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Safety roads: the analysis of driving behaviour and the effects on the infrastructural design

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Abstract

Road design should ensure the correct behaviour of drivers in terms of speed and level of attention. Nevertheless, in some cases users are not able to visualize the carriageway enough correctly, owing to the misled road layout or the loss of visibility.

In this research, road safety management was assessed with the driving and visual behaviour of users, considering the impact of different configurations of pedestrian crossings and road signs in order to reduce accidents. Even if users focus their attention on the zebra crossing (60%) and the vertical sign (24%), 16% of them have had no perception of the pedestrian crossings. This result shows how pedestrian crossings represent critical points that could compromise the safety of vulnerable users also in relation to speed. In fact, driving behaviour highlights 50 km/h of the average speed at 100 meters before the crosswalk, which allows having a too short time to stop the vehicle in safety. Moreover, the maximum speed underlines that users drive beyond the limit imposed by the road's rules. It is thus necessary to require the implementation of road infrastructure so as to modify the driving behaviour. Starting from the Road Safety Review, it was then possible to detect the critical issues and correlate a visual and kinematic analysis so as to intervene accurately.

Keywords: Safety roads; pedestrian crossing; driving behaviour; visual behaviour.

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1. Introduction

Situational Awareness (SA) can be defined as knowledge of the multiple circumstances that can occur while driving. The lack of SA is considered one of the main causes of road accidents attributed to human error (Faure et al., 2016; Walker et al, 2009; Nowakowski et al., 2012). Around the world, road accidents occur on average every 2 seconds; in fact, these are the consequence of one or more errors within a complex system that includes roads, vehicles, and individuals (Goniewicz et al., 2016; Jones et al., 1996; Wright et al., 2004). Evaluating the features of the

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infrastructure and the behaviour of drivers allows to minimize the difference between user expectations and the road itself. A safe road has the peculiarity of being understandable, thus being able to influence the level of attention of the driver and consequently the speed with which he processes and analyzes the information necessary for safe driving. A safe, homogeneous and coherent route has elements that tend to promote a driver behaviour suitable for the infrastructure. In this context, it is appropriate to speak of 'Self-explaining Roads', i.e. roads that allow traveling safely, as they comply with precise parameters of geometric identity, likely to suggest precise conduct to the user in full compliance with the traffic regulation.

Assessment of situation awareness can be carried out directly, subjecting drivers to real driving situations (Sagberg et al., 2015). Indirect measuring methods, on the other hand, involve the observation of behavioral attitudes of drivers, such as eye movements or the evaluation of the time needed to detect a sudden event and workload (Vignali et al., 2019; Kilpeläinen et al., 2007; Gugerty, 1997). The term workload refers to the mental load that an individual is subjected to while performing an action. It is a fundamental parameter in the field of road safety since it allows to estimate how the infrastructure engages the human mind. Therefore, depending on the cognitive load, it is possible to estimate the level of performance of drivers (Acerra et al., 2019). The probability of error increases as the level of performance exhibited decreases. It is necessary, therefore, that the mental load is neither too high, not to exceed the reaction-decision ability of the driver, nor too low, not to cause inattention in the same. For these reasons, the risk of road accidents is greater in geometric elements or specific tasks to which workloads compete or very low or very high (Cuenen et al., 2015; Lyu et al., 2017; Hancock et.al, 2001; Cantina et al., 2009; Filtness et al., 2012).

Mental workload has an impact on changing cardiac, cerebral, respiratory, and visual activity. The problem with physiological responses is that they are not affected by a single event while driving, but also depend on the subjective experience of the driver. According to this consideration, it is necessary to evaluate the elements of the road environment that are most fixed by users, in order to increase road safety (Borghini et al., 2014; Ikuma et al., 2014; Gugerty, 1998). As a result, the driver has to adapt driving to changes in the route, position, speed, presence of other vehicles and road and weather conditions according to the concept of behavioral adaptation (Chandrasekaran et al, 2019; Regan et al., 2011). This paper assesses this factor by considering firstly the implementation of the Road Safety Review of the road object of study in order to find its black points, and secondly combining them with the evaluation of the driver's driving analysis (Ghasemi et al., 2020). The term Road Safety Review means safety analysis on existing roads, by using checklists. Security examination is a procedure for understanding critical issues of a road, comparing the data resulting from the analytical analysis of the technical characteristics (incidentality, traffic, geometry, functionality) with the data obtained from the inspection carried out with the help of checklists. In the case of criticalities or points of accident risk in both analyses, it is necessary to intervene with appropriate countermeasures. The specific inspection sheets for each category of road useful for conducting the inspection shall be reported in the "Road Infrastructure Safety Management Guidelines" (Edwards, 1999).

In these cases, it is possible to intervene by increasing the visibility of certain areas of the road, or by carrying out frequent maintenance. Alternative design solutions suggest the installation of a portal, to emphasize the entrance into a built-up area and therefore the reduction of the maximum speed for the driver or innovative design for the pedestrian crossings. Pedestrian crossings are one of the most important safety-related areas of interest. About 10% of deaths on the road are attributable to vulnerable users who cross the road. For this reason, it is necessary to design these singular points to increase the visual perception of pedestrians and the consequent reduction in the approach speed of drivers. According to Ghasemi (2022), a possible intervention that allows greater visibility of pedestrian crossings and consequently the regulation of drivers' speed is represented by the insertion of pedestrian strips with red background. In fact, this solution allows for increasing the visibility of the pedestrian crossing by about 40%. Another evaluation of the effectiveness of the pedestrian crossings is recommended using the "before" and "after" approach in addition to an assessment of crash statistics at the selected locations.

2. Methods

Fifteen drivers were involved in the study, 9 males (M_{age} = 54.89 years, range: 38–77, SD = 14.67) and 6 females (M_{age} = 40.5 years, range: 29–63, SD = 14.32). The on-site test was localized in Tavullia (PU), in SS 744 Fogliense, where drivers with a car (Toyota Yaris) went along a circuit that included urban and rural areas. Drivers and vehicles were equipped with Eye Tracking Mobile EYE-XG (ME) and VIDEO V-BOX PRO.

The combined use of these technologies allowed to correlate the behaviour of the user to the guide, deduced from the Video V-Box Pro, with his attention and workload, obtained from the results of the Eye Tracking Mobile EYE-XG (ME). The first step of the analysis focused on the data of Mobile Eye Tracker. This tool is composed by:

- Spectral Mounted Unit (SMU), consists of two cameras, mounted above a specific glass. The first, called 'eye camera', is focused on the right eye of the driver and records all the movements of the pupil, thanks to a mirror that reflects the infrared spectrum; the second, called 'scene camera' and directed forward, is dedicated to the recording of the external environment.
- Display Transmit Unit (DTU) i.e. a small display, with a transmission unit, which controls continuously the eye movements and the external scene.
- ME computer, equipped with ASL Mobile Eye-XG software, that allows matching calibrated data sets with video recordings for each participant. The video shows the fixations of the eyes superimposed on the visual scene.

The sampling rate of the ocular movement is 30 Hz (i.e. 33 ms time resolution). Spatial accuracy was 0.5-1 p.m.

During the calibration phase, the subject had to fix specific points of the environment, to obtain an accurate definition of the user's points of view throughout the path. This tool allows for establishing visual behaviour during driving. The visual behaviour of the users represents the identification of the elements of the infrastructure and the street environment that attract more the attention of the drivers. During the test, in fact, drivers have looked at various elements such as dashboard, cars (vehicles present on the road), background (sky and vegetation), road (pavement and safety barriers), left and right mirror, internal mirror (considering only the frames in which the driver looks at the person sitting in the back seat), interior car (everything that is inside the vehicle except for the dashboard), road signs (Fig.1).

Fig. 1. (a) Frame of background; (b) Frame of road signs.

All these elements were subsequently collected in two macro-categories: attention and inattention (Table 1).

Table 1. Macro-categories of attention and distraction.

Attention	Inattention
Road	Dashboard
Road signs	Background
Car	Mirror
	Internal mirror
	Interior car

The second step dealt with the analysis of kinematic parameters of V-Box. This tool was born and developed for motorsports, to record the information concerning the motion of a vehicle during a journey. It combines a powerful GPS with a high-quality multi-camera, made up of two paired cameras working in sync. The Video V-Box Pro was placed in the middle of the vehicle, while the two cameras were placed on the dashboard. The GPS sensor, instead, was placed on the roof of the car in a barycentric place for greater accuracy of the localization.

The different parameters, supplied in output from the GPS and emitted with a frequency of 10 Hz, are the position along the circuit; the lap times; the speed (accuracy of ± 0.1 km/h); the acceleration (1% accuracy), and distance with a 20 Hz sample rate. To extrapolate the V-Box data, it was necessary to use the Circuit Tools program. It allows viewing simultaneously the trend charts and the actual recordings, evaluating the kinematic parameters of the car. The software can analyse in a diagram, the trend of a series of variables chosen in a list (longitudinal and transverse speed; longitudinal and transverse acceleration; the number of satellites visible; latitude and longitude) in the function of time or cover distance.

These innovative technologies were used after the Road Safety Review. This is the procedure that allows understanding of the criticalities of a road through the comparison between the analytical study of the path (i.e. the data on geometry, traffic, and accident) and the data obtained from on-site inspections, conducted based on road-specific inspection cards. The Road Safety Review, therefore, helps to identify situations at risk potential for traffic along the track, studying how different users who use the road perceive and use the space. In the study, this type of analysis was fundamental to identify the critical points of the track, subsequently investigated through the user behavioral analysis and kinematic analysis of the vehicle.

The analysis dealt with two fundamental steps:

- The determination of the first displayed element of the crossing, zebra crossings or vertical sign, using the mobile eye-tracker device;
- Identification of the distance from 100 meters to the crossing with the Video V-Box Pro.

3. Results and discussion

3.1. Visual and driving behavior in the pedestrian crossings

Along the test road, it was recorded the number of frames in which all users pointed to the external scene. The users paid attention to the driving scene considering that the average of frames was 62%, but 38% of frames were connected with inattention. With these results, it could be supposed that there was a large number of users who did not focus their gazes on the driving scene, but they were attracted by something that could compromise road safety. To shed light on this problem, it has been extrapolated the percentage of categories which has more frames.

In decreasing order, the vision categories that received more glances were: background (Average: 34%), cars that composed traffic (Average: 32%) and street (Average: 26%). Although the categories which were included in the attention (cars and street) make up the highest percentage, 34% of frames highlight how users tended to distract themselves because they considered more salient different elements such as bigger or stronger illuminated objects compared to smaller and less illuminated objects as pedestrians (Vignali et al., 2019).

The analysis of attention and inattention focused on pedestrian crossings, which represent the 13 critical points of the urban track. The percentage of frames directed to the crossings, i.e. 8%, underlined the first factor linked to the lack of perception of many users due to the wrong road signs.

The loss of perception of crossings also resulted in an approach speed that was not modulated to predict a pedestrian crossing. For this reason, a specific analysis has been made on the crossings, in order to locate which of them had problems due to the visibility of the infrastructural signs.

First of all, it was extrapolated the first element which was viewed during the circuit for each participant. 68% of drivers have focused on the pedestrian crossings on the way and 54% on the return. Different situation for vertical signs as only 17% of users viewed them on the outward and 28% on the return. The remaining percentage pointed out that crossings are not perceived by users. In fact, only 15% of drivers did not see the crossing on the way; the percentage increased only on the return, reaching 18% of users (Fig.2a).

Fig. 2b shows the second step of the research i.e. the average speed of drivers at 100 meters from the crossing.

Pedestrian crossings with zebra and vertical signs have speeds within the limits imposed by the highway code (Average one way: 49.03 km/h; SD: 11.87 - Average way back: 50.92 km/h; SD: 9.6). The lack of signage highlighted in crossings where there are only zebra signs tracks a trend of higher average speeds both in one way (Average: 52.82

km/h; SD: 0.09) and return (Average: 54.37 km/h; SD: 3.82). By carrying out further analysis, precisely in these crossings, the user not only has a high speed but also does not perceive the presence of the same crossing. In fact, such crossings fall within the 15% of elements not seen present in figure 2a.

This result proved the need for infrastructural intervention in the urban section of the road to increase the perception of the pedestrian crossings and consequently the decreasing of speed.

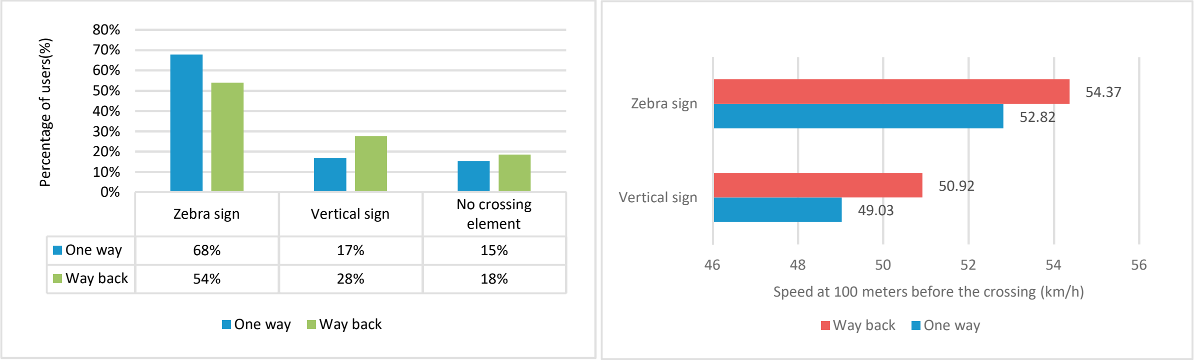

Fig. 2. (a) Percentage of users that see a specific element of crossing; (b) The average speed at 100 meters from the crossings, comparing the crossing with zebra and vertical signs and with only zebra one.

According to these results, it was important to evaluate the average percentage of frames that each user turns towards the zebra signs, to evaluate the visibility. As shown in figure 3, it is possible to consider that the pedestrian crossings appear as the most visible element in the context of crossings, except for numbers 1, 7 and 9. These crossings, in fact, have broken and poorly visible horizontal signs, which could be improved through the insertion of a colorful flooring. Crossing 8, on the other hand, has a large percentage of frames, underlining the lack of visibility of the vertical sign. In this case, the insertion of portals could greatly increase the visibility of the crossing and thus help the security of vulnerable users.

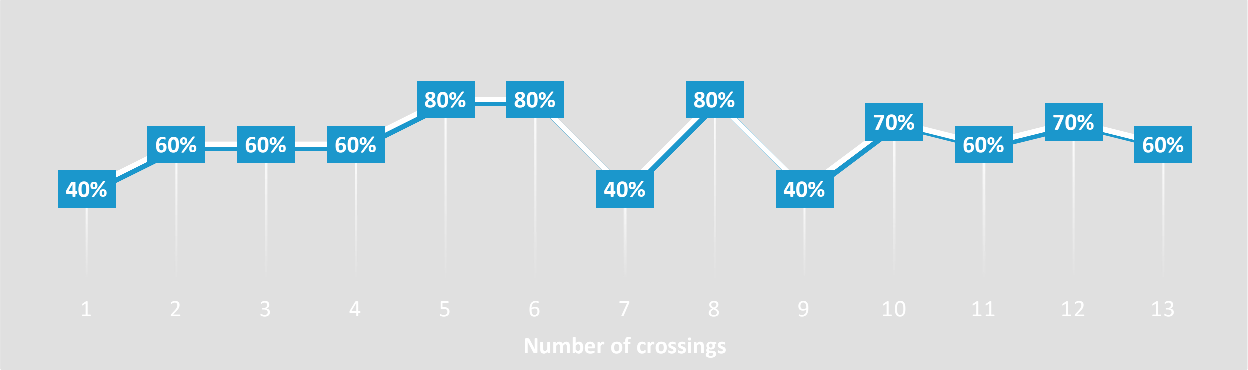

Fig. 3. The average percentage of zebra frames for all the crossings.

Carrying out the road safety review of the road and the visual analysis, it was possible to identify some criticalities related to crossings. In fact, the main reasons for not seeing crossings were linked to various issues including poor maintenance of road markings and lack of warning signs for pedestrian crossings.

Starting from these problems, the crossings which presented more problems (number 1,7,9,8) are the same that registered very high speeds at 100 meters before. Fig. 3a shows the actual state of crossing 8 where it was possible to notice the absence of vertical signs and the low visibility of horizontal ones (Bichicchi et al., 2017). In Fig. 3b is inserted the proposal for infrastructure adaptation linked to the insertion of a portal that focuses on the pedestrian crossing and the maintenance of the road markings.

Fig. 4. (a) The before analysis of crossing that is not viewed during the circuit; (b) The proposal for modifications on the crossing.

Crossing number 7, which was not perceived, had an approach speed of 100 meters equal to 55.71 km/h. In this case, the proposed intervention (Fig. 4b) was represented by backlit warning signs and by the insertion of a colored flooring, an adjustment measure used because of the positioning near the town of Casa Bernardi. The effectiveness of this colored pavement was confirmed by the study of Ghasemi (2021), where an accurate visual analysis underlined the increase of attention of drivers concerning this new design solution.

Fig. 5. (a) The before analysis of crossing that is not viewed during the circuit; (b) The proposal for modifications on the crossing.

3.2. The analysis of speed

The circuit was divided into 3 tracks, considering the typology of the street (urban and rural). In fact, the first and the third track have a speed limit of 50 km/h because they are in the urban area instead of the second track which is in the rural area with 70 km/h as the limit. In Fig.5, it can be possible to highlight the trend of the speed of one user, which is the most representative:

- In the first section, users meet a traffic light (first minimum of Fig.5), followed by a road word zone;
- In the second section, users enter the suburban area;
- In the last section, the speed trend appears with three minimum values in correspondence with the roundabouts.

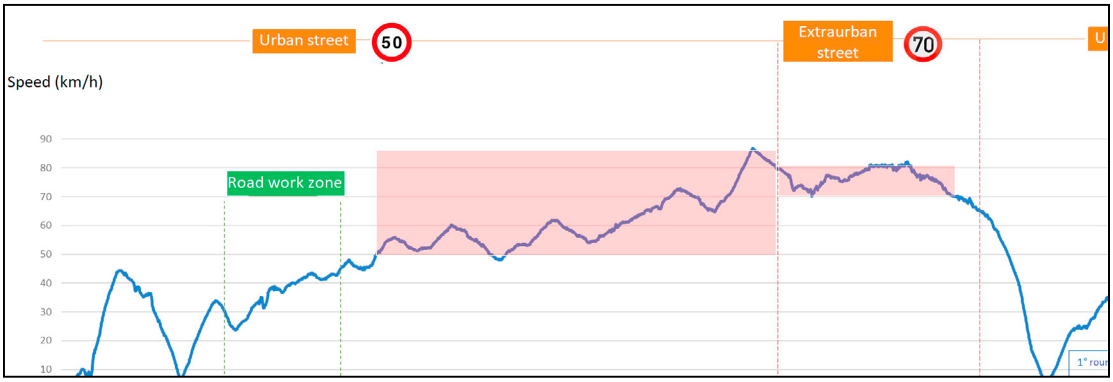

Fig. 6. The trend of speed along the circuit.

Considering the trend for the circuit, the average speed of the participant was not over the limit for all the tracks (Fig 6). In detail, during the one way of section 1, two drivers had higher speeds than the allowed limit, while on the way back the number of users rises to 5. In sections 2 and 3, however, no user exceeded the limit imposed by legislation.

Comparing the average speeds, it can be noted that in track 2 it reaches 65.37, while in sections 1 and 3 it is lower and equal to 47 and 45 km/h respectively. On the way back, however, the trend is the same in track 2 (65.75 km/h) while in the first there is a small increase compared to the one way (48.37 km/h) in contrast to the third where you can see a decrease compared to the one way (42.75 km/h).

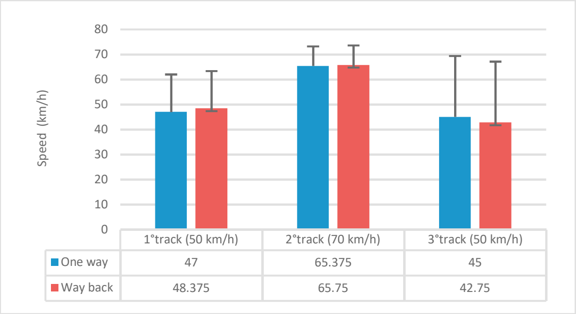

Fig. 7. The average speed of the circuit with the indication of maximum value.

Considering the average maximum speed of participants, it was over the limit in all cases. In fact, in section 1, on the one way, all users exceeded the limit of 50 km/h, up to peaks of 88 km/h. In the return, the same trend was confirmed, considering all peaks contained below 70 km/h. In section 2, however, the maximum speeds had peaks slightly above the limit (about 10 km/h). In section 3, finally, the maximum speeds in the outward journey had up to 25 km/h more than the established limit, while on the way back they arrived at more than 30 km/h.

4. Conclusions

The analysis with the Road Safety Review has revealed some safety criticises both for vehicle drivers and, in particular, for vulnerable users. Thanks to the experimentation carried out, in fact, it has been possible to obtain a response to the problems highlighted within the proposed intervention, such as pedestrian crossings that are not visible and a lack of geometric signs. From the safety analysis, therefore, it is believed that the road problems can be eliminated or mitigated by the specific interventions proposed. The deep analysis of pedestrian crossings, carried out thanks to the interaction between the Road Safety Review and the innovative tools available, showed a poor perception of pedestrian crossings by users, in particular, this problem is more evident for those with fewer signs (worn or absent).

This element has further emerged from the analysis of speeds, as users tend to have a high trend in non-perceived crossings, which occur above the limits imposed by the Highway Road (50 km/h).

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