Visual Behaviour of Pedestrians in Urban Space

City Walk with an Eye-Tracker

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***Abstract*— In this paper an eye-tracking experiment is presented, conducted in real-world urban environment with pedestrians. The aim of the research was to search for common eye movement patterns and strategies, comparing different pedestrian facilities. The share of visual engagement in different types of streets was defined, and the most common sequences of the fixated areas of interest were looked for. First the visual analysis approach is shortly introduced, then exemplary results and experiences are discussed.**

Keywords—pedestrians; eye-tracking; gaze behaviour

I. Introduction

Urban streets and squares are designed for use by humans. But is the design process human-centered enough? Do we really know how pedestrian use the space for orientation, for movement, how do they interact with objects or with other persons?

Observing pedestrian behavior at operational level may bring us closer to understand the use of urban space around us even better. The vast majority of stimuli from the environment are of visual origin. Following eye-movement provides us first-hand information on processing, interpreting, and interacting with the built environment [1]. New technologies, such as portable eye-tracker, wireless data transmission enabled experiments in real outdoor environment, are ensuring free movement of the observer.

Completing a graduate course on urban planning, the first author in her thesis carried out an eye-tracking experiment with walking pedestrians in order to analyze their gaze-behavior [2].

II. Aim of the Measurement

Is there a common strategy (common behavior) among individuals for visual orientation in the street? Is there any relationship between gaze behavior and shape of the urban space? These were the initial, general questions of the research. Before setting out exact questions for the investigation, recent publications on the subject were reviewed.

A. *Former research*

Several eye-tracking experiments have been conducted by car drivers in the last 20 years, adding a lot to road safety and design approaches. However, there are still few experiments performed with pedestrians and cyclists. Some of them give a general overview on orientation and human interaction with urban environment, while others focus on a conflict situation (like street crossing) for better understanding.

1) Visual engagement with cross-sectional element of the street

Reference [3] studied visual engagement with urban street edges. 24 volunteers were included in the study, 12 street sections of two different street types were arranged to two walking routes. The participants chose a random task card before entering each section. The chosen task could be either an optional activity, or a necessary activity.

According to the results, people visually engage with street edge ground floors more than upper floors along both non-pedestrian and pedestrian streets (90% vs. 10%), visual engagement is distributed more towards the wall on the walked side along non-pedestrian streets. The study highlighted that the implemented task has a measurable impact on street edge fixations. Leisure time activities imply significantly higher proportion of focusing on street edges.

Reference [4] compared eye-movement strategies of pedestrians and cyclists: areas of interest (AOI) visit duration and gaze sequences. They found that most attention was paid to the path – larger share for cyclists (29%). Pedestrians were gazing street edges 5-6 times longer than cyclists. Surprisingly, cyclists perform less shoulder checks than pedestrians do, although it was considered an important element of visual orientation.

2) Crossing the street

A major driving force for such pedestrian research is the development of autonomous vehicles. One of the most important issues is unsignalized pedestrian crossings, which require an essential two-way interaction between the vehicle and the pedestrian.

Communication between driver and pedestrian was examined in study [5]. In the experiment pedestrians were asked to cross a road at a marked and at an unmarked pedestrian crossing. The car approached the site with soft yield (slowing down), with hard yield (breaking) and without yield. Participants had to take decision whether and when to cross the street.

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The initial assumption that pedestrians communicate primarily with the windshield and the driver, was rejected by the surveys - measurements found that pedestrians' gazes pay the most attention to the relevant road surface (27%) and vehicle bumpers (24%). It should be noticed that this case study was not a real-world experiment, visual stimuli came from 360 degrees, non-static video to ensure the physical safety of the participants.

In 2020 a literature review on street crossing was prepared [6]. 53 reports analyzing study methods, internal effects (such as age, secondary cognitive tasks) and external effects (real environment, image, VR) influencing the results were considered from the last decade. Age groups play an important role, as younger children constitute a large group of accidents. Their visual exploration is more reduced than of adults, they pay more attention to irrelevant details. There is also a population group that has been left out of research so far: people with disabilities.

3) Visual attention and fixation

The open eyes always fixate somewhere in space, but visual fixations are not synonymous with attention [1]. Significant fixation are gaze locations that reflect where a person's attention is focused. Some significant fixations have more importance in performing the movement, these have been termed critical visual tasks [7]. Critical visual tasks were identified by using secondary cognitive task as an indication of attention level. Critical visual tasks are situations where the visual stimulus is primary to the person - these are situations in which the response time of a parallel cognitive task (a push-button response to sound stimuli) is delayed.

In reference [8] the same research group identified critical visual tasks and compared the share and frequency of AOIs of all fixations and critical fixations during a 900 m long walk. The experiment was carried out with 40 participants in daylight and after dark as well. They found that the largest proportion of all observation were categorized as "Path", then "Environment", "Goal" and "Person", while considering only critical observations, looking at other people seemed to have the largest share.

B. *Research questions*

The main question in the experiment of the authors was to explore differences in the eye movement of the subject walking in different types of streets. The questions in detail:

1. What is the difference in the distribution of focus areas in the street with separated car traffic, in pedestrian streets, as well as in the pedestrian square?

a) What are the differences in the observation of the lateral cross-sectional elements over time?

b) What are the differences between the middle segment of the pavement and the duration of the far-ahead focus?

2. What sequences can be discovered between focus areas in vehicular and pedestrian streets?

III. Method of the measurement

A. *Data collection method*

The method of the observation is determined by the research target. Three main data collection methods concerning pedestrian behavior are: (1) Field observations (2) Controlled experiments and (3) Survey methods [9]. Interactions at the operational level, local interaction with space, objects and pedestrians can be properly observed by controlled experiments.

The activity undertaken by the subject while walking (e.g. strolling, window-shopping, rushing to work) significantly influences gaze behavior, engagement with different areas of interest [1, 3]; so, participants should be given the same task to perform to get comparable results. Another reason for the assignment was to divert the subject's attention from the unusual situation.

The instrument of the measurement was a *Tobii pro 2* mobile eye-tracker, which consists of a head-mounted glass frame with small forward-facing and backward-facing cameras, and a data-capturing unit. Data is forwarded immediately to a notebook carried by the subject for further software data processing. The primary result of the measurement is a video output: the video of the environment with the gaze location projected on it.

B. *Procedure*

A city walk route was set up, embedded in a framework story. According to the story, the subject had a courier task: picking up a small packet, delivering it to the destination, and returning to the basis. The route comprised four street sections, 980 m long in the historical downtown of Budapest. Three types of pedestrian infrastructures were lined: street with one-way car traffic and sidewalks, pedestrianized street, and pedestrianized square.

The aspect of choosing this route was to have a tidy but attractive street view as simple and clear as possible, preferably without trees, vegetation, very conspicuous advertisements, portals, and striking lights.

Participants carried out their task alone, not to distract or to influence their visual attention by any accompanying person – even research staff members were waiting in cover at points 1-2 and 3 (Fig. 1).

Fig. 1. The route of the courier in the downtown of Budapest

A statistically significant sample means around 20-25 subjects, which would have exceeded the capabilities of the study. As it was not a goal to assess generally valid conclusions, measurements were performed with the help of three adult participants, aged between 43 and 60 years. Unfortunately, only one measurement could be evaluated due to validating failures.

IV. Results

A. Data processing

The analysis of the video starts with coding the frames: the location of the focus of the gaze is coded on the basis of the areas of interest (AOI), i.e. cross-sectional elements determined according to the purpose of the examination. The video had 10 frames in one second. The following characteristics can be generated from the code sequence:

- street DNA (Dynamic Narrative Articulation), which is a sequence of coded frames represented by color codes, i.e. a colored ribbon, a timeline,
- the distribution of participants' visual engagement among the cross-sectional elements (the percentage of AOI colors appearing in the street DNA),
- frequency of fixing each focus area (number of strips of the same color),
- sequence matrices (alternation of street DNA colors). The purpose of this matrices is to find the most common consecutive focus areas (sequences).

It can be seen that the choice of AOI categories plays an important role in the evaluation of the results, therefore it is worth formulating the research questions in relation to AOI categories and focus areas.

B. Analysis

This chapter is organized according to the research questions.

Research question 1a: What are the differences in the observation of the lateral cross-sectional elements over time?

The difference between the lateral cross-sectional areas of interest is shown in the following chart (Fig.2). It can be noticed that in streets of similar width, the rate of fixation of the side walls stays in the same interval (30-64%, right and left sides summed up for individual data sets), while in wide pedestrian areas it is much lower. The proportion of left-side (walked side in this case) fixates was higher in all measured sections, and the subject progressed to the center or left side of each section.

Research question 1b: What are the differences between the middle segment of the pavement and the duration of the far-ahead focus?

Based on the processed data, focusing into the distance and focusing above eye level showed higher proportions in "wide" pedestrian spaces and streets than in "narrow" streets. There was no such difference in the category of focusing below eye level.

Research question 2: What sequences can be discovered between focus areas in vehicular and pedestrian streets?

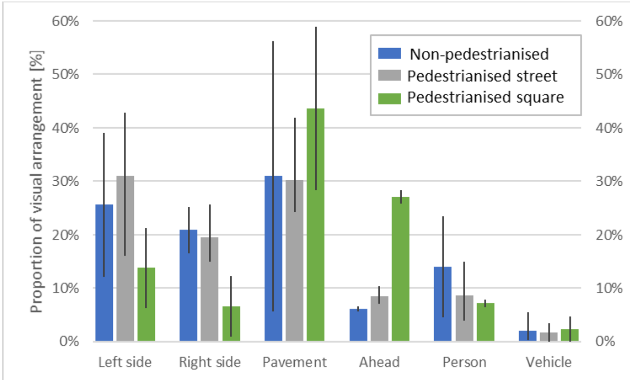

Fig. 2. Proportion of fixation of certain areas of interest – difference between side and middle fixation

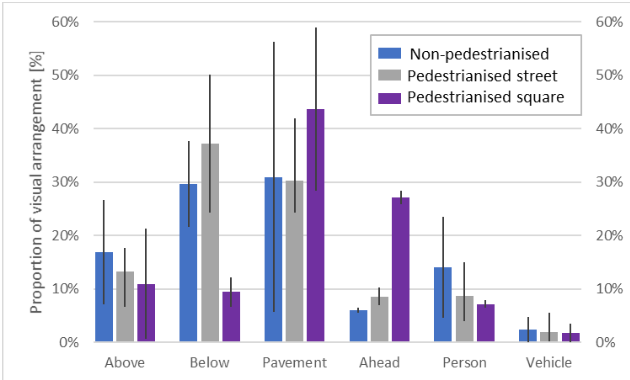

Fig. 3. Proportion of fixation of certain areas of interest – difference between above and below eye level fixation

The most common eye movement sequences in the three types of streets can be seen in Table 1.

TABLE I. Most common gaze movement sequencies

Frequ -ency	**Gaze movement sequencies**		
	AOI1 →	***AOI2 →***	***AOI3***
Non-pedestrian street			
16	Pavement_Left	Wall_Left_Below	Pavement_Left
15	Wall_Left_Below	Pavement_Left	Wall_Left_Below
6	Wall_Left_Below	Pavement_Left	Person
5	Pavement_Left	Wall_Right_Below	Pavement_Left
Pedestrian street			
30	Wall_Left_Below	Wall_Left_Above	Wall_Left_Below
25	Wall_Left_Above	Wall_Left_Below	Wall_Left_Above
19	Pavement_Middle	Person	Pavement_Middle
17	Pavement_Middle	Wall_Left_Below	Pavement_Middle
Pedestrian square			
13	Pavement_Middle	Far_Ahead	Pavement_Middle
11	Pavement_Middle	Person	Pavement_Middle
9	Far_Ahead	Pavement_Middle	Far_Ahead

Frequ -ency	Gaze movement sequencies		
	AOI1 →	*AOI2 →*	*AOI3*
7	Far_Ahead	Pavement_Middle	Person

Comparing the most common sequences, it is remarkable that the pedestrian square is dominated by vertical sequences and the narrower street sidewalks are dominated by horizontal gaze movements. The pedestrian street, the "elongated square", is located between these two: the side walls are frequent areas of focus, but eye movements start from these in both vertical and horizontal directions.

Not only the given street type, but also other circumstances affect the characteristics of gaze behavior:

- Fixations on persons are obviously proportional to the number and density of pedestrians present in the space. Thus, the rate of looking at people was the highest on the narrow and frequented sidewalk (24%), while in the other sections it remained in the range of 4-15%.
- The number of changes of fixation detected in a given section depends not only on the amount of critical visual tasks (the more complex situation, the more eye movements), but also on how many "eye magnets", i.e. eye-catching surfaces, are present in a given section.
- The length of attention to the side walls also depends on the enrichment of the facade.

As it became clear from the diagrams above, eye movements give a significantly different picture even in the same type of streets or even in different directions of the same street. However, during the evaluation of the recordings, the following characteristics and preferences were observed by the subject:

- large glass surfaces illuminated from inside attract attention,
- the doorways must have a brief look,
- the subject paid special attention to the inscriptions on the nearer side wall (plaque, advertisement),
- the facade elements and portals of the more distant side receive significantly less attention,
- pedestrians appearing in the distance are also important, their position and vector of movement must be checked from time to time,
- at the time of the experiment, relatively few people were in the streets, mostly the narrow sidewalk required a lot of human interaction
- vehicles passing in line of sight were mostly followed by the subject, even if the person did not intend to cross the roadway.

V. Discussion

Real urban environments have an infinite large variety in terms of density and diversity of objects, which implies methodological difficulties. These can possibly be mitigated by detailed design of experiments and asking well focused research questions. However, generalizability of results will still be limited, therefore the range of conditions for validity has to be carefully defined.

The experiment presented above was performed on a small number of subjects in order to lay the groundwork for future pedestrian and cycling studies. The behavior experienced during video processing was in line with the notes of the literature cited in Chapter II.A.

When designing similar experiments and comparing their results, it has to be recognized that instructions and tasks (framework story) influences gaze behavior. This is especially true for pedestrians, as they can easily conduct several activities simultaneously when walking. For cyclists and car drivers it is a little bit different, as driving is a more complex task than walking. However, they can also use their mobile phones and talk to their passengers, etc. which influences their gaze behavior.

VI. Further Directions of Research

The results of this experiment will be used in further research of the authors about cyclists' behavior and their perception of traffic signs at designated cyclist facilities.

Exploring the connections between visual behavior, urban space and pedestrian/cyclist movements helps to make pedestrian/cyclist movements more predictable. This knowledge may contribute to the training of autonomous vehicles, or to enhance the safety of networked vulnerable road users in Cooperative Intelligent Transportation System (C-ITS) - in Day2 ("I share my perception data") and Day3 ("I share my intentions") C-ITS services. Setting up C-ITS functions is a very diverse and promising field for CogInfoCom applications [10].

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