

**DOES ROADSIDE VEGETATION AFFECT DRIVING PERFORMANCE?
A DRIVING SIMULATOR STUDY ON THE EFFECTS OF TREES ON THE DRIVER'S SPEED
AND LATERAL POSITION**

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ABSTRACT

This study investigated the effects of roadside vegetation on driving performance on a two-lane rural road. Forty-four participants drove along seven different roadside tree configurations implemented in a driving simulator. Configurations were characterized by two offsets of trees from the road edge (1.5m, 4.0m) and three spacings between trees (10.0m, 17.5m, 25.0m) located on the roadside of a 6.0m wide two-lane rural road. One additional configuration, without trees, was used as the baseline condition. The investigation was developed over five geometric elements: sharp/gentle, left/right curves and tangent. Compared to the baseline condition, it was found that when trees were close to the road edge drivers significantly decreased their speed and moved towards the road centerline. On the contrary, when the offset of trees increased, drivers adopted higher speeds, increasing the distance from the road edge but with a lower left lateral displacement. This occurred along all five geometries, especially on sharp curves. Tree spacing did not affect the driver's speed but significantly influence the lateral position: drivers moved further away from the road edge when tree spacing decreased.

The results demonstrate that drivers balance the useful guidance information that roadside trees provide with the risk associated with their presence: when trees are far, the sense of guidance is predominant and drivers adopt higher speeds; when trees are close, they are seen as a risk by drivers who consequently slow down and move further away from them. Such driving behaviour has direct impacts on the safety implications of roadside trees.

INTRODUCTION

A single-vehicle accident includes run off the road and head-on collisions with an obstacle and is often related to incorrect direction and surplus speed or force (excess acceleration or braking). “Loss of control” accidents are usually a significant component of single-vehicle accidents, mainly caused by inappropriate speed and failure to maintain proper lateral position along the roadway alignment (especially in curves (1)). The European project Roadside Infrastructure for Safer European Roads (RISER (2)) investigated the crash data in seven European Countries and found that, although only 10 percent of the crashes are single-vehicle accidents, they accounted for 45 percent of all fatal crashes. According to the European Road Safety Observatory (ERSO (3)), if only single-vehicle accidents are considered, then almost 130,000 persons had been killed in 19 European Countries from 2001 to 2010, corresponding to one third of all traffic accidents fatalities. Moreover, 70% of fatalities from single-vehicle accidents occurred outside urban areas, especially on two-lane rural roads. In Italy (4), the average number of fatal crashes per 100 run off the road accidents is 4.0, whereas for all the accidents the average is 1.9. According to RISER (2), the main reason for this high crash rate is due to an “unforgiving” road design that can yield to a considerable increase in the severity of crashes.

Therefore, it is evident that roadside elements like vegetation, trees and guardrail barriers play a crucial role in both the outcomes of loss of control and run off the road, as well as in the way drivers perceive the road edge and alignment and behave accordingly. These two issues could be related to the concepts of a forgiving road (2) and a self-explaining road (5), respectively.

With respect to the first concept, the RISER project (2) addressed the risks and consequences of vehicles leaving their travel lane and experiencing a violent event in the areas bordering the roadway. It provided a set of best practice guidelines for improving the state of roadside safety in Europe. Moreover, a set of guidelines for safer road design are published all over the world and several studies have been carried out to assess the safety effects of roadside treatments. According to Nitsche et al. (6), it is possible to group these treatments in three categories: removing/relocating obstacle, modifying and shielding the obstacles. However, when the obstacle is a tree or a line of trees close to the road edge, due to the high cost of removal, it is usually preferred to protect the obstacles by means of barriers in order to reduce the severity of potential accidents.

With respect to the second issue, some authors have evaluated the effects of roadside elements on driver’s perception of roadway geometry by analyzing driving performance in terms of speed, lateral position (7) – (9) and driver’s risk perception (10), (11). Although roadside features could enhance the safety level of a road (i.e. reduce stress, decrease road rage and alleviate depression (12), (13)) and improve driver’s perception of road edge (7), (14) – (16), an in-depth knowledge of driving performance, as influenced by the roadside itself, is surely needed. It is particularly true for two-lane rural roads lined with trees, especially when they feature a narrow cross section. This type of infrastructure is quite frequent in all road networks, and is often characterized by high crash rates. For this type of road, the likelihood and severity of collisions with a fixed object, in case of run off the road, are higher, especially when the roadside is not made to be more forgiving.

This study aims to evaluate the effects of roadside trees on drivers’ performance in terms of speed and lateral position along a narrow two-lane rural road lined with trees. The outcomes may be used for 1) understanding the safety implications of existing roads lined with trees, by means of analyzing the relationships between driving performance and the characteristics of the trees (i.e. offset from the road edge and density) along several geometries of the roadway alignment, and 2) evaluating the appropriateness of planting new trees along the roadside as speed-reducing measures which could ultimately decrease the likelihood of run off the road accidents and head-on collisions.

In other words, the overall objective of this study is to tackle the critical issue of the roadway environment from the viewpoint of the driver, by analyzing a set of roadside configurations and geometry elements of the roadway alignment. To achieve this objective, a full comprehensive study is carried out using the driving simulator of the Inter-Universities Research Centre for Road Safety (CRISS) at Roma Tre University.

THE EFFECTS OF ROADSIDE VEGETATION ON DRIVER'S BEHAVIOR

Several studies aimed at investigating the safety implications of roadway vegetation and trees, or other roadside objects, have been carried out. These studies were usually based on field investigations, driving simulator researches, or static visual evaluations. However, the outcomes have been limited and quite conflicting.

Naderi et al. (7) used driving simulation to compare driving speed in suburban and urban roads with and without trees along the roadside. The authors recorded a positive effect on driver's perception of safety of roads lined with trees, as they aided drivers with sensing the edge of the road. In another study, Naderi et al. (11) found a reduction of almost 5 km/h in mean speed when trees were present along the suburban landscape.

Using a case-wise visual evaluation model of comfort levels for roadways with different lane widths, clear zone widths, vegetation densities and barrier types, Stamatiadis et al. (15), (16) found that vegetation type and density, barrier type and roadway width have a significant effect on driver discomfort that could potentially affect the driver's choice of speed. Specifically, an increase in discomfort was recorded for narrow roadways with dense vegetation. The authors affirmed that roadside features and certain road design elements can be used to affect the driver's operating speeds.

In a driving simulator study, Van Der Horst and De Ridder (14) analyzed the influence of roadside features (trees, guardrails, barriers, panels and emergency lanes) of a two-lane rural road on the drivers' speed and lateral placement. Specifically, they found that trees influenced the driver's speed when they were close (2 m) to the road edge; however, this effect faded rather quickly. In fact, when trees were more than 4.5 m from the lane edge they did not affect the driver's performance.

Jamson et al. (17) found that trees are not seen by the drivers as an immediate threat. Using a driving simulator, the authors analyzed the effects of several speed-reducing treatments in different road environments and found that placing trees on the roadside has no effect on driver's speed on curve and village entry of two-lane rural roads. In the experiments, the authors used 11 m high trees located on average 2 m from the road edge and separated by 5 m on either side of the roadway. In contrast to the findings of Van Der Horst and De Ridder (14), trees did not affect driving speed even when they were close to the road edge.

Fitzpatrick et al. (9) recently investigated the effects of the clear zone size and the presence of roadside vegetation on driving performance. They used a crash data analysis, an online static evaluation and a field validation. In a first phase of the study, 100 drivers had to select the operating speed by watching several videos reproducing both virtual and real driving scenarios characterized by four clear zone/vegetation density combinations: small clear zone (<1.5 m) with dense vegetation; medium clear zone (from 1.5 m to 4.6 m) with dense vegetation; large clear zone (> 4.6 m) with dense vegetation; large clear zone with sparse vegetation. They found that speed increased as the size of the clear zone increased for real drive videos, while no significant differences were recorded amongst the selected speeds over simulation videos. In the field, however, the speeds and lateral positions were found statistically different amongst the four combinations. The authors concluded that a driving simulator study for an in-depth investigation is needed to determine the ideal clear zone size/vegetation density combinations for improving roadside safety and containing the cost of tree removal.

Recently, Bella (8) analyzed the effect of three roadside configurations (only trees, trees and barriers, trees and barriers having undergone a treatment) along a two-lane rural road lined with trees on driving performance, in relation to different cross-sections and geometric elements. The author used the same driving simulator of the present study. The main findings demonstrated that driver's behavior was only influenced by the road cross-sections and geometric elements but not by the roadside configurations. It was affirmed that, although the presence of trees along the road represents a factor that increases the severity of run off the road accidents, drivers do not change their behavior when barriers are not present and trees are not protected.

With the overall aim of establishing a relationship between driver fatigue and monotonous road environment, Zhao and Rong (18) used a driving simulator implementing several scenarios by varying

the density of roadside vegetation. It was found that the optimal spacing of roadside vegetation to keep drivers alert was between 5 and 10 km.

Based on the above findings, it is possible to conclude that most of the studies pointed out that a deeper knowledge of the driver's risk perception and driving performance on roads lined with trees is needed for both improving roadside safety and evaluating the potential use of trees as speed-reducing treatments. With respect to the safety of these roads, the conclusions of the studied literature agree about recommending a major effort to dedicate to the development of comprehensive models of how drivers balance the potential useful guidance information that roadside elements (such as trees) could provide with the risk that is associated with their presence.

In these terms, there are no full comprehensive studies that examined driving performance by varying tree density (or spacing) and offset from the edge of the road. Moreover, as already discussed, the few literature studies that investigated the effects of roadside trees on driving performance provide quite conflicting findings. Finally, the effects of vegetation on driving performance have never been investigated on roadways characterized by narrow cross-sections despite they are really frequent in all road networks and could be considered highly unforgiving in terms of speeds and trajectory mistakes.

METHOD

Apparatus

The experiments were performed using the fixed-based driving simulator of the Inter-Universities Research Centre for Road Safety (CRISS) at Roma Tre University (Figure 1).

It consisted of a real car with a force-feedback steering wheel, brake pedal and accelerator. The system was widely validated in previous studies (19), (20) and used for evaluating driving performance in terms of speed, acceleration and trajectory under different driving conditions and road environments (21) - (28).

Independent Measures

Three independent measures were manipulated in this study:

1. Roadway geometry: in this experiment two curve radii were investigated in both directions. The first was 100 m radius that, according to Italian guidelines (29), represents the minimum radius for the type of rural road here investigated. The design speed of this curve is 60 km/h. In this study, this curve was referred to as sharp curve. The second radius was 400 m wide with a design speed of 100 km/h. This curve was referred to as gentle curve. Moreover, a tangent section was also investigated. Therefore, the roadway geometry manipulation included five options: sharp right curve, sharp left curve, gentle right curve, gentle left curve, and tangent.
2. Offset of roadside trees (o): two different offsets of the trees from the edge of the road pavement were investigated: 1.5 m and 4.0 m.
3. Spacing of roadside trees (s): trees were positioned at three regular intervals corresponding to an average spacing of 10.0 m, 17.5 m and 25.0 m, respectively.

A roadside configuration with no trees was assumed as the baseline condition. Therefore, seven roadside tree configurations (for five geometries) were investigated according to Table 1.

Dependent Measures

The dependent measures selected for evaluating the effects of independent measures on driving performance were driving speed and lateral position. This last is referred to as the distance from the centre of the vehicle to the road centerline and increases when the vehicle shifts to the right away from the centerline. Both measures were processed to obtain the average values amongst the sample of participants for each combination of the investigated independent variables.

Simulated Road Scenarios

In order to accommodate the combinations of independent variables under study, four scenarios were implemented in the simulator. Each scenario reproduced exactly the same two-lane rural road, composed

of two lanes of 3.0 m each with no shoulders. Seven different roadside tree configurations, each with five variations of road geometry, were included into the four scenarios in such a way that each scenario was characterized by at least three different segments of tree configurations. Figure 2 shows some pictures of the simulations. Between two different segments of roadside tree configurations, a transition segment was included in order to vary the characteristics of the trees. Each scenario was 10 km in length, and took approximately 9 min to cross. It was designed in such a way that two horizontal curves were separated by one tangent of 0.5 km in length. Low traffic was present in the opposite lane; however, drivers were not constrained by vehicles ahead (free-vehicle condition).

Procedure

The full experiment included six parts: 1) general instructions to participants and answering a pre-drive questionnaire with some personal data; 2) training drive in the simulator for approximately 10 minutes; 3) driving on two of the four scenarios (with the order counterbalanced among drivers); 4) 1 hour of rest in order to re-establish psychophysical conditions similar to those at the beginning of the experiment; 5) driving on the other two scenarios; 6) filling out a post-drive evaluation questionnaire about the discomfort experienced during the experiment.

Participants

The sample of participants selected for the experiments was composed of forty four volunteers recruited from students and staff at the Department of Engineering at Roma Tre University. The participants had to respect the following constraints: no experience with the driving simulator, at least 4 years of driving experience, and an average annual driven distance on rural roads of at least 3,000 km. Two of the participants who completed the driving tests noted that they had experienced a degree of discomfort, as revealed in the post-drive questionnaire. Consequently, they were excluded from the post processing of data. Two others were also excluded due to problems with the recording system of simulation.

In the sample of the forty remaining drivers, the validation of drivers simulation output was performed, considering as outliers those drivers whose average speed along a single geometric element of the road alignment in one configuration was higher than three standard deviations (SDs) from the sample's average speed on the same geometry. It was decided to exclude from the analysis the drivers that were considered outliers in more than 10% of the cases (more than 4 of the 35 combinations of the independent variables). Under such conditions, two drivers were further excluded from the analysis.

Thus, the final sample consisted of 38 drivers (26 men and 12 women) with an average age of 26.1 years (SD = 4.1 years), ranging from 22 to 47 years. Their average driving experience was 7.8 years, with an average annual driven distance on rural roads of about 9,000 km.

RESULTS AND DISCUSSION

The driving speeds and lateral positions were examined using ANOVA with repeated measures. Firstly, an ANOVA 5x7 was performed, with respect to the geometric element (2 curve radii for 2 directions and one tangent) and the roadside tree configuration (from A to G, see Table 1), considered as within-subject factors. The objective of ANOVA was to evaluate the differences in driving performance amongst the seven configurations (including the baseline configuration with no trees) for the geometries investigated. Secondly, an ANOVA 5x2x3 was performed in order to verify whether the geometric element, the tree offset (2 levels: 1.5 m and 4.0 m), and the tree spacing (3 levels: 10.0 m, 17.5 m, 25.0 m) affect both the driving speed and lateral position.

The driving speeds and lateral positions were found to be normally distributed (using the Kolmogorov-Smirnov test). For multiple comparisons, Bonferroni correction was used. Table 2 gives a summary of the average values and standard deviations (SD) of the drivers' speeds and lateral positions for every combination of the independent variables. Table 3 shows the main and interaction effects of the independent variables on driving speed and lateral position.

Speed

The results of ANOVA 5x7 revealed a significant main effect of the geometric element on the average speed (confirmed also by ANOVA 5x2x3). A contrast analysis revealed significant differences between all the geometries investigated, except for curves characterized by the same radius but with different directions. In fact, the speed difference recorded between right and left curves of the same radius was 1.15 km/h for sharp curves and 0.81 km/h for gentle curves. As expected, the lowest speeds were recorded on sharp curves (66.98 km/h), followed by gentle curves (92.84 km/h) and tangent (101.90 km/h). The results corresponded to those expected: the average speed on curve increases when the curve radius is wider and reaches its maximum values on the tangent. Conversely, the direction of the curve did not affect the drivers' choice of speed. The results are consistent with the Italian design guidelines (29) that somewhat assume the same design speeds as for the investigated geometric elements.

The first ANOVA also revealed a main effect of the roadside tree configuration on the average speed. Pairwise comparisons revealed significant differences between all the configurations that were characterized by a different offset of trees from the road edge. Specifically, the speeds on configurations A, B and C (on average 80.09 km/h) were significantly lower than the speed on configuration G (84.43 km/h) which itself was significantly lower than the speeds on configurations D, E and F (on average 88.49 km/h). The second ANOVA confirmed such significant effect of the tree offset on driving speed. Figure 3 shows the values of speed and lateral position averaged amongst the configurations characterized by the same tree offset for each geometric element. Moreover, the percent differences with baseline condition (G) are also provided.

A possible explanation of such result is that the drivers balance the potential useful guidance information that roadside trees provide with the risk that is associated with their presence. Specifically, compared to the baseline condition, when the trees are far away, the sense of guidance is predominant and drivers adopt a higher speed according to the increased perception of the road edge and alignment. Conversely, when the trees are really close to the lane, they are mostly seen as a risk with the consequence that drivers tend to slow down. This is confirmed when analyzing the effects of roadside tree configuration as a function of geometric elements. In fact, for sharp curves, the average difference between the configuration with no trees and configurations with trees located at 1.5 m was 5.91 km/h, while the difference with configurations with trees at 4.0 m was lower, -3.86 km/h.

When considering gentle curves, the opposite occurred. In this case, the highest difference was observed between the configuration with no trees and the configurations with trees at 4.0 m (-5.68 km/h); when trees are located at 1.5 m, the difference is 3.55 km/h. This is also confirmed by the second ANOVA, where the only significant interaction effect was found between the geometric element and the tree offset, demonstrating that the driver's balance between perceiving trees as a hazard or a guidance feature is more shifted towards the hazard elements along more complex geometries.

As the distance between the driver's trajectory and trees is a significant factor that influences the driver's choice of speed, this could explain the conflicting findings of previous studies that used different tree offsets from the road edge and different road cross-sections. In the study of Jamson et al. (17) the trees did not affect the drivers' speed. The trees were located at 2 m from the road edge, and the two-lane rural road was wider (7.3 m) than the one investigated in this study. It is then reasonable to suppose that this distance between drivers and trees could result in a perfect balance between the driver's perception of trees as hazardous objects (inducing a decrease in speeds) and guidance features (inducing an increase in speeds), in such a way that drivers did not modify their speeds as when trees were not present. Therefore, it is possible to reconsider the use of trees as speed-reducing treatments (combined with protective barriers and eventually with other perceptual measures (17)), placing them along the roadway side, also in relation to the roadway cross-section. Future study plans have been put in place in this direction in order to confirm the results and provide effective suggestions for practitioners.

In contrast, no significant differences in speeds were found amongst the configurations characterized by the same tree offset from the edge. In fact, the tree spacing did not affect the driving speed, as confirmed by the results of the second ANOVA. However, from the data in Table 2, it is interesting to note that, although not significant, drivers increased their speeds when the tree spacing was

shorter and trees were located at 4.0 m (confirming previous results (9) and also the previously discussed prevalent guidance effect that became greater under shorter spacing). Conversely, drivers applied lower speeds under shorter spacing when trees were at 1.5 m, where a tree was mostly perceived as a risk factor and a decrease in tree spacing yielded an increase in risk perception and a reduction in speed.

Finally, except for geometric element*tree offset, no other interaction effect between the independent variables was found to be significant in both ANOVAs.

Lateral Position

As in the driving speed analysis, ANOVA 5x7 revealed a significant main effect of the geometric element and the roadside tree configuration on the average lateral position.

Pairwise comparisons revealed significant differences of lateral positions between all the geometries investigated, with the lowest recorded average values for left curves (averaging amongst the configurations: sharp = 1.18 m; gentle = 1.37 m) and the highest for right curves (sharp = 1.97 m; gentle = 1.83 m). Along the tangent, the average lateral position was 1.54 m. This result indicates that the driver was just in the centre of the driving lane along the tangent, while on curves the driver moved towards the inner edge of the roadway, confirming the tendency of the driver to cut the curves (8). Moreover, this driving behaviour in negotiating a curve element is much more evident for sharp curves.

In general, the presence of trees on the roadside induces drivers to move to the left, towards the centre of the road, inciting them to choose a lateral position which is nearer to the road centerline than that adopted when trees were not present on the roadside. The drivers positioned their vehicles far away from the road edge as the proximity of trees decreased: the average lateral position was 1.65 m, 1.61 m and 1.52 m when trees were respectively not present, at 4.0 m, and at 1.5 m. Such differences in lateral position with the baseline configuration were significant for configurations A, B and C (trees at 1.5 m) but not significant for configurations D, E and F (trees at 4.0 m). In Figure 3, the values of the lateral positions, averaged amongst the configurations characterized by the same tree offset, are provided for each geometric element, along with the percent differences with the baseline configuration.

A significant interaction effect was also found between geometric element and roadside tree configuration which was confirmed on the second ANOVA, where the only significant interaction effect was geometric element*tree offset. In fact, although for most of the cases drivers moved towards the centre of the road when trees were on the roadside (even more when tree spacing was shorter), the differences amongst configurations were significant only on sharp right curves, gentle right curves and tangents. This is probably due to the following: drivers cut right curves and move nearer to the inner edge also when trees are present on the right side. Consequently, by perceiving trees as obstacles, drivers tend to cut less the curves with respect to the baseline configuration. Conversely, by cutting left curves, the distance between the drivers and the right side of trees becomes higher and the effect of tree offset on lateral position becomes almost negligible. Finally, along tangents, drivers drove almost near the centre of the lane; the effect of the tree offset in this case was again found to be significant.

ANOVA 5x2x3 confirmed the significant main effect of tree offset and, in contrast to the speed analysis, also tree spacing. In fact, it was found that the average lateral position was nearer to the road centerline when the tree spacing decreased (it was 1.59 m, 1.56 m and 1.54 m when spacing was 25.0 m, 17.5 m and 10.0 m, respectively). A significant difference in lateral positions was found between tree spacing of 25.0 m and 10.0 m. These results are consistent with previous findings (9) where it was found that clear zone size and vegetation density influenced the driver's lateral position. Therefore, for the lateral position choice, it is possible to assume that trees are always seen by drivers as obstacles: in fact, the drivers always move away from them, especially when trees are nearer to the road edge and denser. In this case too, the results confirmed that drivers move away from lateral obstacles, as demonstrated under other driving conditions (i.e. driving inside tunnels (24)).

Anyway, the trees' effect on lateral position, by inducing drivers to move to the centre of the road, could be quite dangerous in terms of a potential head-on collision, especially when visibility restrictions do not allow the driver to promptly see a vehicle coming in the opposite direction. This could

occur along crest vertical and horizontal curves, and could pose a high risk factor especially on sharp left curves where drivers, moving towards the inner edge of the roadway, almost invade the opposite lane.

CONCLUSIONS AND FURTHER RESEARCH

The effects of roadside trees on driving performance are presented and discussed in this driving simulator study. It is an important road safety issue which is strongly related to human factors and the way drivers perceive the roadside and consequently behave; this has a crucial impact on safety especially on roads lined with trees, which are often characterized by high crash rates and severity. This is even more critical for narrow two-lane rural roads with trees on the roadside that are close to the road edge, on which inappropriate speed and failure to maintain proper lateral position along the road alignment could represent serious “unforgiving” driving mistakes. Therefore, an improvement of knowledge on driving performance, as influenced by roadside trees, is surely needed for providing useful information on the safety implications of existing roads lined with trees.

The main findings of the study indicate that, compared to the baseline condition (no trees on the roadside), drivers significantly decrease their speeds and move towards the road centerline when roadside trees are nearer to the road edge. When trees are far away, drivers adopt significant higher speeds with respect to the baseline condition along with a lower left lateral displacement. This fact occurred along all the investigated five geometries, especially on sharp curves. The tree spacing does not significantly affect the drivers’ speed but influences the lateral position: drivers move further away from the road edge when tree spacing decreases and trees are nearer to each other. Finally, the results demonstrate that drivers balance the useful guidance information that roadside trees provide with the risk associated with their presence: when trees are far away from the road edge, the sense of guidance is predominant and drivers adopt higher speeds; when trees are near, they are seen as a risk and drivers slow down and move further away from them.

The overall findings of this study can be used to enhance our knowledge about driving behavior along roads lined with trees, suggest effective safety measures for these critical road configurations and consider the use of trees as a possible speed-reducing measure. Safety concerns relative to driving along narrow two-lane rural roads lined with trees have been highlighted in this study.

The first concern depends on the fact that drivers increase their speeds when trees are present on the roadside with an offset that is not close to the road edge. This fact, induced by an improved perception of the road alignment (guidance effect of trees), makes trees even more dangerous, especially along complex road geometries such as sharp curves, where excessive speeds could cause run off the road. In addition, when trees are not perfectly lined along the road edges, they could create very critical false guidance information, affecting and misleading drivers’ perception. Therefore, trees must be protected and speed-reducing measures are required especially along sharp curves. Further ongoing simulator studies are underway in order to evaluate the effectiveness of several perceptual treatments as speed-reducing measures along this type of road.

The second safety concern is related to the drivers’ lateral position when trees are present on the roadside: drivers move to the centre of the road away from trees, creating a potential dangerous condition in terms of head-on collisions, especially when visibility restrictions do not allow the driver to promptly see a vehicle coming in the opposite direction (i.e. along crest vertical and horizontal curves). It is even more critical along sharp left curves, as drivers cut the trajectory, move towards the inner edge of the roadway, and almost invade the opposite lane. A further study aimed at evaluating the effectiveness of perceptual treatments for improving lateral position on sharp curves and crest vertical curves is planned.

The third safety implication is associated with the potential use of tree lines close to the road edge as an effective speed-reducing measure. Obviously, trees must be protected with safety barriers (in a previous study (8) it was found that drivers do not change their behavior along two-lane rural roads lined with trees when barriers are present or not) and possible combinations with other engineering treatments should be studied. A research is currently underway in this direction.

Further research will involve an extension of the study cases (roadside tree configurations, road alignment geometries, road cross-sections, vegetation types) and a wide sample of drivers in order to

confirm and generalize the results and then be able to propose effective guidelines for practitioners for specific safety-related treatments of these roads or to effectively design roadside trees as a speed-reducing measure. More specifically, the type of vegetation is surely an important topic to be investigated. In fact, as it is demonstrated that the roadside vegetation can give drivers improved delineation of the road alignment, to effectively design the roadside it would be useful to understand if other types of vegetation, that would not pose the same safety risk if hit by a vehicle (i.e. bushes), could be equally effective in terms of improving the driver's perception of the road alignment. In such a case, they could be used as an effective and efficient safety measure, without spending all the funds needed to add also guardrails to protect vegetation like trees.

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FIGURE 2 Frames of simulation: examples of combinations of the independent variables

FIGURE 3 Average speed and lateral position in relation to tree offset for each geometric element

TABLE 1 Roadside Tree Configurations

Roadside Tree Configuration	Offset [m]	Spacing [m]
A	1.5	10.0
B	1.5	17.5
C	1.5	25.0
D	4.0	10.0
E	4.0	17.5
F	4.0	25.0
G	without trees	

TABLE 2 Average and Standard Deviation of Speed and Lateral Position for Every Combination of Geometric Element and Roadside Tree Configuration

Geometric Element	Roadside tree configuration	Speed [Km/h]		Lateral Position [m]	
		<i>Average</i>	<i>SD</i>	<i>Average</i>	<i>SD</i>
Sharp right curve	A	61.78	9.08	1.80	0.24
	B	63.26	8.88	1.86	0.25
	C	63.89	8.59	1.96	0.21
	D	71.82	9.90	2.02	0.23
	E	71.96	8.96	2.05	0.25
	F	72.09	10.74	2.06	0.20
	G	68.05	8.62	2.03	0.25
Sharp left curve	A	60.31	8.93	1.16	0.25
	B	60.81	8.33	1.20	0.28
	C	61.61	8.84	1.18	0.29
	D	71.34	8.98	1.17	0.29
	E	71.59	9.74	1.15	0.29
	F	71.48	10.07	1.16	0.27
	G	67.65	9.26	1.25	0.29
Gentle right curve	A	88.05	10.41	1.70	0.27
	B	88.87	10.06	1.77	0.22
	C	89.70	10.50	1.80	0.22
	D	98.42	13.33	1.88	0.19
	E	98.11	12.40	1.87	0.20
	F	97.54	10.74	1.90	0.20
	G	92.08	10.47	1.89	0.21
Gentle left curve	A	87.04	9.92	1.31	0.22
	B	87.86	10.28	1.34	0.23
	C	88.76	10.35	1.38	0.24
	D	97.79	11.18	1.36	0.23
	E	97.21	12.58	1.37	0.25
	F	96.64	12.92	1.40	0.25
	G	91.79	10.61	1.43	0.24
Tangent	A	98.57	14.18	1.40	0.26
	B	99.48	14.02	1.48	0.26
	C	101.40	14.30	1.50	0.24
	D	104.32	11.59	1.56	0.24
	E	103.93	12.89	1.57	0.25
	F	103.06	13.49	1.60	0.23
	G	102.58	11.31	1.64	0.26

TABLE 3 Main and Interaction Effects

Independent Variable		Speed		Lateral Position	
		<i>F</i>	<i>p</i>	<i>F</i>	<i>p</i>
ANOVA 5x7	Geometric Element	$F_{(2.80,103.51)} = 519.52$	<.001	$F_{(2.32,85.82)} = 183.40$	<.001
	Roadside Tree Configuration	$F_{(4.52,167.12)} = 29.19$	<.001	$F_{(6,222)} = 14.25$	<.001
	Geom*Config	$F_{(12.58,465.43)} = 1.08$	.370	$F_{(13.02,481.85)} = 1.79$	.042
ANOVA 5x2x3	Geometric Element	$F_{(2.91,107.59)} = 474.12$	<.001	$F_{(2.26,83.81)} = 177.04$	<.001
	Tree Offset	$F_{(1,37)} = 102.16$	<.001	$F_{(1,37)} = 41.09$	<.001
	Tree Spacing	$F_{(2,74)} = 0.53$	.591	$F_{(2,74)} = 10.60$	<.001
	Geom*Tree Offset	$F_{(4,148)} = 4.20$	.003	$F_{(4,148)} = 6.85$	<.001
	Geom*Tree Spacing	$F_{(5.64,208.77)} = 0.05$	.999	$F_{(5.93,219.46)} = 0.64$	.697
	Tree Offset*Tree Spacing	$F_{(2,74)} = 1.13$	.328	$F_{(2,74)} = 1.92$	.154
	Geom*Offset*Spacing	$F_{(5.76,213.30)} = 0.11$	.995	$F_{(8,296)} = 0.41$	.877



FIGURE 1 Driving simulator at CRISS laboratory.

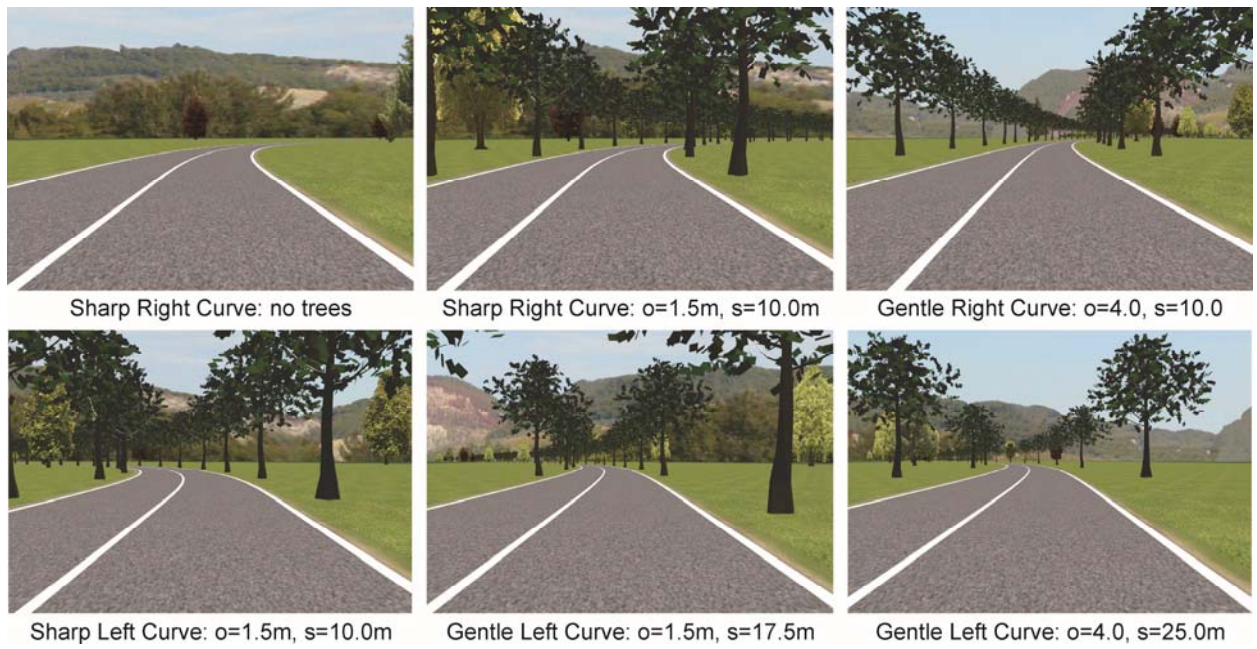


FIGURE 2 Frames of simulation: examples of combinations of the independent variables.

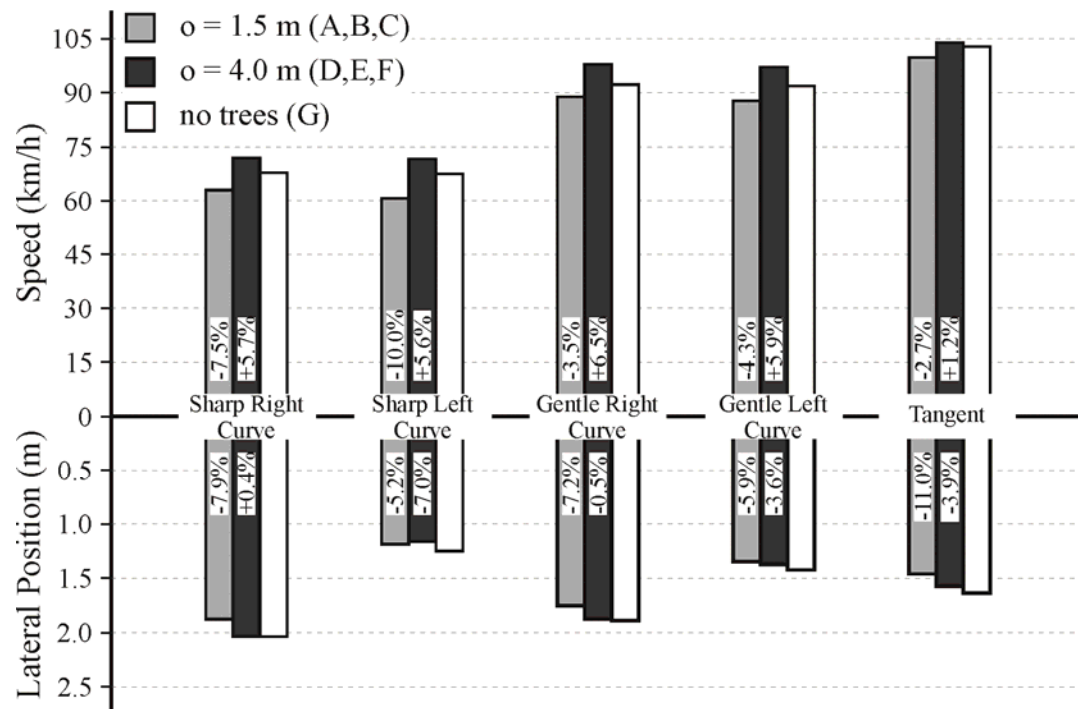


FIGURE 3 Average speed and lateral position in relation to tree offset for each geometric element.