Cyclist’s Gaze Behavior Before and After Obstacle Detection

Lang Bai
1036890

Arun Tom Skariah
1033127

Abstract

Recent years have seen a rise in single-bicycle accidents and subsequent researches trying to find a solution to the reduce the accidents have shown it is necessary to understand visual behavior of cyclists. This study aims in measuring gaze behavior of cyclists before and after detection of obstacles during day and night on a real bicycle path. An eye-tracker was used for measurement of gaze behavior during the experiment. Participants performed two tasks while cycling with a low and a high speed. They had to cycle through a gate formed by two obstacles, and at the same time, shout out loud the orientation of Landolt’s C-rings situated along the path. The result of our study indicates that there is no significant difference between gaze behavior before and after obstacle detection during day time. The report further discusses about the issues experienced during the study and recommendations on how to improve eye-tracking studies.

Introduction

The positive impact of bicycles on environment and health fuelled the popularity of bicycles in many European countries (Juhra et al., 2012). The rise in popularity of cycling, subsequently, has led to a rise in accidents especially single-bicycle accidents (only one cyclist involved), where cyclists collide with obstacles or move away from their lane position (Schepers & Brinker, 2011). The issue of single-bicycle accidents is important, because in Netherlands alone, single-bicycle accidents accounts for 60 percent of all bicycle accidents (Fietsberaad, 2011). The increasing number of cyclists and less reduction in accidents calls for a better understanding of cyclist’s behavior.

Various researches investigated the cause for accidents among cyclists, with some focusing on properties of the bicycle path and others on visual perception of cycling path and surrounding

For example, Nyberg and colleagues, focusing on the path properties, found that a bad road surface, curbs, and objects on the road together account for 45 percent of single-bicycle accidents (Nyberg, Björnstig, & Bygren, 1996). An example of a study focusing on visual perception of cycling path and surrounding is the study by Schepers and Brinker (2011). They focused on visibility information in the peripheral part of the visual field and found that visibility information regarding path and surrounding is important for safe cycling. Their results indicated that it is important to detect obstacles along a cyclist's path at the right time for safe cycling. Although this research shows the importance of visibility information and path condition on safe cycling, research towards cyclist's visual behavior is limited. Hence, to understand riding behavior, it is essential to investigate the elements on which cyclists' focus their attention.

While cycling, cyclists does not look towards the road all the time. They look around for signage, pedestrians, other cyclists and some cyclists will be using mobile phones. Hence, when studying cyclist's behavior, it is required to stimulate such behavior by having a secondary task, which urges cyclists to look away from the road. Previous studies investigated cyclist's behavior while they use mobile phone to make phone calls, listen to music and send messages. But these studies used questionnaires and observations for measuring participants response. An example is the study by de Waard, Schepers, Ormel, and Brookhuis, K. (2010). In their study, participants had to report after the cycling session, objects they saw on the track while cycling. However, since the reporting was done after the session, it is not clear whether unreported objects were missed or was not stored in memory. Hence, a real time analysis of visual behavior of cyclists performing a secondary task is required.

Developments in head mounted eye-tracking devices, allow for the recording of human gaze positions with high precision in both indoor and outdoor environments. Even though eye-tracking has been around for some time and has been used extensively to study behavior among car drivers and pedestrians, its application among cyclists is very rare. Vansteenkiste, Cardon, D'Hondt, Philippaerts, and Lenoir (2013), analysed whether the two-level model of steering adapted by car drivers (Donges, 1978) can be applied to cyclists. According to the two-level model of steering, two visual regions, a distant point in the travel path and the near road region, is used for steering. In this model, car drivers were found to use a gaze strategy by which they fixated on far end of the road and focused on near road region for lane keeping. Vansteenkiste et al. (2013) found that the two-level model of steering explains cyclist's steering behavior partially only. Another study tried to evaluate the variation in gaze allocation by cyclists depending on speed and quality of road (Vansteenkiste, Zeuwts, Cardon, D’Hondt, Philippaerts, & Lenoir,2014). They found that, in wider paths, participants drove faster, and their gaze was directed more towards the end of the lane and to the area around the path. Other studies evaluated cyclist attention allocation during junction negotiation (Frings, Parkin, & Ridley, 2014), and mental workload among elderly cyclists (Vlakveld et al., 2015).

Even though quite a few studies have been done to understand the visual behavior of cyclists using eye tracking, these studies lack realism as they were conducted in a controlled in-door test environment, used videos recorded in real world environment, or simulations thereof. To provide cyclists with a better infrastructure for safe riding, it is essential to understand visual behavior of cyclists in-situ, in addition to the visual behavior in controlled stationary condition. The study presented in this paper is an exploratory study to learn about visual behavior of cyclists in presence of a secondary task, and to learn about the usability of eye-tracker in-situ and at night. Using eye-tracker to explore visual behavior of cyclists during tasks involving obstacle detection can provide information on how cyclists change their viewing pattern once they recognise obstacle. Also, to prevent participants from looking for obstacle on road all the time during the experiment and to stimulate actual cycling behavior a second task is required. The main aim of this study is to gather more information about cyclists’ gaze behavior before and after obstacle detection during day and night. This study also aims to overcome limitations of previous studies by executing the test on a real bicycle path.

Method

Design

In this study, a mixed 2 (low velocity vs high velocity) by 2 (night vs day) experiment was conducted with velocity as within and time of day as between subject variable, and gaze behavior as dependent variable. Each participant cycled along the same track twice (either during the day or night): once at low speed at once at a high speed. In the high-speed condition, participants were asked to cycle as if they were in a rush, and in low speed condition, they used their own preferred speed. Each time, participants had to detect and cycle through two gates. Each gate was created by two obstacles. When people cycle in real life, they not only focus on the road but also look at the environment checking for signs, pedestrians and other cyclists. Hence, to stimulate the actual cycling behavior, it was required by cyclists not only to look on the road but also on the environment around them. For this, Landolt C-rings were placed on the side of the road. While cycling, participants read out aloud the orientation of the C-rings. The position of obstacles and the orientation of C-rings were changed for each trial. This was done to make sure there was no learning curve. Measurements were made using a head-mounted eye-tracker. The video obtained from the eye-tracker was analysed frame by frame to gather information about gaze behavior of cyclists.

Participants

The main goal of this study was to obtain empirical data on the gaze behavior of cyclists. Hence, participants with cycling experience and free of visual problems were chosen. A total of nine participants (8 male and 1 female; and of different demography) took part in this experiment. The participants were selected through personal contacts of the experimenters and was compensated with 15 euros for their participation. Overall, the experiment lasted for about 45 minutes. Of the nine participants, six participated in the experiment during night and three during day time.

Setting and Apparatus

Bicycle

All participants were asked to bring their own bicycle to avoid any effect on participant's cycling or gaze behavior as a result of cycling on an unfamiliar bicycle. Since the testing track was quite far away from the city, some participants asked experimenters to provide bicycles. In total, two participants did not bring their own bicycles. They were provided with a traditional Dutch bike, and were asked to cycle track several times to get acquainted with the bike. All bikes were checked for any aberration, and were fitted with standard cycle lamps during the night condition. These lights allow for detection of the cyclist by other road users, but were not expected to increase the detection of obstacles on the path.

Test Location and Cycle Path

The test took place on High Tech Campus Eindhoven. The test track (see Figure 1) was 160 meters long with 11 lamp posts aligned on one side of the path. Participants biked along a line on the track, and moved away from the line only when they had to manoeuvre the obstacles and return to the line once they crossed the gates.

Figure 1: The 160m long test track at HTC Eindhoven. The red lines represent the border of the cycle path and the green line shows the line cyclists have to keep during the experiment.

On and alongside the path two types of objects were placed: Gates created by two obstacles (see below) and Landolt C-rings. The two gates were kept at a minimum distance of 16 m from each other for every trial such that cyclists had 2.6 seconds to see the obstacle in time. This distance was chosen based on a previous study done by Knippenberg, Paulussen, and Rutten (2017). To reduce the predictability of position of the gates, the gates were kept at different distances from the border of the track. Apart from the gates, six C-rings were placed on the left side of the path on the ground. The C-rings were there to ensure that participants not only focused on the road surface but also looked at the surrounding.

Obstacles

The obstacles were made from foam with size 5x10x2.5 cm (length, width, height) and were painted grey to have a reflection value of 20 percent. Obstacle height was chosen to be of 2.5 cm based on the results from previous study by Knippenberg et al. (2017). Their study found that 2.5 cm is the best height which allowed cyclists to cycle over the obstacle without falling.

The primary task of the participants was to bike through the gates formed by these obstacles. These gates were made by placing two obstacles laterally at 40 cm from each other. The lateral distance of 40 cm was based on steering motion study by Van den Ouden (2011). The study concluded that to keep a steady lane at the velocity of 5m/s, lateral space of 40 cm is required.

Measurements

To evaluate gaze behavior, a Pupil-eye tracker device (https://pupil-labs.com/) was used. This device has two cameras, one recording the world view and the other recording participant's right eye. The world view was recorded with a resolution of 1920x1080 and at a framerate of 30 frames/second. The camera that recorded the eye also has a framerate of 30 frames/second. To record a clear world view at night, an infrared light was also used. To control for the area covered by the infrared light, a diffusor was also attached to the infrared light. Besides the eye-tracker measurement, a count of missed C-rings and obstacle gates was also made for each session.

Procedure

As soon as the participant's arrived, they were briefed about the experiment. They were informed about the purpose of the experiment and that they would be asked to do two tasks while cycling: The first was to bike through the gates created by obstacles, and the second one was to say out loud the orientation of the C-rings. After briefing, participants read and signed the informed consent form.

They were informed that they had to cycle two sessions, each session with different speed. In the one session participants were told that they had to cycle as fast as they could as if they had a train to catch. In the other session, they were asked to cycle at their normal speed. Next, participants were fitted with the eye tracker, a helmet carrying an infrared light, and a backpack with power supply and a laptop. The eye-tracker was then calibrated using manual calibration method. In this calibration procedure, one experimenter held a marker target (concentric circles) approximately 3 meters ahead, and then asked the participants to look at the target by only moving their eyes while keeping their head fixed. The experimenter moved the marker target to different points in the participants' visual field. Seven key points were under consideration, the upper left, the upper right, the upper middle, the bottom left, the bottom right, the bottom middle and the middle point of the visual field. After this, the experimenter took one step away from the participant, and then repeated the procedure.

During the experiment, one experimenter ran behind the participant to count the number of missed obstacle gates while the other experimenter kept track of the number of incorrectly identified C-ring orientations. After each session, participants looked away from the track while the experimenter changed the position of the obstacles and the orientation of the C-rings. At the end of the experiment, questions from the participants were answered.

Data Analysis

The data from eye tracker shows on what areas of the track participants gazed during each trial. The gaze behavior was indicated by coloured dots on the world view recording. The video was coded frame by frame and gaze location was assigned to one of the following area of interest (AOI): on-road and off-road. The area between the red lines in Figure 1 was coded as on-road and outside these lines were assigned as off-road. Percentages of gaze to each area of interest before and after obstacle detection was calculated in Excel. Each session of cycling was divided into four different phases, before object 1, after object 1, before object 2 and after object 2. The four different phases were determined based on detection of the obstacle and crossing over the obstacle : *before object 1* referred to the session from start point to the first detection of obstacle 1, *after object 1* referred to the session after the first detection and before crossing obstacle 1, *before object 2* referred to the session after crossing obstacle 1 while before the first detection of obstacle 2, and *after object 2* referred to the session from the first detection of obstacle 2 to the end point. Frames from start of the experiment until the frame when participants fixate on the obstacle was considered for the before obstacle detection. And, frames from fixation on obstacle till they cross the obstacle was considered for calculating after obstacle detection. The analysis was divided between the experiment leaders and based on the coding scheme the number of frames for each area of interest was calculated manually.

Results

Missed Obstacles and C-rings

A count of missed obstacles and C-rings was kept during the experiment. In total there were 36 obstacles and 108 C-rings to be detected by the nine participants. Of the 108 C-rings, none of the C-rings were missed, resulting in a 100-percentage detection rate.

Overall detection rate of the 36 obstacles gates was 88.9% (32 out of 36), with 100 percent accurate detection for low speed condition and 77.8 percent for high speed condition (14 out of 18). Two participants missed both the obstacle gates at high speed condition.

Gaze Location

In total there were data from 12 trials at night, two per participant (at different speeds), only one session data was good to analyse. The rest of the data was not considered for further analyses because the eye-tracker failed to measure gaze direction. On the other hand, all the data from day time condition (six trials) was quite satisfactory. Due to lack of satisfactory data, statistical analysis was discarded.

Looking at the night-time data for the low speed condition (see Figure 2), the participant seems to look more towards the road after he / she detected the obstacle. The on-road percentage increased from 59.5% to 72.7% after the first gate was detected and to 100% from 65% after the second gate had been detected.

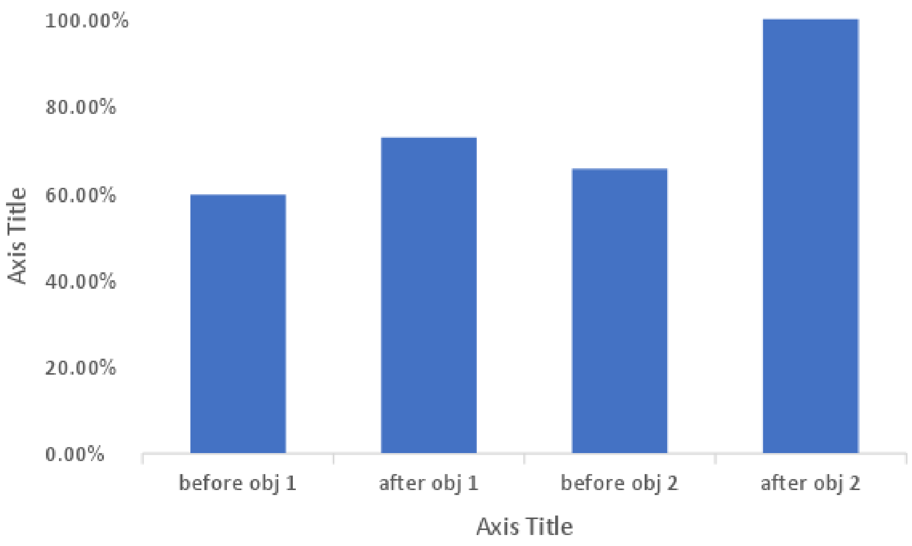
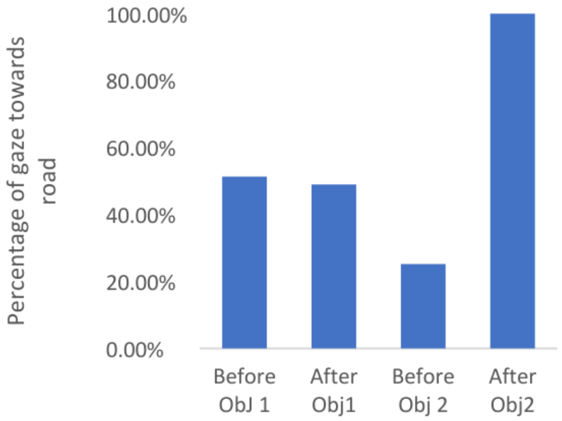


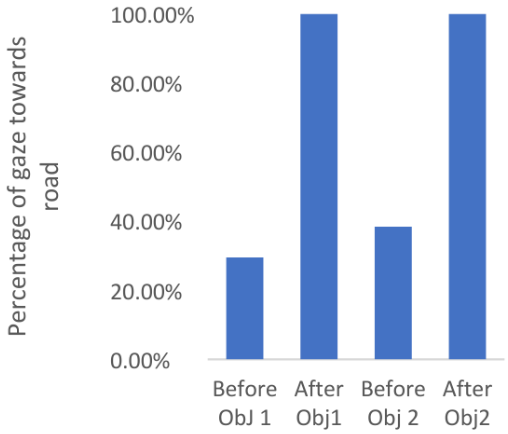
Figure 2: This graph represents percentage of gaze directed towards road before and after obstacle detection during night in low speed condition for participant 2.

The gaze behavior data collected from participants in the day time condition are presented in Figures 3 to 5. Participant 5 in the low speed condition (see Figure 3a) looked less on the road as the trial progressed, with on-road gaze percentage from 51% (before object 1) to 25% (before object 2), and looking 100 % on road after object 2. On the other hand, participant 6 in low speed condition (see Figure 4a), can be seen to gaze progressively on the road with on-road gaze percentage rising to 100% (after object 2) from 27% (before object 1). The on-road gaze percentage for participant 7 in the low speed condition decreased from 76% (before object 1) to 52% (before object 2). In low speed condition participant 7 had a more consistent gaze behavior with less variance in on-road gaze percentage before and after obstacle detection compared to participant 5 and 6.

In high speed condition after object 1 and after object 2, both participant 5 (Figure 3b) and participant 6 (Figure 4b), focused their gaze completely on road. Participant 7 (Figure 5b) did not show any such gaze pattern except for the last obstacle when there was no C-rings on the road. Contrary to gaze behavior of participant 5 and participant 6, participant 7 showed less variance in on-road gaze percentage within high speed condition.

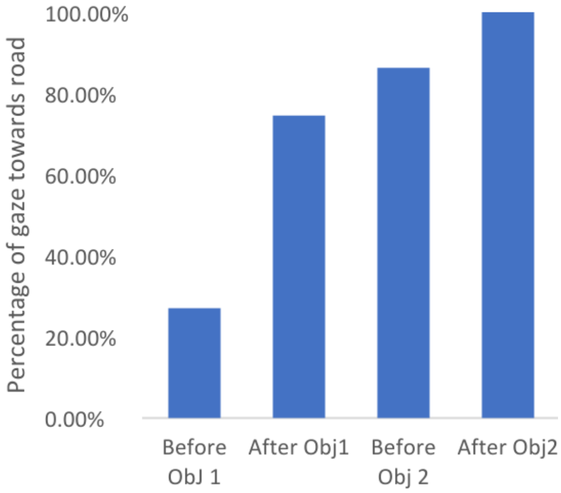


(a)

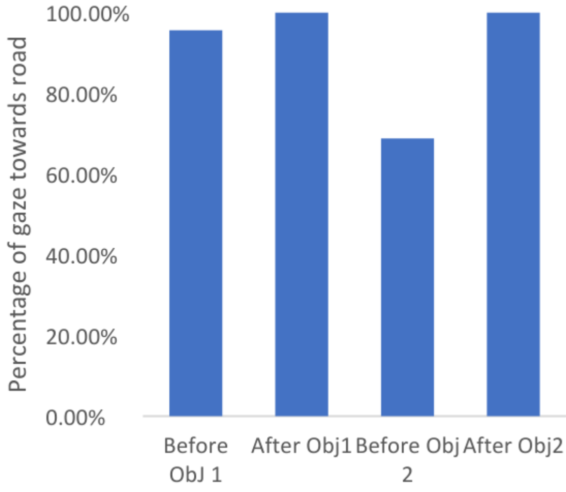


(b)

Figure 3: These graphs represents percentage of gaze directed towards road before and after obstacle detection during day in (a) low speed condition and (b) high-speed condition for participant 5.

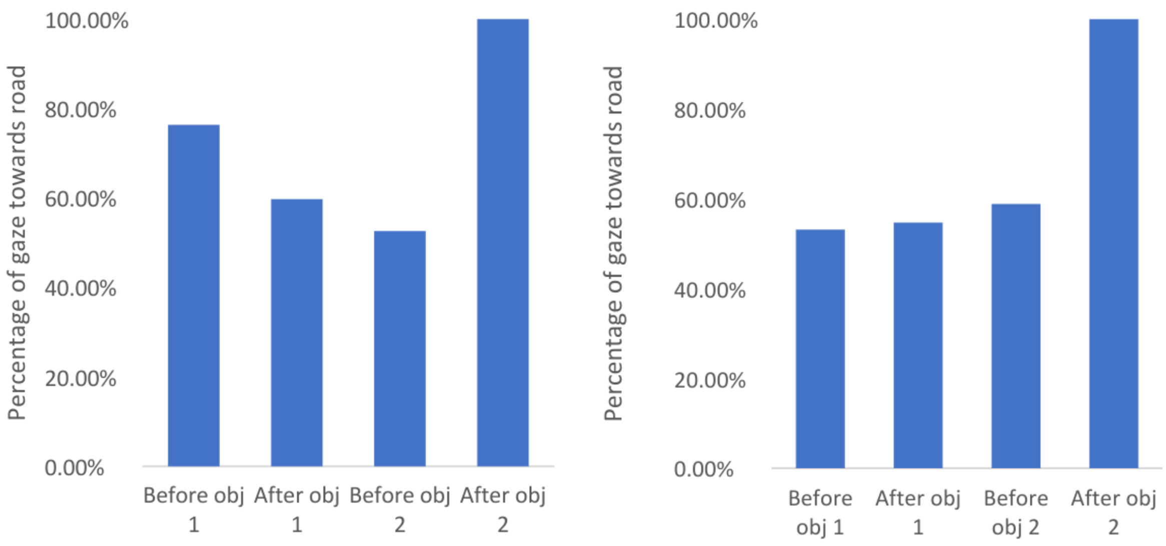


(a)



(b)

Figure 4: These graphs represents percentage of gaze directed towards road before and after obstacle detection during day in (a) low speed condition and (b) high-speed condition for participant 6.



(a) (b)

Figure 5: These graphs represents percentage of gaze directed towards road before and after obstacle detection during day in (a) low speed condition and (b) high-speed condition for participant 7.

Comparing gaze behavior of Participant 5 with Participant 6

In figure 3 and figure 4 (in result section), the percentage of on-road gazes during a trial is given for four different phases as described in method chapter: before object 1, after object 1, before object 2, after object 2. Looking at the results of participants 5 and 6, different gaze behavior is observed, especially during the "before obstacle 2" phase. Participant 5 gazed less towards the path (less than 40%) no matter the speed condition. In contrast, participant 6 gazed more towards the path, with more than 68% in the high speed and 86% in the low speed condition. This may indicate that different participants use different strategies for the same task. This can be seen in Figures 6 and 7. Figure 6 and Figure 7 shows the change of gaze point over time for Participant 5 and Participant 6 during "before obstacle 2" phase respectively, with x-axis refers to frame in time and y-axis gaze direction (0 for on-road and 1 for off-road). Participant 5 appeared to employ a biking strategy of spending more time looking away from the road and scanning the road surface quickly to look for obstacles. Once the participant saw an obstacle the gaze became more towards the road and less towards the surrounding. As soon as the participant crossed the first obstacle, the participant gaze behavior reversed and gazed more towards the surrounding and less towards the road. Participant 6 also started biking with less attention towards roads but once the first obstacle was seen, the participant gazed more towards the road and only made some quick glances towards the surrounding until the end of the session. Figure 8 and figure 9 makes this gaze behavior clearer.

The different strategy used by the participants can be because of the variance in participants speed of biking. It was observed that Participant 6 biked with much higher speed than participant 5 in both conditions. In fact. the speed of participant 5 in the high-speed condition appeared (from viewing the video) more or less comparable to the speed of Participant 6 in the low speed condition. This may be because participant 5 used a bike provided by us and may have been less confident while cycling. Because of the higher speed of participant 6, and the subsequent shaking of the eye-tracker, a lower number of gaze points were measured than for participant 5.

Since reasonably better quality data was collected from day time measurement compared to night time, Wilcoxon rank-sum test was done to see whether any difference is there in gaze behavior before and after obstacle detection. Results of the test did not provide a significant difference between the gaze behavior before and after obstacle detection with p-value of 0.1338.

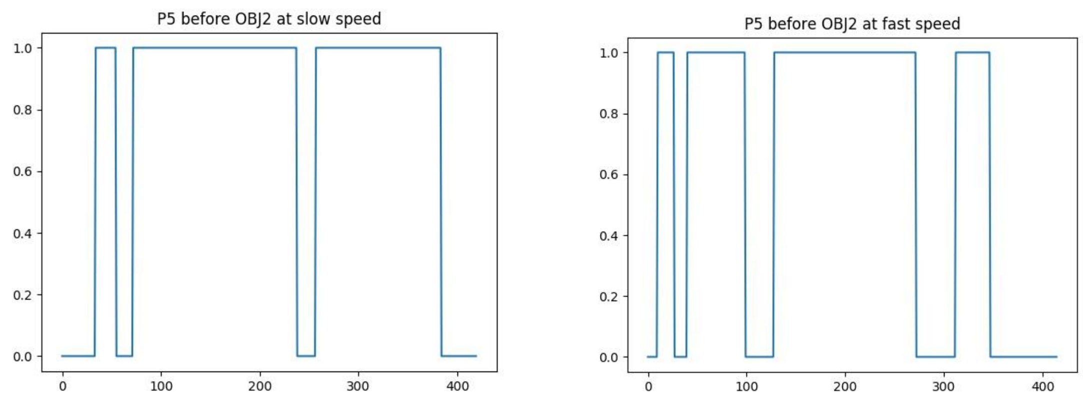


Figure 6: P5’s gaze area (towards/away from path) changes in time in “before object 2” phase at low speed; P5’s gaze area changes in time in “before object 2” phase at fast speed

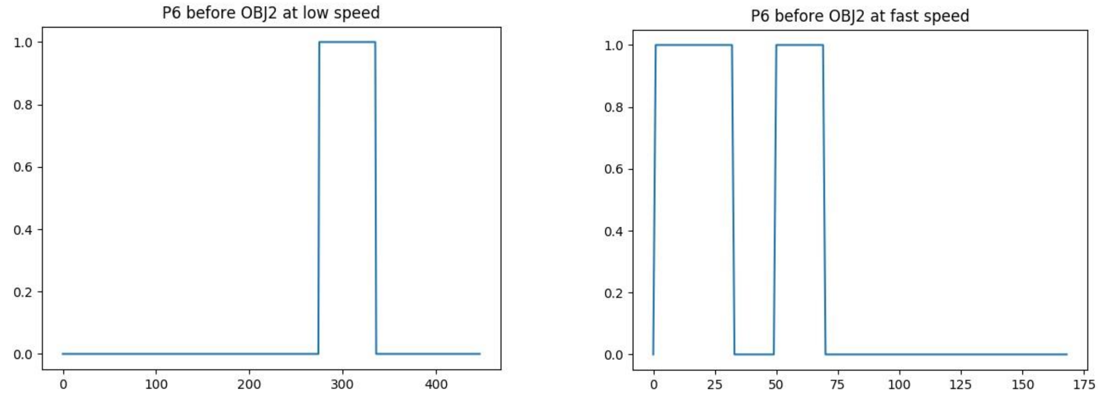
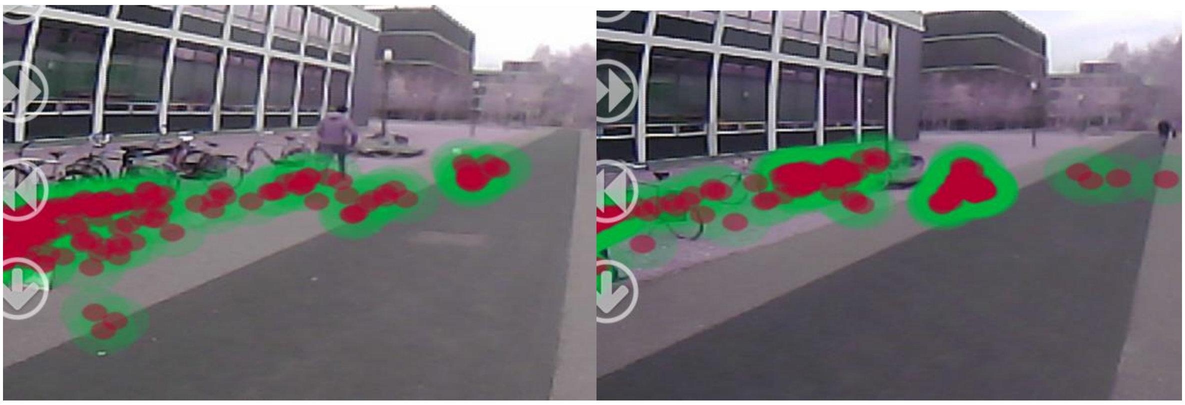


Figure 7: P6's gaze area (towards/away from path) changes in time in "before object 2" phase at low speed; P6's gaze area changes in time in "before object 2" phase at fast speed



(a) (b)

Figure 8: Scan path in the worldview of P5 at (a) low speed and (b) high speed

(a) (b)

Figure 9: Scan path in the worldview of P6 at (a) low speed and (b) high speed. The red points represent the fixation points, and the green circle represents the gaze circle. The different density of the fixation points on the road and peripheral area provides the how participants were allocating their attention to tasks. The figures of worldview were exactly fitted with the analysis of gaze behavior change in time.

Discussions

The main aim of the presented study was to gather more information about cyclist gaze behavior before and after obstacle detection during day and night. We found that there is no significant difference between gaze behavior before and after obstacle detected during day time. Since the data collected from night time was not good, statistical analysis was not done for the data. This chapter further discusses the reflection, limitation and suggestion for future research.

The importance of C-ring

The C-ring task, as a peripheral task, was considered to imitate the natural setting of people cycling on the street where they do not only focus on the surface of the road but also on the surrounding. The results of the experiment showed that when C-rings were not present on the track, participants irrespective of their speed gazed only at the road. Therefore, C-rings are very important to urge participants to imitate natural behavior of participants. Another observation was that even though participants missed the obstacle gates, none of the participants missed the C-rings. This might mean that either the task was too easy, or the focus was on getting C-rings correct. An improvement can be done by reducing the C-ring size especially since during day time when the orientation is quite understandable from far.

Reflection on eye-tracker

Effective calibration is important for accurate measurement of gaze direction. During calibration participants were only allowed to move their eyes, without moving their body. Calibration usually took around 5-10 minutes, and in our experiment, participant biked immediately. From the feedback and the worldview videos from the eye-tracker, it was found that only few participants moved their heads to gaze at the C-ring. Because of this some participant felt “tense” after the experiment as they kept their head still. It is not clear whether this is a natural behavior or was it because of the calibration process. Further studies can ask participants to look around after calibration and then cycle a trial track to get acquainted with the setup.

Limitations

There were several limitations to the present study. First, pupil-labs eye-tracker was not robust in data collection, especially in the night condition. The data collected during night was not good for analysis. Only few pupil movements were detected at night compared to daytime. This is quite a contrast to the performance of the eye-tracker under daylight conditions. Also, the world-view provided by the eye-tracker at night was quite difficult to see, even though an infrared lamp was used to illuminate the road. The videos recorded at night were often too dark, making it difficult to distinguish the exact point where participant was looking at. A much stronger infrared light than the one used for this experiment is required. As a result, we could not determine accurately the gaze behavior of participants. Second, the smoothness of road surface plays an important role in the performance of eye-tracker. In high-speed condition, due to the shake of eye-tracker, some fixation points were lost. In the night conditions, this negative effect of shaking was more pronounced than daytime condition, and in the worst case, there were no fixation points recorded.

Conclusion

The study tried to understand the gaze behavior of cyclists in the presence of obstacles under different speed during day and night time. Although earlier research has been done to study the gaze behavior, our procedure was designed to mimic more closely to actual cycling behavior. This study in order to mimic the actual cyclist behavior was conducted in a real bike path. The results indicate that different participants had rather different gaze behavior, perhaps indicating that different cyclists use different strategies for executing the experimental tasks. Due to the exploratory nature of the study and the limited amount of data, no solid conclusion can be drawn from this study. Nevertheless, we believe that the lessons learned from our experiment will be valuable for future research on understanding cyclists’ visual behavior under different light condition at night time or by manipulating the size of obstacle, position and reflection.

Reference

de Waard, D., Schepers, P., Ormel, W., & Brookhuis, K. (2010). Mobile phone use while cycling: Incidence and effects on behavior and safety. *Ergonomics*, *53*(1), 30-42.

Donges, E. (1978). A two-level model of driver steering behavior. *Human Factors*, *20*(6), 691-707.

Fietsberaad (2011). Grip op enkelvoudige fietsongevalle: Samen werken aan een veilige fietsomgeving. Retrieved from http://www.fietsberaad.nl/library/repository/bestanden/Fietberaadpublicatie%2019a_printversie.pdf

Frings, D., Parkin, J., & Ridley, A. M. (2014). The effects of cycle lanes, vehicle to kerb distance and vehicle type on cyclists' attention allocation during junction negotiation. Accident Analysis & Prevention, 72, 411-421.

Juhra, C., Wieskötter, B., Chu, K., Trost, L., Weiss, U., Messerschmidt, M., . . . Raschke, M. (2012). Bicycle accidents – Do we only see the tip of the iceberg? *Injury*, 43(12), 2026-2034

Nyberg, P., Björnstig, U., & Bygren, L. O. (1996). Road characteristics and bicycle accidents. *Scandinavian journal of social medicine*, *24*(4), 293-301.

Schepers, P., & den Brinker, B. (2011). What do cyclists need to see to avoid single-bicycle crashes? *Ergonomics*, *54*(4), 315-327.

Vansteenkiste, P., Cardon, G., D'Hondt, E., Philippaerts, R., & Lenoir, M. (2013). The visual control of bicycle steering: The effects of speed and path width. *Accident Analysis & Prevention*, *51*, 222-227.

Vansteenkiste, P., Zeuwts, L., Cardon, G., Philippaerts, R., & Lenoir, M. (2014). The implications of low quality bicycle paths on gaze behavior of cyclists: A field test. Transportation research part F: traffic psychology and behavior, 23, 81-87.

Van den Ouden, J. H. (2011). Inventory of bicycle motion for the design of a bicycle simulator. *MSc Thesis. TU Delft, (2011)*

van Knippenberg, R. M. D., Paulussen, K., & Rutten, J. M. T. (2017). Cylist's initial gazing towards obstacles on the road. Unpublished Student Report. Eindhoven, the Netherlands: Eindhoven University of Technology.

Vlakveld, W. P., Twisk, D., Christoph, M., Boele, M., Sikkema, R., Remy, R., & Schwab, A. L. (2015). Speed choice and mental workload of elderly cyclists on e-bikes in simple and complex traffic situations: A field experiment. Accident Analysis & Prevention, 74, 97-106.