The effect of different delineator post configurations on driver speed in night-time traffic: A driving simulator study

Sara Nygårdhs^{*ab}, Sven-Olof Lundkvist^a, Jan Andersson^a, Nils Dahlbäck^b

^aThe Swedish National Road and Transport Research Institute (VTI), SE-581 95 Linköping, Sweden

^bDepartment of Computer and Information Science, Linköping University, SE-581 83 Linköping, Sweden

* Corresponding author. Tel.: +46 13 204330

E-mail addresses: sara.nygardhs@vti.se (S. Nygårdhs), sven-olof.lundkvist@vti.se (S-O Lundkvist),

jan.andersson@vti.se (J. Andersson), nils.dahlback@liu.se (N. Dahlbäck).

Abstract

The aim of the study was to investigate how different delineator post configurations affect driver speed in night-time traffic. In addition, the potential speed effect of introducing a secondary task was investigated. The study was carried out in a car simulator on a road stretch including straight road sections as well as curves with different radii. Fourteen drivers participated in the study and the results show that absence of delineator posts leads to reduced speed. However, provided that there are delineator posts continuously present along the road, the overall driver speed is basically the same, regardless of the spacing between the delineator posts. The results also imply that to reduce driver speed in curves with small radius, using more compact spacing of posts in these curves as compared to in curves with a larger radius, could be a potential strategy. Additionally, the speed reducing effect of a secondary task was only prevailing where the task was initiated.

Keywords

Delineator posts

23 Simulator study

24 Night-time traffic

25 Distraction

26 Driver speed

27 **1 Introduction**

28 Road accidents are a cause for concern in all countries and vehicle speed is a factor strongly
29 contributing to the outcomes of these accidents on the road network. The road authorities often
30 strive to fulfil sometimes conflicting goals of driver safety, accessibility, comfort and others. Road
31 delineator posts are examples of available road equipment measures that can be used in order to
32 fulfil the goals of the road authorities. In the Nordic countries, the aim of delineator posts is to
33 provide drivers with visual guidance in night-time traffic for increased comfort and accessibility
34 (Lundkvist, 2012). Their effect on traffic safety has however been discussed.

35 **1.1 Driver behavioural theory**

36 A field experiment on Finnish two-lane rural roads showed that introduction of delineator posts
37 increased driving speeds as well as the number of injury accidents in darkness on roads with low
38 geometric standard (Kallberg, 1993). This finding is in agreement with the risk homeostasis theory by
39 Wilde (2001), which states that:

40 *In any ongoing activity, people continuously check the amount of risk they feel they are*
41 *exposed to. They compare this with the amount of risk they are willing to accept, and try*
42 *to reduce any difference between the two to zero. Thus, if the level of subjectively*
43 *experienced risk is lower than is acceptable, people tend to engage in actions that*
44 *increase their exposure to risk. If, however, the level of subjectively experienced risk is*

higher than is acceptable, they make an attempt to exercise greater caution. (Wilde, 2001, p.5).

This theory by Wilde can be interpreted as when driving a car, measures meant to help the driver drive more safely, may in fact lead to increased speed in order for the driver to maintain the same experienced amount of risk he or she is willing to accept.

The zero-risk theory, presented by Näätänen & Summala (1976) and explained more in detail by Summala (1986), describes a situation where a driver is maintaining a certain safety margin. The driver's subjective speed variance is smaller compared to the objective variance, both in the driver's own performance and in the environmental conditions (Summala, 1986). Summala does not have high hopes for changing driver behaviour and suggests speed regulation as a necessary condition for efficient traffic safety work. He writes that:

The key for the effective safety countermeasures is thus to prevent drivers from changing their behavior in response to system modifications – i.e. to prevent drivers from satisfying their motives. (Summala, 1986, p.15)

This is in contrast to Wilde, since the risk homeostasis theory assumes that drivers continuously check the amount of risk they feel they are exposed to and adapt to it, while the zero-risk theory, on the other hand, implicates that drivers normally do not feel exposed to any risk.

Like Summala, Fuller (2005) argues that risk of collision is generally not relevant in the decision-making loop when driving. Instead, Fuller proposes task difficulty homeostasis as a subgoal when driving and risk homeostasis, in the sense of risk regarding feelings of risk, as being a special case of the former. According to Fuller, there is an inverse relation between driving task difficulty and the difference between driver capability and driving task demand. Although there are many factors determining task demand, such as environmental factors (e.g. visibility, road alignment, road marking and curve radii), other road users and operational features of the vehicle (e.g. information display),

choice of speed is considered to be a factor over which the driver has immediate control (Fuller, 2005).

What seems to be a common main factor in the theories described by Wilde, Fuller and Summala and Näätänen is driver speed. Therefore, measuring driver speed is significant when investigating how different road equipment measures affect driver behaviour. One measure with the aim to facilitate driver guidance is using road delineator posts.

1.2 Night-time traffic and delineator posts

The human vision deteriorates as the amount of light decreases, which impairs both visual acuity and contrast sensitivity (Fors & Lundkvist, 2009). Since drivers essentially need visual information to carry out their driving task, the amount of available information decreases as the light level is reduced.

Bella and Calvi (2013) compared driving with different road designs during daytime and night-time visual conditions using a driving simulator. They conclude that it is not satisfactory to base speed analysis of tangent-curve transitions only on daytime driving conditions, because potential critical road situations that were identified during night-time driving were not identified from the simulated daytime driving. In order to minimize speed differentials during the night it is suggested to aim at speed reducing measures before entering a curve and also to increase the perception and visibility of the curve.

Since the main task of delineator posts is to provide visual guidance in darkness, i.e. at night-time conditions, they could possibly be used as such a visibility measure that Bella and Calvi recommend.

In a previous driving simulator study, the effect of road marking visibility and presence of delineator posts on a rural two-lane road with posted speed limit of 90 km/h was studied (Ihs, 2006). It was found that delineator posts (with a spacing of 50 m) on this kind of road increased driver speed approximately 2-10 km/h in night-time conditions, depending on road marking visibility. Presence of delineator posts affected driver speed more if the road marking visibility was poor.

Zador et al. studied short- and long-term effects of different curve delineation treatments on driver speed on existing two-lane roads in situ (Zador, Stein, Wright, & Hall, 1987). They found that presence of delineator posts along the outside of curves increased night-time speeds in curves by about 2 km/h. These short-term results were not contradicted by long-term measurements.

Blaauw (1985) tested different configurations of raised pavement markers and delineator posts in darkness on straight road sections and curves with 1000 m radius and 200 m radius, respectively. The study was carried out in the field with constant speed and driver determined visual occlusion. The results showed that drivers observed the road less frequently if the delineator posts were located 1.5 m from the driver lane as opposed to 3.5 m. In addition, all drivers observed the configurations at small curves more often than at large curves, and more seldom at the straight road stretches.

Another attempt to compare different retroreflective delineation treatments in curves was conducted as an instrumented car study on a test track (Jenkins, 1991). For small curves with a radius of 125 m it was concluded that drivers entered the curve faster and tended to brake harder in the curve if there were delineator posts compared to if there were raised pavements markers present. Other research on driving and overtaking in horizontal curves for right-hand traffic in general (based on a field test with an instrumented vehicle) implies that speed is higher in curves to the right than to the left (Othman, Thomson, & Lannér, 2010).

As the use of in-vehicle devices become more common (Jacobson & Gostin, 2010), it is of interest to study whether or not there is a relationship between visual distraction and different delineator post configurations. Although there is no general definition of driver distraction at present, Young & Regan (2007) found in a research review on the subject, that drivers tend to engage in various compensatory strategies in order to maintain an acceptable level of driving performance while interacting with in-vehicle devices. Some of the compensatory strategies mentioned were reducing speed or not using in-vehicle devices at all during driving. In a simulator study by Haigney et al. (Haigney, Taylor, & Westerman, 2000) it seemed that drivers tried to compensate increased cognitive

workload (in the form of mobile phone use) by reducing speed. It was however found that increased cognitive workload was still the case and the authors predicted that drivers would be less able to handle emergency situations or other sudden increases in driving task demands.

1.3 Aim and predictions

In order to find out how different delineator post configurations affect driver speed, a simulator experiment was carried out. The aim of this study was to investigate the effects of delineator post configurations on speed in darkness. Existing delineator post configurations were tested along with baseline and best practice configurations. The delineator post spacing differed depending on curve radius for the chosen configurations. According to the maxmincon principle, where the range of values of research variables should be wide, horizontal curves with large radius (1000 m) and small radius (250 m) were used, in both the left and right direction. Using a car simulator also affords for a controlled environment where all the participants experience the exact same road, environmental conditions and visual cues outside of the car. For the purpose of examining the possible influence of distraction during driving, a distraction task was used. The distraction task was operationalized through a visual in-car device, previously used in the same simulator by e.g. Kircher & Ahlström (2012). By this, possible interactions of visual distraction with delineator post configuration could be observed.

In accordance with the theory and previous references above the following predictions can be made:

- Presence of delineator posts lead to increased driver speed compared to absence of delineator posts on the whole road stretch (Ihs, 2006) and in curves (Zador et al., 1987).
- Given that there are delineator posts present continuously on the road, driver speed is dependent on the spacing between them (Fuller, 2005).
- Drivers reduce their speed in connection to a secondary task (Haigney et al., 2000).

From the predictions made above, an additional prediction can be made:

- There is an interaction between presence of a secondary task and presence of delineator posts, in terms of driver speed.

2 Material and methods

The study was conducted as a simulator study in night-time traffic (i.e. the simulator road was surrounded by complete darkness although the experiment was carried out during the day) directly followed by interviews in March 2012 at the Swedish National Road and Transport Research Institute (VTI) in Linköping, Sweden.

2.1 Participants

The participants were selected through convenience sampling, where some were recruited among those who registered their interest to participate in a simulator study through the VTI website, and the remainder through personal contacts. A selection criterion was that the participants should not be wearing glasses during driving. (Eye tracking equipment was used but these data are not analyzed in this paper.) In total, nineteen participants were recruited for the simulator study. Due to data loss caused by malfunctioned technical equipment and one case of simulator sickness, only fourteen of the participants are included in the analyses. These were five females and nine males, with ages ranging from 25 to 67 years (42 years on average) and they all had a driving license for more than six years (range 7-47 years, 23 years on average). The participants estimated their mileage during the past 12 months to be 2,500-40,000 km (14,400 km on average) whereof the estimated percent of driving in daylight/darkness ranged from 90/10 to 45/55 (70/30 on average). This implies that the participants were fairly experienced drivers and that they did not avoid driving in darkness.

2.2 Simulator

The simulator used in the experiment was the VTI Driving Simulator III at VTI. The advanced moving base of the simulator generates forces with three different systems: a large linear motion to simulate

lateral motion, a tilt motion to simulate long term accelerations such as driving in a curve or longitudinal acceleration and deceleration, and a vibration table to simulate road roughness. The basic functionality of the simulator is described by Nordmark et al. (Nordmark, Jansson, Palmkvist, & Sehammar, 2004), but the visual system has been continuously developed and improved since then and presently consists of three digital projectors providing a 120° forward field of view and three LCD displays for the rear view mirrors. The simulator car was a Saab 9-3 with automatic transmission.

Figure 1. An example view from the driver's position in the simulator, driving in a curve. Source: VTI/Björn Blissing.

Throughout the experiment, the only visual cues for the driver were the delineator posts and the road markings, resembling driving on a pitch-black road. The delineator posts were visible at a distance of 200 m. Figure 1 shows an example view from the driver's position in the simulator.

The main advantage of using a driving simulator in contrast to real driving on the road is keeping the conditions constant. The surrounding environment can be perfectly controlled in terms of road alignment, state of road equipment, weather etc. A disadvantage is of course the validity; that driving in a simulator cannot be directly and thoroughly transformed to driving on a real road. For instance, the consequences of a mistake are not severe in a simulator and in the study that is presented here, there were no oncoming cars. However, a validation study of the VTI Driving Simulator III that was carried out in daylight conditions by Ahlström et al. (Ahlström, Bolling,

Sörensen, Eriksson, & Andersson, 2012) showed no significant driver speed differences between driving in the simulator and in a car.

2.3 Delineator post configurations

The delineator post configurations in Table 1 were tested in the simulator. Configuration A is the current configuration in Norway and Sweden (spacing 50 m on straight road stretches, 25 m in curves), B is the current configuration in Denmark (100 m on straight road stretches, 50 or 33 m in large and small curves, respectively) and C is the current configuration in Finland (60 m on straight road stretches, 30 m in curves). The four additional configurations were chosen by an expert panel consisting of Nordic experts on road equipment, mainly road keepers. The expert panel was encouraged to find interesting configurations for testing, i.e. it would be expected a mix of economic and visual guidance criteria in the search for a best practice. The panel chose to add one configuration that was denser in small curves (D as compared to A and C), one configuration that was denser before and after curves (E as compared to B), one that did not have any delineator posts at straight road stretches (F) and one configuration that had no delineator posts at all (G), which can be seen as baseline. Table 1 shows the characteristics for all the configurations.

Table 1. Delineator post configurations tested in the simulator. The existing Nordic standard configurations are denoted in bold characters. The numerals in the last three columns indicate distance between delineator posts. When delineator posts were present, the reflectors were white, except in configuration B.

Configuration	Curve radius [m]	Straight road stretch [m]	Before/After curve [m]	In curve [m]
A	1000	50	50	25
	250	50	50	25
B^a	1000	100	100	50
	250	100	100	33.3
C	1000	60	60	30
	250	60	60	30
D	1000	50	50	25
	250	50	50	10
E	1000	100	50	50
	250	100	25	25
F	1000	∞	50	50
	250	∞	25	25
G	1000	∞	∞	∞
	250	∞	∞	∞

^a yellow reflectors to the right, white to the left

The closer spacing of the delineator posts, in relation to the straight road stretches, started 100 m before and continued to 100 m after the curve, both for small and large radii.

2.4 Test route

A road stretch of 6 km was implemented in the driving simulator as shown in Table 2. The road width was 9 m and there were six curves along the road stretch, with straight road sections between them. The same road stretch was repeated with the seven different delineator post configurations, with a shorter road stretch in between for all participants. The order of the configurations was balanced between the participants in the sense that each of the seven configurations was the first configuration approached for two of the participants, the second approached for two other participants and so on. Since the number of participants was small, no totally balanced design was possible.

Table 2. Horizontal profile of the road stretch used in each delineator post configuration and trial in the driving experiment.

Distance [m]	Straight	Left curve		Right curve		Start of distraction task [m]
		1000 m radius	250 m radius	1000 m radius	250 m radius	
0-1000	x					800
1000-1296		x				
1296-1796	x					1596
1796-1993					x	
1993-2493	x					
2493-2789				x		
2789-3789	x					
3789-4226				x		
4226-4726	x					4526
4726-4922			x			
4922-5422	x					
5422-5858		x				5522
5858-6000	x					

2.5 Distraction task

The idea of the distraction task was to let the driver decide when and how much he or she wanted to look away from the road, depending on the situation and delineator post configuration. Therefore, a visual distraction task inside the car was used, that was unfamiliar to all of the participants. The distraction task came at four specific spots for each delineator post configuration. Three of them started 200 m ahead of curves and the fourth 100 m after the beginning of a curve (see Table 2). The task was shown on an LCD touch screen placed at the upper centre console in the car. The principle of the distraction task is shown in Figure 2.

Figure 2. Two examples of the principle of the distraction task. To the left, the correct answer is NO, since no arrow is pointing upwards. To the right, the correct answer is YES, since there is an arrow pointing upwards.

The task was to look at the screen for any arrow pointing in the upward direction. If this was the case, the participant should push the button YES. If there was no arrow pointing upwards, the button NO should be pushed.

The tasks were initialized with a sound. When answering, there was a neutral “ping” sound if the answer was correct and a more annoying “vrat” sound if the answer was incorrect. In both cases the task was removed from the screen and the answer was registered. If the participants did not answer within a time limit of 20 seconds, the task was removed and “no answer” was registered. This time limit was chosen in order for the task not to interfere with the next task, regardless of driver speed, and at the same time be long enough for the driver to choose if he or she was willing to answer the task directly or wait for a better opportunity.

2.6 Interviews

Semi-structured interviews, that mainly regarded interviewee strategies for how and when to solve the distraction task, were held immediately after the simulator drives in a smaller room, in the vicinity of the simulator hall. The interviewer and the participant were the only individuals present. The first author of this article interviewed all of the participants, except two, who were interviewed by a colleague at the institute.

2.7 Experimental design

The dependent variable measured in the experiment was mean speed, and since all of the participants were exposed to all of the configurations, both with and without distraction, a within-participant design was used.

There were 14 participants (Participant) carrying out 2 simulator drives (Trial), the first one without and the second one with a distraction task, and there were 7 delineator post configurations (Config) in each simulator drive. Horizontal curves with radii of 1000 m and 250 m were used, to operationalize radius in large and small curves (Radius), respectively. The curves were categorized to be either bent to the left or the right (Bend).

All participants carried out all combinations of Trial and Config and all models include Participant as a random factor. However, since the aim of this study is not to investigate individual differences, no main or higher order effects of Participant are presented in the Results section. For all analyses, a full factorial model was used in the sense that all main effects and all higher-order terms with respect to the fixed factors were included.

In the no distraction trial, the main design was a 7 (delineator post configuration A-G; Config), and the experimental design for curves was 7 (delineator post configuration A-G; Config) $\times$ 2 (250 m radius vs 1000 m radius; Radius) $\times$ 2 (left vs right; Bend). In the comparison between the trial with and without distraction, the main design was a 2 (no distraction vs distraction; Trial) $\times$ 7 (delineator post configuration A-G; Config). To compare the trials in relevant curves, the three curves (Curve) before which the distraction task came in the distraction trial, were analysed. Hence, the experimental design for these three curves was 2 (Trial) $\times$ 7 (Config) $\times$ 3 (Curve). All analyses were conducted using univariate analyses of variance (ANOVAs) including the relevant factors for the designs.

The different models are further described in the result section.

2.8 Procedure

The participants were contacted through phone calls and e-mails with information about the study and their own time slot. When arriving at VTI, they were met in the reception by a test leader who guided them to the simulator hall. There, they were given information about the study both visually and orally and after having their potential questions answered they were asked to fill out a form for informed consent.

Before simulator drive 1 the participants were instructed to drive as they normally would on a road of the kind they would experience. To prevent the speed limit from restricting driver's choice of speed, the speed limit of the road was told to be 90 km/h, which was higher than a typical road of the kind implemented. At the end of each configuration the drivers were asked to estimate on a scale from 1 to 7, where 1 was *very easy* and 7 *very difficult*, how it was to drive with the current configuration of delineator posts. The test leader then asked the driver (during driving) *How easy or difficult was it to drive with the current configuration?* (translated from Swedish) and noted the verbal answer from the driver in a protocol. The participants had a training session directly before the first drive to acquaint themselves with the simulator.

After simulator drive 1 had been carried out, the participants were brought out of the simulator and got written as well as verbal instructions about simulator drive 2. The participants were informed that they would drive exactly the same road as in drive 1, but that there would be an additional distraction task. They were informed that the task would symbolize a distraction of some kind, for instance that the driver needed to adjust the radio, answer the mobile phone or is disturbed by a yelling child in the car. However, their main task was to drive the car in the same way as they did in simulator drive 1. Additionally, at the end of each configuration, the drivers were asked to answer the question by the test leader *How easy or difficult was it to do the distraction task with the current configuration?* Distraction task practice was given before simulator drive 2 started. All participants drove the simulator trial without distraction first, and then the trial with distraction.

When the participants had driven both tasks, they were interviewed in another room, close to the simulator hall. After the interview, they were asked to fill out a form on simulator experience and some background information as well as the remuneration form, before they were walked back to the reception and thanked for their participation. After the experiment, all participants received a taxable reimbursement of 500 SEK.

2.9 Data analysis

To avoid bias between the trials due to the fact that the participants all encountered the trial without distraction tasks first, the harmonized speed was calculated for comparisons between the two trials. In the two right hand curves with 1000 m radius (distance 2493-2789 m and 3789-4226 m from start of road stretch, respectively) no distraction task was ever given, even in the distraction trial (trial 2). Therefore, these unaffected curves were chosen as a basis for harmonization according to the following procedure: The mean speed for participant i in the two right hand curves with 1000 m radius was calculated for the distraction trial, $v_i^{distraction}$, as well as for the non-distraction trial, $v_i^{no\ distraction}$. To harmonize, the sampled speeds for participant i in the non-distraction trial were all multiplied by the quotient $v_i^{distraction}/v_i^{no\ distraction}$. The harmonization thereby results in that the mean speeds in the unaffected curves were equal, irrespective of distraction, for an individual participant. When analyzing only one of the trials, the non-harmonized speed was used.

Because data was collected with the same frequency, 10 Hz, although some participants drove slower and some faster, the amount of collected data was different for each participant. To avoid that the mean speed would be affected more by slowly driving participants, the mean speed was always calculated as an average of the mean speeds for each participant.

Since the 6 km long road stretch, including six equal curves and seven straight road stretches, was the same for all delineator post configurations and for all participants and in both trials (with and without distraction), analyses were carried out on the following sections of road:

- The whole road stretch (6 km)
- (b) Before curve. These sections include the road stretch 200 m before the start of the curve to the start of the curve, which represents the straight road stretch on which the curve is first visible and also the initiation of the distraction task for three curves.
- (c) In curve. These sections represent the road stretch from start of curve to end of curve.
- (a) After curve until next curve is visible. These sections start at the end of each curve and end 200 m before the next curve, which represent the straight road stretch unaffected by the next curve and by distraction tasks.

Figure 3 shows a sketch of the whole road stretch and the road sections used in the analyses. With the division of road sections like this, there is no overlap between road sections. Each of the road sections are affected by one curve and one curve only. To get an overall view the whole road stretch was also object to analyses.

Figure 3. Sketch of the road stretch with the road sections analysed. a-sections = after curves (from end of curve until next curve is first visible), b-sections = before curves (from that a curve is first visible to start of curve), c-sections = in curves (from start of curve to end of curve).

All tests were carried out at a significance level of 0.05.

For every participant only one (the mean) value of speed is used. In analyses with only one value per cell, the error term cannot be calculated and hence there is no interaction estimate.

3 Results

The letter in parentheses after some of the paragraphs refers to the road sections in Figure 3.

3.1 No distraction

3.1.1 Mean speed on the whole road stretch

A univariate ANOVA with mean speed per participant as dependent variable and Config(7) as independent variable was carried out.

The analysis showed that for the trial without distraction, there was a significant effect of delineator post configuration on mean speed over the whole road stretch, $F(6, 78) = 10.54, p < .001, \eta_p^2 = .45$. In the configurations without delineator posts on straight road stretches, configuration G(78.2 km/h) and F(82.1), the mean speeds over the whole road stretch were significantly lower than for the configurations with delineator posts also on straight road stretches; E(89.4), C(89.6), B(89.7), A(90.9) and D(91.2). Figure 4 shows the mean speeds on the whole road stretch with a 95% confidence interval.

Figure 4. Mean speed on the whole road stretch. Error bars show the 95% confidence interval.

3.1.2 Mean speed before curve (b)

A univariate ANOVA was carried out on the straight road stretches where the curve was first visible (200 m before the curve) until entering the curve. The dependent variable was mean speed per participant and independent variables were Config(7) × Bend(2) × Radius(2).

There was a main effect of Radius, $F(1, 13) = 12.23, p = .004, \eta_p^2 = .48$; the mean speeds were higher in curves with 1000 m radius (89.9 km/h) than in curves with 250 m radius (88.2 km/h). There was also a main effect of Config, $F(6, 78) = 8.25, p < .001, \eta_p^2 = .39$. Figure 5 shows the interaction effect of Radius × Config, $F(6, 78) = 2.91, p = .013, \eta_p^2 = .18$. The interaction shows that the speed is almost the same in both small and large curves for configurations A, C and G, which are the configurations where the spacing between the delineator posts is the same for both large and small curve radii. In the configurations where the spacing of the delineator posts is denser in the horizontal curves with a small radius as compared to in curves with a large radius, i.e. configurations B, D, E and F, the speeds are lower before the curves with a small radius. There was no main or higher order effect of Bend before curves.

Figure 5. Interaction effect of radius and delineator post configuration before curve.

3.1.3 Mean speed in curve (c)

A univariate ANOVA was carried out on the road stretch from start to end of curve. The dependent variable was mean speed per participant and independent variables were Config(7) × Bend(2) × Radius(2). The mean speed was lower in curves with 250 m radius (74.0 km/h) than in curves with 1000 m radius (88.3 km/h), $F(1,13) = 73.73$, $p < .001$, $\eta_p^2 = .85$. The mean speed was higher in curves to the right (85.2 km/h) than in curves to the left (81.8 km/h), $F(1, 13) = 11.96$, $p = .004$, $\eta_p^2 = .48$. There was also a main effect by delineator post configuration, $F(6, 13) = 3.74$, $p = .003$, $\eta_p^2 = .22$. Post hoc tests revealed that in curves, mean speeds in configuration G(77.8 km/h) were significantly lower than in the other configurations. Also, mean speeds in configuration F(82.2) were significantly lower than in the other configurations: E(85.5), B(86.0), C(86.0), D(86.4) and A(87.1). This implies that lack of delineator posts on straight road stretches (as in configurations G and F) influences the speed so that the drivers drove slower also in curves. There was a Config × Radius interaction, $F(6, 13) = 12.78$,

$p < .001$, $\eta_p^2 = .50$, because in curves with 250 m radius the mean speed was significantly lower in configurations F, E and G compared to C and A, while in curves with 1000 m radius the mean speed was significantly lower in G compared to all the others and in F compared to B, A, E and D. Figure 6 shows this interaction effect.

Figure 6. Interaction effect of radius and delineator post configuration in curve.

The interaction shows that the configuration completely without delineator posts (G) consistently led to low driver speeds. Adding delineator posts before and in the curve (configuration F) had no effect on speed in curves with 250 m radius but led to significantly higher speeds in curves with 1000 m radius. If, additionally, the straight road stretches between the curves were equipped with delineator posts (configuration E), the speeds were even higher in curves with the larger radius but there was still no effect in curves with the smaller radius.

There was also a Radius $\times$ Bend interaction, $F(1, 13) = 11.27, p = .005, \eta_p^2 = .46$, because the mean speeds were always higher in curves with the larger radius, but even higher if they were additionally curved to the right. Figure 7 shows this interaction effect.

Figure 7. Interaction effect of radius and bend in curve.

There was no interaction effect of Config $\times$ Bend or for Config $\times$ Radius $\times$ Bend in curves.

3.1.4 Mean speed after curve (a)

A univariate ANOVA was carried out on the straight road stretches directly after a curve until the next curve was visible (200 m before the start of next curve). The dependent variable was mean speed per participant and independent variables were Config(7) $\times$ Bend(2) $\times$ Radius(2).

For mean speed after a curve to 200 m before the next curve, there were main effects of Config,

$F(6, 78) = 10.28, p < .001, \eta_p^2 = .44$, Bend, $F(1, 13) = 24.49, p < .001, \eta_p^2 = .65$ and of Radius,

$F(1, 13) = 103.03, p < .001, \eta_p^2 = .89$. The mean speeds were higher (90.4 km/h) after large curves than

after small curves (80.9 km/h), and after curves to the right (88.2 km/h) than after curves to the left

(84.2 km/h). Post hoc tests revealed that on the straight road stretches after a curve but before the next curve is visible, mean speeds in configuration G(76.7 km/h), completely without delineator posts, were significantly lower than in the other configurations. Also, mean speeds in configuration F(81.4), without delineator posts on straight road stretches, were significantly lower than in the other configurations: E(88.8), C(88.9), B(88.9), A(90.5) and D(90.9 km/h). Figure 8 shows the mean speeds after curves for the different delineator post configurations.

There were no significant higher order effects of Config, Bend or Radius.

The results imply that if there are delineator posts in a curve, the speed is higher on the road stretch after the curve than it would have been without delineator posts in the curve. Additionally, there was no difference in mean speed after curves for the configurations with delineator posts both on straight road stretches and in curves.

Figure 8. Mean speeds on the road stretches directly after a curve until the next curve is first visible. Error bars show the 95% confidence interval.

3.2 Comparison of trial: no distraction versus distraction

Throughout this paragraph, the mean harmonized speeds per participant are used (see paragraph 2.9). It also has to be kept in mind that the order of the two treatment conditions was not counterbalanced, since all participants experienced the no distraction trial first and the distraction trial second. For the comparisons in 3.2.2-3.2.4 only the three curves before which the distraction task was introduced (i.e. in the distraction task, the task was initiated 200 m before the curve) are analysed. The effects that we want to examine in this section regard trial (i.e. with and without distraction) and therefore, effects that are not due to trial are not investigated further.

3.2.1 Mean harmonized speed on the whole road stretch

A univariate ANOVA was carried out on the whole road stretch. The dependent variable was mean harmonized speed per participant and independent variables were Trial(2) $\times$ Config(7).

On the whole road stretch, there was a significant effect of delineator post configuration on the mean harmonized participant speed, $F(6, 78) = 8.19, p < .001, \eta_p^2 = .39$. However, there was no speed effect of whether there were distraction tasks or not on the whole road stretch, $F(1, 13) = 0.46, p = .508$. No two-way-interaction effect with Trial was significant.

3.2.2 Mean harmonized speed before curve

To compare the trials in relevant curves, the three curves (Curve) before which the distraction task came in the distraction trial, were analysed. A univariate ANOVA was carried out on the straight road stretches where the three curves were first visible (200 m before the curve) until entering the curve. The dependent variable was mean harmonized speed per participant and independent variables were Trial(2) $\times$ Config(7) $\times$ Curve(3).

The analysis showed that there were significant main effects of Trial, $F(1, 13) = 10.07, p = .007, \eta_p^2 = .44$, because the no distraction trial had higher speeds (89.0 km/h) than the distraction trial (87.0). There were also main effects of Config, $F(6, 78) = 9.77, p < .001, \eta_p^2 = .43$ and of Curve, $F(2, 26) = 22.57, p < .001, \eta_p^2 = .63$. There were no significant interaction effects.

3.2.3 Mean harmonized speed in curve

A univariate ANOVA was carried out in the three curves where there had come a distraction task 200 m before the curve in the distraction trial. Dependent variable was mean harmonized speed per participant and independent variables were Trial(2) × Config(7) × Curve(3).

There were main effects of Config, $F(6, 78)=3.29$, $p=.006$, $\eta_p^2 = .20$ and of Curve, $F(2, 26)=69.7$, $p<.001$, $\eta_p^2 = .84$. There was also an interaction effect of Config × Curve, $F(12, 156)=3.15$, $p<.001$, $\eta_p^2 = .20$. Since there was no significant effect of Trial, this was not investigated further.

3.2.4 Mean harmonized speed after curve

A univariate ANOVA was carried out after the three curves where there had come a distraction task 200 m before the curve in the distraction trial. The dependent variable was mean harmonized speed per participant and independent variables were Trial(2) × Config(7) × Curve(3).

There were main effects of Config, $F(6, 78)=10.13$, $p<.001$, $\eta_p^2=.44$ and of Curve, $F(2, 26)=46.60$, $p<.001$, $\eta_p^2=.78$. There was also an interaction effect of Trial × Curve, $F(2, 26)=5.48$, $p=.006$, $\eta_p^2=.30$.

Figure 9 shows this interaction effect. As can be seen, the interaction is due to an intersection in the graph, which means that the mean harmonized speeds were higher after the curve with large radius for the trial without distraction (88.4 km/h), than with distraction (87.2 km/h), while after curves with small radius, the speeds were higher with distraction (82.6 vs 81.8 km/h in the right curve, 79.7 vs 78.2 km/h in the left curve). This implies that after curves with a large radius, the drivers do not have to speed up much to achieve their preferred speed, even if a distraction has made them slow down so some extent. However, small radius curves where a distraction task is added makes driver speed so low that after the curves the drivers seem to compensate for this by increasing speed more than if they had not been distracted at all.

Figure 9. Interaction effect of Trial $\times$ Curve after the three curves where the distraction came before the curve in the distraction trial.

4 Discussion

From the results it can be concluded that as long as there are delineator posts continuously along the road, mean speeds on the whole road stretch do not differ between different configurations for non-distracted drivers. However, speeds are slower if there are no delineator posts at straight road sections and even slower if there are no delineator posts at all.

Driving through tight curves, speeds are slower than in curves with large radius. Adding delineator posts in a curve, and then additionally on the straight road sections increases speed in curves with a large radius, but does not influence the already low speed in small curves.

It could be observed that drivers prepare for curves differently depending on how the delineator posts are used: If the spacing between the delineator posts is the same for both large and small curve radii, the mean speed is the same when preparing for the curves. If, on the other hand, delineator

483 posts are more closely spaced in smaller curves than in larger, drivers seem to prepare for the
484 smaller curves by slowing down more.

485 It seems that in curves with a small radius, drivers are more or less unaffected by how the delineator
486 posts are configured, probably because of the major need to reduce speed in order to be able to
487 control the vehicle and keep it on the road. In curves with a large radius, driving completely without
488 delineator posts is done at higher mean speeds than for small curves of all configurations, but at
489 even higher speeds if delineator posts are present in the curves, and even more so if there were
490 continuous delineator posts along the road.

491 The effect of small and large curve radius still remains when the curve is passed, in the sense that
492 speeds are higher after curves with a large radius than after curves with a small radius. Furthermore,
493 there is no difference in driver speed after curves between the configurations where the delineator
494 posts were present continuously along the road, whereas drivers drove slower if there were no
495 delineator posts on straight road stretches.

496 Distracted drivers drove somewhat slower before curves than if they were non-distracted. In the
497 curves before which there had been a distraction in the distraction trial, there was no speed
498 difference between distracted and non-distracted drivers. Having left a curve where the distraction
499 task appeared before the curve, distracted drivers drove faster after small curves but slower after
500 large curves, compared to when they were not distracted.

501 Although one of the results from this driving simulator study is that speed increases with delineator
502 posts along the road, we do not know whether this finding means that a driver would take a greater
503 safety (i.e. crash) risk driving with delineator posts at a higher speed or without delineator posts at a
504 lower speed, where he or she may not be able to identify the curve in advance to handle it properly.
505 It should, however, be kept in mind that delineator posts are not the only visual cues along a road
506 and that edge lines show the boundaries of the road, which delineator posts do not.

507 As mentioned in the Introduction, Summala advises speed regulation (Summala, 1986), while there
508 were no speed limit signs present during this study. It should be emphasized that the speed limit was
509 told to be higher than a typical road of the kind implemented (90 km/h as opposed to 70 km/h) and
510 we believe that introducing speed limit signs of 70 km/h would decrease speeds in the simulator,
511 mainly due to participant compliance in the experiment situation. Another question worth
512 consideration is whether the findings in this study hold true for other vehicle categories, e.g. heavy
513 vehicles.

514 To summarize, the outcome of the predictions made in the introductory chapter was the following:

- 515 • Presence of delineator posts did lead to increased driver speed compared to absence of
516 delineator posts seen over the whole road stretch as well as in curves with a large radius.
517 However, the same was not true in curves with a small radius.
518 (Prediction partly confirmed.)
- 519 • Given that there are delineator posts present continuously along the road, driver speed did
520 depend on the spacing between them before and in curves but not after curves.
521 (Prediction partly confirmed.)
- 522 • Drivers did reduce their speed in connection to a secondary task where it was initiated, i.e.
523 before curves, but not in or after the curves.
524 (Prediction partly confirmed.)
- 525 • There was no interaction between presence of a secondary task and presence of delineator
526 posts, in terms of driver speed either before, in or after curves.
527 (Prediction not confirmed.)

528 As can be seen from the bullet list above, the results of this study somewhat contradict the
529 predictions made based on previous studies and theory about delineator posts and the traffic
530 environment. While a previous field study (Zador et al., 1987) showed presence of delineator posts
531 to increase speeds in curves, the present simulator study showed that this was not true in curves

with a small radius. However, the study by Zador et al. was carried out at “curves that varied systematically in direction and degree of curvature and in steepness of grade” (Zador et al., 1987, p.2), which does not necessarily mean that curves with as small a radius as 250 m were included in their study.

Since the results of this study somewhat contradict the predictions made from previous knowledge and theory about delineator posts and the traffic environment, there is reason to believe that some of the effects override other effects. For instance, the effect of a curve having a small radius means that driver speed is affected to such an extent that the effect of delineator post configuration does not contribute further. Additionally, the lack of interaction between presence of a secondary task and presence of delineator posts implies that the two effects on driver speed cancel each other out before the curve, because since the secondary task makes drivers slow down before curves, presence of delineator posts increases speed before curves with a large radius.

The result that the drivers reduced their speed only when the secondary task was initiated, i.e. before the curve, could be of interest to investigate further. Maybe the drivers had already handled the distraction task before the curve and did not have to concern themselves with the task anymore driving in the curve? Whether drivers have different strategies in handling the distraction task, and in that case, whether speed differs depending on these strategies could also be of interest to examine. Other things to look at could be how the drivers handled the distraction task depending on delineator post configuration and other factors that potentially could affect driver behaviour.

5 Conclusions

The main finding from this study is that as long as there are delineator posts continuously present along the road, the overall driver speed is essentially the same, regardless of how the delineator posts are spaced. Presence of delineator posts will lead to higher speeds than if there are no delineator posts present.

Curvature of the road affects driver speed and in general, speeds are slower in connection to curves with small radius than with large radius. The results of this study imply that by using more closely spaced delineator posts in curves with a small radius compared to when the curve radius is large, there is a potential to slow down driver speed even more.

Another finding was that the speed reducing effect of a secondary task was only prevailing where the task was initiated, when it was initiated before a curve, which implies that the driver is adaptive in a given context. This simulator study does not discriminate between the theories by Wilde, Fuller, Summala and Näätänen but rather confirms what they have in common, that driver behaviour is influenced by environmental factors, such as delineator posts as discussed in this study.

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