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# A Visual Comparison of Gaze Behavior from Pedestrians and Cyclists

Mathias Trefzger  
Karlsruhe University  
of Applied Sciences  
mathias.trefzger@  
outlook.com

Tanja Blascheck  
Inria Saclay  
tanja.blascheck@  
inria.fr

Michael Raschke  
Blickshift GmbH  
michael.raschke@  
blickshift.de

Sarah Hausmann  
Karlsruhe University  
of Applied Sciences  
sarah.hausmann@  
hs-karlsruhe.de

Thomas Schlegel  
University of Applied  
Sciences Karlsruhe  
thomas.schlegel@  
hs-karlsruhe.de

## ABSTRACT

In this paper, we contribute an eye tracking study conducted with pedestrians and cyclists. We apply a visual analytics-based method to inspect pedestrians' and cyclists' gaze behavior as well as video recordings and accelerometer data. This method using multi-modal data allows us to explore patterns and extract common eye movement strategies. Our results are that participants paid most attention to the path itself; advertisements do not distract participants; participants focus more on pedestrians than on cyclists; pedestrians perform more shoulder checks than cyclists do; and we extracted common gaze sequences. Such an experiment in a real-world traffic environment allows us to understand realistic behavior of pedestrians and cyclists better.

## CCS CONCEPTS

• **Human-centered computing** → **Visual analytics**; *Empirical studies in ubiquitous and mobile computing*;

## KEYWORDS

eye tracking, pedestrians, cyclists, visual analytics, real-world environment, traffic situations, multi-model data

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## 1 INTRODUCTION

In recent years, the number of injured pedestrians in Germany has increased from 33.499 in 2013 to 34.050 in 2016 and the number of injured cyclists has risen from 77.439 in 2013 to 87.992 in 2016<sup>1</sup>. Most of the registered accidents, during which people were

<sup>1</sup><https://www.destatis.de/>

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injured, happened in urban regions and within city velocity limits. Therefore, pedestrians and cyclists are often involved in accidents.

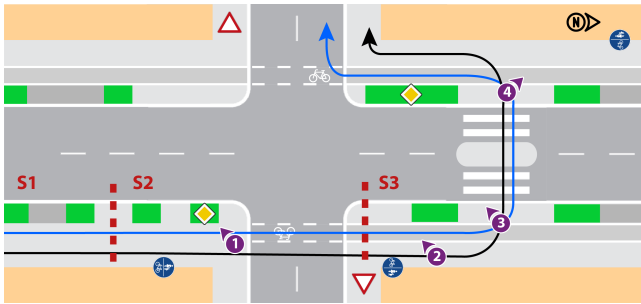
Eye tracking experiments support to analyze if drivers, cyclists, and pedestrians are aware of each other. Whereas researchers have analyzed the visual perception of car drivers in many eye tracking experiments [Kapitaniak et al. 2015], there are only few experiments performed with pedestrians and cyclists. In recent years, researchers have published a growing number of eye tracking experiments analyzing pedestrians and cyclists (e. g., [Davoudian and Raynham 2012; Kiefer et al. 2012; Mantuano et al. 2016; Vansteenkiste et al. 2014; Wenczel et al. 2017]). In this paper, we apply a visual analytics-based method to analyze gaze behavior of pedestrians and cyclists in a real-world eye tracking experiment.

## 2 RELATED WORK

The use of mobile eye tracking solutions for analyzing pedestrians and cyclists has been steadily increasing. In the beginning, researchers mainly used mobile eye trackers in controlled settings, for example, in artificial laboratories simulating a traffic environment [Bock et al. 2015; Igari et al. 2008; Jäger et al. 2015; Marigold et al. 2007; Zito et al. 2015] or performing experiments indoors [Jovancevic-Misic and Hayhoe 2009; Schnitzler et al. 2016; Vansteenkiste et al. 2013]. However, these eye tracking experiments do not reflect the realistic behavior and situation of pedestrians and cyclists in traffic environments. Therefore, researchers are now executing a growing number of experiments in real-world environments. Multiple eye tracking experiments exist that analyze pedestrians' [Brügger et al. 2018; Davoudian and Raynham 2012; Fotios et al. 2015a,b; Kiefer et al. 2014, 2012; Wenczel et al. 2017] or cyclists' behavior [Mantuano et al. 2016; Schmidt and von Stülpnagel 2018; Vansteenkiste et al. 2014]. In contrast to existing works, we are presenting a visual analytics-based approach to explore patterns, extract common eye movement strategies, and enable a combined analysis of the multi-modal data.

In our eye tracking study, we use a visual analysis method to analyze our data. Multiple examples for using a visual analytics approach are available in the eye tracking literature [Andrienko et al. 2012; Blascheck et al. 2016c; Kurzhals et al. 2014, 2016; Kurzhals and Weiskopf 2013; Raschke et al. 2014]. In their state-of-the-art report, Blascheck et al. [2017] have collected many different visualization techniques for eye movement data.

In addition, a combination of multiple data sources is beneficial. Previous work gives examples of visualization techniques incorporating multiple data sources for analyzing eye tracking data. For example, a combination of eye movement data and interaction logs [Crowe and Narayanan 2000]; eye movement data and



**Figure 1: Segment of the route divided into three sub-segments: 1) straight pavement where cycling is allowed, 2) non-traffic regulated crossing, and 3) crosswalk. Map legend: bicycle lane (blue line); pedestrian lane (black line); parking lines (dark gray rectangles), grassed areas (green rectangles); houses (light orange rectangles); shoulder check positions (purple circles).**

think-aloud protocols [Franchak et al. 2010]; eye movement data, video data, and paper notes [Fouse et al. 2011; Weibel et al. 2012]; or eye movement data, interaction logs, and think-aloud protocols [Blascheck et al. 2016a,b,c].

### 3 VISUAL ANALYSIS OF PEDESTRIAN AND CYCLIST BEHAVIOR

In the following section, we present an eye tracking experiment conducted in a real-world traffic environment with cyclists and pedestrians. We analyze the data using a visual method, which we shortly introduce. Then, we discuss exemplary results and experiences gained during the experiment.

#### 3.1 Experiment Design and Questions

To investigate behavior of pedestrians and cyclists, we conducted an experiment, in which participants had to follow a predefined route in an urban area of a town in Germany. Participants had to cycle and walk the route.

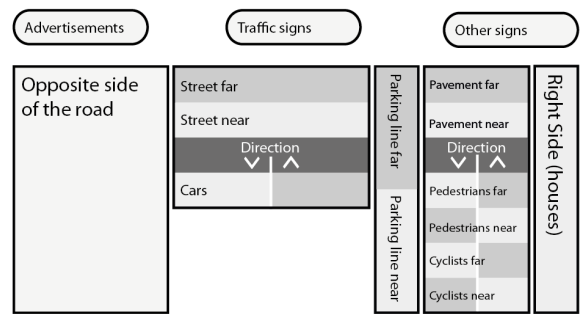
With the collected data, we want to answer multiple questions:

- Which objects as well as obstacles are focused on most and how distracting are advertisements at the side of the road (Section 3.5.1)?
- What common gaze sequences do pedestrians and cyclists perform and how does their behavior differ (Section 3.5.2)?
- How long and when do pedestrians and cyclists perform shoulder checks, especially if entering a potentially dangerous traffic situation (Section 3.5.3)?

In this paper, we only analyze a part (160 m) of a longer route (1.5 km) participants had to cycle and walk. We sub-divided this part of the route into three sub-segments (cf. Figure 1).

#### 3.2 Participants

We performed the experiment with 27 participants in total. However, due to difficulties with the eye tracking equipment, we were only able to use eye movement data with sufficient accuracy of 13 pedestrians (2 females; age:  $M = 27.8 \text{ years} \pm 8.86$ ) and 14 cyclists



**Figure 2: Example of the abstract reference image of the 21 AOIs for segment S1.**

(3 females; age:  $M = 27.9 \pm 8.69$ ). All participants had normal or corrected-to-normal vision.

#### 3.3 Experimental Procedure

We asked participants to walk or cycle the predefined route. We counter-balanced the order of participants walking or cycling to avoid learning effects when performing the route a second time. At the beginning of each trial, we asked participants to sign a consent form and fill out a demographic questionnaire. We used the Tobii Pro Glasses 2 to record the data and we performed the 1-point calibration procedure to calibrate the eye tracker. Afterwards, we checked the calibration by asking participants to focus on different points. We did the calibration indoors to ensure accuracy.

Because the goal of the experiment was to understand behavior of pedestrians and cyclists, we did not give participants a specific task. We only instructed them to walk or cycle the given route. However, we gave participants three instructions before they started their trip, to ensure a safe travel within the traffic environment:

- (1) By foot and while cycling the participants should cover the route on the right side of the street.
- (2) While cycling the participants should only ride on paths allowed for cycling.
- (3) Participants should exactly follow the given route.

#### 3.4 Multi-modal Visual Analysis Approach

We apply a visual analysis approach, which combines multi-modal data collected during our eye tracking experiment with pedestrians and cyclists. The applied method consists of the three steps:

- (1) Data collection
- (2) AOI Mapping
- (3) Data Analysis

**3.4.1 Data Collection.** We recorded the eye movement data with the Tobii Pro Glasses 2 at 50 Hz. The eye tracking glasses also record the accelerometer data and a video of the field of view. Participants wore the glasses, which feature a recording unit. We conducted the experiment outside during different weather conditions. Therefore, we had to exclude some data of participants with a precision lower than 80%.

**3.4.2 AOI Mapping.** Because of the complex traffic environment, we use an abstract reference image of the scene to define AOIs and map fixations to them (cf. Figure 2). The eye movement data is

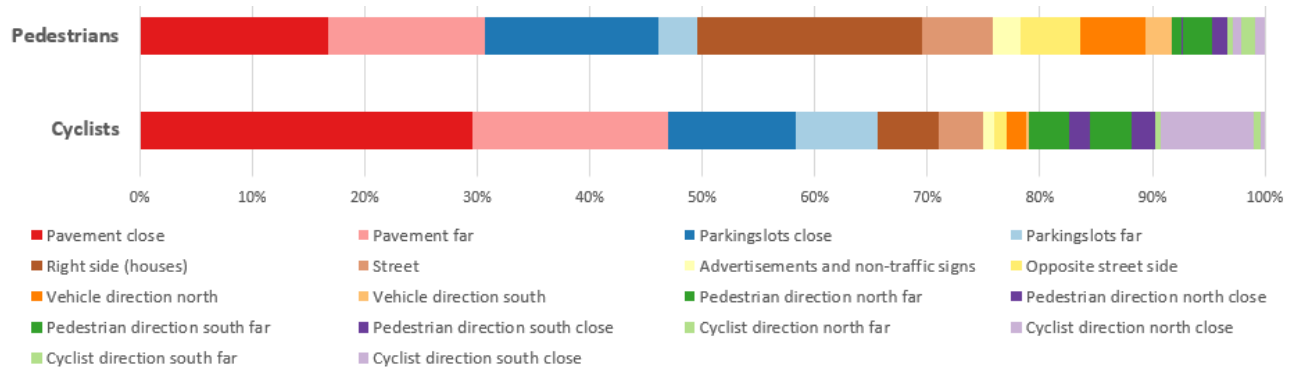
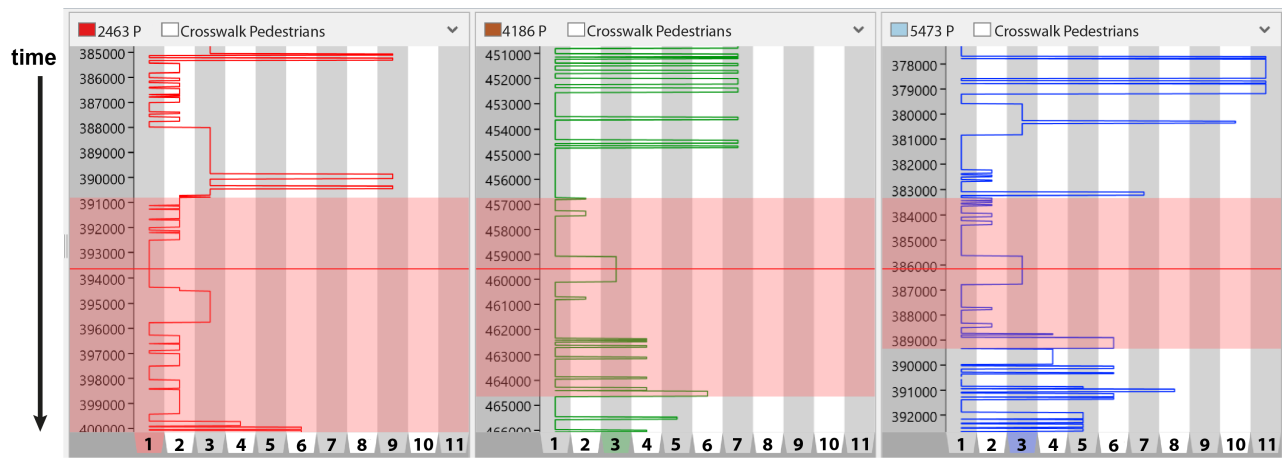


Figure 3: AOI visit duration of pedestrians (top) and cyclists (bottom) for different AOIs for segment S2.1.



**Areas of Interest**

- |                        |                  |                        |                                 |
|------------------------|------------------|------------------------|---------------------------------|
| 1. N/A                 | 4. Pavement far  | 7. Right side (houses) | 10. Opposite side of the road   |
| 2. Junction right      | 5. Pavement near | 8. Street far          | 11. Junction right (road users) |
| 3. Shoulder check left | 6. Parking line  | 9. Street near         |                                 |

Figure 4: Parallel scanpath visualization showing the five AOI long gaze sequence *junction right – shoulder check left – junction right – pavement far – parking line* for three participants colored in red, green, and blue.

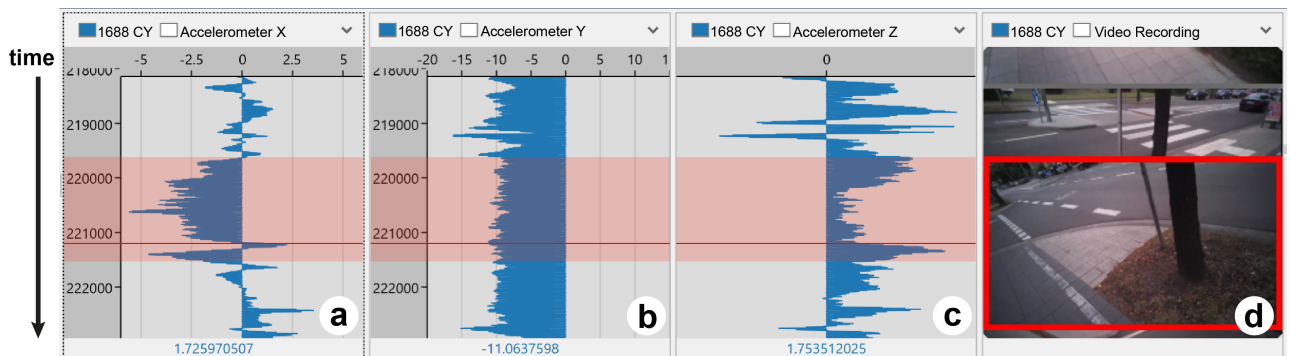


Figure 5: Line graph showing data of the accelerometer: a) x-direction, b) y-direction, which represents gravity, c) z- direction, and d) a frame from the video recording. The red highlight shows the time when the cyclist performed a shoulder check.

mapped frame-by-frame onto the abstract reference image. We also define *distractor* AOIs [Devillez et al. 2017] to capture other road users (i. e., car drivers, cyclists, pedestrians) and the direction in which they were heading. This allows us to answer the question how other road users influence attention. In total, for each sub-segment we defined AOIs: S1 has 21 AOIs (cf. Figure 2), S2 has 27 AOIs, and S3 has 16 AOIs.

**3.4.3 Data Analysis.** After mapping fixations to AOIs, the next step is an annotation of interesting situations and an explorative visual analysis. For annotating and analyzing the data, we use a parallel visualization of video recordings, eye movement and sensor data. Thereby, we can complement the different data streams if data points are missing or hard to interpret. This allows us to receive more detailed and accurate data. Additionally, we use the parallel scanpath visualization by Raschke et al. [2012; 2014] to search for common sequences in the eye movement data.

**Annotation.** In traffic, performing *shoulder checks* before switching lanes or turning is important to avoid accidents. Because such eye movements occur fast fixations are missing. Therefore, we semi-automatically annotate the instances when participants look backwards. Figure 5 shows a plot of the accelerometer data. Figure 5 (a) depicts the *x*-direction of the accelerometer sensor, (b) the *y*-direction (representing gravity), and (c) represents the *z*-direction. Figure 5 (d) shows the current frame of the video recording. A spike in these graphs indicates a rapid change of the acceleration. We can label each instance of a shoulder check, in which the *x*-direction is  $\leq 0$  and the *z*-direction is  $\geq 0$ .

**Visual Analysis.** Additionally, we analyze common sequences of AOIs using the parallel scan path method [Raschke et al. 2012, 2014]. This parallel visualization of video recordings and eye movement data allows us to identify interesting sections for different traffic situations visually. Using a visual analytics-based pattern search algorithms based on the Levenshtein distance [Levenshtein 1966], we find common eye movement strategies, respectively common behavior of the participants.

## 3.5 Analysis and Results

In the following sections, we discuss different observations to show how to analyze the collected multi-modal data. Based on the questions in Section 3.1, we first investigate segment S1 (cf. Section 3.5.1) to understand which objects and obstacles are focused on most and how distracting advertisements are at the side of the road. Next, we analyze segment S2 (cf. Section 3.5.2) to find common gaze sequences of pedestrians and cyclists and investigate how their behavior differs. Last, we explore segment S3 (cf. Section 3.5.3) to understand how long and when pedestrians and cyclists perform shoulder checks.

**3.5.1 Segment S1 – Focus on Obstacles.** Our first question (cf. Section 3.1) is about understanding, which objects and obstacles participants focus on most. In addition, we explore how distracting advertisements are at the side of the road. Therefore, we analyze the eye movement data based on the AOIs defined in Figure 2 for segment S1. Figure 3 shows an overview of how much attention pedestrians and cyclists paid to individual AOIs. Most attention was

paid to the path itself (red AOIs), for cyclists more than for pedestrians. Another observation is that both pedestrians and cyclists focus on pedestrians (dark green and purple AOIs) longer than on cyclists (light green and purple AOIs). Advertisements (light yellow AOI) attracted the attention of pedestrians as well as cyclists, however, only minimally.

**3.5.2 Segment S2 – Gaze Sequences.** With the parallel scan path technique [Raschke et al. 2012, 2014], we found the longest sequence with five AOIs in the eye movement data of the pedestrians: *junction right – shoulder check left – junction right – pavement far – parking line*. Figure 4 shows this sequence. It represents a specific gaze behavior, which we classify as a gaze sequence for safe traveling, because it increases the probability that participants perceived the situation in its entirety. We also found shorter common AOI sequences for pedestrians, such as *pavement near – pavement far* as well as *pavement far – pavement near*. For cyclists common AOI sequences were *parking line – sidewalk near – parking line*, *pavement near – pavement far – pavement near*, or *pavement near – advertisement – street (right)*.

**3.5.3 Segment S3 – Shoulder Checks.** One goal of the experiment was to measure and analyze if participants performed shoulder checks at important positions on the road. To analyze this, we defined four positions in the segment (cf. Figure 1, purple circles). As described above, we manually annotated shoulder checks using the accelerometer data and video recording of participants.

Overall, cyclists perform less shoulder checks and the average duration of shoulder check times are shorter than for pedestrians. The only exception is shoulder check SC 3 before cyclists cross the crosswalk. Another observation is that cyclists did not perform shoulder check SC 2; however, this could also be, because here pedestrians had to cross the bicycle lane. While the missing shoulder checks are likely to have a negative impact on the safety, we believe the shorter shoulder checks of cyclists are a necessity, because of the higher speed, which leads to longer distances in blind flight that can be dangerous.

## 4 CONCLUSION AND DISCUSSION

In this paper, we analyzed and compared gaze behavior of pedestrians and cyclists using a visual analysis approach of multi-modal data. We collected eye movement and accelerometer data as well as a video recording to enable a holistic analysis of pedestrians and cyclists' behavior. When investigating eye movement data in real-world traffic situations, we had to define a high number of AOIs. Therefore, we use an abstract reference image for mapping eye movement data onto AOIs. For the analysis of the recorded multi-modal data, we use a visual approach for a detailed analysis and comparison of the data. The visual analysis showed that the explorative analysis with multiple data streams leads to an efficient overview of the collected data. We exemplarily analyzed data from a real world eye tracking experiment. Our main results of the analysis are that participants paid most attention to the path itself; advertisements do not distract pedestrians and cyclists much; and participants focus more on pedestrians than on cyclists. We were also able to extract common gaze sequences, and we analyzed how often pedestrians and cyclists perform shoulder checks.

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