Chapter 2

Effects on the Design of Transport Systems of Pedestrian Dynamics

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Additional information is available at the end of the chapter

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Abstract

In the study, transportation-architecture-people-focused triple, urban transportation, design of transportation systems, pedestrian-oriented design and pedestrian walkable spaces will be emphasized. However, by analyzing the effects of pedestrian dynamics, transport systems aim to present a mechanism with an improved model that will define dynamics for the first time to explain the processes underlying design decisions. Four hundred and twelve healthy volunteers were selected from 18–65 years of age. First, three-dimensional (3D) virtual city is designed to understand the experiences of the pedestrians. Later, it was provided to navigate the three-dimensional virtual glasses in the city where the broadcasts were designed. During this navigation, pedestrian dynamics were observed, and spaces where pedestrians cautioned were identified. Following this determination, the “attractive” locations will be shown on the macroscale, with the eye-tracking method, it has been in both virtual city navigation and analysis with eye-tracking technology, the cognitive activities of the broadcasts were tested with electroencephalogram (EEG). This approach will in general bridge an empirical and theoretical link between transport-architectural literature in understanding pedestrian movements/behaviors and combining architectural-pedestrian interactions with transport research. However, by analyzing the way-finding behavior, the study interprets its effects on the spatial area.

Keywords: pedestrian dynamics, transportation architecture, human behavior, pedestrian-based design, neuro-architecture science

1. Introduction

In recent years, pedestrian dynamics (movements and behaviors) have been linked to safety [1]; building evacuation [2]; transportation [3, 4] and physics, urban planning, and real-time practice [5]. Many different methods have been developed to understand pedestrian dynamics, among which the most commonly used are the "cellular automata model" [6, 7]; "The social force model" [8, 9] and the "agent-based model" [10, 11]. At the same time, the visual perceptions that surround the tracks during the course of the road respond positively/negatively [12, 13]. In other words, "visual perception" and "environmental stimuli" are two important influences that affect the dynamics of the pedestrian. Studies in the literature show that visually is related to pedestrian dynamics (movement and behavior). In many pedestrian models developed, because of the difficulties of real-time simulations of the pedestrians, the selection sets (directions) are divided into a limited number, then the desired walking direction of the pedestrians; the desired walking speed is determined by specific rules and mechanisms. However, in the models of previous pedestrian dynamics, the arc was regarded as the main dynamic, visual and other stimuli were ignored. Pedestrians are affected by many factors (stimulants) when walking in the city. Even if the objects are attractive enough, they can re-establish their standing in front of them. Although movement is a major influence on behavior, the interaction between the visual and the environment of the pedestrians is one of the inferences in the literature. However, in pedestrian dynamics, pedestrian-visual-environment relation, movement and/or behavior should be considered as directly affecting. One of the goals of this work is to develop a simulation model that can reveal realistic pedestrian dynamics and explain its mechanism. In this model, the effects of "architectural structures" on pedestrian dynamics, which are not mentioned in the literature, are examined. The developed model is called "attention-based visual motion (ABVM)."

This model tests the pedestrians, architectural visual attractors and then examines the characteristics of the attractor and the cognitive state of the stimulus to see whether the pre-defined roots of attention will dissipate. A three-dimensional (3D) small-scale city was designed for the model and different architectural stimuli were placed in the city. These different stimuli, distinctive façade designs and urban furnishings can attract direct attention of the pedestrians. It should not be forgotten that transportation design should benefit from simultaneous analysis of strategic and macroscopic cognitive states of pedestrians. The features of the stimuli (external attractors) in the 3D virtual city are defined and evaluated along with the necessary visually appealing characteristics of how these stimuli affect the pedestrian dynamics.

Existing studies in the literature have examined pedestrian dynamics in the context of transportation science. Besides, the analyses mentioned above have been made in the urban design scale, but the same methods have always been emphasized as methods. Moreover, none of these studies have examined in detail how pedestrian movements and/or behavior affect and shape the design. The study will evaluate this question in terms of design and cognition and will examine it both in the spaces where the pedestrians move constantly and in the space scale. The main aim of this study is to determine the effects of pedestrian dynamics (pedestrian movements and behaviors), visual and perceptual environment and architecture and to determine the architectural effects of these dynamics.

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2. Material and method

In this study, it is aimed to determine the effects of pedestrian dynamics on visually and behaviorally structured environment and transportation systems and to determine the contribution/effect of architectural design. Depending on this purpose, the research will be carried out in three different parts, and three different research methods will be used in the study in stages and/or at the same time. In the study, this method, which is called the multiple analysis method, is a platform where three analytical techniques come together (Virtual Reality Glasses (3DVRG), eye tracking and electroencephalogram (EEG)) to interact with each other. This study generally analyzes pedestrian behavior in three different ways (eye tracking, 3DVR and EEG). Especially in the context of making sense of human movements, it is thought that the use of multiple analysis techniques together will be meaningful in the analysis of pedestrian dynamics.

2.1. Participants

Four hundred and twelve healthy volunteers were selected from 18–65 years of age. Two hundred and one man and 211 women have been participated in this experiment. Average age of man participants: 38,55. The average age of women is 35.66. Participants were informed about not taking any alcohol products 24 hours before the experiment. Since the participants should not use certain psychiatric medication, this question was asked during the election. It has been confirmed that there is no problem in the normal vision of the participants. In addition, participants should not use glasses or lenses, as the eye-tracking device used is not superior in feature, so only participants who have good vision and no apparatus are selected.

2.2. Instruments

An electroencephalogram (EEG) is a test used to evaluate the electrical activity in the brain. One 14-channel EEG was used for the experiment. These EEG channels have been used in this experiment: AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8 and AF4. Also, we used eye-tracking technology that eye-tracking data are collected using either a remote or head-mounted "eye tracker" connected to a computer. With eye-tracking technology, it is possible to determine where participants "look" and "for how long." However, 3D virtual reality glasses were used to make participants feel themselves in the virtual city environment. The recorded brain signals include artifacts such as muscle movement, eye blinking and so on. The signals were downsampled further to 128 Hz.

The eye-tracking device used in the experiment is binocular (double eye) tracking with data acquisition frequency of 120 Hz, eye movements can be recorded with 0.5° recording error. The refresh rate of the device was 120 Hz. The instrument can be individually calibrated in a very short time for each participant before the experiment. In the scope of the study, the eye-tracking measurements used were determined as "visual attention pattern" and "total fixation time." The visual angle of the screen used in the experimental phase is 32 × 29 and the visual angle of the stimuli is about 16° × 18°.

2.3. 3D virtual city

A virtual city is designed so that the pedestrians can feel themselves in the real environment. In this virtual city, there are elements such as walkways, buildings made according to different architectural styles, city furniture, landscapes and showcases. The movement of the pedestrians in the designed city was provided by the wii commander. The city has been visited in daylight. Because the 3D render in the daylight is more realistic and makes people more adaptable to the atmosphere. Examples of the designed 3d city are shown in **Figure 1**.

People who are seen in the city figure also act in the experiment. However, the vehicles act like people, which make the work more realistic.

2.4. Procedure

The total time for the entire experiment was set at 450 seconds. Three hundred seconds of this is a city tour. In the city tour, this part of experiment was conducted using 3D glasses. Participants passed the rest phase after 300 seconds. During this time, the software designed for this study identified "spaces explored for more than 10 seconds." These are called "attractive spaces." The participants were then again tested with eye tracking apparatus and maintained for 150 seconds. The experiment was terminated and removed from the participant list in order to feel symptoms such as dizziness and nausea during use of the virtual 3D glasses.

Participants are equipped with an EEG device and a virtual reality glasses during navigation. In order to be able to measure the net responses of the pedestrians, it was ensured that the EEG records were abstracted from different stimuli. The areas where they have been standing on the tracks are determined by video recordings. That is, if the pedestrians are too

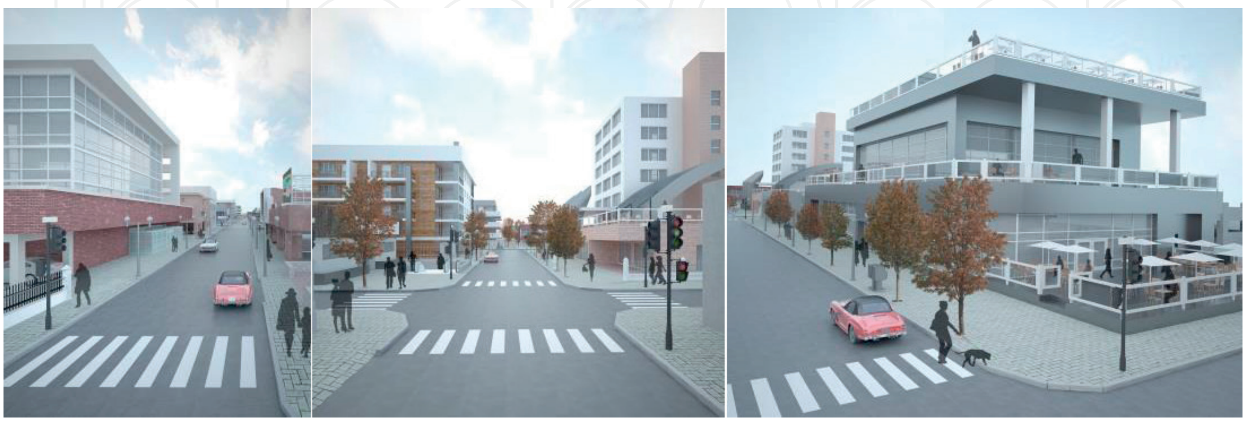

Figure 1. 3D urban area.

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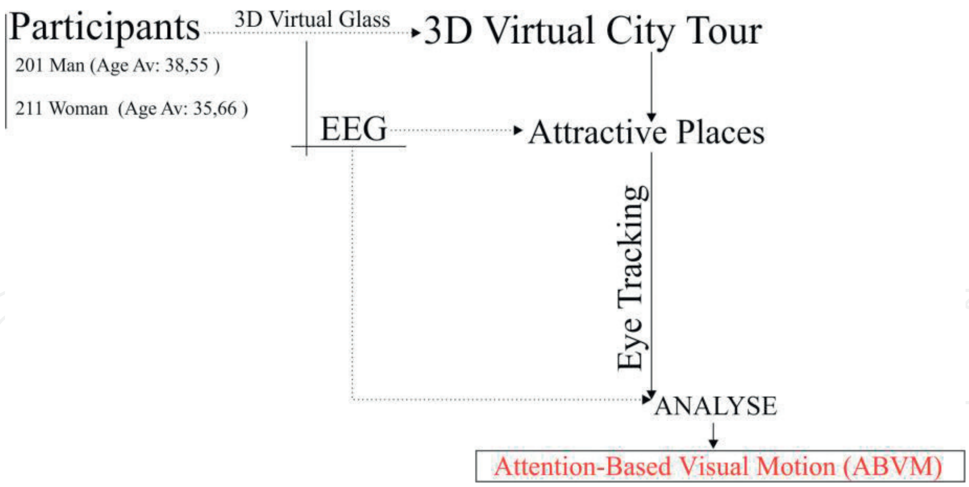

Figure 2. Experiment flowchart.

much to witness on a space (building front, walkways, landscaping, etc.), the system records the attractive space. Therefore, it will be possible to have information about why it stays so long and to be able to conduct a detailed examination. In detail, the test scheme is shown in **Figure 2**.

3. Data analyze

Many features are used in the literature to classify EEG data in brain-computer interface (BCI) for various mental tasks. Some of these are: band powers [14], power spectral density [15], autoregressive and adaptive autoregressive parameters [16], time-frequency features [17–20] and inverse model-based features [21–23]. In 1998, Norden E. Huang from NASA proposed a new signal analysis method named Hilbert-Huang transform (HHT) and it is applied to analyze nonlinear and non-stationary signals and was regarded as an important progress since the fast Fourier transform (FFT) [24]. Huang et al. [24] stated that the HHT method includes two steps. In the first step, the original data will be transformed into an intrinsic mode function (IMF), which satisfying the requirements of the Hilbert transform, by the method of empirical mode decomposition (EMD). In the second step, Hilbert transform method will be used on each order of IMF above to calculate its instantaneous frequency. All those results can be used to create an integrated time-frequency figure finally. In this study, Hilbert-Huang transformation, which is a classical time-frequency analysis method, was chosen.

According to [25, 26], for a real-valued g (t) time series, the Hilbert transform can be obtained as in Eq. (1).

$$g(t) \;=\; H\{g(t)\} \;=\; \frac{1}{\pi} P \int_{-\infty}^{\infty} \frac{g(\tau)}{t-\tau} \tag{1}$$

In Eq. (1), P represents the basic value of the complex integral Cauchy.

The Hilbert transformation given in Eq. (1) gives the analytic binary virtual part for the real data g(t) to obtain. However, to an original analytical signal, g (t) allows us to reach in Eq. (2).

$$g(t) = g(t) + \hat{g}(t) = G(t)\, e^{j\theta(t)} \tag{2}$$

The instantaneous frequency for the resulting signal, if the signal is a single component, θ(t) of the phase function is easily obtained by taking the derivative of the time in Eq. (3).

$$w(t) = \frac{d\theta(t)}{dt} \tag{3}$$

4. Experimental result

4.1. EEG data analyze

Given the features extracted from each participant's EEG data, the analysis attempted to determine which of the α, β, γ, $\theta \wedge \delta$ components of the EEG exhibited the highest mutual information with the objects that reflect the individual participant's preferences. During each of the different EEG channels, the normalized mutual information between the class tag and each of the four main EEG band powers was determined. Mutual information has been determined between 0 and 1. The detailed illustration of this is shown in **Figure 3**.

One of the most rewarding results of the study is a clear difference between the mutual information values obtained by symmetric channels in the left and right hemispheres in each of the EEG bands during city tour. It is thought that this difference shows asymmetrical activities in terms of strength of the EEG bands while making decisions about the places, the streets and their combination of the two, the triple combination preferred by the participants. Because some of the participants were concentrated on the street where the shops were concentrated, others were only directed toward the landscape areas. F3, F4 and O1 channels exhibited the

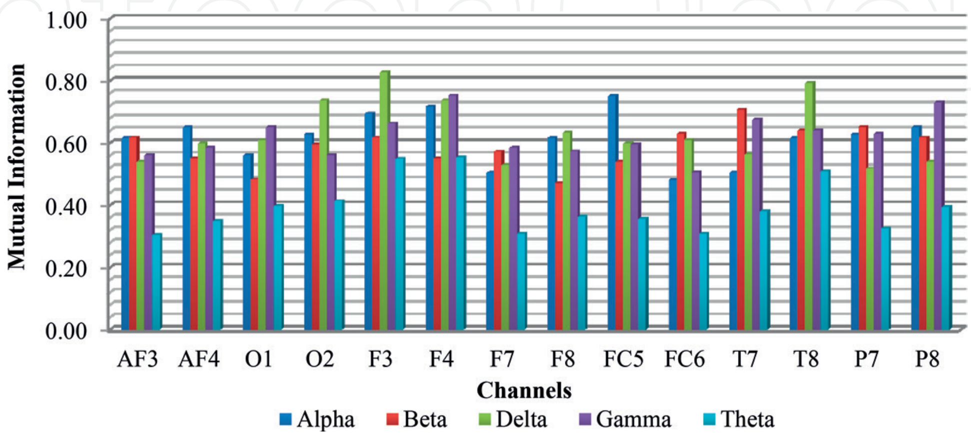

Figure 3. The normalized mutual information between the class tag and each of the four main EEG band powers.

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highest mutual information in delta band. Delta oscillations are present in the background EEG activity not just in sleep, but in awake state and are thought to be generated by cortical networks [27]. Also, these oscillations play a significant role in large-scale cortical integration [28–30]. There are studies confirming the usability of the delta channel to distinguish the striking objects [31, 32]. It is noteworthy that the importance of the delta band during participant's way-finding preferences. In other words, serious subjects were taken especially in the channels F3 and F4 in the subjects who had difficulties in their preference of direction. During the way-finding of participants, information was observed in AF3, AF4, F3 and F4 channels, especially in those who have difficulty making decisions. The information of these channels indicates that this activity is predominantly in the frontal lobe.

Participants were observed to have differences in theta band when they inserted the eye-tracking device and questioned their preferences in detail. Theta band exhibited very high mutual information with the preference in the frontal region, especially in the channels F3, F4, FC6 and AF4. Theta band was especially associated with female participants, especially if there is a shopping mall between their preferences. That is, 78% of the female participants spent a long time in front of the stores. Therefore, mutual information was observed in the O2 and P8 regions in the case of detailed examination with eye-tracking technology. On the other hand, this information was observed only in the P8 region in some of the male participants. If the Theta band is thought to be associated with emotional situations [33, 34], it should not be surprising that this region differs in women. However, it was observed that they were standing in front of participants in the moment of passing Atatürk posters placed in certain shadows of the city. When they stopped, there was an increase in theta band in 83% of the participants.

Regarding the beta wave, the highest mutual information values are seen especially in the temporal and occipital regions in the city. In the eye-tracking phase, the frontal regions were again displayed with changes in the reference beta-spectrum. However, it is noteworthy that the changes in the F7 and F8 channels in brain activity during the eye-tracking phase, especially the façade's restoration feature. This can be interpreted as an indication of the changes in the emotional mode of people in the old built environment. Participants were encouraged to analyze that part of trying to pause in high-intensity horticultural gardens while touring landscape areas. A total of 394 people standing in colorful gardens recorded significant increases in beta bands in the occipital region. After leaving the colored garden and turning completely toward the green areas, the beta waves in the occipital area were recorded as declining. This may be an indication that the beta wave behaves in accordance with the color stimulus.

The highest spectral changes in F4 and P8 and O2 were observed, supporting the importance of both frontal and parietal regions in the gamma band.

According to the flow chart of the experiment, the participants are looking at a stimulus twice. In other words, they first look at the places that they see during the city tour and are determined to be interesting by using the eye-tracking device for the second time. The EEG device records in both stages. The areas that participants often identify as "attractive places" are listed below:

- Shopping center: The mall has designed modern façade. Participants have spent a long time viewing the broad front of the building.
- Historical street: While the participants are walking around the city center, there are five different streets to visit. Nearly all participants (96%) needed to visit the historic street.
- Atatürk bust and photographs: They spent a long time in front of the busts and photographs of Atatürk, the person with the highest degree of nationality.
- City square: The city square is the urban area where people can walk, sit and have living areas.
- Boutique stores: Stores are often attracted to women. On the other hand, posters and posters which are used as design items on the store also increase the attractiveness.
- Landscapes: Nearly all (98.7%) of the people have spent a large part of their time to see and even navigate the landscape area.

The relationship between the navigation in the modern areas and the historical sites has been examined. Beta and theta waves were used to help identify the relationship between these areas.

As shown in **Figure 4**, only the EEG is moving around the city (beta wave), showing mutual information in the back of the brain. However, in a more detailed analysis using eye-tracking

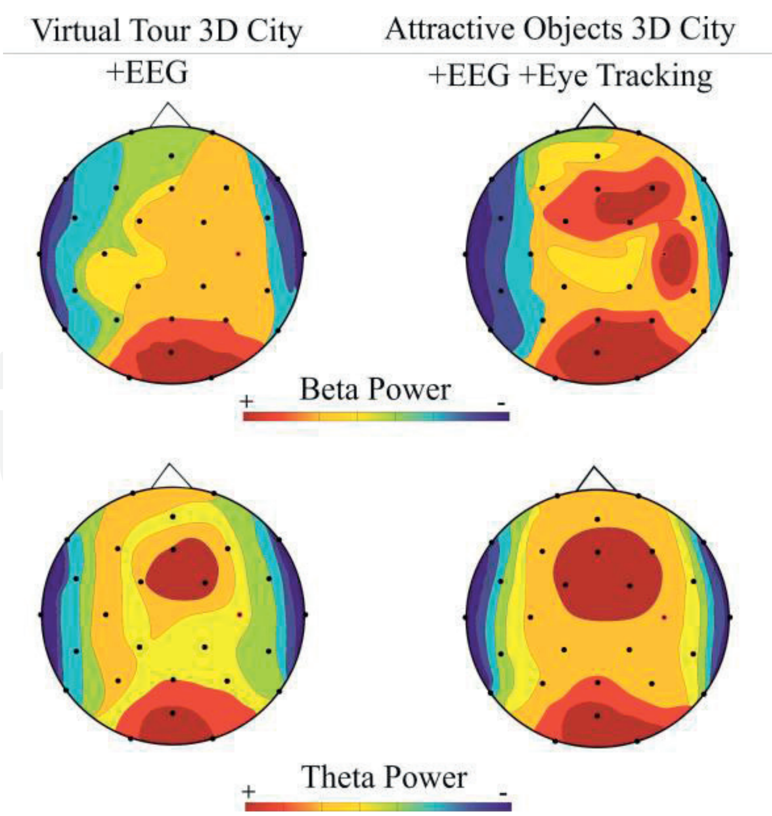

Figure 4. The difference between pedestrian brain map and pedestrians who make city tours with EEG device and those who examine both EEG and eye tracking.

technology, mutual information was observed in both the middle and frontal regions. But in theta wave, this information is not as remarkable as beta.

Here, there was an increase in brain activity, especially when walking through urban squares and green areas of the arcades. In addition, activities were recorded on both the beta and theta waves in areas where they prefer color landscapes rather than green landscapes and where there are colorful landscapes during this city tour.

The shops were placed in different locations on the walk and promenade routes of the designed 3D city. Some of these shops are ground floor and some are in the first floor. In this case, the interest of the pedestrians has been researched. When women's brain maps were examined, there was no difference between boutiques on the ground floor and boutiques on the first floor. So whether you are in the ground floor or the first floor is almost the same level of interest and attraction. However, both women and men spent more time in historical sites. Located on a modern street, the shopping center is focused on the spot after it has entered the view point, the shops that have been visited to the shopping center have been ignored and many have not been seen.

4.2. Eye-tracking data analyze

Areas where each participant has been standing for too long have been identified. In this case, the number is 3 in some participants and 8 in some participants. When you focus on a specific place for more than 10 seconds, the system records it automatically.

Figure 5 shows the number of places the total participants are focused on.

As shown in **Figure 5**, female participants are much more "affected by space" than men. More explicitly, the average locus of attractiveness of female participants throughout the city was 3.77; in males, this ratio remained at 2.29 (SD: 2.01).

Furthermore, It is also called the focus on focusing on one particular point [35, 36]. A factorial ANOVA was conducted to determine whether the total focus period on subjects of interest in the stimulus varied according to the content and participant's viewpoint ($p<0.05$).

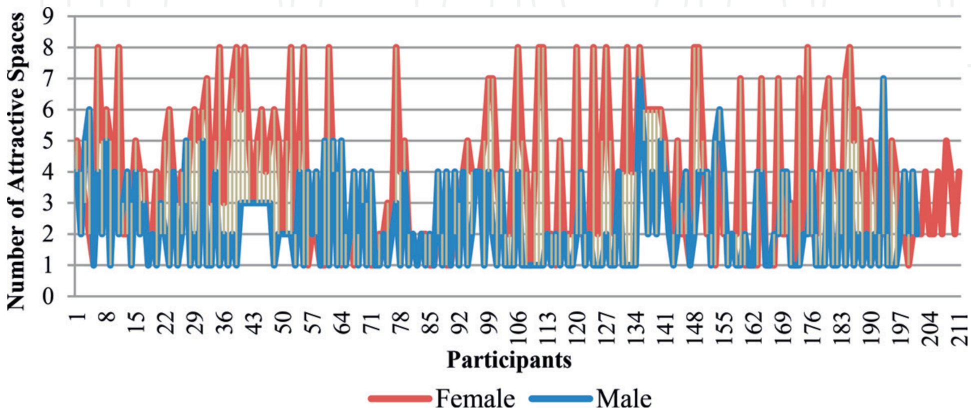

Figure 5. Number of spaces where each participant has held more than 10 seconds in the city tour.

Accordingly, the total duration of the focusing of the female participants during the excursion of the city to the details of the stimuli is longer than that of the male participants. This supports the view that the female participants are more interested in the stimuli (building façade, shops, etc.).

It is also possible to visualize the focus of participants' cognitive environment details with heat maps [37–39]. Heat maps show where participants look more at stimuli and are graded on a range of colors ranging from light green to red. The areas shown in green indicate that participants have fewer focuses, whereas the areas shown in red indicate that participants have more focus.

Figure 6 shows the details of some of the analyzed areas, which we can also call visual attention pattern.

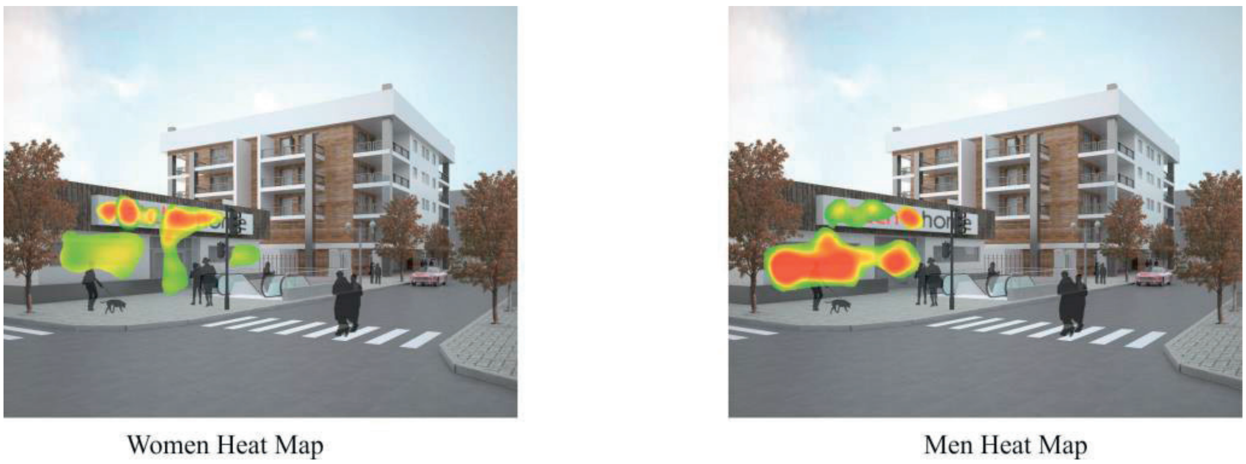

Figure 6. Detailed display of visual attention pattern of some places.

In the section of the visual attention pattern examined separately for women and men, it is seen how much attention the female participants are paying attention to. As seen from the heat maps, males are usually concentrated on the "building entrance" directly. However, a large proportion of female participants were initially identified as "logos." We can see that this female cognitive behavior is not only in shopping mall structures but also in many store entrances.

5. Discussion

Findings include that the effects on the pedestrian moods of building facades, the green space on their health and the data about urban environments on their social interactions.

Behaviorally, people are often satisfied without going out of the green areas, but it has been found that the excitement understood from the analysis of the EEG records has increased in areas with more delicate landscape.

Naturally, it is thought that pedestrians prefer colored landscapes to green landscapes. The green areas that are the transportation axes to landscaping areas are preferred. In other words,

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the greening of the landscaping areas leads people to that point emotionally. This finding is very important for the design of walking paths. Because, if the designer wants to finish the hiking trail with landscaping areas, then designing the landscape along that trail is worthwhile in terms of giving people the feeling of directing them there.

However, in general, low spatial frequency components (large lines) have a high contrast, and high frequency components (small lines) have a low contrast. Simply, the scenes in the nature have lines that tend to exclude each other; so no lines appear in the picture when they are added. Therefore, in the nature, repetitive situations do not strike the eye; all the design elements are spread in a certain order. But this is not the case in urban scenes. Urban scenes violate the rule of nature: buildings tend to have regular, repetitive patterns due to the common use of design features such as unnatural landscapes, transportation systems and faulty restorations. There are studies [40, 41] in which the natural landscape structures positively affect the human brain. However, it is quite interesting that as a contribution to all studies, landscape areas also prefer "more colorful" areas of spring.

The shopping center is positioned within the city's modern buildings. An easy and central place has been chosen for vehicle access. However, a walkway has been connected in terms of reaching the arcades.

Because of this, the pedestrians have passed through many vehicles and reached the shopping center. This was detected by EEG, which increased the fear and anxiety mood during the transportation. From here, it can be thought that the pedestrians may be a problem to "pedestriate" from different vehicle routes until reaching such a central structure. Therefore, it would be appropriate to connect the pedestrian roads to the shopping centers and even to separate these roads from the roads.

From the architectural point of view, it is quite natural that the façades of the shopping center are closed and usually covered with advertisements. Therefore, it is noteworthy that in the analysis made by eye-tracking technology, the advertisement which is close to the entrance gate rather than the advertisement which is bigger is attracting attention. In other words, it is determined that the most focus point is seen from the eye-tracking heat map of the advertisement near the front entrance door. This shows that the closest ad to the frontline is the most striking when it comes to architectural design of the shopping center front.

The city square is an area where both women and men enjoy their time. However, the correct design of these areas is crucial both in terms of user satisfaction and design success. Another important feature of urban squares is that all transportation is united. In the 3D city that is designed, it is seen that the pedestrians move toward the city center. After reaching the center of the city, it was seen that the pedestrians were looking for a seating area or even heading toward outlying people.

The "green living areas" located in certain areas of the city center are located within the city. Almost all participants turn toward these areas. The artificial pools that are placed in the said space are the other preferred points. Therefore, it is seen that in urban centers, people turn to artificial pools first and secondly to green living areas and then to other living areas, starting from the orientation (moving toward that point) and eye-tracking data. Therefore, the satisfaction of broadcasting in the design of urban centers is much more important than in other places.

It has been determined that the springs have more time in the city than in other areas even if they are directed to the historical area designed in the city. At this point, it is particularly striking that women look more closely at the historical cities compared to men who travel more slowly. It is seen from the eye-tracking analysis that women are looking at the building facades while visiting the historical city, even examining some architectural items (beaks, beads, etc.) in detail. In addition to this, men's trips to historical cities have been determined from a general point of view. At the beginning of the modern constructions that started at the end of the designed 3D city, both women and men had right-lobe activities.

There are different boutiques that are designed and placed in different parts of the virtual city (by the side of the walkway, in the middle of modern buildings, next to the old city, etc.). These are small shops from different sectors such as footwear stores, electronic gadgets, books and stationery and music centers. It is observed that women spend more time in all kinds of boutiques than men and even spend a long time in front of the stores. On the other hand, in the direction of the data obtained from the eye-tracking technology, it was determined that women first looked at the brands of the magazines and later they looked for the entrance doors.

The point of interest is the similarity of the reaction with the eye-tracking technology of the female volunteers participating in the experiment from almost all ages. So, first they were interested in the magazine brand and then examined the entrance door details. In the EEG records, more dominant information was observed in women in the right brain region.

Therefore, aesthetic concern in the design of a woman's boutique keeps the front panel. Conversely, most of the male participants (85%) have not observed any movement in this region. I mean, when you go shopping for a boy, you get cheap, good quality, you care about your worries.

We had these results by measuring how the brain affected the images of natural and urban scenes. There are two ways to measure productivity; the first is to build simple computer models in the form of calculating the views of nerve cells. Any kind of design broken from the nature in the study leads to an increase in brain activities. It was observed that participants who spent time in areas not particularly affected by nature of urban areas, especially constructed from gummy concrete, glass, were active in both brain regions. In addition, a different fluctuation was observed especially in the frontal lobe compared to other lobes.

It may be thought that the pedestrians are seriously forcing the brain in designs that are completely human in nature and do not benefit from the slightest object of nature. In other words, such images make more effort to process the brain. One of the most striking aspects of the work is that it is irritating to distinguish nature from the design rule, and it has been detected both by cognitive and eye-tracking technology that artificial surroundings harm human beings. In addition, participants were found to move 1.4 times faster than digger sites in order to avoid such ultra-modern areas.

The worries and anxieties that arise in the fields of broadcasts reduce their satisfaction; thus, turning navigation into a negative direction. At the same time, it is evident that traveling in such spaces affects people emotionally.

It is remarkable that spatial studies of aesthetics are questioned and design is questioned [42, 43]. The role of design in different disciplines such as the effect of light design, the mathematical view of visual images [44], the research ability of design in terms of neuroscience [45], the meaning of building facades and human perception [46, 47].

However, in this study where the analysis and effect of transportation systems are discussed, it can be seen that while the transportation systems are designed, both the utilization of architectural discipline and the support of different disciplines such as brain science and cognitive science will facilitate the design of the systems and even turn them into a certain system.

6. Conclusion

Analyzing how the built environment influences your brain through blood-based research, the transport engineer or architects can provide you with the insight necessary to make healthier and more socially conscious designs.

Designing the system by following the behavior of the pedestrians and the user-oriented nature of this system will be appropriate in terms of future living spaces. It should be assumed that designs in which both transportation systems and architectural disciplines coexist are human-centered. Therefore, if the first focal point of the design is thought to be "human," then the human-oriented design logic will also be true. However, in order to be able to do this, deriving conclusions from the behavior and viewing of the pedestrians can open up both the strength of design and the correct design of the delivery systems. In this study, the areas in which emotions they feel when they navigate in the virtual environment are analyzed by EEG and then found "attractive" are analyzed by eye-tracking technology. As a result, it has been found that people are more likely to spend more time in areas where water and landscaping are enjoyed, which they like more about nature. It has been determined that people are more "comfortable" in such spaces. However, in the areas where modern structures exist, "uneasiness" and "anxiety" conditions have increased during the trips. These places are among the most important finds to see the bushes look good and do not focus.

The design should have areas that are not just about the look, but that can be functional as well as the look that they can experience, suitable for its purpose, capable of raising the quality of life, improving our health, social behavior and productivity.

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