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The safety and conspicuity of pedestrian crossing at roundabouts: The effect of median refuge island and zebra markings

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(Article begins on next page)

1 **The safety and conspicuity of pedestrian crossing at roundabouts: the effect of median refuge island**  
2 **and zebra markings**

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4  
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6  
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9  
10 **Abstract**

11 Roundabouts are one of the most used road intersections because, compared to signalized ones, they reduce  
12 conflict points between traffic flows and moderate driving speed. Great attention should also be paid to  
13 vulnerable road users at roundabouts. According to accident statistics, in fact, accessibility of pedestrians and  
14 cyclists is not always ensured.

15 This paper has evaluated the effects on the visibility of pedestrian crossing before and after the displacement  
16 of zebra markings, moved before intersections, and the introduction of media refuge islands and “Yield here  
17 to pedestrians” vertical signs. The above effects have been assessed by before-after analysis of speed and  
18 visual behaviour of drivers approaching the crosswalk.

19 Moreover, the analysis of the drivers’ eye movements has highlighted the most salient elements of the  
20 pedestrian crossing. The relation between the drivers’ visual behaviour and the vehicle speed have also been  
21 calculated. Results have confirmed that the intervention carried out has increased both visibility and safety of  
22 the studied pedestrian crosswalks.

23 Zebra markings and the median refuge island have turned out to be the most glanced elements, respectively  
24 seen by 93.75% and 56.25% of the drivers, followed by the “Yield here to pedestrians” vertical sign. The mean  
25 distance of first fixation of the crosswalk increased from 21.98 m before the intervention, to 40.69 m after it.  
26 The drivers perceived the pedestrian crossings from a longer distance after the intervention, and they  
27 continued to glance at the crosswalk while approaching it, enhancing their visual attention.

28  
29 **Keywords:**

30 Eye tracking; Pedestrians; Driver behavior; Roundabout; Median refuge island; Zebra markings; Urban road;  
31 Conspicuity; Road safety; Vertical sign.

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## 64 **1 Introduction**

65 Road safety is influenced by road design and signalling which affect the drivers' perception of the external  
66 environment and the possible dangerous situations (Bucchi, Sangiorgi, & Vignali, 2012; Dondi, Simone,  
67 Lantieri, & Vignali, 2011). In recent years an increasing attention has been paid to traffic problems which could  
68 modify the drivers' cognitive and emotional condition (Chu, Wu, Atombo, Zhang, & Özkan, 2019). Driving is a  
69 complex situation, requiring a constant attention and prompt reactions to fast changes. During long trips, the  
70 drivers' behaviour might result into stressful responses due to an excessive cognitive workload (Ringhand &  
71 Vollrath, 2019).

72 In order to increase safety, fluidity of road traffic and to reduce the velocity, roundabouts are often built  
73 especially in urban areas (Hydén & Várhelyi, 2000). They allow a higher entry capacity than grade intersections  
74 and a reduction of conflict points, from 32 for a grade intersection, to 8 in case of a roundabout (Gross, Lyon,  
75 Persaud, & Srinivasan, 2013; Turner, 2011). In addition to facilitating the traffic flow, roundabouts also reduce  
76 the velocity and the drivers' stress (Hydén & Várhelyi, 2000). The negative aspects of roundabouts are linked  
77 to crosswalks which reduce the roundabout capability and are critical points as far as pedestrian safety is  
78 concerned (Bergman, Olstam, & Allström, 2011; Meneguzzo & Rossi, 2011; Vijayawargiya & Rokade, 2017).  
79 Studies related to roundabout safety have generally focused on drivers, overlooking the importance of safety  
80 of the vulnerable users, pedestrians and cyclists (Perdomo, Rezaei, Patterson, Saunier, & Miranda-Moreno,  
81 2014). In urban areas, pedestrians need to cross at intersections, and zebra crossings are often present close  
82 to access and exit ramps of roundabouts. Pedestrian crosswalks at roundabouts are useful for pedestrians  
83 and increase safety. They should be placed in a proper way both to attract the maximum number of  
84 pedestrians, who would otherwise cross the street at random, and to give drivers enough time to stop safely  
85 (Cohen, Bar-Gera, Parmet and Ronen, 2013).

86 Recent studies have shown the importance of a correct design for pedestrian crossings at the intersections.  
87 More attention should be paid to pedestrian safety, as the number of victims among people crossing at  
88 intersections is constantly increasing year after year (Bungum, Day, & Henry, 2005; Olszewski, Szagała,  
89 Wolański, and Zielińska, 2015). Literature does not suggest many countermeasures aimed at reducing the  
90 problems for pedestrians crossing at roundabouts (Perdomo et al., 2014). Anyway, a significant reduction of  
91 speed of vehicles in a complex road environment, such as collector roads provided with signalled intersections,  
92 roundabouts, road circles or stop signs, would be highly recommended and it can only be obtained with  
93 different multi-purpose countermeasures.

94 A refuge island, for example, makes the road narrower thus slowing the traffic. It also helps drivers to realize  
95 that pedestrians are crossing the road. Pedestrians may also stop on a refuge island and cross the road in two  
96 stages, increasing the attention paid at the traffic in both directions. Refuge islands are widely self-explaining,  
97 and they immediately give the idea of a not fast traffic road (Leden, Gårder, & Johansson, 2006; Sanca, 2002).  
98 Literature shows evidence of a significant speed reduction of vehicles in the presence of a refuge island (Fildes,  
99 Fletcher e Corrigan, 1987; Kolsrud, 1985; Vey & Ferreri, 1968; Yagar e Van Aerde, 1983). Mako (2015) has  
100 shown that implementation of refuge islands at pedestrian crossings has reduced the number of fatalities for  
101 pedestrians by 64%. Without a refuge island the drivers' movement is 4% more irregular than in presence of  
102 a refuge island. As for pedestrians, without a refuge island they tend to cross irregularly instead of waiting for  
103 a vehicle to stop giving them the priority.

104 Curb extensions may also help vehicles to slow down while approaching a pedestrian crossing. Extensions of  
105 a sidewalk edge are commonly present along roads with parking areas on the lane side. These extensions  
106 increase the visibility of pedestrians and reduce the drivers' speed behaviour inducing prompt yielding (Hawley,  
107 Henson, Hulse, & Brindle, 1992; Huang & Cynecki, 2001; Macbeth, 1995; Replogle, 1992). Bella and Silvestri  
108 (2015) have proved that more than 80% of the drivers they tested clearly perceived the effectiveness of curb  
109 extensions. This means that, in presence of curb extensions, the drivers were much more prompt to yield since  
110 pedestrian crossings were better seen.

111 Prompt yielding is often the response to "Yield here to pedestrians" vertical signs. These are mounted on poles  
112 on the right side at crosswalks or on supporting arms over the traffic lanes (Beeber, 2011). To improve their  
113 visibility, LED flashes with an irregular flash pattern can be mounted, too. Van Houten, Ellis and Marmolejo  
114 (2008) showed that LED flashers installed on simple pedestrian signs, increased the drivers' yielding and  
115 reduced evasive manoeuvres as well as the number of pedestrians trapped in crosswalks at the centre of the  
116 road without a refuge island. Sherbutt, Van Houten, Turner and Huitema (2009) carried out three different  
117 experiments on the effects of flashing pedestrian vertical signs on drivers' behaviour. The results showed an  
118 increase of yielding from 18.2% to 81.2%. Bram De Brabander Lode Vereeck have shown that the number of  
119 accidents with serious injuries involving vulnerable road users increased at intersections with no signalization  
120 before the roundabout.

121 A further countermeasure may be guardrails at roundabouts. These direct pedestrians to safe crossing areas  
122 and prevent bursting into the road (Retting et al., 2003). The main benefits of installing guardrails are  
123 channeling pedestrians to the crossing (Stewart, 2007) and making footpaths safer. Cohen, Bar-Gera, Parmet  
124 and Ronen (2013) have shown that the number of pedestrians jaywalking with no guardrails at a roundabout  
125 exceeds 20-30% the number of pedestrians committing the same violation when guardrails are installed.

126 Although any countermeasures aiming at increasing safety of pedestrian crossings are very important, the  
127 drivers' behaviour should also be taken into consideration. Getting closer to a roundabout, drivers are often  
128 distracted and do not pay attention to the road environment, including crosswalks. Inattention of drivers causes  
129 most of the accidents (Xu et al., 2018). Electronic and radio devices present inside the vehicle and used while  
130 driving, in addition to other distractors including the road environment, are the main causes of the drivers'  
131 inattention and carelessness (Oviedo-Trespalacios, Haque, King, & Washington, 2017). High speed of  
132 vehicles approaching a roundabout along with drivers' lack of attention represent the main problems for the  
133 safety of pedestrians crossing at roundabouts (Vijayawargiya & Rokade, 2017; Fortuijn, 2003; Gross et al.,  
134 2013). Speed reduction of vehicles is one of the key elements to reduce the probability of death of pedestrians  
135 involved in an accident (Gonzalo-Orden, Pérez-Acebo, Unamunzaga, & Arce, 2018; Guo, Liu, Liang, & Wang,  
136 2016; Hakkert, Gitelman, & Ben-Shabat, 2002; Haleem, Alluri, Gan, 2015; Kröyer, Jonsson, Várhelyi, 2014;  
137 Rosén & Sander, 2009; Rosén, Stigson, Sander, 2011; Tefft, 2013; Zeeger & Bushell, 2012).

138 However, the present traffic safety laws (road safety measures) are not to be the only instrument capable of  
139 reducing the number of accidents and fatalities (Ward et al., 2010). In fact, a road safety culture should be  
140 established, both for drivers and pedestrians (Chu et al., 2019; Obeng-Atuah, Poku-Boansi, & Cobbinah,  
141 2017). A road safety culture, deep-rooted in society, sounds like a long-term project not easy to be achieved,  
142 anyway. On the contrary, road infrastructure, especially at crosswalks near roundabouts, might be immediately  
143 improved in order to increase pedestrian safety and drivers' perception of the risk. Many studies with positive  
144 results have been taken into account aiming at improving road safety while reducing drivers' speed in proximity  
145 of pedestrian crossings (Bella & Silvestri, 2015; Gonzalo-Orden et al., 2018a). These studies usually rely on  
146 motion parameters, such as the operating speed or the stopping distance. They do not consider the drivers'  
147 behaviour in terms of detection and perception of crosswalk elements at the roundabout, whereas these  
148 parameters are very important to assess the drivers' attention level and hazard anticipation. An eye-movement  
149 recording tool can be very useful for this purpose since it allows a quantitative assessment of the drivers' risk  
150 anticipation when approaching a roundabout (Costa, Bonetti, Bellelli, Lantieri, Vignali, & Simone, 2017;  
151 Kapitaniak, Walczak, Kosobudzki, Józ'wiak, & Borkiewicz, 2015; Taylor et al., 2013; Topolsek et al., 2016;  
152 Ghasemi et al., 2019).

153 Assessing the driver's vision may be useful to point out safe or unsafe behaviours on roads. Eye tracking is  
154 used to evaluate the drivers' perception and acknowledgments of the road elements as well as to develop  
155 driving strategies and prevent crashes. According to several studies, the drivers' visual inattention is  
156 responsible for a large amount of traffic accidents (Bongiorno, Bosurgi, Pellegrino e Sollazzo, 2017; Costa,  
157 Simone, Vignali, Lantieri, Bucchi, & Dondi, 2014; Costa, Bonetti, Vignali, Lantieri, & Simone, 2018; Costa,  
158 Simone, Vignali, Lantieri, & Palena, 2018; Costa et al., 2019; Di Flumeri et al., 2018; Inman, 2012; Kapitaniak  
159 et al., 2015; Lantieri et al., 2015; Mantuano, Bernardi, & Rupi, 2017; Vignali et al., 2019). In order to prevent  
160 those accidents, some studies have been carried out about the driving behaviour using the mobile eye tracking  
161 tool. This methodology is particularly interesting when analysing the driver-pedestrian interaction. Only a few  
162 studies have applied this method by now (Trefzger, Blascheck, Raschke, Hausmann, & Schlegel, 2018) most  
163 of which take only the pedestrian behaviour into consideration (Biassoni, Confalonieri & Ciceri, 2018; Bock,  
164 Brustio & Borisova, 2015; Davoudian & Raynham, 2012; Fotios, Uttley, & Hara, 2013; Trefzger et al., 2018;  
165 Zito et al., 2015). An exam of the drivers' behaviour when approaching a crosswalk was carried out by Ciceri,  
166 Ruscio, Confalonieri, Vangi and Virga (2013). They set different road situations and the outcome was that a  
167 complex street environment, with a lot of road signs, resulted into a lack of attention from the driver towards  
168 the pedestrian. The driver, in fact, realized the movement of pedestrians on the crosswalks quite late.

169 Moreover, using the eye tracking measurements Grüner et al. (2017) studied the difference between the  
170 driver's behaviour in urban and rural roads. The results showed a higher number of driver's eye movements  
171 in residential areas compared to city roads. This means that the less the traffic is, the higher the driver's  
172 expectation of a careless behaviour of pedestrians when crossing roads will be.

173 In addition to this, according to the studies carried out by Dukic, Ahlstrom, Patten, Kettwich and Kircher (2013)  
174 and Maxera, Kledus and Semela (2015), eye tracking measurement proved that drivers always detected  
175 pedestrians late when driving at night. Increasing size and visibility of an object, making it more illuminated  
176 and salient for example, proved to be useful to avoid the problem. This can be applied both to objects and  
177 pedestrians by using different marking patterns (Muttart, Dinakar, Vandenberg, & Yosko, 2016; Crescenzo et  
178 al., 2019).

179 Using a simulator, Fisher and Garay-Vega (2012) compared the drivers' behaviour at crosswalks signaled  
180 by mid-blocks, advanced yield markings and "Yield here to pedestrians" vertical signs to crosswalks showing  
181 just standard markings. In the former situations the drivers' behaviour consistently changed reducing  
182 pedestrian-vehicle crashes and increasing the drivers' attention towards pedestrians. The distance at which a  
183 pedestrian was first seen increased and the drivers performed a prompt yielding. Gómez et al. (2013)  
184 confirmed the above issues. With advance yielding markings fewer accidents occurred and drivers payed a  
185 higher attention to pedestrians. Most of these studies, anyway, used eye-movement tracking with simulators  
186 but not in real traffic environments. Moreover, while using the same methodology, these research studies have  
187 analysed the detection of pedestrians by drivers but only few of them focused the attention on factors improving  
188 the real crosswalk conspicuity.

189 The aim of the present study, on the contrary, was a before-after evaluation of a combined intervention on  
190 pedestrian crossings near roundabouts in a real road context, assessing both vehicle speed and eye-  
191 movements approaching a sequence of crosswalks before and after the intervention.  
192 Four crosswalks were included in the study. Specifically, the crosswalks were moved further before the  
193 intersection, median islands were added, and a “Yield here to pedestrians” vertical sign was added. This  
194 intervention at roundabouts is of simple installation and it may be of high effectiveness on the drivers’  
195 behaviour.  
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## 197 2. Materials and methods

### 198 2.1 The experimental protocol

199 Ten drivers, 3 males ( $M_{age} = 28.87$  years, range: 23–39,  $SD = 8.96$ ) and 7 females ( $M_{age} = 35.86$  years, range:  
200 25–52,  $SD = 10.79$ ), were recruited and involved on a voluntary basis in this study. They had normal vision  
201 and none of them wore eyeglasses or lenses, to avoid artefacts in eye-movement monitoring. All participants  
202 had a Category-B driving license (for cars) and no prior driving experience on the road segment object of study,  
203 in order to control the effect of familiarization with the road environment.

204 The experiment was conducted following the principles outlined in the Declaration of Helsinki of 1975, as  
205 revised in 2000. Informed consent and authorization to use the video graphical material were obtained from  
206 each subject on paper, after the explanation of the study. One car was used for the experiment, with diesel  
207 engine and manual transmission. The subjects had to drive the car along a circuit designed to include the four  
208 pedestrian crossings object of study placed along the routes via Testi and via Fornarina, a single carriageway-  
209 two lanes road, located in Faenza in the north of Italy, in the Emilia Romagna region. These two roads connect  
210 the centre of the town to its suburbs. The circuit was 1.52 km long, with a width of about 9.00 m (two 3.00 m  
211 wide lanes and one 1.50 m wide sidewalk) and the speed limit was fixed at 50 km/h (Fig. 1). The route also  
212 included two mini roundabouts, spaced at 340 m, the first one located between via Testi and via Cesarolo and  
213 the second one between via Fornarina and via Saviotti. The pedestrian crossings were placed on straight  
214 sections before and after the two roundabouts, at an average mutual distance of about 22 m.  
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216 Figure 1. Outline of the experimental route. In red the mini roundabouts object of study.  
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219 The route was characterized by the highest number of accidents in the Province of Faenza in the years 2009-  
220 2011, with 12 injured, number which involved very high social costs. The main accident causes were the  
221 drivers’ distraction and high-speed driving which increased both vulnerability of weak users and car-pedestrian  
222 crashes. To solve this problem, different safety countermeasures had been installed in order to slow down  
223 vehicles approaching the four pedestrian crossings object of study.

224 Before the works, all crosswalks had white zebra markings, with stripes which were 1.50 m long, 0.50 m wide  
225 and spaced 0.50 m from each other according to the Italian Highway Code (Ministry of Infrastructures and  
226 Transports, 1992). These zebra markings were positioned after the roundabout stop line. Only two of them  
227 had standard vertical “Yield here to pedestrians” signs, one for each side, placed on the sidewalk of the road  
228 in proximity of the markings (Fig. 2).  
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Figure 2. Pedestrian crossing design before the works.

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After the works, all crosswalks were characterized by (Fig. 3):

- median refuge island, allowing a safer and easier two-stage crossing for pedestrians. According to the Italian Highway Code (Ministry of Infrastructures and Transports, 1992), it was 4 m long and it had a continuous boundary marking and a 0.10 m high curb. A yellow reflective obstacle delineator, coupled with the sign “passage allowed to the right”, was installed on the curb nose;
- white zebra markings, which were moved in advance of the intersection and positioned 10 m before the roundabout stop line, in order to increase pedestrian safety with vehicles approaching the intersection;
- kerb ramps, improving mobility of people with disability, on both sides of the road;
- “Yield here to pedestrians” vertical signs, on the right side of the road, one on each side.



Figure 3. Pedestrian crossing design after the works.

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Apart from the introduction of median refuge island, zebra markings displacement in advance of the intersection, and the improvement of “Yield here to pedestrians” vertical sign, the design of pedestrian crossings was the same as before. Each subject had to repeat the driving task two times on different days, before and after the works (Fig. 4).

Data collection started at 9 a.m. and finished at 1 p.m. on two different days, always in summer, in a period with low traffic and good meteorological conditions. The two driving tasks were conducted in the same conditions in terms of weather, visibility conditions and traffic driving scenario. In this study the pedestrian presence near the crosswalk was not considered.

Participants didn't know the route in advance. At the beginning of the “after” study, participants were asked whether they remembered of the “before” task and nobody identified any elements of the route.

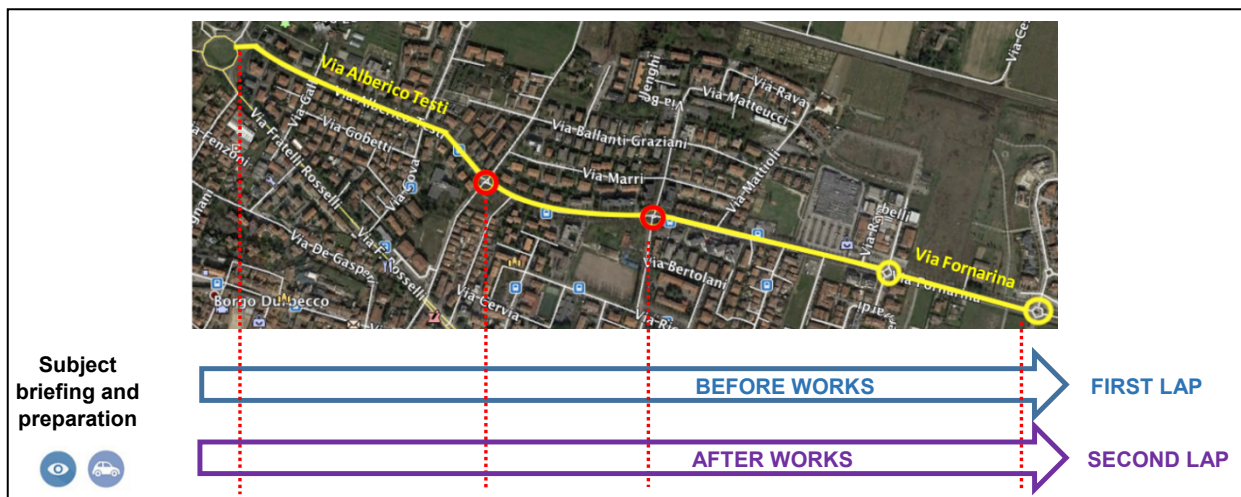


Figure 4. Overview of the experimental protocol, consisting of two driving tasks, 1.5 km from via Testi to the end of via Fornarina, performed before and after the works.

During the whole experimentation, an ET device recorded the eye gazes while a professional device mounted on the car (a Video VBOX Pro) detected data about the drivers' behavior. Eye movements of participants were recorded through an ASL Mobile Eye-XG device (ET), a system based on lightweight eyeglasses equipped with two digital high-resolution cameras, one recording the right eye movements, and the second one recording the visual scene. Not to obscure the normal field of view of the drivers, a mirror capable of reflecting the infrared light was installed in the eye camera recording the activity of the right eye. As already tested in Costa et al. (2014), the sampling rate for the eye-movement recording was 30 Hz (33 ms time resolution) with an accuracy of  $0.5 \pm 1^\circ$  (approximating the angular width of the fovea).

A preliminary calibration procedure was carried out for each subject inside the car before starting driving, asking them to fix their gaze on thirty fixed visual points spread across the whole scene, in order to get a good accuracy of the eye movement recorder. A video for each participant was created using the ASL software with a cross superimposed to the scene showing the eye fixations. This allowed researchers to detect the sequence of points of the scene fixed by the driver. The car was equipped with a Video VBOX Pro (Racelogic Ltd), a system able to continuously monitor the cinematic parameters of the car, integrated with GPS data and videos from four high-resolution cameras. The system was fixed inside the car, in the center of the back floor, in order to put it as close as possible to the car barycentre, while two cameras were fixed over the top of the car. The system recorded speed (accuracy: 0.1 km/h), acceleration (1% accuracy), and distance with a 20 Hz sample rate. The ET and the Video VBOX Pro devices were installed on the back seats of the car, monitored by one of the researchers, who was asked not to talk to the driver except for giving instructions about the direction or assistance in case of necessity.

## 2.2 Performed analysis

The performed analysis aimed to evaluate the effect on safety and visibility of the studied pedestrian crossings produced by the introduction of median refuge island, the displacement of zebra markings in advance of the intersection, and the improvement of "Yield here to pedestrians" vertical sign. To this end, both vehicle speed and drivers' eye-movements approaching crosswalks were analysed and compared before and after the works. The recording of driver's eye-movement allowed an assessment of the more salient visual elements along the road and near the pedestrian crossing as well as an evaluation of the driver's visual behaviour related to the vehicle speed. The experimental route was a back-and-forth trip, so each of the four crosswalks was crossed twice and the average value between the two directions for each crosswalk was taken into consideration.

A before-after operating speed comparison is commonly used to evaluate the safety of a road modification (World Road Association, 2003). Therefore, in the present study, the Video VBOX Pro output video was analysed for each participant before and after the works in order to evaluate the operating speed. The ET video, on the contrary, was analysed frame-by-frame, in order to verify the target fixed by each participant. The targets under analysis were "Yield here to pedestrians" vertical sign, zebra markings and median refuge island (only in the after-intervention condition). For each target the number of fixations and the duration of fixation were computed, multiplying by 33 ms the number of frames in which a single target object was fixated. An object was considered as fixated when it was fixed for a minimum duration of two frames (66 ms), as defined by the intersection area of the cross on the video (Fig. 5). The threshold of 66 ms, which is lower in comparison to a common filtering of 100 ms or higher as usually found in eye-tracking studies (Holmqvist et al., 2015), was dictated by the specific setting of this study that involved the recording of eye movements while driving. Although lower values are shown in literature (Velichkovsky et al., 2000; Domhoefer et al., 2000; Sodhi et al., 2002), Lantieri et al. (2015), Costa et al. (2018) and Costa et al. (2018) reported that in real traffic situations, that are highly dynamic driving contexts, fixation duration is much lower than in other contexts or in

306 experimental settings. In a real driving setting with a dynamic visual scene, as in the case of the present study,  
 307 rapid fixations may occur. Since the distribution of fixation duration is positively skewed and not normal,  
 308 medians are reported instead of means (Costa, Bonetti, et al., 2018; Costa, Simone, et al., 2018). For each  
 309 studied pedestrian crossing target the distance of first fixation was computed, considering any element of the  
 310 crosswalk (zebra markings, “Yield here to pedestrians” vertical sign, or median refuge island). The first fixation  
 311 for each crosswalk was assessed thanks to the synchronization of the speed data and the ET data, obtained  
 312 by the methodology used in Costa, Bonetti et al. (2018) and in Costa, Simone et al. (2018) (Fig. 5). The  
 313 obtained values were compared to the operative stopping distance which was computed using a mathematical  
 314 equation in accordance with the Italian regulations (Ministry of Infrastructures and Transports, 2001). The  
 315 operative stopping distance depended on the travelling speed (the vehicle speed at the first-fixation position),  
 316 on coefficient of available friction, and on road average longitudinal slope (4%).  
 317 In order to avoid conflicts between vehicles and pedestrians entering the road area from any side of it, the first  
 318 fixation distance should be longer than the operative stopping distance so that the driver has enough space  
 319 for a prompt yielding. The comparison between the distance of first fixation and the operative stopping distance  
 320 allows a correct evaluation of the yielding space under safe conditions (World Road Association, 2003; Jurecki  
 321 et al., 2014). When the distance of first fixation was shorter than the stopping distance, the driver’s behaviour  
 322 was classified as “unsafe”, while when the distance of first fixation of the crosswalk was longer than the  
 323 operative stopping distance the driver’s behaviour was considered as “safe”.  
 324 To assess the behaviour of drivers in the two situations before and after the combined intervention of  
 325 pedestrian crossings near the roundabouts, univariate ANOVA was used. The parameters that were evaluated  
 326 with the univariate ANOVA are the difference in median fixation duration of each pedestrian crossing element,  
 327 the distance of first fixation of crosswalks and the operating stopping distance at each single crosswalk and  
 328 for each participant.  
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330  
 331 Figure 5. Synchronization of the ASL eye-tracking mobile video output with the VBOX PRO video output.  
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### 334 3. Results

335 The Video VBOX Pro results showed that the drivers’ average speed when approaching the crosswalk (0 m  
 336 distance condition) was 32.64 km/h (SD = 6.35, N = 74) before and 27.04 km/h (SD = 9.19, N = 48) after the  
 337 intervention, with a reduction of 5.6 km/h. An ANOVA tested a significant difference:  $F(1, 138) = 2.97$ ,  $p = .04$ ,  
 338  $\eta^2 = 0.02$ .

339 Figure 6 shows the results of the comparison between the percentage of drivers that looked at zebra markings,  
 340 at “Yield here to pedestrians” vertical sign and at median refuge island, before and after the works.

341 The results were determined by 80 observations (10 participants  $\times$  4 crosswalks  $\times$  2 sides).

342 The performed statistical analysis revealed a significant increasing of drivers that looked at zebra markings  
 343 (+31.25%,  $\chi^2 = 7.11$ ,  $p = .002$ ) and at “Yield here to pedestrians” vertical sign (+8.75%,  $\chi^2 = 6.32$ ,  $p = .002$ ).  
 344 After the intervention 56.25% of drivers glanced at median refuge island which was not part of the crosswalk  
 345 design before the works.  
 346



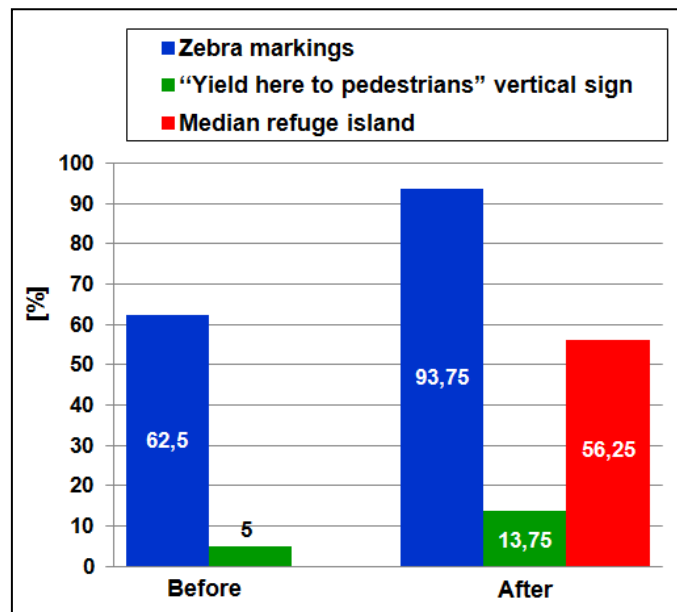


Figure 6. Percentage of drivers that looked at zebra markings, at "Yield here to pedestrians" vertical sign and at median refuge island, before and after the works, N = 80 observations (10 participants × 4 crosswalks × 2 sides)

Univariate ANOVAs were applied in order to test the difference in median fixation duration of each pedestrian crossing element before and after the works (Figure 7). The difference was significant for "Yield here to pedestrians" vertical sign:  $F(1, 27) = 4.02$ ,  $p = .02$ ,  $\eta^2 = 0.12$ . The average fixation time was 150 ms (SD = 46) before and 300 ms (SD = 200) after the works.

The difference was also significant for zebra markings:  $F(1, 62) = 9.17$ ,  $p = .002$ ,  $\eta^2 = 0.12$ . Before the median fixation was 267 ms (SD = 122), after the works it increased to 700 ms (SD = 317). The average fixation time at the median refuge island was 700 ms (SD = 62).

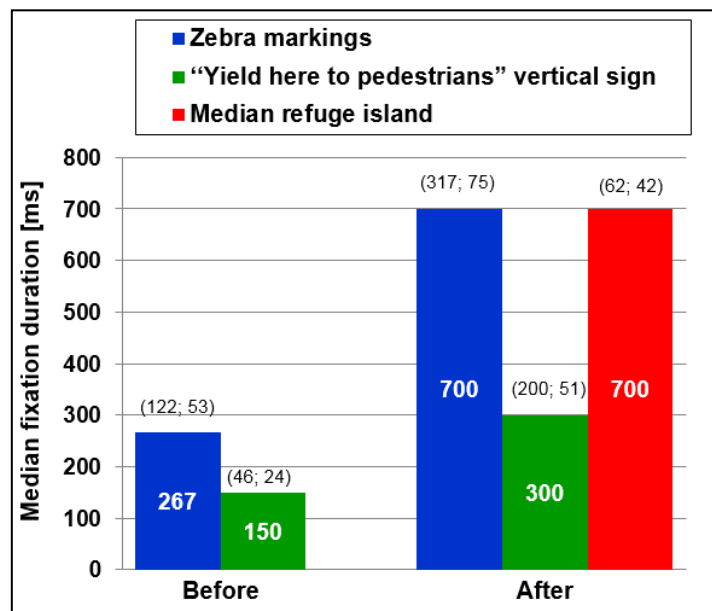


Figure 7. Before-after analysis of median fixation duration at the pedestrian crossing elements (standard deviation and number of observations are reported between parentheses).

Univariate ANOVAs were also applied in order to test and compare distance of first fixation of the crosswalks in before and after conditions. The mean distance increased from 21.98 m (SD = 16.76, N = 48) to 40.69 m (SD = 19.66, N = 73), showing a significant difference:  $F(1, 85) = 108.19$ ,  $p < .001$ ,  $\eta^2 = 0.37$ .

The operative stopping distance at each single crosswalk and for each participant was tested using ANOVA. The average operative stopping distance before was 39.30 m (SD = 17.22), while after the works it was 34.42 m (SD = 13.97), with a significant difference:  $F(1, 73) = 3.59$ ,  $p = .02$ ,  $\eta^2 = 0.04$ .

372 Obtained values showed that before the intervention 78.1% of the cases were “unsafe”, with operative stopping  
373 distances far exceeding the distance of first-fixation. After the intervention the “unsafe” cases decreased to  
374 30.1%, with a significant reduction of 48.0%. The difference was tested by a Chi-square test as follows:  $\chi^2 =$   
375 18.02,  $p < .001$ . After the zebra markings displacement and the installation of the median refuge island and of  
376 the “Yield here to pedestrians” vertical sign the crosswalk conspicuity and visibility increased and the drivers’  
377 first-fixation was at a distance that allowed a safe stop in case of pedestrians entering the crossing area.  
378 At the moment of first fixation of the crosswalk, the drivers’ mean speed changed was 37.94 km/h (SD = 10.91,  
379 N = 74) before and 31.03 km/h (SD = 11.25, N = 48) after the works, with a reduction of 7 km/h. The difference  
380 was significant:  $F(1, 85) = 4.73$ ,  $p = .02$ ,  $\eta^2 = 0.04$ .

381 The effect of driving speed on first-fixation distance was tested with a linear regression considering operating  
382 speed as independent variable and distance as dependent variable. The regression value was significant:  $t =$   
383 2.004,  $p < 0.001$ ,  $R^2 = 0.067$ . The standardized coefficient between the two variables amounted to  $\beta = 0.21$ ,  
384 showing that the less speed was, the longer the distance at which the drivers saw the crosswalk was.  
385

#### 386 4. Discussion

387 In the present study different engineering countermeasures, aimed to increase conspicuity and visibility of  
388 pedestrian crossings at roundabouts, have been tested in order to assess their impact on road safety. These  
389 countermeasures included installation of a median refuge island, displacement of zebra markings in advance  
390 of the intersection, and placement of “Yield here to pedestrians” vertical signs. The safety evaluation was  
391 performed by a before–after analysis of both speed and drivers’ visual behaviour approaching the crosswalks  
392 in a real road experimental setting. All obtained results confirmed that adopted countermeasures increased  
393 conspicuity and safety at pedestrian crosswalks, because drivers’ attention to the road increased and the  
394 speed decreased accordingly. The analysis of the drivers’ eye movements was very useful to assess the  
395 visibility of pedestrian crossings as well as to study the drivers’ behaviour and the data obtained may help to  
396 improve the crosswalk design in order to prevent accidents.

397 Statistical analysis of the number and duration of fixations confirmed that they were significantly higher after  
398 the new elements had been installed near the crosswalks. The drivers’ attention focused on the roadway with  
399 a decrease of distraction caused by the surrounding road environment. According to Bichicchi et al. (2017),  
400 zebra markings and median refuge island were the best perceived elements by all drivers, with a median  
401 fixation duration respectively of 700 ms, followed by “Yield here to pedestrians” vertical sign (300 ms).

402 The elements near the centre of the road were fixated longer than the vertical sign, probably because of their  
403 position and their angular distance from the line straight ahead the driver. This was also confirmed by Costa  
404 et al. (2014, 2018) and by Yuan et al. (2011), who found that vertical signs, falling outside the foveal visual  
405 field of the driver, required specific saccadic movements or peripheral vision to be seen. The more the angular  
406 distance increased, the poorer the visibility was, since the sign was seen at a shorter distance. On the contrary,  
407 zebra markings and median refuge island were placed on the road, directly in front of the drivers, and so they  
408 had a higher effectiveness in influencing the drivers’ behaviour.

409 These data are more significant considering that participants had never driven along the study route before.  
410 Previous studies, in fact, have shown that novice drivers have a longer eye-fixation duration than expert  
411 drivers, but the fixation location is differed between novice and expert drivers. Novice drivers tend to focus on  
412 roadside longer than expert drivers, to determine the position of their vehicles (Shinohara and Nishizaki, 2017;  
413 Mourant and Rockwell, 1972; Satoh, 1993; Laya, 1992). Drivers who are familiar with the route spend more  
414 time looking ahead and can better detect events that may lead to situations that affect traffic flow or cause  
415 collisions. The results lend support to the hypothesis that the peripheral area of the eye is used to monitor  
416 other vehicles and the road lane markers in order to direct the fovea for closer examinations when the situation  
417 demands it (Shinohara and Nishizaki, 2017).

418 After the intervention all the drivers detected the crosswalks in advance, since the mean distance of first fixation  
419 of crosswalk increased accordingly. They were seen at a longer distance increasing hazard anticipation and  
420 detection. Before the works, drivers saw the crosswalk at a very shorter distance (21.98 m), which didn’t allow  
421 them to adjust speed and slow down their velocity. After the countermeasures, drivers perceived the pedestrian  
422 crossings from a longer distance (40.69 m), and they continued to glance at the crosswalks while approaching  
423 them, enhancing their visual attention. This was due also to the average speed reduction approaching the  
424 crosswalk. After the works, in fact, the drivers perceived in advance the crosswalk presence and therefore they  
425 decelerated earlier reducing the probability of fatal accidents. The drivers’ average speed reduction was of 5.6  
426 km/h after the intervention.

427 The lower the speed, the longer the distance of crosswalks detection was. At a low speed the driver may tend  
428 to look at and monitor the road more carefully than at a high speed, better perceiving any critical element  
429 placed ahead. The longer the distance of first fixation of crosswalk, the longer the operative stopping distance  
430 of the drivers was. After the works, a reduction of 48.0% of the “unsafe” cases were obtained.

431 As said above, these data are very interesting considering that participants had never driven the study route  
432 before.

433 Several previous studies, in fact, have found that familiarity with the driving situation has a great influence on  
434 the driving speed. Expert drivers tend to drive faster than the novice drivers and, under increased speed

435 conditions, subject tended to fixate relevant items near the centre of the road with increased frequency  
436 (Spijkers, 1992). Drivers detect fewer elements in the central visual field when driving slowly and they detect  
437 fewer elements in peripheral vision when driving fast (Kayser and Hess, 1991; Miura, 1985 and 1987; Rogé et  
438 al, 2004).

439 A relatively small sample of drivers and situations was considered in this study and future studies will test the  
440 effects of a similar intervention on a larger sample. Nevertheless, the significant variations in the drivers'  
441 behaviour recorded after the works were particularly remarkable in terms of crosswalk visibility and conspicuity.  
442 Future researches might evaluate drivers' behaviour in the presence of a pedestrian on the crosswalk area.

443

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447

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681

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