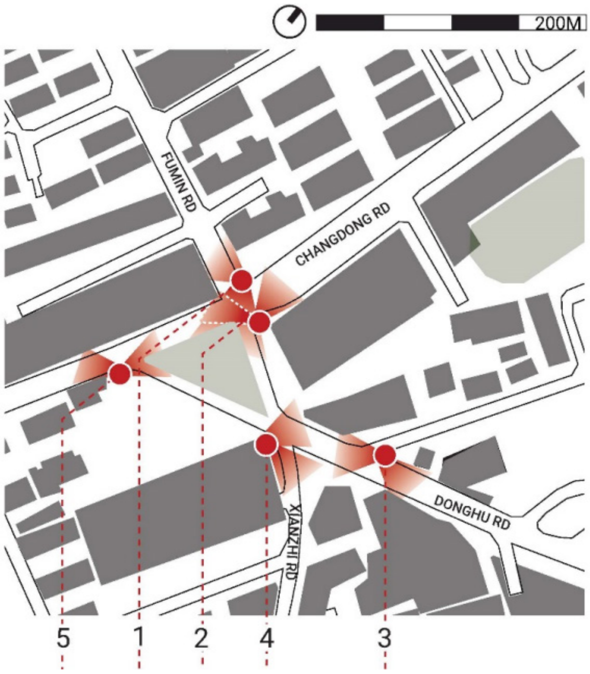

Figure.7- Experiment locations around the 6-way street intersection

Figure.8- Custom sensor kit and portable camera as worn by one of the subjects

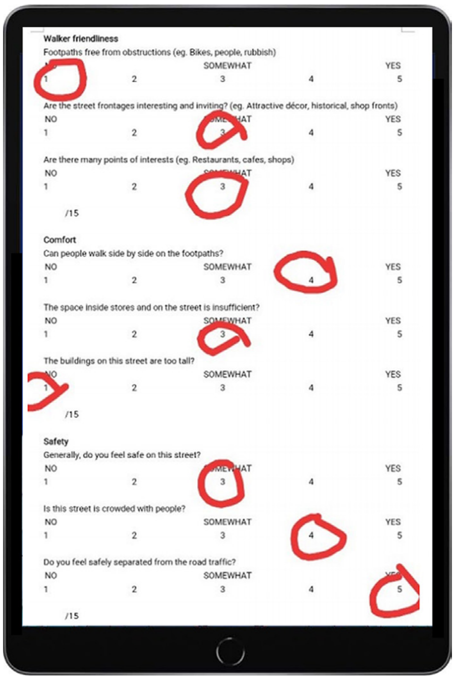

Figure.9- Comfort Scoring Questionnaire

Once the visibility of the sky was measured, the continuity of the walls and the proportional variables of the sections were measured. These numbers have been normalized. This value for each variable is summarized in the enclosure rating formula. This calculation was made for each corner of the road at intersections 1, 2, 3, 4 and 5 (Figure 7).

RESULTS

Enclosure Rating

Based on Tables 1 and 2, the enclosure rating value (0.021 – 1.231) is higher than the corner value (0.531 – 0.951), indicating that the street views of subjects are more closed. Street 1 has the highest enclosure rating of 2.101. This is mainly because of the low visibility of the sky (normalized value=0.081). The smallest difference in the space between the intersection and the street view was the location 1 (space difference = 1.151). At the same time, the difference between street 5 and corner 5 is the smallest, 0.041. This means that if the difference in enclosure is higher, there is more contrast in the features of the street features (e.g., greener areas, higher buildings, wider roads and a facade of a porous wall façade).

Table.1- Normalized variables for Street

Street No.	Physical variables normalised			Street Enclosure Index
	Sky visibility	Wall continuity	Cross-sectional proportion	
1	0.88	1.00	0.22	2.10
2	0.49	0.55	0.20	1.24
3	1.00	0.00	0.57	1.57
4	0.72	0.32	0.41	1.45
5	0.31	0.07	0.50	0.88

Table.2- Normalized variables for Corner

Corner No.	Physical variables normalised			Corner Enclosure Index
	Sky visibility	Wall continuity	Cross-sectional proportion	
1	0.23	0.50	0.22	0.95
2	0.05	0.28	0.57	0.89
3	0.00	0.00	1.00	1.00
4	0.37	0.16	0.00	0.53
5	0.16	0.035	0.65	0.84

Response of Heart Rate

There were 15 subjects (n = 15) who participated, whose heart rate was measured in four circumstances. In general, the average response to heart rate measured in the intersection condition (72.771 – 113.931) was greater than in the street condition (70.651–109.521). This trend has been observed, regardless of whether participants wear headphones. This shows that the lower the enclosure rating on average, the higher the heart rate. This indicates that subjects are under considerable stress in the open streets. In addition, from both points of view, the range of heart rate within headphones condition is higher than that of the condition while wearing headphones. For example, the results of the subjects are presented in Table 3. A consistent pattern showed a lower heart rate than the heart rate of the absence of headphones in the absence of headphones, showing that the response to heart rate was influenced not only by the physical form of the street, but also by sound (Table 4).

Table.3- Heartrate Response with Background Noise

Background Noise				
Streetscape no.	Participant	Heart rate		Enclosure Index difference
		Corner Heartrate	Street Heartrate	
1	1	113.93	109.92	1.15
	2	88.63	83.68	
	3	102.91	99.61	
2	4	99.44	97.22	0.35
	5	101.90	98.12	
	6	106.20	104.4	
3	7	104.11	101.41	0.57
	8	98.37	94.2	
	9	88.00	85.62	
4	10	73.42	70.32	0.92
	11	83.05	83.02	
	12	76.5	73.00	
5	13	74.21	74.06	0.04
	14	72.77	70.65	
	15	87.1	86.50	

Table.4- Heart Rate Response without Background Noise

No Background Noise				
Streetscape no.	Participant	Heart rate		Enclosure Index difference
		Corner Heartrate	Street Heartrate	
1	1	110.95	107.15	1.15
	2	87.05	84.17	
	3	110.95	108.64	
2	4	97.22	96.22	0.35
	5	99.58	96.05	
	6	97.22	95.33	
3	7	100.58	99.08	0.57
	8	97.43	92.55	
	9	100.58	98.70	
4	10	71.05	68.05	0.92
	11	82.10	79.58	
	12	71.05	68.75	
5	13	72.77	72.77	0.04
	14	71.63	70.23	
	15	72.77	71.89	

t-test: Ratings for Comfort

A t-test was performed to determine whether the heart rate response and comfort scores were correlative. Because all p-values are below 0.05, the correlation is statistically significant. Consequently, low heartbeats are associated with higher comfort scores.

Correlation

In the ‘no-headphone condition’, the difference is calculated between the distance of the heart rate from the street view and the corner. This gives a moderate positive correlation ($R^2 = 0.581$). This calculation of heart rate was also made for the microphone situation. This indicated a moderate correlation that is also positive ($R^2 = 0.451$). The similarity of the trend line indicates that the higher the difference in the speed of the enclosure, the higher the difference in the speed of the heart. In both conditions, the results showed that the heart rate of the pedestrians decreased when facing the street (Figure 10).

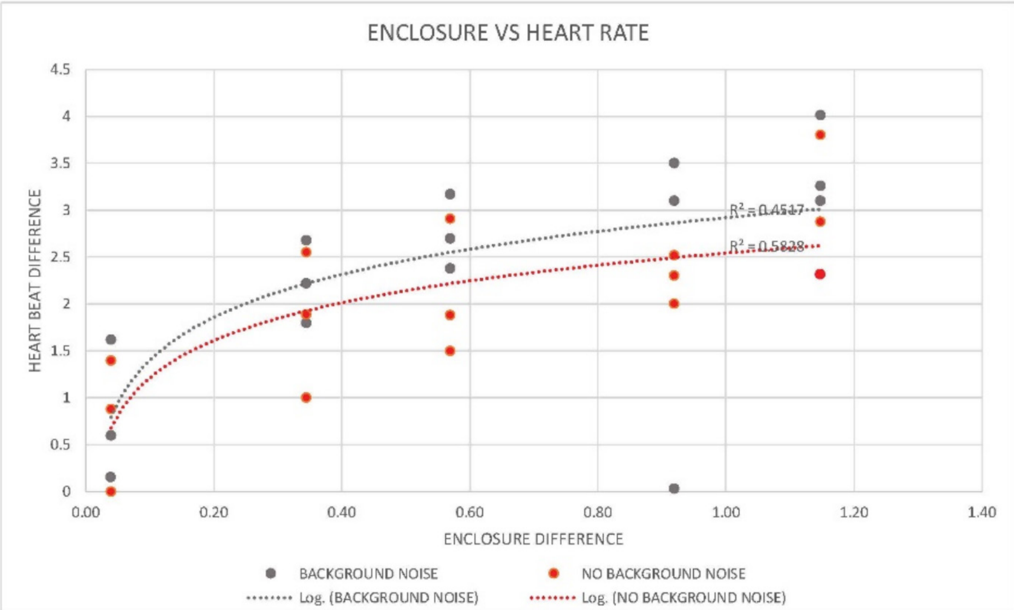

Figure.10- Correlation between enclosure and heart rate

DISCUSSION

The results of our study indicate that the perception of street shapes has a major impact on human physiological responses. In general, according to the results, it is understood that the higher the enclosure rating, the lower the heart rate is. This indicates that they are more relaxed. As a result, a higher heat rate means a higher degree of stress and discomfort. Use of t-test was supported because the value of p between the street and the corner is less than 0.05 ($p<0.05$), which means that the statistical correlations are relevant.

Higher enclosure ratings are largely credited to the number of tree canopies that cover the view of the sky. Despite the canopies blocking the view, the leaves are not fully opaque and light can filter into the street, creating an environment that is visually comfortable (Tang and Long, 2019, p. 1-18). Second, streets with permeable façade (higher wall continuity values) meant more windows and openings on the store side. With a larger number of stores, there were more opportunities for social interaction between the walls and pedestrians. The more porous streets create a higher degree of social interaction with the facades of the walls. A pedestrian who can see more social interactions that occur on the street correlates with a higher comfort score. Street 1 was the most stable and Street 1 scored the highest average comfort score (street 1 scored 1.001, average comfort rating 32.671).

Although intersection views have high wall continuity values (more porous), motorways contribute significantly to the higher values mentioned above. The participants indicated in the questionnaire their comfort rating; Traffic-related noise was stimulating and stressful. This concept is supported by a higher heart rate than without headphones in a headphone situation. This shows that visual stimulation is not only the influence of human neurophysiology and emotion, but the role of urban noise needs to be further studied. There were no physiological differences between participants of different backgrounds. Although the local participants know the area, the heart rate of the participants under different conditions is similar. This may be due to the sounds on the streets that have already been discussed (Figure 11 -12).

Figure.11- Visualization of subject's heart-rate average values under headphones condition compared against enclosure rating.

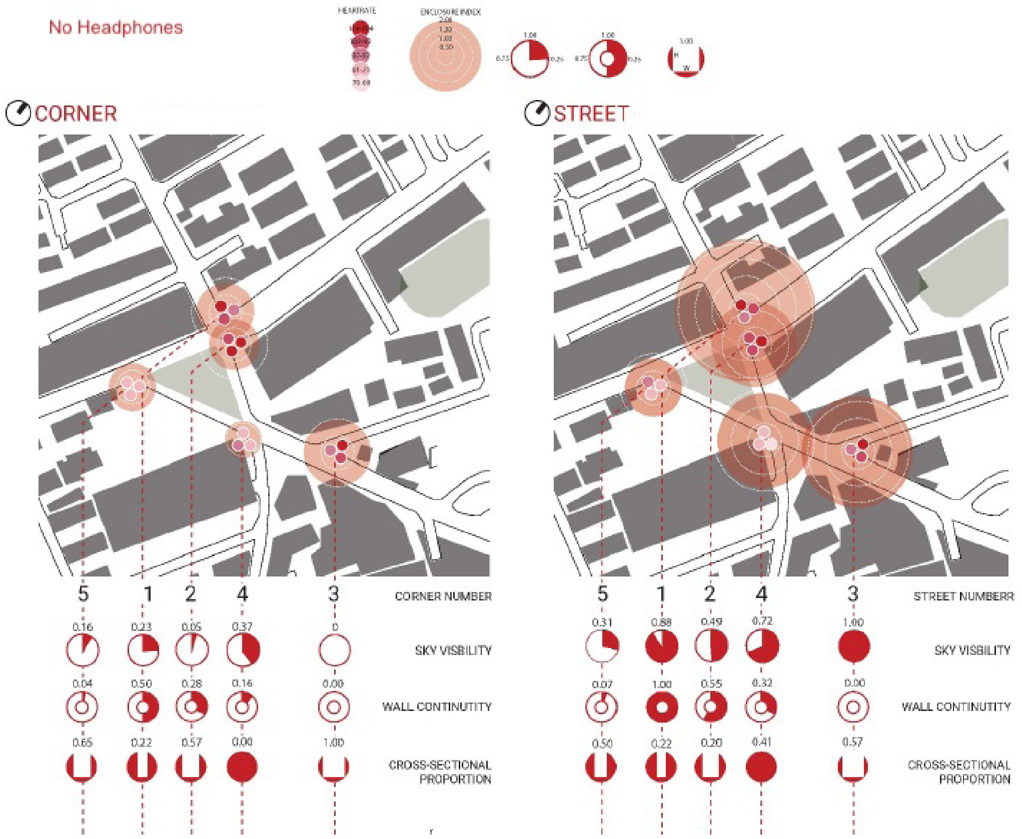

Figure.12- Visualization of subject's heart-rate average values under no-headphones condition compared against enclosure rating.

CONCLUSION

This study shows the physiological reaction of pedestrians to the building environment. This relationship can provide insight to architects and urban planners to gain insight into design to create a social environment that is a positive and comfortable built environment. Furthermore, the proposed measures for measuring the structure of the street can be used to better understand the human reactions to different street functions (schools, business districts, etc.). Continuous improvements to existing construction frameworks and theories can help to come up with better guidelines, especially regarding the design of intelligent public spaces. Finally, this study provides information on the potential impact of AI technology in construction environments. Machine learning and wearable sensors have shown the potential to integrate more advanced technologies and data collection devices.

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Conflict of Interest

The authors declare that the study conducted has no conflict of interest.

Author Contributions

EG writing of the original draft and editing of the manuscript; DYÖ review of the manuscript. All authors have read and approved the version of the submitted manuscript.

Financial Disclosure:

The authors declared that this study has received no financial support.

Ethics Commitee Approval:

The study was carried out according to the Declaration of Helsinki guidelines and was approved by the Human Research Ethics Committee of Istanbul Technical University Health and Engineering Sciences. Approval Number: ITÜ-SM.INAREK-2021-05.

Legal Public/Private Permissions:

A written and signed consent was obtained from all subjects involved in the study. Upon completion of the study, participants received a 60 RMB cash gift to compensate for their participation and time.

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