Analysis and Comparison of the Gaze Behavior of E-Scooter Drivers and Cyclists

Depending on Road Surface Quality in a Real Test Environment

Mathias Trefzger[1], Waldemar Titov[1], Karol Sgodzaj[1], Thomas Schlegel[1]

Abstract: In this paper, we contribute an eye tracking study to evaluate the gaze behavior of e-scooter drivers and cyclists on high and low quality road surfaces. We recorded the surface quality with sensors and put the different surfaces in relation to the gaze behavior. We recorded eye movements of the participants and performed an Area of Interest (AOI) sequence analysis to identify gaze patterns. Found sequences show that on the high quality surface participants focused most commonly the distant road section and then shifted to nearer sections. Individual advantageous gaze sequences are omitted if the surface is poor. We found a significant difference in the attention distribution of the two means of transport. In addition, we can confirm previous results showing that low quality road surfaces cause the gaze to shift forward. However, the participants did not adapt their speed to the worse surface.

Keywords: Bicycle; E-Scooter; Eye tracking; Sensors; Traffic safety; Visual analytics

1 Introduction

Since June 15 2019, e-scooters are permitted to drive on german roads. Shortly afterwards there were many reports of accidents. These have contributed that many people perceive the e-scooter as a dangerous means of transport. We want to check this first impression with the help of proven eye tracking methods. Starting with the question on how the road surface quality influences the gaze behavior of e-scooter drivers, we conducted a first study to break down the gaze behavior. Our approach is based on two studies by Vansteenkiste et al. [Va14, Va17]. To make the traffic behavior of e-scooter drivers comparable, we conducted a study with e-scooter drivers and cyclists. We have chosen this comparison because both means of transport move with similar speeds and use the same infrastructure like cycle paths and roads. In addition, both have an almost unrestricted visual field, are subject to environmental conditions like weather and have to balance while driving respectively riding.

In this paper, we investigate the gaze behavior on high quality and low quality road surfaces and compare the differences between e-scooters and bicycles. In order to make the difference between the selected route sections visible, we have recorded the vibrations caused by the

[1] Institute of Ubiquitous Mobility Systems (http://iums.eu), Karlsruhe University of Applied Sciences, Moltkestr. 30, 76133 Karlsruhe, Germany, iums@hs-karlsruhe.de

doi:10.18420/inf2020_108

roads in a preliminary study using a mobile application [Ti19]. Monitoring and classifying road conditions using bike-mounted smartphones has been a rising topic in the last few years. The reason for the rise is the availability and user acceptance of mobile devices, and general market penetration. Modern smartphones are equipped with many highly sensitive sensors and have a high computing capability. Therefore, mobile devices can be utilized for monitoring conditions in context of safety and traveling comfort of non-motorized transport types. Many authors among others [Mo08, Mo13] have stated the suitability of smartphones being used for road condition determination.

A study conducted by [La11] examines the suitability of smartphone sensor data for road condition determination. Two android devices with different sensors and computing capacities are evaluated in terms of data quality and data density by capturing the acceleration data of a smartphone. The results indicate a relatively high deviation caused by different utilized suspensions. Tackling this challenge, we use a bicycle and an e-scooter without any suspension in our study.

Because of the higher task complexity on low quality road surfaces, we expect a higher percentage of gaze in the functional space [La91] and less irrelevant fixations [Va13]. Due to the significantly poorer suspension of the e-scooter, we expect that this effect will be more pronounced with e-scooters.

2 Methodology used for Selecting a Suitable Real Test Environment

To evaluate whether the road surface quality has an impact on the attention distribution of cyclists and e-scooters, we set up a study concept consisting of two studies. Prior to the eye tracking study, we evaluated the road surface condition in a pre-study. Aiming to select suitable and meaningful representative high and low quality road sections, as our real test environment, we used our prior developed road surface evaluation tool. In [Ti19] we introduced the crowd sensing monitoring tool for road surface condition called GyroTracker. Furthermore, we made sure that the test routes had the same conditions in terms of lane width, type of road and traffic. The following subchapters introduce the method that we utilized in the pre-study to determine the road surface conditions.

2.1 Pre-Study for Accessing the Road Surface Quality

The assessment of the road surface quality uses a two-stage condition recording and evaluation procedure. In [Ti19] we previously described the two-stage procedure of data collection and classification in more detail.

In the first stage, data is collected via mounting the smartphone on the handlebar of a bicycle respectively of an e-scooter using a bicycle navigation mount as shown in figure 1. Once the app is started, the location service of the device will run in the background.

Upon completion, user's own location will be displayed on the map. Due to the high spatial relevance of the measurement data, the data recording can only begin after the device's location is available. Once located, users can start recording of both location and sensor data. During the bicycle or e-scooter ride, GyroTracker reads the four sensors: location, gyroscope, acceleration, and linear acceleration and stores the data into the smartphones database. After the completion of a recording, the measurement-id is incremented in the background, ensuring the identification of each recording.

Fig. 1: Left: Collecting road data with the gyrotracker app. Right: Vertical Acceleration values

In the second stage, the recorded data is cleaned to be further processed and analyzed. To ensure the assignability of the three streaming sensors (acceleration, gyroscope and linear acceleration) with the location data, the location data must be interpolated. For that purpose, we used the simultaneously recorded timestamps of the individual sensors. After the data preparation, we analyzed the recorded data based on the concepts of the international roughness index [Du14 and Sa95]. Therefore, we used the vertical component of the linear acceleration values to calculate the road surface roughness. Dependent upon our way of mounting the smartphone the vertical acceleration components, shown in figure 1, can be extracted. Thereby the vertical component of linear acceleration is calculated as the sum of modulus of y-values and modulus of z-values of the linear acceleration data as shown in formula 1.

$$\sum |y - values| + |z - values|(1) \tag{1}$$

Based on the described approach the road surface conditions of our test environment were measured and evaluated. The results of the monitoring are compared to each other for a founded statement of the road surface conditions that our eye tracking study then is based on.

2.2 Results of the Road Surface Quality Measurements

The analyzed acceleration data collected by the bicycle and the e-scooter is shown in figure 2. The blue graphs display respectively the data of the high quality road surface with the orange graph being the mean value.

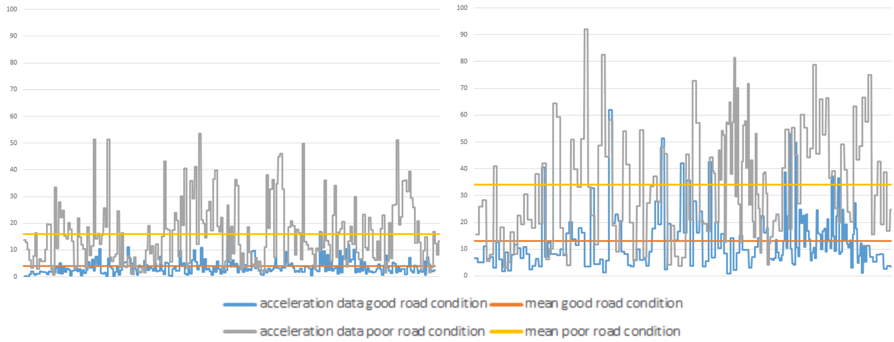

Fig. 2: Recorded road surface acceleration data with a bicycle (left) and an e-scooter (right) on low and high quality road surface

The gray graphs display respectively the data of the low quality road section with the yellow graph being the mean value. A significant deviation between the good road surface section and the poor road surface section can be seen.

The mean value of the acceleration data collected by a bicycle on a road section with high quality road surface is 4^2. Which is exactly four time less than the mean value of the acceleration data collected by a bicycle on a road section with poor road surface quality amounting to be 16 m/s^2.

In comparison to the data collected by the e-scooter it is overall higher for both road sections. The mean value of the acceleration data collected by the e-scooter on a high quality road surface is 13 m/s^2. Which is close to the mean of the acceleration data collected by a bicycle on the low quality road. The mean value of the acceleration data collected by the e-scooter on the low quality road sums up to be 34 m/s^2.

Comparing both used modes of collecting the acceleration data the bicycle (as expected) seems to be a much smoother transportation type. The ratio of the data collected by the bicycle amount to be exactly 4, the ratio of the e-scooter data amounts to be 2.6.

Additional to acceleration data we analyzed the rotation speed data collected by the gyroscope sensor. A significant deviation between the road surfaces labeled high and low quality surface is shown. Furthermore, figure 3 indicates a significant difference in perceived road surface quality between the two types of transport.

During the pre-study road surface evaluation, all participants were equipped with Samsung Galaxy S6 Edge with the android version 6.0.1 and 4 x 2.1 GHz processor devices. Deviating

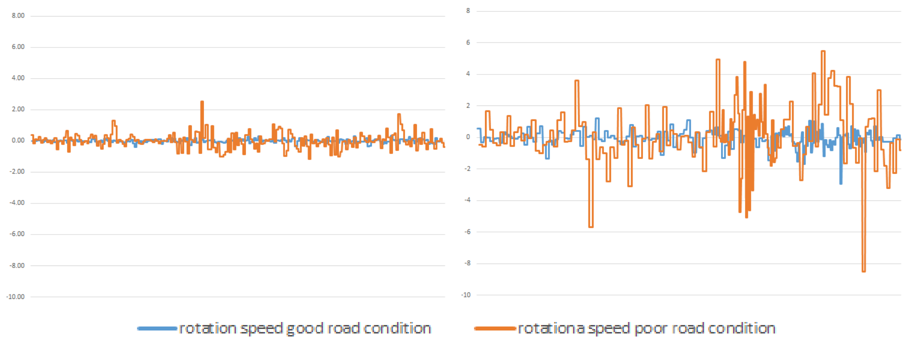

Fig. 3: Rotation speed on high and low quality roads with a bicycle (left) and e-scooter (right)

from [La11], our evaluation focus is on the method used for classification of collected data; therefore, the collection of measurement data by further devices was omitted. In the short period of our pre-study, eight measurements of different road surface qualities were carried out. The result was a data set with over 35.000 individual measuring points consisting of 945.000 single sensor values. After analyzing the collected sensor data, the road best suiting our requirements for the eye tracking evaluation was chosen. The requirements and the chosen road section is presented in the next chapter.

3 Study design

3.1 Participants

25 volunteers participated in the study. Of these, 24 eye tracking recordings were usable. 14 male and 10 female volunteers aged from 18 to 62 years participated (7 from 18-29; 12: 30-49, 4: 50-62, 1: > 63). Among them were trainees, students and employees. They showed different use of the bicycle and e-scooter in everyday life and the experiences associated with it. The average participant owned a bicycle and used it daily during spare time for errands and on the way to work. Only five participants had used an e-scooter before.

3.2 Used Devices and Transportation Modes

We used head mounted Tobii Glasses 2 to record eye movements and gaze location. The eye tracking recordings were started and stopped using a laptop with the Tobii Pro Glasses Controller Software.

The participants were provided with a bicycle and an e-scooter. Thus, all test persons used the same means of transport. The bicycle used was a conventional ladies' bicycle without suspension. The used e-scooter was a Trekstor E.Gear (EG 3178) scooter also without suspension.

3.3 Protocol

Participants arrived individually to the dedicated location at a scheduled time. First of all a list of traffic rules in public road space was used as a reference. Afterwards the course of the study was explained to the test persons. Next, a declaration of consent had to be signed. The lenses of the eye tracking glasses were adjusted to the visual acuity of the test persons if required. Then the test persons put on the glasses and the helmet. Afterwards the eye tracking glasses were calibrated using the One Point Calibration Method. Next, the test persons were taught how to operate the e-scooter and then took a test drive to get used to it. Following, the course was explained. Then the actual ride with the e-scooter and the bicycle started. At the end of the study, the test persons had to fill in a questionnaire.

3.4 Testing Environment

The test track used is an approximately 200-meter long road section in Mannheim, Germany. The route was chosen because one-half of the road had a smooth surface (this will be referred as high quality track: HQ) and the other half contained bumps and potholes (referred as low quality track: LQ). Otherwise, the conditions were almost identical. Another advantage of the chosen road section was the low traffic volume so that the distraction caused by other road users was minimal.

Both routes had a junction where the test persons had to pay attention to the oncoming traffic. During the study, the participants had to drive back and forth along the road first using the bicycle and then the e-scooter.

3.5 Data analysis and statistics

We evaluated the eye tracking recordings using Tobii Pro Lab and Blickshift Analytics. For the evaluation of the gaze behavior, we used two similarly constructed reference images for the HQ and LQ side (see figure 4). In contrast to Vansteenkiste et al. [Va14, Va17], we divided the AOI "road" into three parts: near (“Road 1”: approx. 0-8 m), middle (“Road 2”: 8-16 m) and far (“Road 3”: ≥16 m). With this classification, we wanted to determine how the attention of the participants shifts with different road qualities. The length of the individual AOI road sections was chosen based on the prior experimentally evaluated breaking distance of an e-scooter from 20 to 0 km/h. The breaking distance of the bicycle was found shorter, thus being ignored.

Thereby we calculated the speed of each participant and individual type of transport in retrospect by dividing the length of the field test route by the needed time. Differences between HQ and LQ speeds were statistically tested using a t-test. Significance level was set at P≥0.05.

For the evaluation, the gaze points had to be assigned to a reference picture frame by frame by hand in the analysis software Tobii Pro Lab. Therefore, distribution to the AOIs may contain small inaccuracies. Nevertheless, differences in gaze behavior become visible.

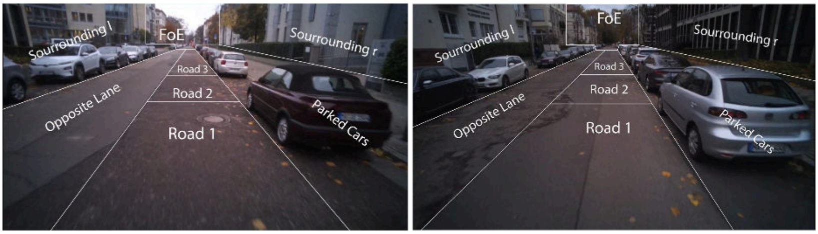

Fig. 4: Reference picture of the low (left) and high quality (right) road surface with AOI overlay.

After the evaluation with Tobii Pro Lab we used Blickshift Analytics to take a look into the gaze patterns of the participants using the Tool "Sequence Analysis" as well as visual analytic methods like Scarf Plots.

4 Results

4.1 Speed

There is no significant difference in speed for e-scooters (t=1.470 p=0.155) and cyclists (t=-1,620 p=0.119) while riding respectively driving on a good surface or bad surface. As shown in table 1 the e-scooter drivers drove approx. two km/h slower on both the LQ (t= -4.705 p=9.715^{-05}) and HQ (t=-3.650 p=0.001) route than the cyclists.

Tab. 1: Cycling speed (in km/h) of e-scooter drivers and cyclists on the high and low quality road surface tracks

E-Scooter Speed		**Bicycle Speed**	
High quality	Low quality	High quality	Low quality
15.93 ± 2.80	15.34 ± 2.56	17.84 ± 3.04	18.48 ± 2.97

4.2 Fixation Metrics

Additionally to the speed, we analyzed standard eye tracking metrics (Total Visit Duration, Average Visit Duration, Visit Count) to highlight the differences in the gaze behavior by the different vehicles and road surface qualities. A visit is defined as the period of time when a participant first focuses on a region until the person looks away from that region. That means a visit can consist of at least one or multiple fixations.

Total Visit Duration

The Total Visit Duration for all AOIs was calculated to find how much time the participants spent on the AOIs (Table 2). Comparing the HQ and LQ surface a significant shift of the gaze from more distant road sections to nearer sections are visible (see fig. 5). The views on the three road AOIs increase a little bit (E-Scooter: 17%, Bicycle: 12%). Overall, e-scooter drivers spent more time looking on the road AOIs then the cyclists. On the LQ surface, the e-scooter drivers look 52% longer on the nearest road section "Road 1".

It is also noticeable that with the better road surface, the views on the parking cars are significantly longer. This is useful for protecting against doors suddenly opening in traffic.

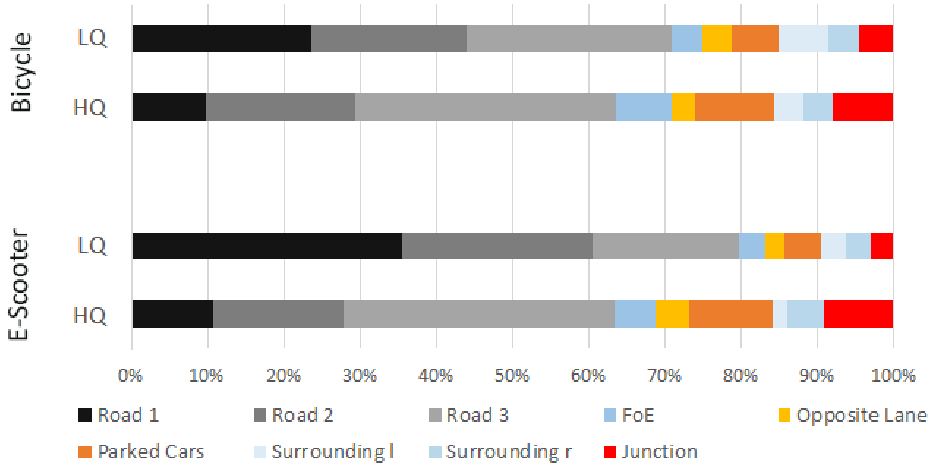

Fig. 5: Total Visit Duration percentages towards the 9 AOIs per vehicle and road type.

Tab. 2: Total Visit Duration (incl 0) in seconds

AOI	Means of Transport	Road Surface	
		High quality	Low quality
Road 1	E-Scooter	3.80 ± 3.66	13.97 ± 10.53
	Bicycle	3.02 ± 3.29	7.23 ± 6.44
Road 2	E-Scooter	6.00 ± 3.20	9.71 ± 4.27
	Bicycle	5.89 ± 3.72	6.22 ± 2.91
Road 3	E-Scooter	12.49 ± 8.13	7.53 ± 6.44
	Bicycle	10.31 ± 6.11	8,22 ± 6.87

FoE	E-Scooter	1.85 ± 2.08	1.33 ± 1.41
	Bicycle	2.18 ± 2.70	1.22 ± 2.10
Opposite Lane	E-Scooter	1.55 ± 1.35	0.96 ± 1.08
	Bicycle	0.96 ± 0.74	1.19 ± 1.18
Parked Cars	E-Scooter	3.85 ± 2.09	1.91 ± 2.42
	Bicycle	3.13 ± 2.26	1.87 ± 1.44
Surrounding l	E-Scooter	0.73 ± 0.71	1.27 ± 1.41
	Bicycle	1.15 ± 1.24	2.00 ± 1.65
Surrounding r	E-Scooter	1.64 ± 0.98	1.23 ± 1.12
	Bicycle	1.17 ± 0.82	1.22 ± 1.02
Junction	E-Scooter	3.20 ± 3.04	1.18 ± 0.96
	Bicycle	2.40 ± 2.03	1.36 ± 0.87

Average Visit Duration

Looking at the Average Visit Durations in table 3, it shows that the average time spent on the nearest road section “Road 1” increases significantly when comparing the HQ and LQ surface. This is the case for both the e-scooter and the bicycle. The difference on “Road 2” is minor and on “Road 3” the Visit Durations become a little bit shorter.

Tab. 3: Average Visit Duration in seconds

AOI	Means of Transport	Road Surface	
		High quality	Low quality
Road 1	E-Scooter	0.36 ± 0.14	0.70 ± 0.37
	Bicycle	0.37 ± 0.17	0.56 ± 0.33
Road 2	E-Scooter	0.42 ± 0.23	0.49 ± 0.21
	Bicycle	0.47 ± 0.21	0.38 ± 0.10
Road 3	E-Scooter	0.63 ± 0.31	0.50 ± 0.27
	Bicycle	0.65 ± 0.52	0.53 ± 0.39
FoE	E-Scooter	0.48 ± 0.22	0.38 ± 0.19
	Bicycle	0.55 ± 0.49	0.48 ± 0.38
Opposite Lane	E-Scooter	0.36 ± 0.15	0.34 ± 0.23
	Bicycle	0.30 ± 0.14	0.29 ± 0.19
Parked Cars	E-Scooter	0.41 ± 0.18	0.35 ± 0.24
	Bicycle	0.42 ± 0.24	0.34 ± 0.15
Surrounding l	E-Scooter	0.23 ± 0.10	0.35 ± 0.16

	Bicycle	0.33 ± 0.30	0.39 ± 0.24
Surrounding r	E-Scooter	0.35 ± 0.20	0.32 ± 0.18
	Bicycle	0.32 ± 0.17	0.39 ± 0.37
Junction	E-Scooter	0.59 ± 0.36	0.55 ± 0.36
	Bicycle	0.56 ± 0.35	0.48 ± 0.21

Visit Count

In this study, the Visit Count indicates the visual effort participants spent on the different AOIs. Table 4 shows the average visit count on the nine AOIs. As indicated in the Total Visit Duration, the number of visits to "Road 1" and "Road 2" increases from HQ to LQ. For "Road 3" the number decreases. Cyclists perform significantly fewer visits in the two nearby street AOIs than e-scooter drivers do. The number of visits by e-scooters on parked cars is almost halved. With the cyclists, the effect is not quite as pronounced.

Tab. 4: Visit Count (incl 0)

AOI	Means of Transport	Road Surface	
		High quality	Low quality
Road 1	E-Scooter	9.63 ± 7.78	18.58 ± 9.46
	Bicycle	7.38 ± 6.63	13.00 ± 8.48
Road 2	E-Scooter	14.83 ± 6.85	20.04 ± 6.60
	Bicycle	13.33 ± 6.87	16.42 ± 6.60
Road 3	E-Scooter	19.42 ± 6.44	14.38 ± 6.62
	Bicycle	17.21 ± 7.60	15.13 ± 5.89
FoE	E-Scooter	3.67 ± 3.23	3.42 ± 3.31
	Bicycle	3.92 ± 3.88	2.46 ± 2.30
Opposite Lane	E-Scooter	4.13 ± 2.85	2.75 ± 2.47
	Bicycle	3.33 ± 2.46	4.00 ± 3.30
Parked Cars	E-Scooter	9.58 ± 4.58	5.25 ± 4.11
	Bicycle	7.75 ± 3.00	5.21 ± 3.12
Surrounding l	E-Scooter	2.88 ± 2.29	3.33 ± 2.78
	Bicycle	3.58 ± 2.90	5.13 ± 2.97
Surrounding r	E-Scooter	5.25 ± 3.47	3.58 ± 2.32
	Bicycle	3.58 ± 1.47	3.67 ± 2.30
Junction	E-Scooter	5.13 ± 2.82	2.29 ± 1.43
	Bicycle	4.25 ± 1.94	2.83 ± 1.40

4.3 Visual Analysis

We use scarf plots [Ri05] for our AOI sequence analysis, which enables a closer assessment of the participants gaze behavior compared to heat maps or gaze plots. Therefore, scarf plots better illustrate the visual distribution of gaze patterns on the identified AOIs.

The following sections describe observations of the AOI sequence analysis, by first going through the main patterns observed across the e-scooter drivers and cyclists. Then we highlight noticeable patterns depending on the road surface quality, which we will later discuss.

Common Gaze Patterns

In our dataset, we searched for the most common gaze patterns. They are shown in Table 5. Generally, it can be seen that with the HQ surface the participants fixate most commonly a distant road AOI and then shift their gaze to nearer parts of the road. With the LQ surface, the gaze sequence is reversed: The nearest road AOI is fixated first then shifts to next road AOI.

Tab. 5: Most common gaze sequences found in the dataset. Legend: Road 1 (R1); Road 2 (R2); Road 3 (R3); Parked Cars (PC); Surrounding right (Sr)

Subsequence in % of input sequences	E-Scooter		Bicycle	
	HQ	LQ	HQ	LQ
100%	R3-R2	R1-R2	R3-PC	R1-R2 R2-R3
90%	R3-PC PC-R3 R2-R3 R1-R3	R3-R1-R2	R2-R3 R2-R3	R1-R2-R3
80%	R3-R1 R3-Sr R2-PC	R1-R2-R1 R1-R2-R3 R2-R1-R2	R2-PC	R2-R1-R2
70%	R3-R2-R3 R3-R1-R3 R2-R3-R2	R1-R2-R1-R2	R2-R3-R2 R3-R2-R3	R2-R1-R3 R2-R3-R2 R3-R1-R2

On the HQ surface 100% of the cyclists performed, the sequence “R3-PC” as well as 90% the e-scooter drivers performed the sequence “R3-PC” and “PC-R3”. Therefore, those AOIs seem closely related – after looking at the end of the road the view to the parked cars follows. This short gaze sequence serves for the traffic safety. Looking on the sequences on the LQ surface less than 60% of cyclists and e-scooter drivers perform that gaze pattern.

Group specific patterns

We could not find consistent patterns unique for each vehicle. Therefore, we discuss more general patterns found or shared between some of them. We found that some participants tend to look at the different AOIs longer and therefore jump less back and forth between the AOIs. In contrast to this group, there are also test persons who look at the individual AOIs very briefly and constantly jump back and forth. This can be seen in figures 6 and 7.

5 Discussion

We designed our study in a way to allow us to determine how different road surface qualities have an effect on the gaze behavior on e-scooter drivers and cyclists and if there are differences between the two vehicles.

As Vansteenkiste et al. [Va14, Va17] we found no effect of the road surface quality on the cycling and driving speed. Neither cyclists nor e-scooter drivers did adapt their speed to the worse road surface. As can be seen in the graphs above (figure 2), the deflections due to unevenness of the LQ road surface are clearly visible compared to the HQ road surface condition. The driving comfort is thus significantly reduced. The vibrations themselves seem not to be the main cause for different gaze behavior: The vibrations for the e-scooter drivers on the HQ surface was almost the as on the LQ for the cyclists.

The e-scooter drivers drove approximately 2 km/h slower than the cyclists did on the different surfaces. There was therefore a significant effect on the participants in the study. This could be due to insecurity with the vehicle, caused by the lack of experience with the newer type of vehicle or due to the stronger vibrations caused by the lack of proper suspension. To test this hypothesis a further study with experienced e-scooter drivers is necessary.

In comparison with the study of Vansteenkiste et al. [Va14], there is, contrary to our expectations, only a comparatively small difference in the distribution of cyclists’ attention between poor and good road surfaces (54% and 47% in our study compared to 63% and 25% from Vansteenkiste et al.). Although part of the difference is due to the different test tracks, the difference between the two studies is high. Another reason for the difference may be the different width of the roadway. It is conceivable that, with a considerably narrower roadway of 1.3 m (LQ) to 2.0 m (HQ), more attention must be paid to ensuring that the driver does not drive over the lane boundary For a detailed comparison of the studies see table 6.

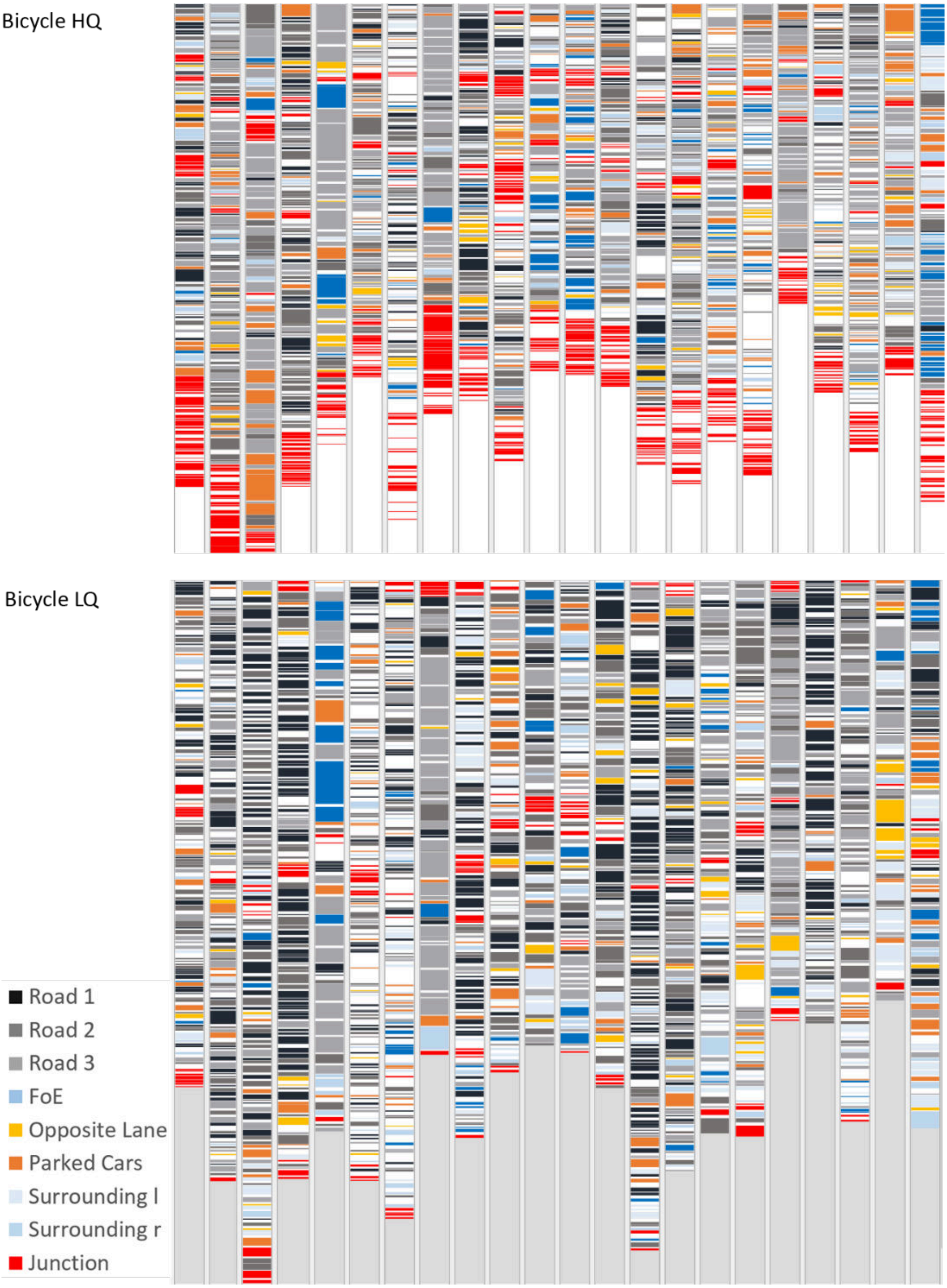

Fig. 6: Scarf Plot of all participants riding a bicycle. All visualizations have been normalized to the same height.

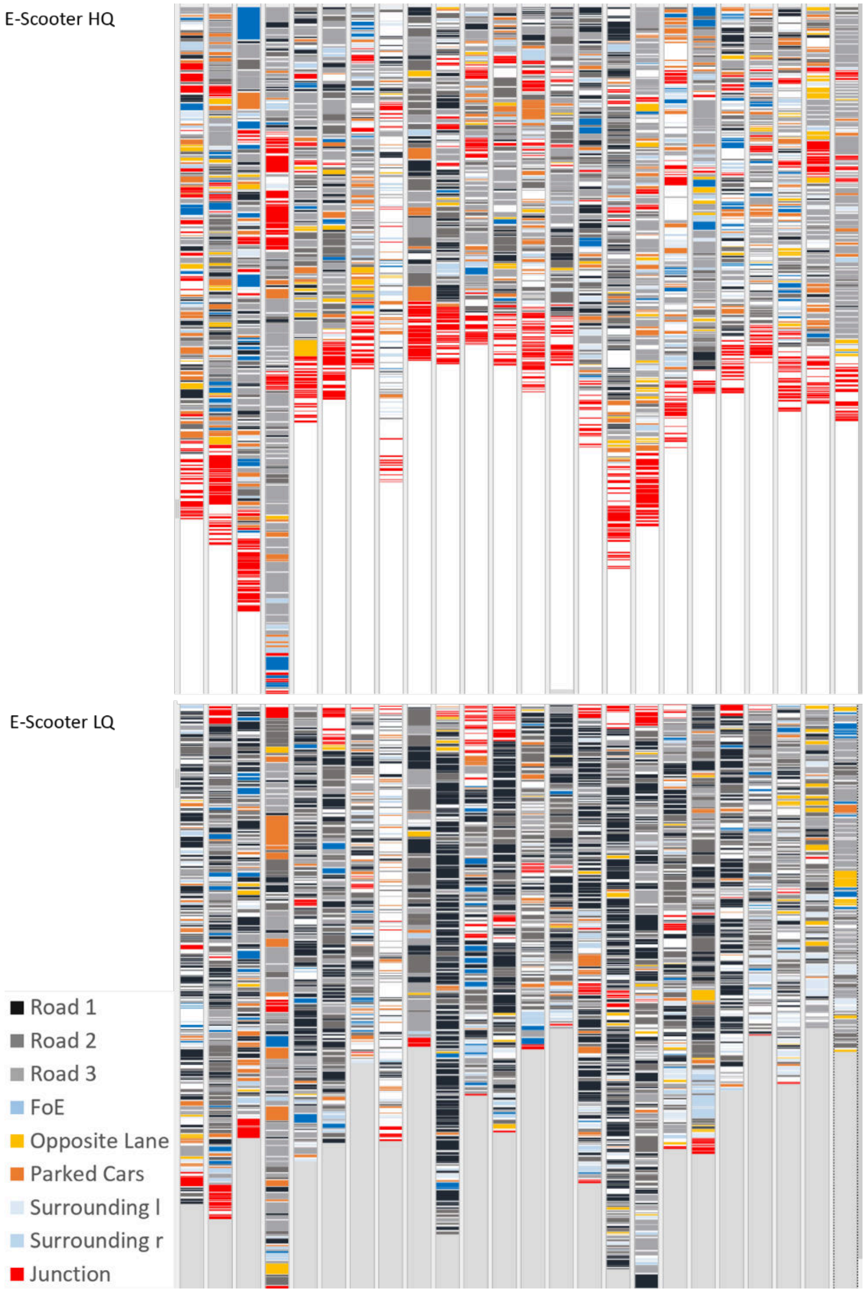

Fig. 7: Scarf Plot of all participants driving an e-scooter. All visualizations have been normalized to the same height.

Tab. 6: Key data from the two studies of Vansteenkiste et al. compared to our study

	Va14	**Va17**	**Our Work**
Participants			
Number	5	15 adults, 12 children	24
Gazepoint density	all over 80%	Participants were included when share of NoData was less than 50%	E-Scooter: 86,8 ± 6,57 Bicyle: 83,13 ± 7,11
age	22-24	adults 25.93 ± 2.71, children 9.08 8 ± 2.07	18-62
gender	1 male, 4 female	adults: 8 female, 7 male children: 8 female, 4 male	14 male, 10 female
User frequency	daily	-	daily – never
Purpose	Main means of transport	-	free time, errands, work, main means of transport, no use
Study route			
Location	Ghent, NL	Ghent, NL	Mannheim, GER
Evaluated Route Distance	120 and 136m	120 and 136m	200 m each
Lane width	HQ 2m, LQ 1,3m	HQ 2m, LQ 1,3m	HQ 3m, LQ 3m
Other			
device	IviewX Head Mounted Eye	SMI Eye Tracking Glasses 2.0	Tobii Pro Glasses 2
weather	overcast	clear	Overcast
Means of transport	bicycle	bicycle	bicycle and e-scooter

Also surprising is the relatively small difference in the distribution of attention of e-scooter drivers compared to cyclists. Due to the much stronger vibrations while driving the e-scooter (shown in figure 2), the participants focused significantly longer on the nearest road AOI in front of them compared to the cyclists. However, it can be clearly seen that the views of more distant road sections shift to nearer parts of the road. While the high quality road hardly shows any difference between e-scooter drivers and cyclists, the low quality road shows a different distribution of the road AOIs. The e-scooter drivers focus largely on the near road AOI (29% to 19%) and the second nearest road AOI (21% to 17%). The share on the most distant road AOI thus falls shorter to 16%. Leading to a less foresighted style of traveling. With the good road surface, a full 30% of the e-scooter drivers looked at the most distant road AOI. This shows that the gaze distribution is drawn into closer areas due to poorer surface quality. In addition, a low quality surface has a greater impact on the vision of e-scooter drivers than on cyclists. If the road surface is good, there is little difference in gaze behavior between the two means of transport. The increasing Average Visit Durations from HQ to LQ strongly indicate a higher perceived risk by the participants.

Chapman and Underwood describe that dangerous situations are characterized by a narrowing of visual search, shown by an increase in fixation durations and a decrease in saccade angular and a reduction in the variance of fixation durations [Ch98]. These signs were also observed in our study. From the results, we conclude that poor road surface quality increases the risk that e-scooter drivers and cyclists are more likely to overlook other road users. The risk is greater for e-scooter drivers than for cyclists. If one considers that tourists, who usually are not familiar with the roads, often drive e-scooters we assume that the risk increases further.

6 Conclusion and Future Work

In this paper, we reported on the findings of an eye tracking study conducted with adult participants who rode the provided bike respectively drove the e-scooter on a high and low quality road. Our main goal was to analyze participants gaze behavior and patterns. Low quality road surfaces cause a shift of the visual attention at nearer road sections. We measured with our “Gyrotracker” app that the vibrations caused by the road surface were significantly stronger with the e-scooters. Therefore, we conclude that in addition to the quality of a road surface, the suspension of a vehicle also has a strong influence on the distribution of vision.

The evaluation of the gaze patterns showed that on the high quality surface most participants focused most commonly first on the most distant road section and then shifted to nearer parts of the road. With the low quality surface, this pattern is reversed.

On the high quality surface almost all e-scooter drivers and cyclists performed the sequence of first focusing the most distant road section and then the parking cars. On the low quality surface this pattern is significantly used less, which likely increases the risk of accidents through opening car doors.

With our analysis, we could not find unique patterns for the different vehicles. However, seemingly the participants can be grouped into persons who look on the AOIs shorter and jump frequently between them, as well as persons who focus longer at the AOIs but therefore jump less frequently between them.

In future work we want to evaluate the gaze sequences in even more detail. We therefore want to compare the gaze behavior of different groups of people, for example regular cyclists and people who hardly ride a bike at all. Here we want to find out if certain parameters or properties influence the gaze behavior and patterns. In addition, we want to extend the eye tracking with additional metrics, which will be recorded by additional sensors on the vehicles. This will allow us to include the external conditions in evaluating the traffic behavior.

7 Limitations

Most participants never drove an e-scooter before. Therefore, insecurity could have had an influence on the gaze behavior. This issue could be clarified in future research when participants are experienced driving e-scooters.

Bibliography

[Ch98] Chapman, R.; Underwood, G.: Visual search of driving situations: Danger and experience. In: Perception 27, p. 951-964, 1998. DOI: 10.1068/p270951

[Du14] Du, Y.; Liu, C.; Wu, D.; Jiang, S.: Measurement of international roughness index by using-axis accelerometers and GPS. Mathematical Problems in Engineering, 2014, 2014. Jg. DOI: https://doi.org/10.1155/2014/928980.

[Ho13] Hoffmann, M.; Mock, M.; May, M.: Road-quality classification and bump detection with bicycle-mounted smartphones. In: Proceedings of the 3rd International Conference on Ubiquitous Data Mining- Volume 1088. CEUR-WS.org, p. 39-43, 2013.

[La91] Laurent, M., & Thomson, J. A.: Anticipation and control in visually- guided locomotion. International Journal of Sport Psychology, 22(3-4), p. 251–270, 1991

[La11] Lauer, J.; Jochem, A.; Zipf, A.: Straßenzustandsermittlung durch Klassifikation mobiler Sensordaten von Smartphones. Doktorarbeit. Master's thesis, Abteilung Geoinformatik Geographisches Institut, Universität Heidelberg.

[Mo08] Mohan, P.; Padmanbhan, V.; Ramjee, R.: Nericell: rich monitoring of road and traffic conditions using mobile smartphones. In: Proceedings of the 6th ACM conference on Embedded network sensor systems, p. 323-336, 2008. DOI: https://doi.org/10.1145/1460412.1460444.

[Ri05] Richardson, D.; Dale, R.: Looking To Understand: The Coupling Between Speakers' and Listeners' Eye Movements and Its Relationship to Discourse Comprehension. In: Cognitive Science 29 (6), p. 1045 – 1060, 2005.

[Sa95] Sayers, M.: On the calculation of international roughness index from longitudinal road profile. In: Transportation Research Record, Nr. 1501, 1995.

[Sc11] Schepers, J.P.; Den Brinker, B.P.L.M.: What do cyclists need to see to avoid single-bicycle crashes? Ergonomics 54 (4), p. 315–327., 2011. DOI: https://doi.org/10.1080/00140139.2011.558633.

[Ti19] Titov, W.; Schlegel, T.: Monitoring Road Surface Conditions for Bicycles – Using Mobile Device Sensor Data from Crowd Sourcing. In HCII 2019: HCI in Mobility, Transport, and Automotive Systems. Springer, p. 340-356, 2019. DOI: 10.1007/978-3-030-22666-4_25.

[Va13] Vansteenkiste, P..; Cardon, G.; D'Hondt, E.; Philippaerts, R.; Lenoir, M..: The visual control of bicycle steering: The effects of speed and path width. Accident Analysis & Prevention Volume 51/2013, p. 222-227, 2013. DOI: https://doi.org/10.1016/j.aap.2012.11.025.

[Va14] Vansteenkiste, P.; Zeuwts, L.; Cardon, G.; Philippaerts, R.; Lenoir, M..: The implications of low quality bicycle paths on gaze behavior of cyclists: A field test. Transportation Research Part F: Traffic Psychology and Behaviour Volume 23/2014, p. 81-87, 2014. DOI: https://doi.org/10.1016/j.trf.2013.12.019.