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Road sign vision and driver behaviour in work zones

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ROAD SIGN VISION AND DRIVER BEHAVIOR IN WORK ZONES

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ABSTRACT

The effectiveness of roadwork signs on drivers' safety is a poorly investigated topic. The present study examined visual fixations of 29 participants to work zone signs, while driving 27 km along rural roads. The drivers' visual fixations on the work zones signs were recorded with an eye tracking device, synchronized to a GPS recorder that collected kinematic data. The routes crossed 23 roadwork zones, including a total of 69 vertical work zone signs. Visual behaviour to roadwork signs were compared to visual behaviour to permanent vertical signs. The results revealed that drivers glanced at both temporary and permanent signs along the roadwork areas with a similar 40% frequency. In addition, they glanced at single roadwork signs more often and for longer than at multiple-roadwork signs. The main findings of this paper lead to conclude that driver behaviour, investigated by comparing instant speed and visual fixations, is frequently unsafe.

KEYWORDS

1 Roadwork signs, Roadwork zones, Vertical road signs, Driver perception, Eye tracker, Speed,
2 Fixations.

3

4 1. INTRODUCTION

5 1.1 Safety in roadwork zones

6 Roadwork zones are unsafe locations, as they disrupt the drivers' expectations about the road
7 geometry, meaning that they have to make sudden adjustments to their driving speed. Recent
8 research seems to agree that the presence of work zones is likely to increase the crash rate
9 (Yang, Ozturk, Ozbay, & Xie, 2015).

10 Because of ageing roads, maintenance work is becoming ever more common, so that it is
11 possible to affirm that accidents at roadwork sites are likely to increase and, for this reason,
12 countermeasures should be taken to prevent them.

13 The overall knowledge about work zone safety was mainly referred to main roadways (such
14 as highways and motorways) and major worksites (those that in general relate to standardizing
15 road layouts). There is little research that addressed safety issues in roadworks in rural roads

16 that are simpler, smaller in size and generally short-termed. Despite that, even rural road
17 crashes may have a considerable social and economic cost.

18 An extensive literature who analyses work zone collisions mostly rely on simple approaches,
19 such as investigating crashes frequency, external factors, characteristics of the work zones
20 and the type of crash. Observational studies that compared crash rate before and during
21 roadworks have been carried out to test the safety level at specific roadway maintenance sites,
22 by assessing the increase in crash frequency caused by roadworks. Khattak, Khattak, &
23 Council (2002) examined the combined effect of increasing length and duration of freeway
24 worksites in California, finding that there was a significant increase in crash rate compared to
25 the baseline. According to the USA Transportation Research Board (TRB), the occurrence of
26 rear-end and fixed-object collisions increases in correspondence with work zones (Campbell
27 et al., 2012). Similarly, recent data on Italian roads indicate that, between 2007 and 2012, there
28 were 762 collisions in roadwork zones (with 21 fatalities and 1,252 injuries). Rear-end
29 collisions were the most frequent, followed by single-vehicle accidents and lateral crashes
30 caused by the driver changing lane (La Torre, Domenichini, & Nocentini, 2017). Besides crash
31 frequency, crash severity in roadwork areas was also investigated. A recent study revealed
32 that advanced-warning, activity and termination areas of a work zone were all associated with
33 higher injury severity crashes (Osman, Paleti, & Mishra, 2018).

34 Other investigations have similarly developed methodologies to predict crash frequency (Crash
35 Prediction Model), adapting the general equations of the Crash Modification Factor (CMF) to
36 roadworks. CMF is a multiplicative factor that computes the expected number and severity of
37 crashes after implementing a given countermeasure at a specific site (AASHTO - American
38 Association of State Highway and Transportation, 2010). Different methodologies and CMF
39 formulations were developed to estimate the expected number of crashes through the use of
40 prediction model weight (Gross, Persaud, & Lyon, 2010). Crash severity relating to work-in-
41 progress zones is connected to different factors, as the vehicle speed or the involvement of
42 road workers. On this latter point, Kröyer, Jonsson, & Várhelyi (2014) found that at increasing
43 speed there is a significant increase in fatal collisions involving pedestrians. More precisely,
44 they found that the risk of fatality in collisions between a car and a pedestrian is 4 to 5 times
45 higher at 50 km/h than at 30 km/h. Therefore, forewarn drivers about the presence of working
46 areas represent the simpler practice to induce a speed reduction.

47 However, speed limits are frequently ignored on road sections with hazardous conditions, such
48 as when there is work-in-progress. Bella (2009), for example, simulated a crossover work zone,
49 with the outcome that mean speed was below the limit only when drivers faced physical
50 constraints. It seems that drivers make adjustments to their driving speed in reaction to
51 contextual changes in the road, rather than simply in compliance with the road sign content.
52 This means that drivers are more likely to comply with speed limits if they see that they match

53 a concomitant danger, as workers or police on the road (Blackman, Debnath, & Haworth,
54 2014a). The drivers' average speed decreased only if they perceive the necessity to do so
55 (Finley, Jenkins, & McAvoy, 2015). A similar study also examined the drivers' subjective
56 evaluation about whether work zone features had any influence over their choice of speed.
57 The feature that was evaluated as most effective was workers activity, police presence and
58 speed feedback displays (Blackman, Debnath, & Haworth, 2014b).

59 A main factor in determining whether a crash will occur is linked to whether a work zone is
60 easily visible and recognized. Temporary road signs are the most common tools to achieve
61 both work zone conspicuity and legibility (Bella, 2009), because they inform drivers about the
62 oncoming road conditions beforehand. The effectiveness of signage is related to the "priming
63 effect", the ergonomic paradigm consisting in the anticipation of some information (stimulus)
64 that would influence the response to a subsequent stimulus. In this field, the presence of
65 warning signs informs the driver about the upcoming worksites and get him ready to take the
66 appropriate action before reaching the hazard. Several studies have proved that being warned
67 beforehand about something enables people to react more quickly, inducing a more correct
68 driving behaviour (Charlton, 2006; Crundall & Underwood, 2001). The capacity to respond to
69 the sign is however influenced by the experience of the context and by the overall driving
70 expertise.

71 Some studies support the theory that even unconsciously perceived signs (i.e., that drivers do
72 not recall later) are effective in terms of reducing speed, as they implicitly warn drivers about
73 hazards, inducing them to exert proper control over their vehicles (Fisher, 1992; Summala &
74 Hietamaki, 1984).

75

76 *1.2 Readability of roadwork signs*

77 Both temporary and permanent signage cover an important role in the passive protection of
78 vehicles, passengers, workers and site equipment, since they are used to signal work zones.
79 According to this, it is fundamental to consider their capacity to be easily readable.

80 Firstly, several studies supports the importance of visual graphics in signage equipment (Costa
81 et al., 2014; Ullman, Trout, & Dudek, 2009; Ullman & Brewer, 2014) and, moreover, the
82 European Union has set up standards for vertical road signs, including graphics such as shape,
83 background colour, border colour, size and symbols (Vienna Convention on Road Signs and
84 Signals, 1968).

85 Literature offers several studies investigating the role of sign visibility and legibility in relation
86 to the sight distance (Costa et al., 2014; Discetti & Lamberti, 2011; Zwahlen, 1995), but none
87 of them evaluated specifically temporary signage.

88 Regarding sign design (graphic content, positioning and orientation) Lewis (1989) made a
89 great effort in highlighting the importance of a standardization in work zone signs positioning,

90 also in terms of terminology and definitions. A correct positioning, in fact, means that the road
91 can be more easily monitored, which in turn can avoid the problem of not being warned about
92 the potential negative side-effects of the roadworks, which can include traffic jams, which are
93 a major factor in the increased risk of crashes (Beijer, Smiley, & Eizenman, 2004). In addition,
94 a recent study regarding sign positioning, confirmed that it plays a key role as it affected the
95 drivers' perception–response time and speed (Discetti & Lamberti, 2011). A correct positioning
96 practice, also, suggests to avoid sign overcrowding, as 'visual pollution' from roadside
97 information (intended as billboards, warnings and installations) can distract drivers (Edquist,
98 Horberry, Hosking, & Johnston, 2011) or let drivers to lose important information (Liu, 2005).
99 Besides, the content of roadwork signs is supposedly to be crucial for the comprehension of
100 drivers' reaction. Several ergonomics studies, in fact, confirm that sign effectiveness does not
101 depend solely on the readability, invoking thus the credibility principle. A study measuring
102 vehicle speed in the presence of different signs found that drivers lift their foot from the
103 accelerator more often and more pointedly when they saw signs they considered to be
104 significant (Summala & Hietamaki, 1984).

105

106 *1.3 Roadwork activity*

107 A relevant factor for the investigation of drivers' behaviour at work zones is the conspicuity of
108 roadworks, by which we mean the visibility of site operations, workers and active vehicles.
109 Visible site activity, in fact, seems to be an essential requirement on speed modulation.
110 According to the results of a recent study (Steinbakk, Ulleberg, Sagberg, & Fostervold, 2017),
111 higher speed was preferred at work zones without visible roadwork activity and roadwork
112 activity was the strongest predictor of preferred speed. An interesting study by Benekohal and
113 Wang (1994), involving more than one hundred drivers, computed the actual speeds that
114 drivers were travelling at when reaching a road site where work-in-progress was clearly
115 indicated, informing them that they were approaching an operational work site . The findings
116 revealed that the drivers' speed adjustment was strictly connected to their initial speed. Also,
117 it was noted that all the drivers, including those speeding, generally reduced their speed and
118 continued to do so while transiting through the work zone. "Extremely" speedy drivers
119 represented an exception, slowing down in the advance-warning area and speeding up
120 immediately after passing it.

121 Similarly, the drivers' choices of speed were investigated in presence or absence of road
122 workers. Here, the results show that drivers are significantly more cautious in the presence of
123 workers, as they chose to drive more slowly (Blackman et al., 2014b). Another study confirmed
124 that the size of this effect is dependent on whether the workers are conspicuous. If drivers see
125 solitary or small groups of workers, they are less likely to reduce their speed than if they see
126 larger groups of workers (Haworth, Symmons, & Mulvhill, 2002).

127 1.4 *The application of eye tracking techniques to roadwork zone safety*

128 Eye trackers make possible to investigate the integrated and complex relationship between
129 drivers, traffic, environment and road infrastructure (Bucchi, Sangiorgi, & Vignali, 2012; Dondi,
130 Simone, Lantieri, & Vignali, 2011). This technology allows the assessment of fixation events
131 (i.e., when the eyes focus on a specific point of the scene), distinguishing fixations from
132 saccades (i.e., quick movement of the eyes), providing a direct measure of whether signs are
133 glanced. In addition, fixation duration provides important information on the depth of visual
134 processing.

135 Literature offers a vast body of evidence that eye tracking technology could be exploited to
136 determine how road equipment affects drivers (Costa et al., 2014; Costa, Simone, Vignali,
137 Lantieri, & Palena, 2018; Filtness et al., 2017; Lantieri et al., 2015; Mantuano, Bernardi, & Rupi,
138 2017; Taylor et al., 2013; Topolšek, Areh, & Cvahte, 2016; Zwahlen, 1995), involving both
139 simulated and real driving environments.

140 Nevertheless, a few eye tracking applications has been carried out to investigate drivers' visual
141 behaviour at work zones. For example, drivers' gazing patterns were monitored in a virtual
142 scenario where there were traffic signs belonging to the maintenance roadwork operation. The
143 eye tracker recordings proved useful in concluding that repeated exposure to signs was
144 beneficial to drivers and that interference between permanent and temporary signs is to be
145 avoided, as the drivers' attention is split between them (De Ceunynck et al., 2015). Another
146 study focused on temporary dynamic message signs, and it found that drivers spent longer on
147 fixing their gaze on signs that warned about the presence of road workers (Rahman,
148 Strawderman, Garrison, Eakin, & Williams, 2017).

149 As most of the experimental research were conducted in driving simulators, this paper aims to
150 fill the gap analysing drivers' gaze to roadwork signs in a real driving test.

151

152 **2. METHODS**

153 *2.1. Participants*

154 Twenty-nine participants were recruited among researchers, graduate and undergraduate
155 engineering students. Twenty were men (mean age: 32.95 years, *SD*: 11.72, range: 19-56)
156 and 9 were women (mean age: 36.1 years, *SD*: 12.00, range: 22-54). They all held a regular
157 driving license for cars, with a mean driving expertise of 14.39 years (*SD*: 9.95) and a mean
158 value of kilometres per year of 14,770 (*SD*: 9,604). Participants had normal vision without
159 glasses or contact lenses, that prevented the recording of eye movements. They were not
160 informed about the true aim of the study, having been told instead that they were testing the
161 use of a mobile eye tracker device during a driving task. At last, their participation was
162 voluntarily.

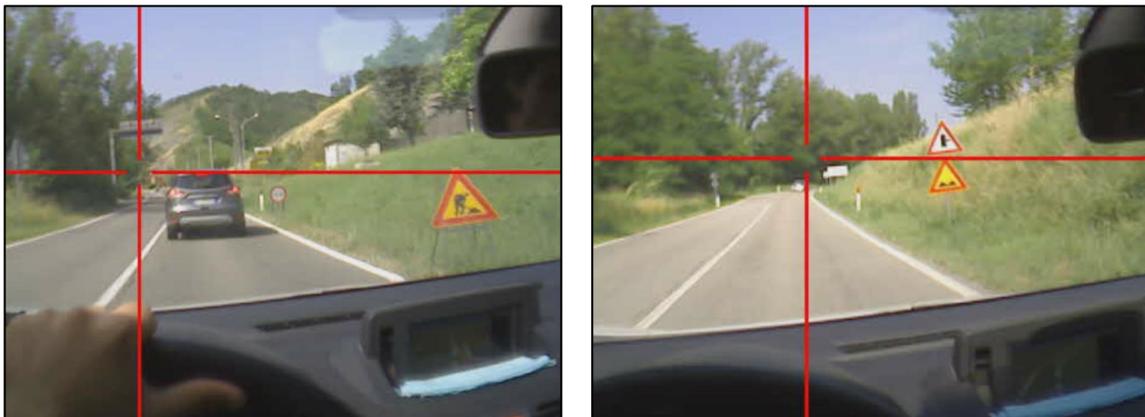
163

164 **2.2 Experimental settings**

165 Driving tests were carried out on rural roadways in Northern Italy, throughout the provinces of
166 Bologna and Reggio Emilia. The selected routes typically had high accident rate and many
167 scattered small-sized road maintenance work zones. The road geometry was consistent along
168 the route, and was a single carriageway with two 3.75 m wide lanes, a shoulder width of 1.5 m
169 (not always present), and a signalled speed limit of 70 km/h.

170 Along the experimental route, drivers encountered 23 small-sized roadwork zones, with no
171 reduction in lane width at either side. Urban roadworks were excluded from the data analysis.
172 In relation to the signs in the work zones, each driver encountered a total of 69 vertical signs,
173 all with static content, belonging to both temporary (yellow background) and permanent (white
174 background) road vertical signs. The signs with a yellow background were mostly warning
175 signs, while the permanent signs were mostly regulatory road signs. Ten of the considered
176 work zones displayed a single sign (roadworks of negligible length), while the remaining 13
177 work zones displayed multiple signs (more than two, with an average length of the work zone
178 of 152.61 m). The single signs were all placed at road level, mounted on tripods with an
179 elevation of 0.6-1.20 m from the road surface, beyond the edge-line markings. Work zones
180 with more than two signs included both tripod-mounted and pole-mounted signs, the latter with
181 a maximum height of 2.20 m and placed at 0.3÷1 m from the roadside, in compliance with
182 Italian regulations (Figure 1). Roadwork activity, in terms of presence of visible workers or
183 active vehicles, was encountered in 14 sites over the total of 23 included in the study.

184



185

186 Figure 1: Tripod-mounted temporary sign (left) and pole mounted temporary sign (right). All
187 temporary signs were triangular in shape, with a yellow background and a red border.

188

189 **2.3 Apparatus**

190 Experimental vehicles were a Fiat Panda and a BMW series 1 car. Data was collected from
191 9.30 to 12.00 and from 14.00 to 16.30, to avoid peak rush hours. Driving tests were conducted
192 under good weather conditions, with a dry road surface and complete visibility.

193 The test vehicles were provided with a Racelogic Video V-Box Pro, a GPS data logger capable
194 of detecting and recording kinematic parameters (forward and lateral acceleration, speed).
195 Two cameras and a GPS antenna, connected with cables to the Video V-Box, were positioned
196 on the top of the cars and recorded the external road scenario, as well as data on acceleration,
197 speed and GPS coordinates. Each driver was given a trial run to get used to the car before
198 starting out along the test route. Speed was recorded with an accuracy of 0.1 km/h and
199 distance accuracy was ± 50 cm. The recorded data were analysed using Performance Tools
200 software. The eye tracking equipment and the Video V-Box Pro equipment were kept on the
201 back seat of the car and were monitored by one of the experimenters, who was instructed not
202 to talk to the driver except if assistance was requested.

203 The combined use of eye tracking monitoring and vehicle kinematic data meant allowed an
204 accurate assessment of the driver' behaviour in work zones. Eye-movement data were
205 available for 29 drivers and kinematic data for 28 drivers, due to technical problem to the Video
206 V-Box equipment in one participant.

207 Eye movements were recorded with an ASL Mobile Eye-XG tracker. Two digital high-resolution
208 cameras were attached to lightweight eyeglasses. One camera recorded the visual scene
209 while the other camera targeted the participant's eye. The eye tracking recordings were only
210 carried out for the driver's right eye and a calibration process was conducted for each
211 participant. The calibration process took place in a parking lot in a stationary car and involved
212 asking the participants to look at a minimum of 15 visual points spread across the whole scene.
213 The calibration points were chosen between the vertexes and the centres of small objects of
214 the driver's visual scene.

215 During the tests, the eye movement sampling rate was 30 Hz (i.e., 33 ms time resolution).
216 Spatial accuracy was 0.5–1°. The ASL Mobile Eye-XG software allowed the researchers to
217 match the calibrated datasets with the video recordings and to create, for each participant, a
218 video showing the eye-fixations superimposed to the visual scene (example in Figure 1).

219

220 *2.4 Data analysis*

221 *2.4.1 Personal data*

222 Personal data (age, driving licence category, years of car driving, kilometres per year, accident
223 history, prior knowledge of the experimental route) were collected at the end of the experiment,
224 after the driving test. Self-evaluation of driving skills was asked to participants according to
225 four levels: "poor", "average", "good" and "excellent". In particular, 24% of the participants had
226 been responsible of at least one accident and 62% of them had a prior knowledge of the route
227 selected for this study.

228

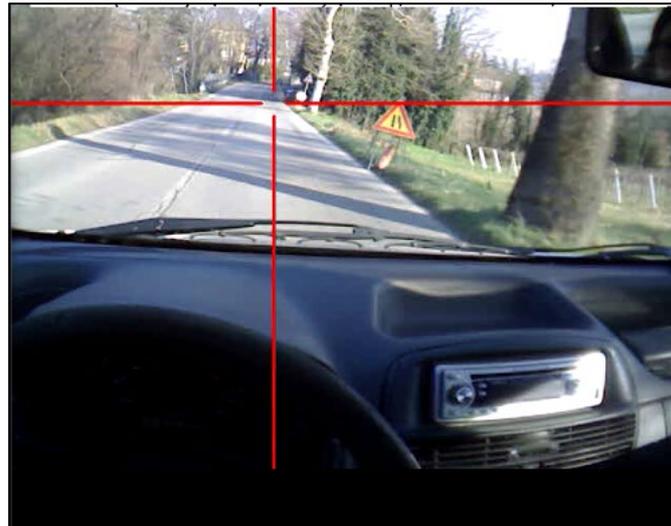
229 *2.4.2 Eye-movement data*

230 Drivers' eye fixations on the road signs were assessed through a frame-by-frame analysis of
231 the ASL Mobile Eye-XG video output. Drivers were considered to have fixated a work zone
232 sign if the fixation point (the intersection between the horizontal and vertical line in Figure 1)
233 was superimposed over the road sign area (AOI: Area of Interest) for at least two frames (66
234 ms), to avoid the inclusion of saccadic movements. Although research practice normally
235 considers higher temporal thresholds for the definition of a fixation (Holmqvist et al., 2011), the
236 authors' choice was justified by the highly dynamic environment in which eye movements were
237 recorded. Under such conditions, differently from a recording in a virtual environment or in a
238 more controlled setting as in a laboratory, the highly dynamic optical flow of a real driving
239 context implies a rapid sequence of saccades and short fixations (Costa, Simone, et al., 2018).
240 The total fixation duration was computed multiplying 33 ms by the number of frames in which
241 the road sign was fixated.

242 Once the scorer detected an eye fixation on a work zone sign, the distance of this visual fixation
243 (longitudinal distance on approach to the sign) was acquired by synchronizing the eye tracker
244 video with the Video-V-Box output (Figure 2). The distance between the first fixation to a road
245 sign and the position where the car was perpendicular to the sign (overtaking the sign) was
246 computed using the Video-V-Box distance parameter. In the case of multiple fixations, the
247 distance was computed considering the first fixation.

248

249



250



251

Figure 2: Video V-Box (bottom) and Mobile Eye Tracker (top) synchronization for the computation of the distance of first-fixation to a road sign.

252

253

254 2.4.3 Speed analysis

255 Speed was entered in the analysis considering these parameters:

- 256 - instant speed, as the speed at the time of first-fixation to the road sign;
- 257 - approaching speed, as the speed at 100 m before the first sign of the work zone;
- 258 - speed reduction, differential between the speed at the time of first-fixation and the
- 259 speed at the time the driver crossed the road sign;
- 260 - work zone speed: the average speed along the whole work zone.

261

262 3. RESULTS

263 3.1 Road sign fixation rates

264 Table 1 shows the fixation frequency and the absolute frequency of the road signs included in
265 the work zones considered in the study.

266 In decreasing order, the road signs that received more glances were: Slippery road (64.2%),
 267 Uneven road (53.85%), Generic danger (50.41%), Loose chippings (50%). The road signs that
 268 were glanced with a percentage lower than 50% were: No overtaking (47.92%), Roadworks
 269 (44.01%), Keep left (35.17%), Speed limit (35.17%), Work zone ahead (37.14%), Give priority
 270 to vehicles from opposite direction (28.57%), Work zone end (27.78%), Road narrows (22.5%),
 271 Modified visibility (14.29%), Hump (0%).

272

273 Table 1:

274 *Fixation frequency and absolute frequency for each road sign included in the work zones.*

Road sign	Sign icon	#	Fixation frequency
Roadworks		17	44.01%
Generic Danger		9	50.41%
Hump		2	0.00%
Road Narrows		3	22.50%
Loose Chippings		2	50.00%
Uneven Road		2	53.85%
Modified Viability		1	14.29%
Work Zone Ahead		4	37.14%
Work Zone End		2	27.78%
Slippery Road		2	64.29%
Give priority to vehicles from opposite direction		2	28.57%
Speed Limit		12	35.17%
No Overtaking		6	47.92%
Keep Left		5	35.78%
TOTAL		69	40.14%

275

276 Table 2:

277 *Fixation frequency for temporary and ordinary road signs along the work zones considered in*
 278 *the study.*

Sign classification	Sign typology	#	Fixation frequency
Temporary Signs (Yellow Background)	Warning	36	40.37%
	Direction	6	
Ordinary Signs (White Background)	Warning	2	39.78%
	Regulatory	25	

279

280 The overall mean fixation percentage, weighted according to the frequency of each sign, was
281 40.14% (*SD*: 17.09%).

282 The distinction between temporary and permanent signs was not critical for fixation frequency:
283 (mean value 40.37% and standard deviation 18.51 for temporary signs; mean value 39.78%
284 and standard deviation 14.11 for permanent signs) (Table 2).

285 Fixations on work zone signs were not influenced by age ($r = 0.07$, n.s.) or gender ($F(1,131) =$
286 0.282 , n.s.). Two linear regression models tested the effects of kilometres per year and years
287 of driving experience on the fixation percentage to the road signs included in the work zones.
288 Both regressions were not significant ($p = 0.58$ and $p = 0.37$ respectively).

289 Road sign positioning on approach to the work zones was also considered. Specifically, we
290 compared fixation frequency to the first work zone sign and the following road signs. The
291 fixation frequency was higher for the first sign (M: 41.74%, *SD*: 11.80), than for the following
292 road signs (M: 38.94%, *SD*: 17.87).

293 Fixation rate to the first temporary sign in the work zone was compared considering the
294 presence-absence of visible roadwork activity. For work zones with visible activity, the fixation
295 rate to the first temporary sign in the work zone increased to 62.96% (*SD*: 33.95). Chi-square
296 test was used and resulted equal to 5.7273 with a p-value of 0.0167.

297

298

299 3.2 Fixation duration

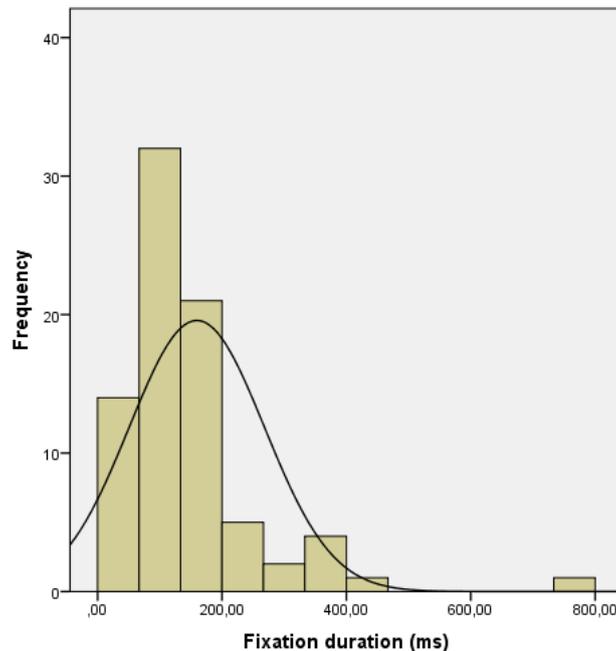
300 The distribution of fixation durations to the road signs is shown in Figure 3. Since the
301 distribution was not normal we report the median as a measure of centrality. The median
302 fixation length was of 132 ms (*SD*: 108.67, mode: 66). The distribution resulted to be highly
303 asymmetrical and positively skewed, with a kurtosis of 14.08 (*SD*: 0.052) and an asymmetry
304 of 3.06 (*SD*: 0.027). Both Kolmogorov-Smirnov and Shapiro-Wilk normality tests were
305 significant ($p < .001$), showing that the distribution was not normal.

306 The average fixation time was also specifically computed considering users' self-evaluation of
307 their driving skills. This was 107.25 ms (*SD*: 31.60) for the drivers who self-evaluated their

308 driving skills as “average”, 169.32 ms (*SD*: 104.34) for those professing “good” skills and
309 156.75 ms (*SD*: 45.34) for those who thought that they had “excellent” driving skills.

310 At last, results show that the fixation duration was not influenced by drivers’ age, gender or
311 prior experience with the experimental route.

312



313

314

Figure 3: Distribution of fixation duration to the road signs included in the study.

315

316 3.3 Fixation distance

317 Results revealed that first-fixation to work zones were generally recorded at a mean distance
318 of 43.5 m (*SD*: 32.5, range 15-80), increasing to 48.48 m (*SD*: 34.85) if ongoing activity was
319 present. The difference in first-fixation distances with or without ongoing visible activity was
320 not significant. In addition, the ANOVA test for assessing the effects of visible activity as an
321 independent variable on first-fixation distance resulted as non-significant $F(2, 74) = 2.257$.

322 Also, the mean distance of first fixation was not significantly different considering work zones
323 with one road signs versus work zones with multiple road signs.

324

325 3.4 Speed

326 In average, drivers fixated the first sign at each work zone at an instant speed of 55.34 km/h
327 (*SD*: 13.92). Speed limit (70 km/h) was exceeded by 14% of the participants.

328 The correlation between instant speed and distance of first fixation was equal to $r = 0.22$,
329 $p=0.049$. If work zones are distinguished by visible activity, none relevant relationship with
330 sight distance is obtained (Figure 4).

331

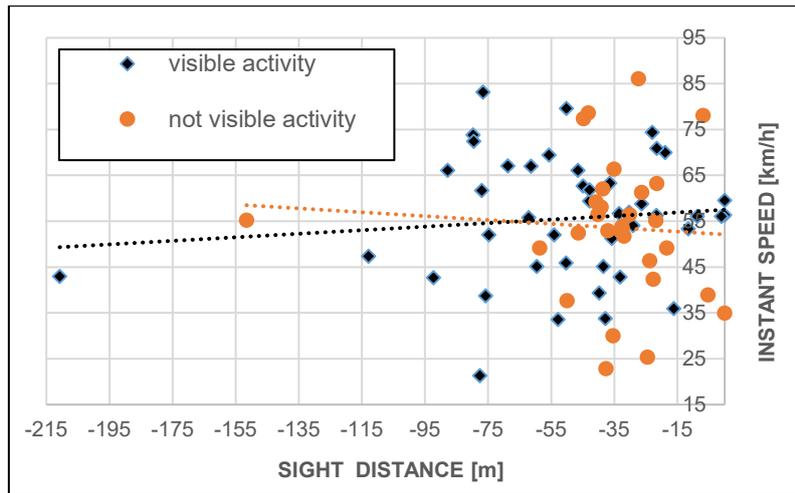


Figure 4. The distribution of first gaze distance/speed, by visible activity.

332

333

334

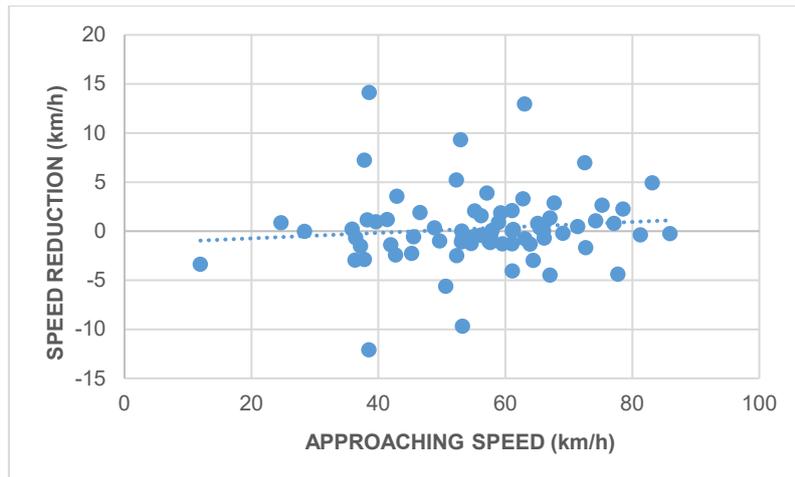
335 To determine whether the first fixations occurred at an instant speed that allowed a safe stop
 336 of the vehicle in the case of an unexpected obstacle, the distance of first-fixation was compared
 337 to the stopping distance. The latter is dependent on travelling speed and has been evaluated
 338 as the sum of the reaction distance (reaction time*initial speed) and braking distance,
 339 according to Italian regulations (Ministero delle Infrastrutture e dei Trasporti, 2001; World
 340 Road Association, 2003). The results showed that distance of first-fixation exceed stopping
 341 distance only in 19.48% of cases.

342 The other speed parameters were:

- 343 - average approaching speed: 55.69 km/h (*SD*: 14.04);
- 344 - average speed reduction: -21.89 km/h (*SD*: 26.85);
- 345 - average whole work zone speed: 52.21 km/h (*SD*: 12.18).

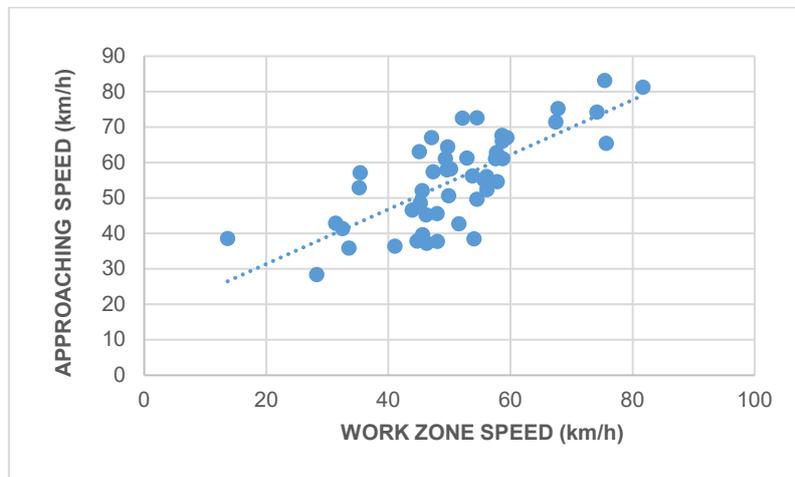
346 In terms of driving performance, the linear regression between approaching speed and speed
 347 reduction after the first fixation in the work zone was non-significant (Figure 5). To the contrary,
 348 the linear regression between approaching speed and the whole work zone average speed
 349 was significant ($R^2 = 0.55$ and $p = 0.05$ in Figure 6).

350



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Figure 5: Relationship between approaching speed and speed reduction.



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Figure 6: Relationship between work zone speed and approaching speed.

357 Speed reduction was significantly related to the driver's age ($r = 0.35, p < 0.001$) and driving
358 expertise ($r = 0.340, p < 0.001$). The work zone average speed results to be related to the
359 drivers' driving expertise ($r = -0.249, p=0.043$).

360

361 4. DISCUSSION

362 The drivers' visual behaviour revealed that work zone signage received very little attention
363 overall, with a mean 40.14% probability of looking at roadwork signs. The frequency was
364 similar for permanent and temporary road signs. In a recent previous study by Costa et al.
365 (2014), that used a similar experimental protocol but focused on roads without work zones,
366 vertical signs were generally looked at with a 25% frequency. This comparison clearly shows
367 that in work zones the frequency of road sign glances was higher than in normal road sections.
368 Assuming, however, that the work zone sign primary role is to trigger drivers' attention on
369 modified road setting, the signs failed to be glanced on average in 60% of the cases, which is
370 very high. This data is even more significant when considering that the participants wore an

371 eye tracker device, drove an unfamiliar car and knew that their driving behaviour was being
372 studied. This frequency, however, does not take into account a possible involvement of
373 peripheral vision in road sign detection and identification (Costa, Bonetti, Vignali, Lantieri, &
374 Simone, 2018).

375 Gender and age had no influence on fixation frequency, fixation length, fixation distance and
376 speed. For gender, the result confirms previous studies that have monitored eye movements
377 during driving (Costa et al., 2014; Lantieri et al., 2015). The sample, however, was rather low
378 and included only nine females.

379 Driving expertise had no influence on fixation frequency but correlated significantly with speed
380 reduction approaching the work zone and work zone average speed, coherently with Duncan,
381 Williams, & Brown, (1991).

382 About the knowledge of the route, drivers' experience of the route did not have any influencing
383 effect on the fixation frequency. The novelty effect potentially owned by work zone signs has
384 not influenced fixations neither for the drivers who already experienced that road section, nor
385 for unexperienced drivers. To the contrary, experienced drivers had a higher speed crossing
386 the work zones.

387 About the driving-skill self-evaluation, the drivers who judged their own driving skills as limited
388 drove more carefully exhibiting lower speed. This result is consistent with a study concerning
389 the reliability of drivers' self-reports (West, French, Kemp, & Elander, 1993). The same
390 category of drivers exhibited also lower fixation times to road signs.

391

392 *4.1 Work zone features*

393 Concerning work zone features, it is possible to consider that:

- 394 - about the single/multiple temporary signs, isolated single signs in work zones caught more
395 attention by the drivers (in terms of both frequency and average duration of the fixations)
396 than a sequence of signs along a work zone. This could be explained by the height of the
397 signs, as single signs frequently were tripod-mounted and positioned at the bottom of the
398 drivers' visual field (0.6-1.20 m from the road surface) and are perceived to be narrower,
399 confirming previous studies (Bella, 2009);
- 400 - about the ongoing activity on the work zone, ongoing visible activity on the work zone
401 slightly anticipated the distance of first-fixation to the road signs, probably because the
402 presence of dynamic elements on the visual scene increase the conspicuity and
403 detectability of the work zone. Ongoing visible activity had no influence on speed.

404

405 *4.2 Safety considerations*

406 The present study addressed the importance of understanding the influence of work zone
407 elements on drivers' road sign vision and behaviour. The comparison between average

408 approaching speed and average speed reduction revealed a useful test of the efficacy of
409 roadworks signage. Age and poor expertise were predictors for higher speed reductions, but
410 not for fixation rates. Also average whole work zone speed resulted adequate.

411 The analysis that had a direct implication for road safety is the comparison between the fixation
412 distance and the correspondent stopping distance. The sight distance, whose importance has
413 been extensively discussed in literature (Discetti & Lamberti, 2011), was frequently lower than
414 stopping distance. Practically, the inadequate effectiveness of signage would not allow a safe
415 stop in case of a sudden obstacle on the road. The knowledge provided would have a strong
416 practical utility for increasing work zone safety levels using appropriate signalling.

417 In fact, to generalize the presented outcomes, further driving tests should be devised to include
418 diversified road geometries and work zone settings (as length of the advance-warning area,
419 type of first sign, novel instalments as flashing lights, electronic variable message signs and
420 flaggers). On the contrary, authors highlight the importance of maintain the focus of attention
421 on small work zones and consequently on rural environment scenarios, as the risk of severe
422 crashes has been previously proved (Osman et al., 2018).

423 The reduced sample dimension represents a further limitation of the presented study and
424 certainly will be considered for future testing.

425

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429

430 **REFERENCES**

- 431 AASHTO - American Association of State Highway and Transportation. (2010). *Highway*
432 *Safety Manual* (2010th ed.). Washington, D.C.
- 433 Beijer, D., Smiley, A., & Eizenman, M. (2004). Observed Driver Glance Behavior at Roadside
434 Advertising Signs. *Transportation Research Record: Journal of the Transportation*
435 *Research Board, 1899*, 96–103. <https://doi.org/10.3141/1899-13>
- 436 Bella, F. (2009). Effects on driver behaviour of different signalling schemes of work zones.
437 *Advances in Transportation Studies, 18*, 55–68.
- 438 Benekohal, R., & Wang, L. (1994). Relationship between initial speed and speed inside a
439 highway work zone. *Transportation Research Record, 1442*, 41–48.
- 440 Blackman, R. A., Debnath, A. K., & Haworth, N. L. (2014a). Influence of visible work activity
441 on drivers' speed choice at roadworks. In *Proceedings of the 2nd Occupational Safety in*
442 *Transport Conference, CARRS-Q, Queensland University of Technology*, 1–10.
- 443 Blackman, R. A., Debnath, A. K., & Haworth, N. L. (2014b). Work zone items influencing
444 driver speeds at roadworks: worker, driver and expert perspectives. In *Australasian*

445 *Road Safety Research, Policing and Education Conference (RSRPE 2014), 12-14*
446 *November 2014, Melbourne, Victoria.*

447 Bucchi, A., Sangiorgi, C., & Vignali, V. (2012). Traffic Psychology and Driver Behavior.
448 *Procedia - Social and Behavioral Sciences, 53*, 972–979.
449 <https://doi.org/10.1016/j.sbspro.2012.09.946>

450 Campbell, J. L., Lichty, M. G., Brown, J. L., Richard M., C., Graving, J. S., Graham, J.,
451 O’Laughlin, M., Torbic, D., & Harwood, D. (2012). *NCHRP Report 600: Human Factors*
452 *Guidelines for Road Systems, Second Edition* (Second). Washington, D.C.:
453 Transportation Research Board. Retrieved from
454 http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_600Second.pdf

455 Charlton, S. G. (2006). Conspicuity, memorability, comprehension, and priming in road
456 hazard warning signs. *Accident Analysis and Prevention, 38*(3), 496–506.
457 <https://doi.org/10.1016/j.aap.2005.11.007>

458 Costa, M., Bonetti, L., Vignali, V., Lantieri, C., & Simone, A. (2018). The role of peripheral
459 vision in vertical road sign identification and discrimination. *Ergonomics*.
460 <https://doi.org/10.1080/00140139.2018.1508756>

461 Costa, M., Simone, A., Vignali, V., Lantieri, C., Bucchi, A., & Dondi, G. (2014). Looking
462 behavior for vertical road signs. *Transportation Research Part F: Traffic Psychology and*
463 *Behaviour, 23*, 147–155. <https://doi.org/10.1016/j.trf.2014.01.003>

464 Costa, M., Simone, A., Vignali, V., Lantieri, C., & Palena, N. (2018). Fixation distance and
465 fixation duration to vertical road signs. *Applied Ergonomics, 69*, 48–57.
466 <https://doi.org/10.1016/j.apergo.2017.12.017>

467 Crundall, D., & Underwood, G. (2001). The priming function of road signs. *Transportation*
468 *Research Part F: Traffic Psychology and Behaviour, 4*(3), 187–200.
469 [https://doi.org/10.1016/S1369-8478\(01\)00023-7](https://doi.org/10.1016/S1369-8478(01)00023-7)

470 De Ceunynck, T., Ariën, C., Brijs, K., Brijs, T., Van Vlierden, K., Kuppens, J., Van Der
471 Linden, M., & Wets, G. (2015). Proactive Evaluation of Traffic Signs Using a Traffic Sign
472 Simulator. *European Journal of Transport and Infrastructure Research (EJTIR), 15*(2),
473 184–204.

474 Discetti, P., & Lamberti, R. (2011). Traffic Sign Sight Distance for Low-Volume Roads.
475 *Transportation Research Record: Journal of the Transportation Research Board, 2203*,
476 64–70. <https://doi.org/10.3141/2203-08>

477 Dondi, G., Simone, A., Lantieri, C., & Vignali, V. (2011). Bike lane design: The context
478 sensitive approach. *Procedia Engineering, 21*, 897–906.
479 <https://doi.org/10.1016/j.proeng.2011.11.2092>

480 Duncan, J., Williams, P., & Brown, I. (1991). Components of driving skill: experience does
481 not mean expertise. *Ergonomics, 34*(7), 919–937.

482 Edquist, J., Horberry, T., Hosking, S., & Johnston, I. (2011). Effects of advertising billboards
483 during simulated driving. *Applied Ergonomics*, 42(4), 619–626.
484 <https://doi.org/10.1016/j.apergo.2010.08.013>

485 Filtness, A. J., Larue, G., Schramm, A., Fuller, J., Rakotonirainy, A., Han, C., & Cairney, P.
486 (2017). Safety implications of co-locating road signs: A driving simulator investigation.
487 *Transportation Research Part F: Traffic Psychology and Behaviour*, 47, 187–198.
488 <https://doi.org/10.1016/j.trf.2017.04.007>

489 Finley, M. D., Jenkins, J., & McAvoy, D. S. (2015). Motorists' Speed Response to
490 Nonvariable and Variable Work Zone Speed Limits and Other Work Zone Conditions.
491 *Transportation Research Record: Journal of the Transportation Research Board*, 2485,
492 70–77. <https://doi.org/10.3141/2485-09>

493 Fisher, J. (1992). Testing the Effect of Road Traffic Signs' Informational Value on Driver
494 Behavior. *Human Factors*, 34(2), 231–237.
495 <https://doi.org/10.1177/001872089203400208>

496 Gross, F., Persaud, B., & Lyon, C. (2010). *A Guide to Developing Quality Crash Modification*
497 *Factors. Report No. FHWA-SA-10-032*. Washington, DC.

498 Haworth, N., Symmons, M., & Mulvihill, C. (2002). *Safety of Small Workgroups on Roadways*.
499 Victoria, Australia.

500 Holmqvist, K., Nyström, M., Andersson, R., Dewhurst, R., Jarodzka, H., & Weijer, J. Van De.
501 (2011). *Eye Tracking: A comprehensive guide to methods and measures*. Oxford:
502 Oxford University Press.

503 Khattak, A. J., Khattak, A. J., & Council, F. M. (2002). Effects of work zone presence on
504 injury and non-injury crashes. *Accident Analysis and Prevention*, 34(1), 19–29.
505 [https://doi.org/10.1016/S0001-4575\(00\)00099-3](https://doi.org/10.1016/S0001-4575(00)00099-3)

506 Kröyer, H. R. G., Jonsson, T., & Várhelyi, A. (2014). Relative fatality risk curve to describe
507 the effect of change in the impact speed on fatality risk of pedestrians struck by a motor
508 vehicle. *Accident Analysis and Prevention*, 62, 143–152.
509 <https://doi.org/10.1016/j.aap.2013.09.007>

510 La Torre, F., Domenichini, L., & Nocentini, A. (2017). Effects of stationary work zones on
511 motorway crashes. *Safety Science*, 92, 148-159.
512 <https://doi.org/10.1016/j.ssci.2016.10.008>

513 Lantieri, C., Lamperti, R., Simone, A., Costa, M., Vignali, V., Sangiorgi, C., & Dondi, G.
514 (2015). Gateway design assessment in the transition from high to low speed areas.
515 *Transportation Research Part F: Traffic Psychology and Behaviour*, 34, 41–53.
516 <https://doi.org/10.1016/j.trf.2015.07.017>

517 Lewis, R. M. (1989). Work-Zone Traffic Control Concepts and Terminology. *Transportation*
518 *Research Record*, 1230, 1–11.

519 Liu, Y. C. (2005). A simulated study on the effects of information volume on traffic signs,
520 viewing strategies and sign familiarity upon driver's visual search performance.
521 *International Journal of Industrial Ergonomics*, 35(12), 1147–1158.
522 <https://doi.org/10.1016/j.ergon.2005.06.009>

523 Mantuano, A., Bernardi, S., & Rupi, F. (2017). Cyclist gaze behavior in urban space: An eye-
524 tracking experiment on the bicycle network of Bologna. *Case Studies on Transport*
525 *Policy*, 5(2), 408–416. <https://doi.org/10.1016/j.cstp.2016.06.001>

526 Ministero delle Infrastrutture e dei Trasporti (2001). Norme Funzionali Geometriche per la
527 Costruzione delle Strade.

528 Osman, M., Paleti, R., & Mishra, S. (2018). Analysis of passenger-car crash injury severity in
529 different work zone configurations. *Accident Analysis and Prevention*, 111(2018), 161–
530 172. <https://doi.org/10.1016/j.aap.2017.11.026>

531 Rahman, M. M., Strawderman, L., Garrison, T., Eakin, D., & Williams, C. C. (2017). Work
532 zone sign design for increased driver compliance and worker safety. *Accident Analysis*
533 *and Prevention*, 106, 67–75. <https://doi.org/10.1016/j.aap.2017.05.023>

534 Steinbakk, R. T., Ulleberg, P., Sagberg, F., & Fostervold, K. I. (2017). Analysing the influence
535 of visible roadwork activity on drivers' speed choice at work zones using a video-based
536 experiment. *Transportation Research Part F: Traffic Psychology and Behaviour*, 44, 53–
537 62. <https://doi.org/10.1016/j.trf.2016.10.003>

538 Summala, H., & Hietamaki, J. (1984). Drivers' immediate responses to traffic signs.
539 *Ergonomics*, 27(2), 205–216. <https://doi.org/10.1080/00140138408963478>

540 Taylor, T., Pradhan, A. K., Divekar, G., Romoser, M., Muttart, J., Gomez, R., Pollatsek, A., &
541 Fisher, D. L. (2013). The view from the road: The contribution of on-road glance-
542 monitoring technologies to understanding driver behavior. *Accident Analysis and*
543 *Prevention*, 58, 175–186. <https://doi.org/10.1016/j.aap.2013.02.008>

544 Topolšek, D., Areh, I., & Cvahte, T. (2016). Examination of driver detection of roadside traffic
545 signs and advertisements using eye tracking. *Transportation Research Part F: Traffic*
546 *Psychology and Behaviour*, 43, 212–224. <https://doi.org/10.1016/j.trf.2016.10.002>

547 Ullman, B. R., Trout, N. D., & Dudek, C. L. (2009). Use of Graphics and Symbols on Dynamic
548 Message Signs: Technical Report, 7(2).

549 Ullman, G., & Brewer, M. (2014). Driver Perceptions of Traffic-Calming Versus Active
550 Enforcement Efforts in Work Zones. *Transportation Research Record: Journal of the*
551 *Transportation Research Board*, 2425, 25–31. <https://doi.org/10.3141/2425-04>

552 Vienna Convention. (1968). Protocol on road signs and signals. In *Journal of*
553 *chromatographic science*, 51. <https://doi.org/10.1093/chromsci/bms220>

554 West, R., French, D., Kemp, R., & Elander, J. (1993). Direct observation of driving, self
555 reports of driver behaviour, and accident involvement. *Ergonomics*, 36(5), 557–567.

556 <https://doi.org/10.1080/00140139308967912>
557 World Road Association (PIARC), 2003. Road safety manual.
558 Yang, H., Ozturk, O., Ozbay, K., & Xie, K. (2015). Work zone safety analysis and modeling: a
559 state-of-the-art review. *Traffic Injury Prevention, 16*(4), 387–396.
560 <https://doi.org/https://doi.org/10.1080/15389588.2014.948615>
561 Zwahlen, H. T. (1995). Traffic sign reading distances and times during night driving.
562 *Transportation Research Record, 1495*, 140–146.
563