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Road Safety Review update by using innovative technologies to investigate driver behaviour

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Abstract

Urban arterial roads provide high-speed passage to facilitate traffic in urban areas. However, unlike freeways, they consist of ramps, roundabouts and unique characteristics due to the limited space in the urban (or semi-urban) environment. The existing studies use the Road Safety Review (RSR) to evaluate geometry, identifying high accident concentration sections and to classify the network based on expert judgment. Therefore the classical methodology does not consider the interaction between driver and infrastructure. The present study aims to investigate the road safety of an urban arterial motorway, integrating traditional checklist with innovative solutions applied in an experimental site test with participants. The driver visual behaviour has been recorded by head-mounted eye tracker that is used to find the gaze behaviour. The vehicle used for the test was equipped with the satellite positioning system (GPS), inertial measurement unit (IMU), vehicle CAN data reader (OBD2) and video recorder to monitor the driver behaviour and vehicle trajectory during the track. The results showed that the use of innovative techniques could improve the RSR, by identifying new hazardous points based on driver behavior.

Keywords: Driver Behaviour; Road Safety Review (RSR); Eye Tracker (ET); Vehicle Monitoring Systems; GPS; IMU

1. Introduction

Approximately 1.35 million people die each year as a result of road accidents around the world, which makes road

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traffic crashes the first cause of death for children and young adults (World Health Organization, 2018). In the European Union, only more than 1 million crashes were reported in 2016 and 1.4 million people left injured (Annual Accident Report, 2018; Wang et al., 2018). Many researchers have analysed road fatalities and serious injuries and their correlations with driver behaviour (Rothengatter, 1982; Vaa, 1997). These studies have considered legislation, enforcement and education as the main factors in avoiding road crashes and users are mainly blamed for the problem. Therefore, the solutions are aiming to improve road user behaviour.

Road infrastructure safety is strongly linked to collisions risk and accidents severity and the improvement of the road condition is critical for the safety of the road users (Batrakova, 2016). While design standards already exist in most of the countries, regular inspection has still to be made in order to ensure the safety of the existing road infrastructure. The road infrastructure management approach is the standard method to technically evaluate the design characteristics of the infrastructure project that covers all stages, from planning to intervention. However, these measures are only considering the auditor judgment and not the driver perspective. The Road Safety Review (RSR) is an independent, detailed, systematic safety check of the state of road infrastructure. It consists of identifying the high accident concentration sections in order to plan the necessary interventions for improving the safety level of the road. Considering the Italian legislation, the operational methodology of the RSR is composed of four steps: network analysis, inspection, classification and intervention. The network analysis consists of the state of the motorway, road type, traffic data and accident analysis. The inspection program includes planning stages and assigning the expert team for examining the geometrical and functional characteristics of the road. During this phase, several parts of the infrastructure will be investigated depending on the stage of the project. These parameters consist of geographical location, junctions, crossings path, number of lanes, meteorological conditions, driving speed, signaling, safety barrier condition, presence of obstacles, road environment vegetation, visibility, lighting and pavement condition (Directive 2008/96/EC, 2008).

According to the road infrastructure management directive, the road will be classified using indicators. Main types of indicators used for the ranking are accident rate. The classification of the road includes the priority list of corrective actions, economic evaluation (cost-benefit analysis) and programming for interventions. According to the type of problem and network priorities, the intervention will be selected from the list of standard actions. Therefore, the final report must contain all the identified problems, possible solutions and planning for the interventions.

However, the road safety assessment depends on the integrated and complex relationship between various components: the driver behaviour, the vehicle and the road infrastructure (Bucchi et al., 2012). Indeed, the scope of the problem can be achieved by analysing several issues, linked to each other: the status of the infrastructure, the behaviour of drivers and the vehicle characteristics (Wang et al., 2002). These aspects are studied in this paper with the use of innovative techniques that allows the monitoring of the driver and the vehicle, using cameras and sensors. The objective is to introduce a methodology for the driver-centred road safety assessment by investigating the driver behaviour, vehicle feedback and accident history.

In the paper, the experimental methodology will be discussed along with the test procedure, instrumentation, studied road segments and traffic condition. The data analysis chapter considers the experiment site and confronts the accident analysis on each road section with the driver visual behaviour and the participant’s effective speed variation. The results contain identified sections that are described by RSR and re-investigated with the use of innovative technologies and follows by discussion and conclusion.

2. Experimentation Methodology

2.1. Experimental site

The Faenza ring road is a branch of the SS9, which connects Rimini to San Donato Milanese. The studied part of this road is an urban arterial that collects traffic from Faenza urban areas. It is a single carriageway (Category D) with two lanes in each direction with a total length of 4.2 Km. Annual average daily traffic in the year 2018 is estimated at 12000 AADT for this section. The speed limit is set at 70 km/h during the track, unless where there is an entrance to the road section, where the speed limit is reduced to 50 km/h. Taking into account the "Guidelines for the management of infrastructure safety" regarding the purpose of assessing the safety of the infrastructure, the road was divided into 12 sections and 3 roundabouts with as it is shown in Figure 1.

Fig. 1. Division of tracks and location of the roundabouts in the Faenza urban arterial road

2.2. Task and procedure

The experimentation was carried out during the day between 8:30 and 13:00 in two separate days to avoid peak traffic hours. The drivers started the track from roundabout "R3" (Figure 1), then they reached roundabout "R1" and they were returned to the "R3". All the participants carried out the same circuit which was about 10 minutes. During the driving session, no accident occurred and all the drivers were able to perform the driving task.

2.3. Participants

Nine volunteer drivers were involved in the study, 3 males (M_{age}=28; SD=7.07) and 6 females (M_{age}=32.33; SD=6.42). The participants had a driving license with normal eye vision and none of them wore eyeglasses; to avoid artefacts in eye-tracking monitoring. During the experimentation, the participants were not informed on the study's objective but were told that the experiment aimed to test the mobile eye tracking (ET) device during the driving session. None of the participants was familiar with the road.

2.4. Apparatus and data collection

A Ford Fiesta with manual gear shifting was used for all the participants. Two sets of instruments were used during the experimentation: Mobile Eye XG was used for recording the visual behaviour of the drivers and Vbox HD2 to monitor the vehicle states and trajectory. The vehicle trajectory was registered by a roof mounted GPS antenna with 10 Hz frequency, while the front scene of the vehicle was recorded with two cameras fixed on the front windshield with 1080 HD resolution at 30 frames per second (Lantieri et al., 2015; Costa et al., 2014, 2018). The inertial measurement unit (IMU) was used to collect data on the acceleration of the vehicle. The IMU provided highly accurate measurements of pitch, roll and yaw rate, using three rate gyros with a dynamic range of ± 450 (°/s), as well as x, y, z acceleration with a range of ± 5(g). As soon as the vehicle passes through a tunnel or area suffering from GPS signal, the data from the vehicle CAN data (OBD2) was being used to reproduce the velocity profile. The Vehicle CAN reader (OBD2) captured data from the vehicle electronic control unit and was registering several parameters such as engine rpm, wheel sensor, cabin information, pedal position. The ET instrument used to monitor the driver visual behaviour during the experimentation was a head-mounted Mobile Eye XG from ASL (Applied Science Laboratory). The ET Spectacle Mounted Unit consisted of two cameras, the eye camera records the movement of the right eye pupil while the camera dedicated to the external scene (camera scene) records the surrounding environment as observed by the user (Costa et al., 2018). Data recording sampling rate used during the ET experimentation is 30 Hz that provides an angular accuracy of 0.5°–1°. ASL software is used later to create a video for each participant, in which eye-fixations were shown by the intersection between vertical and horizontal red lines. These lines were added to the video of the scene camera and present the gaze point of the participant. The visual fixation of the users was used to investigate the driver visual behaviour during the tracks, in proximity to the intersections and the speed camera (Vignali et al., 2018, 2019). Driver visual behaviour of the users were analyzed from the ASL Mobile Eye-XG video. Areas of interest (AOI) were defined to measure attention and distraction of the driver to the road environment and the scenario. The elements considered as attention were: pavement, vehicle, car mirrors, traffic divider, vertical and horizontal signals, intersections and road signals. The elements considered as distraction were: vehicle interior, environment (tree, sky, etc.) and speed camera. Visual behaviour of drivers was analyzed frame by frame in the scenario to verify the visualized elements by the user at each frame. In a real driving task, car movements and the complex optical flow of the dynamical visual scene could cause rapid fixations. In order to avoid the inclusion of saccadic eye movement, an element was considered fixated if at least the user was focusing on the elements for more than 2 consecutive frames (66 ms) (Costa et al., 2017, 2019; Di Flumeri et al., 2018).

3. Data analysis

The driving behaviour analysis is reported together with the historical accident data from the urban arterial road of Faenza. Municipal Police of Faenza provided the accident data for a time interval of ten years (from 2006 to May 2017). These number accidents were localised using the reports to identify road sections with high accident concentration according to annex III Directive 2008/96/EC and confronted with the driver visual behaviour and speed variations during the experiment with participants on each track (Figures 2, 3 and 4).

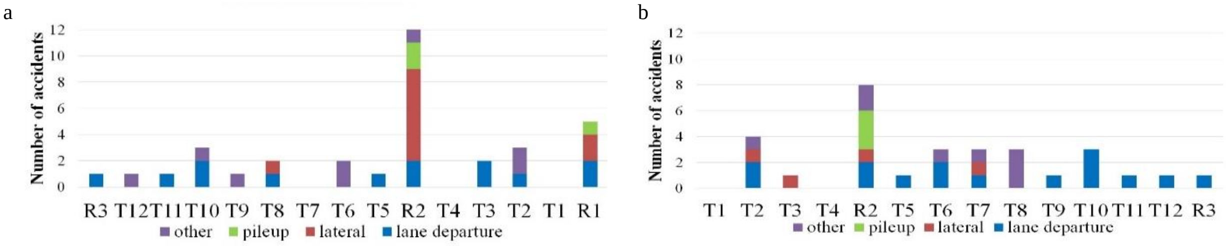

Fig. 2. (a). Accidents frequency and type toward Imola (2009-2017) ; (b) Accidents frequency and type toward Forli (2009-2017)

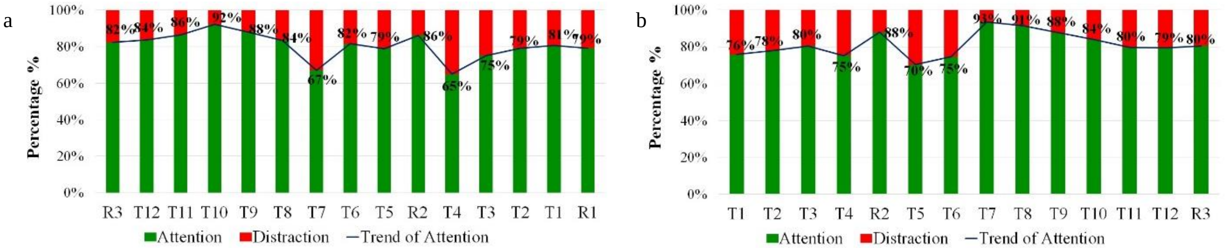

Fig. 3. (a) Driver's visual attention/distraction towards Imola; (b) Driver's visual attention/distraction towards Forli

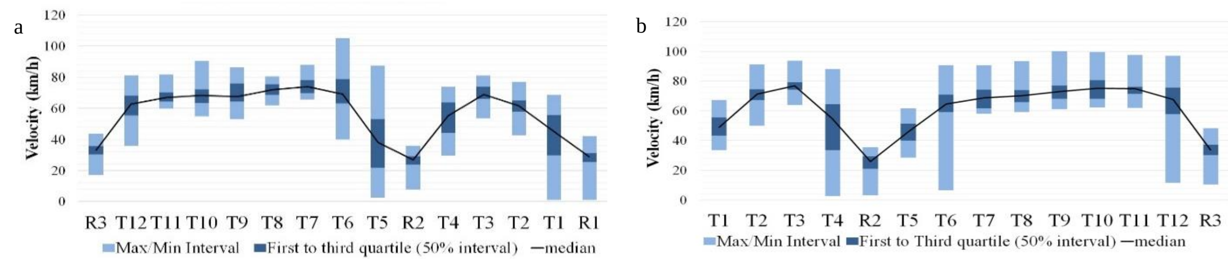

Fig. 4. (a) Driver's speed variation towards Imola; (b) Driver's speed variation towards Forli

64 incidents were reported from 2006 to 2017, 2 of which mortal and 47 reported with injuries. 23 accidents occurred at roundabouts, 1 of which was fatal, and 13 accident reported in correspondence of the entries or diversions present along the route. Therefore, more than half of the accidents were located near intersections. By analysing the type of accidents, it found out that the majority of the accident was lane departure (run-off-road) with

a frequency of 37%. The “lateral accidents” reported with 22% and placed mostly in the roundabouts, 20% of the accidents were reported as “pileup” accident, which also occurred in the roundabouts. Considering the accidents frequency in the various sections of the road, the highest number of the accident was reported at roundabout “R2” (Figure 2).

By looking at the data from the experiment, it can be noticed that the participant’s visual behaviour in term of attention towards the road environment showed high attention rate at the roundabouts, while the minimum attention of the drivers to the road towards Imola was observed in track “T4” with 65% of attention rate and track “T7” with 67% of visual attention rate. On the Forli direction, the driver’s attention rate dropped at track “T5” with 70 % rate of attention and on tracks ”T4” and “T6” the attention rate reported as low as 75% (Figure 3).

The drivers’ speed in the straight part of the road was reported high with sudden variations in the section near to the roundabouts (Figure 4). The maximum driver’s velocity was at the track of “T6”, just before the intersection “I2” with a registered velocity of more than 100 km/h in the direction towards Imola. The maximum speed of the participants for the road towards Forli is reported at track “T9” with 100 km/h. Figure 4 shows the speed variation of all the participants by using the “Boxplot”. The dark blue box shows 50% interval of the driver’s velocity values in each track, while the light blue box is the maximum and minimum interval of the driver’s speed during each track. The median value of the velocities also reported with the black line.

4. Results

The Road Safety Audit report, outlined necessary intervention for several existing problems in the ring road of Faenza, according to the annex 1 of the Directive 2008/96/EC. The studied road is a type D urban arterial which is being used by light and heavy vehicle traffic. In the Road Safety Review (RSR), the presence of vegetation and building in lateral bends was reported with medium severity which reduces the visibility, especially next to the intersections and also obstructs the visibility of the vertical signs. Insufficient visibility of exit in T8 is reported with a high severity level, which is caused by road signalization and in 3 other cross section in T8 and T11. The same reduced visibility is reported with medium severity due to high vegetation. The operative velocity of the track reported greater than the allowed velocity in most of the track. The intervention has been suggested for the discontinuity of the road safety barriers in some part of the track (T2, T9, and T10) since it could not guaranty a sufficient level of safety in the case of an accident. The presence of a bridge column in track T9 is reported as a high severity unprotected obstacle. The absence of the median strips to separate opposing traffic in several parts of the track (T1, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12) is reported as a high severity issue of the road which might increase the accident risk in the mentioned tracks, therefore a median stripes with a minimum width of 1.8 m is suggested according to D.M. 5/11/2001. The right side road shoulder is about 40 cm which is less than the limit of 1 m for category D and reported with a medium severity issue in the RSR. The road width (except T2) is less than 3.25 m indicated in the D.M.5/11/2001 and reported as a medium severity issue. The signaling were mentioned with medium severity problem, horizontal signaling was not visible in tracks (T9, T10, T11, T12, R3) and vertical sign in (T5, T2, T3), Moreover no signs were placed for indicating the parking places. Pavement deformation is another high severity issue, which according to the auditors, in tracks (T1, T2, T3, T4, T5, T9, T10, T11, and T12); the road pavement cannot guaranty the adequate safety level for the road. In the next section, some identified critical tracks by the RSR have been re-investigated using the innovative technologies during the experimentation in which 9 participants participated. In the update of the RSR, 3 main problematics were studied from the experiment: Driver’s effective speed, pavement condition, and insufficient visibility.

4.1. Driver’s effective speed

One of the main problems addressed by the RSR is the high effective speed of the drivers, which was mentioned with medium gravity, in particular where there is a presence of intersections. The normalized driver’s effective speed with respect to the maximum allowed velocity in each track is presented in Figure 5. The drivers never respected the speed limits (0%) in track “T8”, located before “I1” intersections with an average velocity of 71 km/h. The allowed velocity on the tracks “T3” was respected only for 23%, with an average speed of 68 km/h and in track “T2” only 19% of the driver’s velocity were below limits, with an average velocity of 61 km/h.

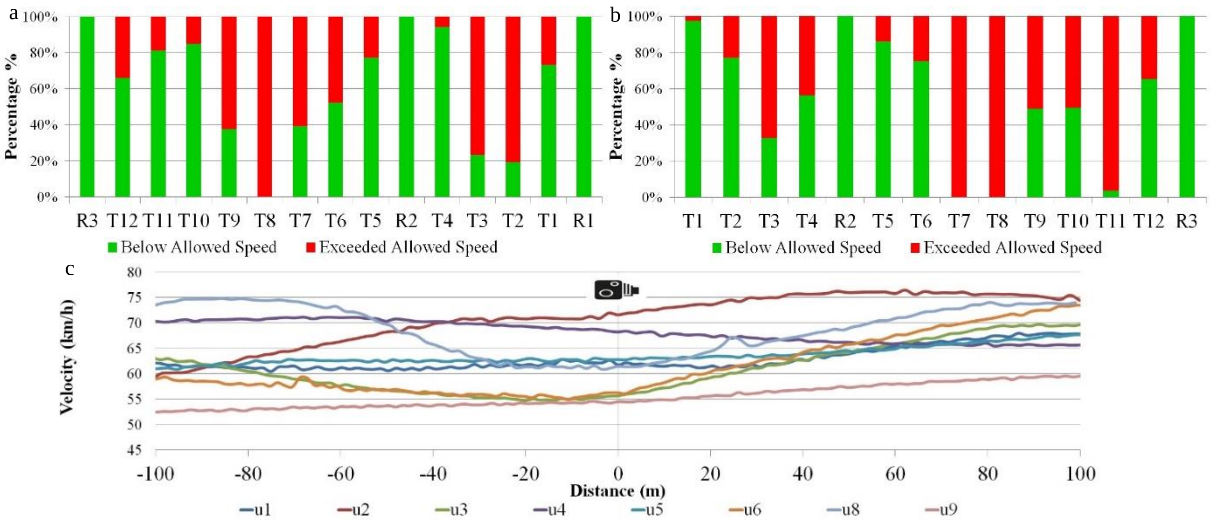

Fig. 5. (a) Driver's effective/allowed speed dir. Imola; (b) Driver's effective/allowed speed d. Forli; (c) Speed profile of the users at speed camera

The speed of the participants was investigated and the driver's effective speeds in "T7" and "T8" towards Forli, just before "I2" intersection always exceed the limit value with an average speed of 68 km/h and 70 km/h respectively. Regarding track "T11", just before "I3" intersections only in 4% of the track the velocity limits were respected with an average speed of 75 km/h.

The behaviour of the drivers in the proximity of speed camera in track "T6" was studied to find the effectivity of the speed radar. The user's speed in an interval of 100 m before and after the speed camera was investigated and presented in Figure 5c. The average velocity of the user 100 m before the speed camera was measured 62,2 km/h (SD=6.65), while the average speed at 100 m after the speed camera reached up to 69.0 km/h (SD=5.02). Considering the recorded average velocity of the user at the speed trap of 61.5 km/h (SD=6.08), the users increased the speed right after the speed trap for an average of 7.5 Km/h. As presented in figure 6, the majority of the drivers decided to accelerate right after passing the speed camera.

The visual behaviour of the drivers was investigated by the duration and frequency of the looking behaviour of the users towards the speed camera. The drivers looked at least once to the speed camera with an average visualization duration of 1.32 s (SD=1.05), and they were distracted from the road environment. This shows that the speed camera is distracting the drivers, while it is only effective in a very short part of the track T6, where only 50% of the users respected the velocity limits.

4.2. Pavement condition

The road pavement condition in the RSR is reported "with defect" in many sections including; "T1", "T2", "T3", "T4", "T5", "T9", "T10", "T11" and "T12" with a high gravity indicator. By considering the vertical acceleration measured by the inertial measurement unit (IMU) in Figure 6, it is possible to confirm that the pavement conditions caused very high vertical acceleration for the vehicle in the identified sections during the experiment. For example, in tracks "T10" towards Imola, the vertical acceleration reached to a maximum of 3 m/s^2 and on the tracks "T9" and "T11", the vertical acceleration was registered more than 2 m/s^2 during the experiment (Figure 6.a). The maximum measured vertical acceleration for the direction towards Forli was found at "T12" section with 2m/s^2 and in the "T2", T3", "T4", "T9", "T10" and "T11" tracks, the pavement caused elevated vertical accelerations (Figure 6.b). The results illustrate that the inertial measurement unit (IMU) can provide additional information on the percieved accelerations, which can be used to assess the pavement condition and to plan for necessary interventions.

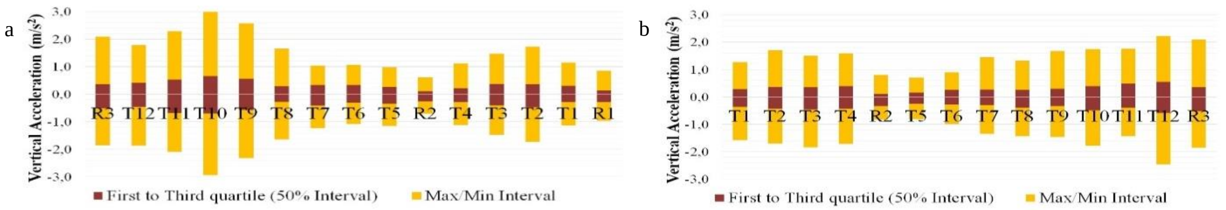

Fig. 6. (a) Vehicle vertical acceleration toward Imola; (b) Vehicle vertical acceleration towards Forli

4.3. Insufficient visibility

The RSR addressed several problems regarding the visibility of the vertical signs and the intersections. The visibility is mostly compromised because of the presence of trees, high vegetation and vertical signage. This loss of visual could involve a non-safe entry in the principal road and increase the risk of accidents in this intersection. The use of ET device enables to monitor the eye movement of the participant during the experimentation, the speed of the vehicle was also investigated in order to study the driver behaviour near a place where there is insufficient visibility. Looking at the driver behaviour in the proximity to the studied intersections in Table 1, it can be noticed that "I1" intersection was visible for the majority of the participants (67%) from distance of 87 m (SD=64.63) while driving with an average speed of 72 km/h. However, intersection "I2" was perceived only by 2 users (22%), from a distance of 92 m (SD=41.2), while the posted speed was never respected. The perception distance of intersection "I3" reported as low as 68 m (SD=35) and could be dangerous with the average high speed of the participants (75 km/h). Intersection "I4" was visible for most of the participants with an average speed of 68 km/h.

Table 1. Investigated parameters on the intersection

Driver behaviour parameters	I1	I2	I3	I4
Visibility percentage among users %	66,67%	22,22%	55,56%	66,67%
Average visibility duration of the driver (s)	0,75	0,16	0,29	0,37
Average attention rate on the track (%)	84%	91%	80%	84%
Median Intersection perception distance(m)	99,25	92,50	68,50	85,75
Average velocity on the track (Km/h)	72,00	71,96	75,71	68,44
Standard deviation of velocity (Km/h)	4,07	8,86	8,91	6,41
Respected Velocity limit (50Km/h) %	0,00%	0,00%	3,68%	66,11%
Number of accidents in 10 years (64 total)	2	3	1	1

Table 2. Investigated Parameters on the vertical signs

Driver behaviour parameters	RS1	RS2	RS3	RS4	RS5	RS6	RS7
Visibility percentage among users (%)	22%	11%	55%	22%	22%	0%	0%
Average visibility duration of the driver (s)	0,28	0,23	0,29	0,47	0,50	-	-
Average attention rate on the track (%)	88%	79%	79%	80%	84%	67%	70%
Average velocity on the track (Km/h)	69,14	38,57	60,51	77,53	75,72	73,95	45,61
Standard deviation of the velocity (Km/h)	7,41	18,88	7,20	6,26	9,03	5,30	7,69

7 vertical signs studied using the ET results, it found out that none of the participants looked at the "RS7" and "RS6" vertical sign that is presented in Figure 7 (b) and (c), while "RS2" vertical sign in figure 8 (a) was seen only by 1 user (11%). The visibility of other vertical signs is shown in Table 2, with the user's speed in the track. The trees reduced the visibility of the vertical signs and the driver's visual behaviour, like RSR report.

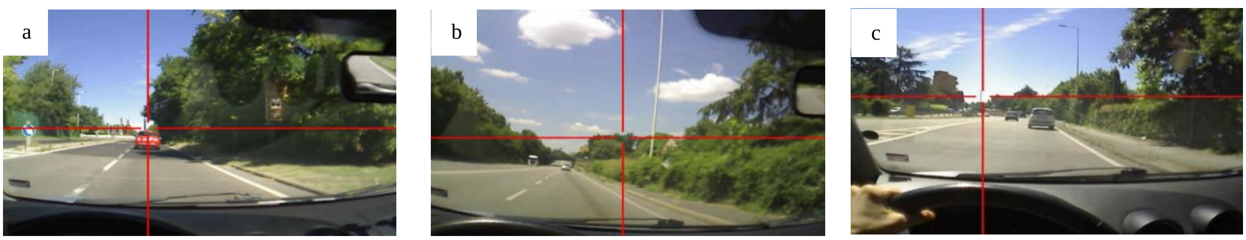

Fig. 7. (a) driver's gaze at "RS2" vertical sign; (b) driver's gaze at "RS6" vertical sign; (c) driver's gaze at "RS7" vertical sign

5. Discussion and Conclusion

In this paper, several problems reported in the RSR of an urban arterial road were re-investigated with the result of the test with participants using innovative techniques. Detailed analysis of the driver behaviour confirmed the identified critical sections of the Road Safety Audit and provided additional measures to plan better for the interventions. The use of satellite positioning device made it possible to measure the effective speed of the drivers during all the track and to identify the sections in which the drivers tend to drive with a higher velocity. The speed profile of the users demonstrated that the driver increases their speed only 100 m after the speed camera. The vertical acceleration investigated by the use of IMU sensor during the tracks and it confirmed the identified section of the RSR where the pavement is damaged. The use of eye tracking device allowed to monitor the driver visual behaviour during the entire road. The driver attention/distraction indicator towards the road environment, analyzed frame by frame for all the users and the part of the road where the attention of the driver was low have been identified. The vertical signs which were not visible for the users were recognized, and the average fixation duration of drivers was also compared in a different position. The presence of several intersections was reported in the RSR as one of the main hazardous points, which the analyze of the driver's speed revealed that the driver's effective speed is very high near the intersections and the visual behavior of the driver showed that some drivers were unable to perceive the intersections from a distance, because of the lack of visibility caused by high vegetation or obstacles.

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