

Interaction between car drivers and vulnerable road users at roundabouts

Abstract

Roundabouts represent one of the most used road intersection. The reduction of conflict points between traffic flows, associated with the moderation of the driving speed, in fact, makes them preferable to signalized intersections. However, great attention should be paid to bicycle and pedestrian paths present in the roundabout, because incidental statistics show that not always secure accessibility of these vulnerable users is ensured. According to this, the design approach of roundabouts must consider not only the transportation aspects, but also the drivers' behavior. Their mechanisms of understanding, recognition and decision, in fact, heavily influence the mutual interaction with pedestrians and cyclists. Furthermore, considering that users widely scan with eyes the surrounding environment during the driving task, searching for the relevant information on their spatial and temporal position, is crucial to consider which elements of the road environment are seen and considered by drivers, in order to design roundabouts that are safe for all categories of users. This paper reports the results of an experimental test, which involved a sample of drivers who have traveled by car along a road section including two roundabouts. By an innovative eye tracking equipment, able to track the eye movements (saccades), the sight point of the drivers' eye and their visual behavior in entering, circulating and exiting from the roundabouts have been analyzed. The interaction with non-motorized users was focused, obtaining useful information for the design of cycling and walking paths in these intersections.

Keywords: roundabout, pedestrian, bicycle, road safety, eye tracking equipment

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Introduction

Many research studies show that roundabouts allow a general improvement of road safety compared to the signalized intersections because.¹⁻⁴

- i. Have fewer conflict points, since they eliminate the maneuver of left turn. The circulatory vehicle movements at roundabouts eliminate or drastically reduce the critical conflicts resulting from red light running, left-turns against opposing traffic, right-angle conflicts at corners, and rear-end collisions. As a result, roundabouts significantly reduce vehicular crashes;
- ii. Control and reduce the vehicles speed. Lower speed is associated with better yielding rates, reduced vehicle stopping distance, and lower risk of collision injury or fatality;
- iii. Decrease the severity of accidents, since in roundabouts most of circulating vehicles travel at similar and reduced speed.

Also considering the pedestrians, the mentioned trend is confirmed. At roundabouts, in fact, pedestrians cross a shorter distance of only one direction of traffic at a time, since the entering and exiting flows are separated. In this way, the pedestrians have a reduced number of points to be checked before crossing and, in addition, often their safety is further amplified by the presence of splitter and divisional islands.⁵ Concerning the relationship between cyclists and roundabout, worldwide there are different opinions.^{6,7} In general, compact single lane roundabouts are safe for cyclists, because bicycles and vehicles speed are similar and all users follow similar trajectories between them. On the opposite, multi-lane roundabouts have a large ring diameter, higher speed differences and a remarkable variance in preferential trajectories.

The cycling path in roundabouts can be shared or exclusive. In the first case, the cycling flows share the carriage space with cars (Figure 1A). In the second, instead, the cycling lane can be located:

- I. Inside the ring, on its outer side, by different coloring of the relative pavement or with a white separation marking between motorized vehicle and bicycle flows (Figure 1B). Thus, cyclists have always the right of way with respect to vehicles entering or leaving the roundabout. This can lead to conflict between the cyclists, traveling along the ring, and the vehicles in exit from it, since very often the first ones are not visible in the side mirrors of the seconds.
- II. Outside the ring, on a bike path separated from vehicular lanes, with right of way for cyclists (Figure 1C). The cycling path, which cyclists can travel entirely without stopping, must have the same geometric profile of the central island, in order to facilitate the crossing maneuver inside it. Is preferable, moreover, that it has only one lane, with the same flow direction of the central island, in order to minimize the number of conflict points.
- III. Outside the ring, on a bike path separated from vehicular lanes and with no right of way for cyclists (Figure 1D). A cycling path perpendicular to vehicular lanes entering and leaving the intersection is preferable. It should be maintained a distance of approximately 5m between the different cycling crossings and the roundabout ring, in order to avoid the stop of the cycling flow caused by vehicles waiting to enter the roundabout. This solution allows the possibility of a double directionality of the cycling ring.

In order to design round about that are safe for all categories of

users is very important to analyze the interaction between car drivers, pedestrian and cyclists in entering, circulating and exiting from the intersection. To obtain significant results is necessary to consider not only the transportation aspects, but also the drivers' behavior. Their mechanisms of understanding, recognition and decision, in fact, heavily influence the mutual interaction with pedestrians and cyclists. Furthermore, considering that drivers widely scan with eyes the surrounding environment during the driving task, searching for the relevant information on their spatial and temporal position, is crucial to consider which elements of the road environment are seen and considered by drivers. Understanding vision helps to explain safe or unsafe behavior on roads.⁸⁻¹⁰ In this research study, the analysis of the interaction between car drivers and vulnerable road users (pedestrian and cyclists) at roundabouts has been assessed by an experimental study, which involved a sample of drivers. They drive on a specific route that comprises two roundabouts. The analysis has been conducted by not only the investigation of speed parameters but also by recording of the eye movements of the driver's through an innovative eye tracking equipment.



Figure 1 Roundabout cycling crossings.

The mobile eye tracker is a methodology that has been used extensively in driving research.¹¹⁻¹⁵ The main applications of mobile eye tracking in driving behavior have been steering, braking, multitasking, city driving, learning to drive and race driving.

Methods

In order to analyze the interaction between car drivers and vulnerable road users (pedestrian and cyclists) at roundabouts, an experimental study has been conducted in a selected road track belonging to the municipality of Castenaso (Bologna). Nineteen drivers, 14 men and 5 women (mean age 27, 8 ± 9.2), took part in this study. All participants were Psychology or Engineering undergraduate students and researchers, with a class B driving license (for cars) and driving experience of at least 5 years. All had normal vision and none of them wore glasses, to avoid artifacts to the eye movement recording system. They were not informed about the study's true aims, but were told that its aim was to test a mobile eye device during driving. Nobody was paid. Each one has been driving on a single carriageway secondary road, the SP 253 "San Vitale", provided with one lane in each direction. The total length of the trial was 8.5km, with a speed limit of 60km/h. For the first three kilometers they traveled across a high-density residential and commercial area (urban area), elsewhere they traveled through less densely inhabited areas. The

route included two roundabouts. The first large roundabout is located at the beginning of the trial, has a central island with a diameter of 60m and five entries and exits. All entries and exits as well as the circulating carriageway have two single lanes, except one that has only one single lane. The central island is circular and elevated by curbs. Grass and trees cover it. The pedestrian and bicycle tracks are outside the circular ring, separated from vehicular lanes, with right of way for their users. So pedestrians and cyclists can travel entirely the roundabout, without stopping (Figure 2). The drivers started and ended at the same roundabout. Half-way along the route, they reached a second roundabout and then returned along the opposite way to the starting point.



Figure 2 First roundabout of the experimental site.

The second roundabout as a central island with a diameter of 60m and four entries and exits with only one single lane. The circulating carriageway, instead, have two single lanes. The central island is circular, elevated by curbs and covered by grass and trees (Figure 3). In order to avoid participants feeling disoriented, the route was planned in very simple orientation terms. Starting from the first roundabout, the driver proceeded ahead to the next one, and then was given instructions to return along the same road back to the starting point. The average time in which the distance was covered was about 10min.



Figure 3 Second roundabout of the experimental site.

Data collection was carried out from 10.00 to 12.00 and from 14.00 to 16.00, in order to avoid peak rush hours. Three sessions took place on three different days. It was sunny during both sessions. All participants drove a BMW 1 Series car. The car has been equipped with a VBOX PRO data logger, for recording of acceleration, speed and GPS coordinates of the vehicle (Figure 4). Two cameras and a GPS antenna were positioned on the top of the car and connected with cables to the VBOX. Each driver was given a trial run to get used to the car, before starting along the test route. Each participant has been equipped with the ASL Mobile Eye-XG eye tracker. It is a mobile eye tracker, an eyeglass with two digital high-resolution cameras (Figure 5). One camera recorded the scene image and the other the participant's eye. Eye tracking was performed on the right eye. Data recording was at a speed of 30Hz and an accuracy of $0.5-1^\circ$.^{11,12} ASL software was used to create a video for each participant, in which eye-fixations were showed by a cross, at the intersection between a vertical and a horizontal red line (Figure 6). These lines were superimposed to the video of the driver's scene, allowing researchers to detect each

saccadic movements and what specific point of the scene was being seen by the participant. A calibration procedure was carried out for each driver, in order to get a good accuracy of the eye-movement recorder. The process took place in a parking area, with the car being stationary, and involved asking participants to look at least 15 visual points spread across the whole scene. Calibration points were chosen between vertexes and centers of small objects present at the scene.



Figure 4 Video V-Box Pro.

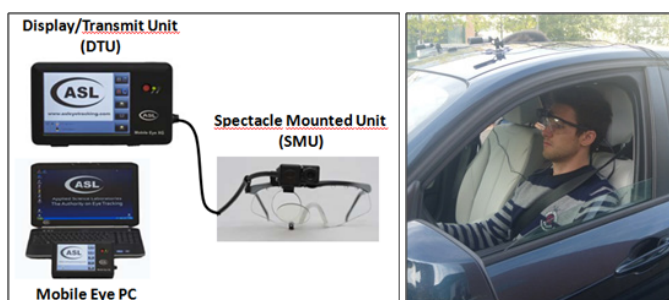


Figure 5 ASL Mobile Eye-XG eye tracker.



Figure 6 Zebra-crossing seen (on the left) and not seen (on the right) by the driver.

The eye tracking equipment along with a computer and the VBOX PRO equipment were kept on the back seat and were monitored by one of the experimenters, who was instructed not to talk to the driver except for giving instructions as to direction and if there was a request for assistance.

Results

The interaction between car drivers and vulnerable road users (pedestrian and cyclists) has been evaluated in entering, circulating and exiting from the roundabout analyzing different factors.

- The vehicle velocity.
- How much each road sign was looked at for the entire sample of participants.
- The gaze movements for each participant.

From the results obtained by VBOX PRO equipment the velocity of the vehicle has been evaluated for each participant, in order to estimate the influence on the drivers behavior of pedestrian and bicycle

crossing located near the entries and the exits of the roundabout. In this position, in fact, the driver must see the crossing area and must adequate his driving behavior if there are vulnerable road users in waiting or cross walking. For each participant the same behavior has been observed (Figure 7).

- Coming near the roundabout, the driver decrease his velocity, stopping the vehicle when he arrives at the circular carriageway. In this position, in fact, the circulating traffic has priority over the entering traffic. Approaching the intersection, the drivers check with attention the zebra-crossing area and overpass it at low velocity. So, they perceive the crossing as an important road element at which give great attention, offering the priority to pedestrians or cyclists over passing the entries and exits;
- Exiting from the roundabout, the participants maintain an opposite driver behavior. They accelerate and do not verify the presence of pedestrians or cyclists at the zebra-crossing. They do not check the crossing area, continuing to accelerate with great safety risk.

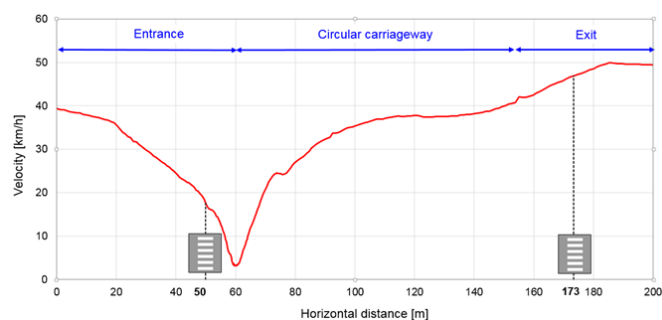


Figure 7 Driver velocity in entering, circulating and exiting from the roundabout.

Starting from these obtained results, the influence of the horizontal and vertical road signs on the interaction between drivers and vulnerable road users has been evaluated. For the roundabout object of study the horizontal signs are the zebra-crossing and the triangle warn, depicted in white on the road pavement of the entries. The obtained results show that in approach to the intersection all the drivers look the zebra-crossing and only the 68% look the give-way signal. The vertical signs, instead, are a combined signal with give way and roundabout panels; keep right, entrance/end of cycling and pedestrian path, roadway directions. Half of the users observe most they give way sign, followed in descending order by roadway directions (41%) and keep right (27%). On the opposite, less seen signs are cycling and pedestrian path: only the 23% of users visualized that one located at the entrance of roundabout and only the 9% visualized that one in exit. It is confirmed, therefore, that car drivers show a higher level of attention to vulnerable users while approaching than exiting from a roundabout. These data are even more significant considering that participants wore eye-tracking glasses, drove an unfamiliar car and knew that their driving behavior was being studied. One can assume that their driving style was more careful and thorough than under real-life conditions, when the quantity of their looking behavior to signs can be expected to be reduced further. Results obtained by Mobile Eye-XG has been also analyzed in terms of drivers' eye movements in entering, circulating and exiting from the roundabout. For each driver in approach to the intersection, the location point at which the pedestrian crossing is observed for the first time has been registered. The Recognition Distance (DR), which is the curvilinear distance

between this last point and the zebra-crossing, has been calculated. Table 1 shows that drivers visualize the crossing at an average DR of 40.5m. Covering DR, the drivers decelerate of almost 14km/h. In the covering of the distance DR, the driver visualization frames have been divided according to four classes of observations: pedestrian-cyclist crossing (Figure 8A), vertical road signs (Figure 8B), the presence of vehicles in the left quarter-crown of the circular carriageway (Figure 8C) and all other not related to driving task objects inside the vehicle and environmental distractions Figure 8D.

Table 1 Speed at which the pedestrian crossing is observed for the first time (VA) and in correspondence of the zebra-crossing (VB)

| | DR [m] | VA [km/h] | VB [km/h] | Δ [km/h] |
|--------------------|--------|-----------|-----------|-----------------|
| Average | 40.5 | 37.18 | 23.95 | 13.23 |
| Standard deviation | 12.16 | 3.48 | 3.17 | - |

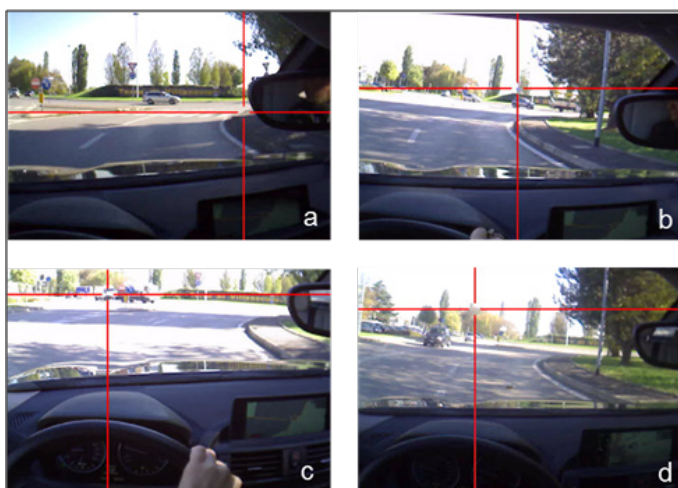


Figure 8 Analyzed frames for recognition.

The obtained results show that the four classes are observed respectively for 68.70%, 3.59%, 20.95% and 6.76% of the total time of the approach. The percentage of time spent watching the pedestrian crossing should be considered as percentage in which it results visible within the users' visual field. For many participants, in addition, the visual search of vehicles passing along the left side of the crown begins before that the perception of the zebra-crossing. Regards to the traffic flows on the circular carriageway and exiting the roundabout, when traffic volumes are low, users' task is primary focused on the maintenance of the trajectory, without searching other additional information, and eye movements all direct forward. In these conditions, driver look at the previous vehicle for maintaining the safety distance, and occasionally divert the sight to visualize road signs or pedestrian-bicycle paths.

This behavior is protracted also during the exiting maneuver and it is maintained until the previous vehicle oversteps the pedestrian and cycling crossings. In that moment, the visual attention moves to the crossing area in order to detect the presence of pedestrians and/or cyclists on the central island or on the access ramp to the sidewalk (Figure 9). When the absence of vulnerable users is confirmed, the sight point focuses back again to the previous vehicle. The eye saccades, however, does not implicate that users slow down the speed, as emerged from the analysis of kinematic parameters of the vehicle.

Considering the situation in which the level of traffic is higher, the frequency of observation and the research of information in the visual field increase. When traveling along the ring, users frequently modify the sight points in order to maintain a safe distance from the previous vehicles both inside and in the entrance of the roundabout.



Figure 9 Exiting roundabout sight point progress.

Table 2 shows that, during the exiting from the roundabout, drivers visualize the zebra-crossing at an average distance of 40m, similarly to the value of the entering maneuver. Nevertheless, the substantial difference is represented by the speed increase from about 35km/h to 42km/h, despite the percentage growth of time in which the crossing is within the driver visual field (80.24%). If compared to the entry in the roundabout, drivers increase the attention towards the vertical signs (+3.6%) and they decrease the consideration to the objects not related to the driving task (-8.87%), as reported in Table 3.

Table 2 Speed at which the pedestrian crossing is observed for the first time (VA) and in correspondence of the zebra-crossing (VB)

| | DR [m] | VA [km/h] | VB [km/h] | Δ [km/h] |
|--------------------|--------|-----------|-----------|-----------------|
| Average | 40 | 34.12 | 41.87 | 7.75 |
| Standard deviation | 5.18 | 3.9 | 4.25 | - |

Table 3 Average time for each visualization class

| | Pedestrian-cyclist crossing | Vertical road signs | Vehicles in the left quarter-crown | Other not related to driving task |
|---|-----------------------------|---------------------|------------------------------------|-----------------------------------|
| % | 80.24 | 7.19 | 0.49 | 12.08 |

Conclusion

The analysis of the interaction between car drivers and vulnerable road users (pedestrian and cyclists) in entering, circulating and exiting from the roundabout has been revealed interesting findings for the design of cycling and pedestrian tracks.

To summarize, it is possible to conclude that:

- The eye-tracker equipment has proved a useful and effective tool for tracking eye movements of drivers, which allows to evaluate what the user actually look at and how much, and consequently to investigate his driving style adaptation.
- Pedestrian and cycling crossings are confirmed as significant elements for the safety of a roundabout, which design should be treated with extreme caution in terms of geometry and positioning on the carriageway. Psychological interaction between driver and road infrastructure must be considered in addition to current standards conformity.
- Drivers of vehicles show a higher level of attention to vulnerable users when are in approach to the roundabout than in exit. In

the latter case, the presence of a pedestrian or a cyclist has a little influence on the deceleration of the vehicles.

- iv. The obtained results show that in the design of pedestrian and bicycle tracks is useful to provide the following guidelines.
- v. The crossing should be properly spaced with respect to the outer side of the circular carriageway and it must be stopped in advance from the gyratory crown. This arrangement allows pedestrians and cyclists to pass behind the incoming car waiting to enter in the roundabout;
- vi. In correspondence to one leg of the roundabout, the zebra-crossing on the exit lane should be more distant from the ring center than the one on the entry lane. These, moreover, should be separated by a central island, allowing vulnerable users to intercept a vehicular flow one by one. Separation islands geometrically restrict the width of the lane, causing a vehicles' speed decrease.
- vii. It is, at last, important to highlight that the safety of each road element is closely related to drivers that use it and to their driving style. Therefore, to achieve remarkable results in terms of accidents reduction, road safety education of drivers plays a very important key role.
- viii. A further step of the research is represented by a nighttime experimental field to verify results also in those lighting conditions.

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None.

Conflict of interest

The author declares no conflict of interest.

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