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Does the effect of traffic calming measures endure over time? – A simulator study on the influence of gates

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ABSTRACT

Accident statistics show that transitions from rural to urban areas are accident prone locations. Inappropriate speed and mental underload have been identified as important causal factors on such transitions. A variety of traffic calming measures (TCM) near rural-urban transitions has been tested in field experiments and driving simulator studies. Simulator experiments where drivers are exposed a single TCM in one session are well reported in the literature. However, the extents to which drivers' behavior will be consistent over time when exposed to the same treatment over time are relatively scare and unclear.

This study examined drivers behavior when exposed to the same treatment (a gate construction located at a rural-urban transition). Over a period of five successive days, seventeen participants completed a 17 km test-drive on a driving simulator with two thoroughfare configurations (gates present or absent) in a within-subject design. Results indicate that gates induced a local speed reduction that sustained over this five-day period. The effect on standard deviation of acceleration/deceleration and lateral position was rather limited.

Overall we conclude that gate constructions have the potential to improve traffic safety in the direct vicinity of rural-urban transitions, even if drivers are repeatedly exposed. Notwithstanding, we advise policy makers to appropriately use this measure. Best is to always carefully consider the broader situational context (such as whether the road serves a traffic- rather than a residential function) of each particular location where the implementation of a gate construction is one of the options.

Keywords: traffic calming measures, gates, rural-urban transitions, driving simulator, repeated exposure.

INTRODUCTION

Experimental research shows that the transition from rural to urban areas is a serious problem in terms of traffic safety (Charlton et al., 2002; Galante et al., 2010; Taylor and Wheeler, 2000). It is hypothesized that accidents are largely caused by inappropriate speed and mental underload (Charlton, 2007). Insufficient driver alertness and the (unconscious) tendency to speed in turn, could be related to the combination of a changing road environment (the spatial and structural properties of rural areas are typically less complex than those of urban areas and probably generate less mental arousal) and a suddenly changing speed limit (i.e., typically from 70 kph to 50 kph) (Ariën et al., 2013; Forbes, 2011). Appropriately designed transition zones are therefore of crucial importance.

Previous field experiments and driving simulator studies examined the effect of a variety of traffic calming measures (TCM) on major cross-town roads. TCMs are treatments that intend traffic calming. The Institute of Transportation Engineers (Ewing, 1999) defined traffic calming as: "the combination of mainly physical measures that reduce the negative effects of motor vehicle use, alter driver behavior, and improve conditions for non-motorized street users". Forbes (2011) grouped the transition zone treatments into four categories: geometric design (e.g., chicanes or central islands), traffic control devices (e.g., variable message signs or speed cameras), surface treatments (e.g., speed humps or transverse rumble strips) and roadside features (e.g., as gateways or landscaping). In this study we focus on a gate construction with non-parallel axis displacement and central island which is located at a rural-urban transition (see Figure 1b).

In general, the surrounding context and the type of TCM have a large influence on the established results (Forbes, 2011). The County Surveyor's Society (1994) analyzed 24 village traffic calming schemes and obtained mean speed reductions between 2 kph and 16 kph, which resulted in a decrease of all injury accidents and fatal/serious injury accidents by about 25% and 50% respectively. The Federal Highway Administration (2009) reported speed reductions up to 24 kph in France, Denmark and the UK. However, speed reductions of 8-10 kph appear to be more typical (Department of Transport, 1993). Hallmark et al. (2007) examined seven low-cost TCMs in a before-after field experiment (data collection at 1-, 3-, 6-, 9- and 12-month intervals) and obtained changes in 85th percentile speed from -14 kph to +6 kph. However, a detailed look at the results showed that, while the speed reduction effect of some TCMs sustained over time or even increased, other speed reductions diminished under repeated exposure. This 'habituation' effect is also reported by Charlton et al. (2002).

Various driving simulator studies (e.g., Ariën et al., 2013; Dixon et al., 2008; Galante et al., 2010; Molino et al., 2010) reported speed reductions from 3 kph to 17 kph for TCMs in the transition zone. It is noteworthy that the results of Dixon et al. (2008), Galante et al. (2010) and Ariën et al. (2013) all indicate that these speed reductions are limited in terms of distance. Generally, speed reductions stretch out from 97 m before to 400 m after the TCMs studied, thus covering not much more than the nearby vicinity. Overall, transition zone treatments complemented with measures further along the through route are most effective (Forbes, 2011; Harkey and Zegeer, 2004; Taylor and Wheeler, 2000).

Although the main purpose of a TCM is the reduction of driving speed, we aim to investigate both longitudinal (mean speed, standard deviation of acceleration and deceleration (SDAD)) and lateral (standard deviation of lateral position (SDLP)) driving parameters because we want to approach driving behavior as a multi-dimensional, rather than a single-dimensional concept (Rosey et al., 2008). Although little is known about the influence of TCMs on SDAD and SDLP, Ariën et al. (2013) found that both parameter values increased in the near vicinity of a gate construction located at a rural-urban transition.

The advantage of field experiments is that they collect speed measurements for a large number of vehicles over an extended period of time. However, they are costly and not without methodological constraints such as for control over factors like weather and traffic conditions. On the other hand, driving simulators provide researchers extensive control over the various driving conditions that matter. In addition, simulator experiments are safe and cost efficient and a variety of driving performance data can be collected at a continuous high rate (Nilsson, 1993; Rudin-Brown et al., 1999). However, according to Jamson and Lai (2011) "the simulator community should – amongst the usual challenges of simulator validity, participant self-selection and simulator sickness – also consider the potential influence of novelty effects on driving performance data".

Evidently, novelty effects do not only apply to the simulator systems themselves, but also to the specific treatments (for instance TCMs) being tested. Interestingly however, most of the simulator experiments carried out exposed participants only once to the treatment under investigation. Authors often acknowledge this as an important limitation to their results since indeed, it remains unclear what would happen with the treatment effects found in case participants would be exposed repeatedly to the same treatment (e.g., Ariën et al., 2013; Charlton, 2007; Comte and Jamson, 2000; Jamson et al., 2010; Kircher, 2007). To the best of our knowledge, there is only a handful of simulator experiments exposing subjects multiple times to an identical treatment. Roughly, these can be subdivided into two groups.

A first group of studies exposed participants several times to the same treatment by means of one single simulator session. For example, Brown (2001) and Lewis-Evans and Charlton (2006) exposed subjects quite intensively to a new in-vehicle lane departure warning system (30 min) and to different road widths (25 km) respectively in order to find out if 'getting used' to these treatments would induce so-called 'behavioral adaptation' effects. A comparable setup was used by Jamson and Lai (2011). In this study each participant passed the same TCM four times in a single session.

A second collection of studies also exposed participants several times to the same treatment but by means of multiple simulator sessions spread over different days, instead of only one single session. For instance, Manser and Creaser (2011) investigated the effect of a rural intersection support system on drivers' behavior and made participants drive 12 times a day for a period of five days with the system turned on at days 2, 3 and 4. Jenssen et al. (2007) examined an adaptive front light system within a study design where each test- and control participant had to complete one driving session per day for a period of six consecutive days. We are aware that more simulator studies have been published where participants had to complete multiple driving sessions and thus were repeatedly exposed to a (highly) identical driving scene (Åkerstedt et al., 2010; Charlton and Starkey, 2011; Domeyer et al., 2013; Lenné et al., 1997; Martens and Fox, 2007). Yet, the focus of interest in these studies is too different from ours which is to test the impact of road infrastructural treatments on drivers' behavior. Since they fall outside the scope of this paper we limit ourselves to just mentioning them.

To summarize, when it comes to testing the impact of infrastructural and/or technological treatments on drivers' behavior under conditions of repeated exposure, the literature available is rather scarce. Turning more specifically to road infrastructural TCMs, the study by Jamson and Lai (2011) is the only reference we are knowledgeable of. Their main conclusion is that the observed behavioral effect after familiarization depends on the type of TCM. Participants' behavior in relation to countdown signs and hazard marker posts didn't change after multiple exposure, whereas for pedestrian refuges and rumble strips future behavior could not be predicted by initial behavior because the initial behavior showed a stronger (or weaker) effect. This brings us to the main objective of this paper and the more specific research questions being addressed.

OBJECTIVE & RESEARCH QUESTIONS

The present study is investigating the effect of gate constructions at rural-urban transitions on the driving behavior of a sample of participants that is repeatedly exposed to this specific type of TCM. We formulate the main research questions as follows:

1. Are gate constructions at a rural-urban transition influencing driving behavior?
2. How far is the influence of gate constructions at a rural-urban area reaching?
3. Is the effect of gate constructions at a rural-urban transition changing when the same subjects are repeatedly exposed?

METHODOLOGY

Participants

Twenty-nine volunteers with a full driver's license participated in the study. They were recruited via e-mail at Hasselt University and at XIOS University College. Twelve participants were excluded: three did not finish the experiment due to simulator sickness, eight participants could not complete the five experimental days due to technical problems and one participant was identified as outlier (drove during more than 25% of the analysis section faster than three inter-quartile distances from the group's mean). Thus, 17 participants (9 men) remained in the sample (mean age: 27.2; SD age: 11.6). All gave informed consent and had (corrected to) normal vision. Age and gender were not taken into account as between-subject factors in the statistical analysis.

Apparatus

The experiment was conducted on a medium-fidelity driving simulator (STISIM M400; Systems Technology Incorporated). It is a fixed-based (drivers do not get kinesthetic feedback) driving simulator with a force-feedback steering wheel, brake pedal, and accelerator. The simulation includes vehicle dynamics, visual and auditory feedback and a performance measurement system. The virtual environment was presented on a large 180° field of view seamless curved screen, with rear view and side-view mirror images and depiction of the speedometer. Three projectors offer a resolution of 1024 x 768 pixels and a 60 Hz refresh rate. The sounds of traffic in the environment and of the participant's car were presented. Data were collected at a 60 Hz frame rate.

Simulation scenario

The 17 km driving scenario contained two thoroughfares, alternated with filler pieces. One rural-urban transition contained a gate construction while the other had no additional treatments to mark the transition zone. Figure 1 gives an overview plan of the scenario and a screenshot of the simulator view.

Both thoroughfares had a length of 1270 m and were equipped with signs marking the beginning of the urban area and the 50 kph speed limit. In each thoroughfare, four intersections with right of way and accommodated by zebra crossings were alternated with four horizontal curves (40° left curves and 30° right curves with a curve length of 100 m). The ribbon development (Albrechts, 1999), present 200 m before and after the thoroughfare, merged into a stretch of continuous buildings inside the urban area. The road approaching to and inside the urban area was divided in two lanes (3.25 m width) with one lane per travel direction. The cycle lanes were separated from the traffic lanes by a parking strip inside the urban area and by a green strip outside the urban area.

Gate constructions with non-parallel axis displacement and central island were located just after and before the border signs of the urban area in the thoroughfare with gates. According to CROW (2004, p. 812) this type of gate construction is the best alternative besides a roundabout and a parallel axis displacement.

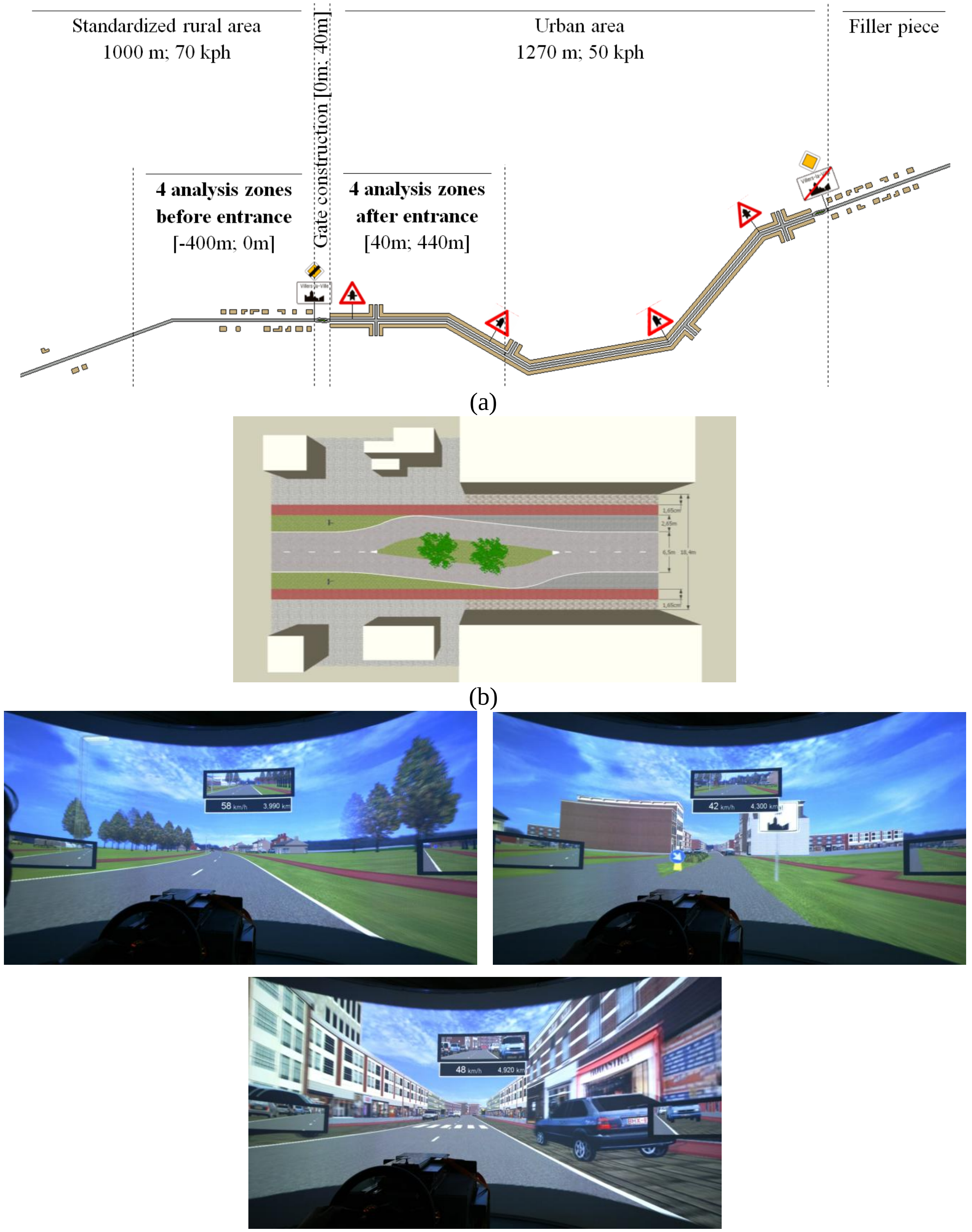


Figure 1 Plan view of (a) the scenario and (b) the gate construction; and (c) simulator view of a rural road section, the rural-urban transition with gate construction and an urban area section

The two thoroughfares were alternated with rural filler pieces of 4 km and 7 km long. They were different from the thoroughfares with respect to design, speed limit (variations of 70 kph and 90 kph and a short segment of 30 kph and 50 kph) and surrounding environment and provided some variation while driving. In addition, the filler pieces were used to provide some variety in the driving scene as well as in the interaction with other road users. In order to prevent interference from these small day-to-day variations the last kilometer before the urban area was always standardized. Weather conditions were sunny and dry.

Procedure

Subjects agreed to participate for a period of five consecutive weekdays. In order to minimize effects of time of day variations (Lenné, Triggs, & Redman, 1997; Reimer, D'Ambrosio, & Coughlin, 2007), each participant presents oneself daily at the same time, however the start time between different participants varied. On the first day, participants were asked for their informed consent and to fill out a form with their personal data (e.g. date of birth, gender). After a general introduction to the driving simulator, a practice session with two scenarios (4 km rural road with some slight curves; 7 km with successively a motorway, a 70 kph rural road and an urban area equipped with a gate construction at the rural-urban transition) followed in order to get participants acquainted with the simulator. Afterwards, participants drove the 17 km test drive in which they passed two thoroughfares (i.e., with or without the gate construction) in a counterbalanced order. During the next four days, participants drove the same 7 km practice scenario followed by the 17 km test drive.

Subjects were instructed to drive as they normally would in their own car and to apply the traffic laws as they would (or would not) do in reality. A GPS voice gave the necessary route guidance instructions.

Data collection and analysis

Measures for longitudinal and lateral control were recorded by the simulator. Mean speed [kph] is a typically selected indicator for safe driving (Safetynet, 2009) as well as standard deviation of longitudinal acceleration/deceleration (SDAD) [m/s²] which gives a good indication for the extent to which drivers are able to keep speed variations under control (Marchesini and Weijermars, 2010). Lateral trajectory control is analyzed by means of the standard deviation of the lateral position (SDLP) [m].

Data analysis for these three dependent measures were based on 8 successive analysis zones of 100 m (4 outside and 4 inside the urban area), starting at 400 m before the entrance of the urban area and ending at 440 m after the entrance (see Figure 1). The 40 m road segment containing the gate construction itself (i.e., [0 m; 40 m]) was excluded from the analysis. Therefore, a 2 (gate) × 5 (day) × 8 (analysis zone) within-subject multivariate analysis of variance (MANOVA) was conducted on mean speed, SDAD and SDLP. Additional post-hoc univariate tests and ANOVA's were performed and p-value was set at 0.05 to determine statistical significance.

RESULTS

The multivariate and univariate statistics are reported in Table 1.

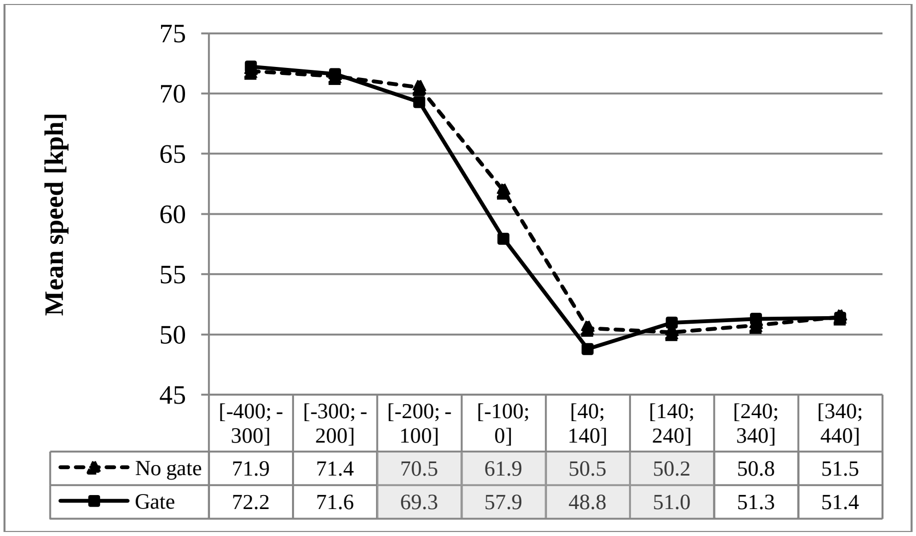
Table 1 Multivariate and univariate statistics

Variable	***F (dfs)***	***p***
MANOVA (Wilks' Lambda)		
Gate	1.7 (3, 14)	0.214
Day	1.2 (12, 164)	0.260
Analysis zone	69.3 (21, 316)	**<.0005**
Gate × Day	1.0 (12, 164)	0.419
Gate × Analysis zone	5.3 (21, 316)	**<.0005**
Day × Analysis zone	2.0 (84, 1335)	**<.0005**
Gate × Day × Analysis zone	1.1 (84, 1335)	0.198
Univariate statistics (Greenhouse-Geisser)		
Mean speed		
Analysis zone	400.5 (2, 35)	**<.0005**
Gate × Analysis zone	16.1 (3, 47)	**<.0005**
Day × Analysis zone	1.7 (7, 118)	0.120
SDAD		
Analysis zone	37.0 (1, 24)	**<.0005**
Gate × Analysis zone	1.0 (2, 31)	0.408
Day × Analysis zone	3.6 (4, 71)	**0.007**
SDLP		
Analysis zone	8.8 (3, 55)	**<.0005**
Gate × Analysis zone	2.2 (4, 59)	0.079
Day × Analysis zone	1.0 (8, 122)	0.631

Mean speed

Besides a main effect of *Analysis zone* subsidiary univariate analyses for mean speed resulted in an interaction of *Gate × Analysis zone*. Since there was no significant interaction between the factors *Day* and *Gate* or between the three factors, we can conclude from the interaction of *Gate × Analysis zone* that mean speed varied across the different analysis zones in function of the presence or absence of a gate construction, but not in function of the day. This means that the effects generated by a gate construction on a certain day were not significantly different from the other four days.

Figure 2 shows values for mean speed in each of eight analysis zone, separated for the condition with or without gate but irrespective of the day. As can be seen, drivers started to decelerate from 300 m before the entrance urban area until the first 100 m after the entrance after which they continued close to the speed limit (50 kph). Post-hoc analysis showed that mean speed was 1.2 kph to 4 kph lower from 200 m before the entrance of the urban area to 100 m after the entrance when a gate was present ([-200 m; -100 m]: $F_{(1, 16)} = 7.9$, $p = 0.012$; [-100 m; 0 m]: $F_{(1, 16)} = 20.8$, $p < .0005$; [40 m; 140 m]: $F_{(1, 16)} = 7.4$, $p = 0.015$). In spite of this major speed reduction, participants slightly accelerated again between 100 and 200 m after the gate to a mean speed which was higher than when there was no gate construction present ($F_{(1, 16)} = 7.8$, $p = 0.013$). From 200 m after the entrance of the urban area, there were no significant differences in mean speed between the condition with or without gate.

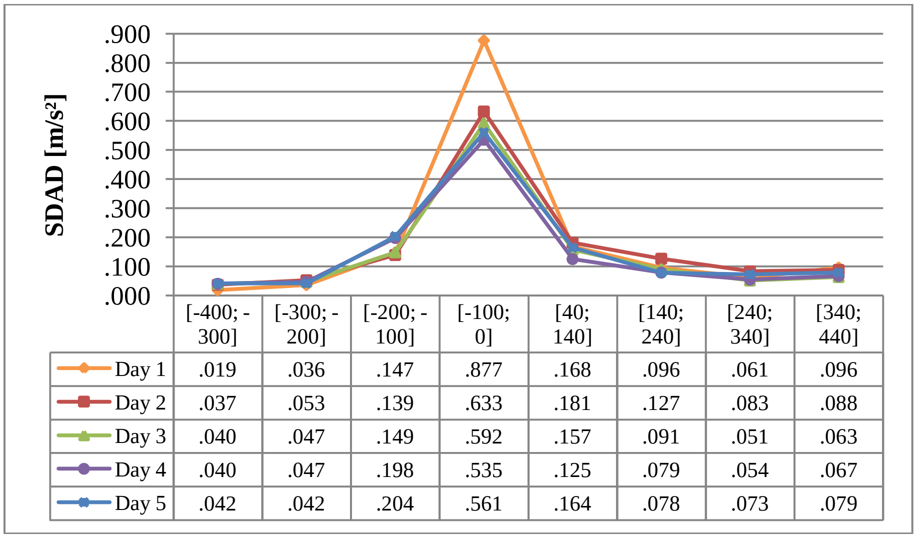


	[-400; -300]	[-300; -200]	[-200; -100]	[-100; 0]	[40; 140]	[140; 240]	[240; 340]	[340; 440]
No gate	71.9	71.4	70.5	61.9	50.5	50.2	50.8	51.5
Gate	72.2	71.6	69.3	57.9	48.8	51.0	51.3	51.4

Figure 2 Mean speed for the interaction of *Gate* × *Analysis zone*
(Gate construction was located between 0 m and 40 m)

Standard deviation of longitudinal acceleration/deceleration (SDAD)

A main effect of *Analysis zone* and an interaction of *Day* × *Analysis zone* was revealed by the univariate tests for SDAD, resulting in values for SDAD which varied across the different analysis zones in function of the day.
Figure 3 contains one plot per day, representing values for SDAD that where first averaged over the absence or presence of a gate and subsequently set out over the eight analysis zones. Post-hoc analysis showed a general increase of the SDAD during the ultimate 100 m before the entrance of the urban area. However, this increase was significantly higher on the first day compared to the other four days ($F_{(2, 36)} = 5.9$, $p = 0.005$).

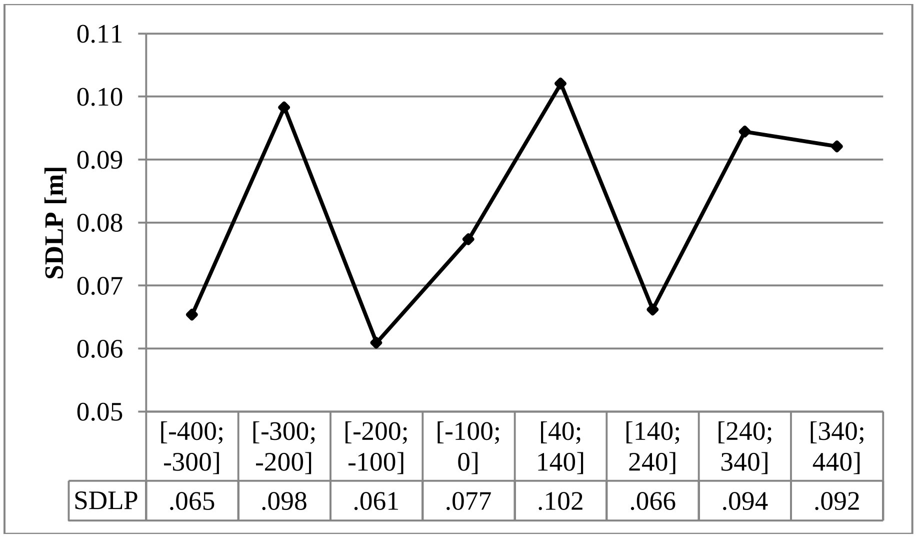


	[-400; -300]	[-300; -200]	[-200; -100]	[-100; 0]	[40; 140]	[140; 240]	[240; 340]	[340; 440]
Day 1	.019	.036	.147	.877	.168	.096	.061	.096
Day 2	.037	.053	.139	.633	.181	.127	.083	.088
Day 3	.040	.047	.149	.592	.157	.091	.051	.063
Day 4	.040	.047	.198	.535	.125	.079	.054	.067
Day 5	.042	.042	.204	.561	.164	.078	.073	.079

Figure 3 SDAD for the interaction of *Day* × *Analysis zone*
(The entrance of the urban area was located at 0 m)

Standard deviation of the lateral position (SDLP)

Subsidiary univariate tests for SDLP revealed only a significant main effect of *Analysis zone*. An overview of the SDLP per analysis zone can be found in Figure 4. It is important to note that these values were averaged over the five days and are irrespective of the presence or absence of a gate. Post-hoc analysis showed that the values for SDLP varied significantly between the successive analysis zones, except in the last two (i.e., between [240 m; 340 m] and [340 ; 440 m]).



	[-400; -300]	[-300; -200]	[-200; -100]	[-100; 0]	[40; 140]	[140; 240]	[240; 340]	[340; 440]
SDLP	.065	.098	.061	.077	.102	.066	.094	.092

Figure 4 SDLP for the main effect of *Analysis zone*
(The entrance of the urban area was located at 0 m)

DISCUSSION

Mean speed, SDAD and SDLP were analyzed to find out (1) whether a gate construction located at a rural-urban transition influences driving behavior; (2) how far the influence reaches and (3) whether the effect would change when the same subject is repeatedly exposed during a period of five days.

Results for **mean speed** showed that the gate only had a local speed reduction effect from 200 m before to 100 m after the entrance of the urban area with speed reductions between 1.2 kph and 4 kph. For speed reductions of that size, Elvik’s Power Model for urban roads (Elvik, 2009, p. 58) estimates a decrease in fatal accidents and injury accidents up to 12% and 8% respectively. The established speed reductions are in line with the 3 kph speed reduction obtained by Ariën et al. (2013). The different speed limits used in the studies by Galante et al. (2010) and Taylor and Wheeler (2000) (i.e., from 90 kph to 50 kph instead of from 70 kph to 50 kph) might by an explanation for the fact that the size of the speed reductions in their gateway studies (i.e., reductions between 5 kph and 24 kph) is larger than in our study. The speed reductions generated by the TCMs (e.g. transverse pavement markings, a speed feedback sign, a speed table, lane narrowing with centre island etc.) investigated by Hallmark et al. (2007) are closer to our results.

The fact that the speed reduction effect of the gate is restricted to the direct vicinity of the entrance of the urban area is in line with previous field and simulator experiments in which speed reductions did not reach beyond 97 m (Ariën et al., 2013), 250 m (Charlton et al., 2002) or 400 m (Galante et al., 2010, only in the base scenario with low speeds) after the gate.

Because the speed reduction effect established in this experiment was independent of the day, we can conclude that the speed reduction will preserve over a time period of at least five days. This is in line with the results of the longitudinal driving simulator experiment by Jamson and Lai (2011) where “initial behavior is predictive of future behavior” for countdown signs and hazard marker posts.

After the speed reduction generated by the gate, participants slightly accelerated again between 100 and 200 m after the gate to a mean speed that was higher than when there was no gate present. However, after this slight acceleration, participants continued at the same speed than when there was no gate present (i.e., close to the speed limit of 50 kph). The fact that drivers accelerate after the gate resembles a so-called ‘kangaroo’ effect which also has been discovered near the treatment zones of speed cameras (Safetynet, 2009; Thomas et al., 2008). The driving simulator study of Molino et al. (2010) also showed that mean speed increased again in the middle of the town after passing a chicane at the beginning of the city center. According to Safetynet (2009), there is however no scientific evidence that such a ‘kangaroo’ effect leads to (more) dangerous situations or accidents.

Even though not influenced by the gate construction, **SDAD** increased during the last 100 m before the entrance of the urban area, and this rise was significantly larger on the first day compared to the other four days. It is highly probable that the increased SDAD relates to drivers having to decelerate from 70 kph to 50 kph when entering the urban area. The fact that variations in acceleration and deceleration where significantly higher during the last 100 m before the entrance on the first day compared to the other days might suggest that participants were not yet fully adapted to handle the brake and gear pedals very precisely on the first day. Yet, participants were given the opportunity to familiarize with the simulator controls by means of a 10 min practice session (two trips of 4km and 7km respectively), which is in line with numerous other driving simulator studies (e.g., Bella, 2007; Calvi et al., 2012; Charlton, 2007; Galante et al., 2010; Montella et al., 2011).

Finally, we found variations in **SDLP** across the successive analysis zones which were independent neither of the day, nor of the presence or absence of the gate. The first and final peak values in SDLP can be explained by the presence of two slight curves. The increased values nearby the rural-urban transition can be related to multiple factors such as the increased complexity of the road environment and the presence of parked vehicles on the parking lane.

LIMITATIONS AND FUTURE RESEARCH

Although we are unable to pronounce upon the long term effect of this gate construction as in a before-after field experiment, this experiment provided the opportunity to examine driving performance during five successive days. Based on these results, we tried to anticipate the potential influence of novelty effects of a gate construction on driving performance data and find out whether the effect of gate constructions change when the same subjects are repeatedly exposed. In addition, it is worth mentioning that this experimental setup is – besides the study of Jamson and Lai (2011) – quite unique compared to the ‘common practice’ in driving simulator research in which each participant is exposed only once to the treatment under investigation.

External validity is an issue that often arises when discussing the results of a driving simulator experiment. Although moving base simulators provide a more correct rendering of real driving behavior and a greater degree of realism (Bella, 2009), there are strong indications that geometric design issues are examinable in fixed-base driving simulators in a perfectly adequate way (e.g., Bella, 2007, 2008; Calvi et al., 2012; Charlton, 2004; Federal Highway Administration, 2007). In addition, the seamless curved screen with a 180° field of view used in this study satisfies the prescribed minimum of 120°field of view for the correct estimation of longitudinal speed (Kemeny and Panerai, 2003).

Future research about gate constructions could focus on different geometric design configurations or the influence of complementary TCMs along the thoroughfare. In addition, a naturalistic driving experiment in which a sample is observed during a longer time period might also reveal interesting results. Furthermore, novelty effects in driving simulator research should receive more attention. To gain more insight in this effect, one could compare the results of this experiment with a driving simulator experiment in which each participant will be exposed several times in a single simulator session to the TCM, thus comparable with the study of Jamson and Lai (2011).

CONCLUSION AND POLICY RECOMMENDATATIONS

In conclusion this study overall indicates that gate constructions have the potential to improve traffic safety in the direct vicinity of rural-urban transitions, even if drivers are repeatedly exposed. The central island with non-parallel axis displacement examined in this simulator experiment generated a significant speed reduction (i.e., 1.2 kph to 4 kph) between 200 m before to 100 m after the entrance of the urban area. Even though participants were inclined to accelerate again once passed by this gate configuration, they always kept driving at an appropriate speed, i.e., close to the imposed limit of 50kph. We did not find any negative side effects on SDAD or SDLP.

Based on this outcome we advise (local) policy makers to at least consider gate constructions such as the one examined in this study as a potential traffic calming measure at rural-urban transitions with an increased accident risk. It goes without saying that with regard to the installation of such a gate, different aspects have to be taken into account in order to make this measure effective. For instance, in order to avoid frontal collisions, gate constructions should always be clearly visible and marked if necessary. Also, it should be avoided that drivers are required to execute (too) difficult steering wheel movements when they come along gates. Finally, the implementation of additional TCMs along the through route might help in further extending the speed reducing effect triggered by the gate. This is especially worthwhile to consider in thoroughfares with a residential function because vulnerable road users benefit even more from these speed reductions (Elvik, 2009, p. 50).

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REFERENCES

Åkerstedt, T., Ingre, M., Kecklund, G., Anund, A., Sandberg, D., Wahde, M., Philip, P. and Kronberg, P. (2010). Reaction of sleepiness indicators to partial sleep deprivation, time of day and time on task in a driving simulator – the DROWSI project. *Journal of Sleep Research*, 19(2), pp.298–309.

Albrechts, L. (1999). Planners as catalysts and initiators of change. The new structure plan for Flanders. *European Planning Studies*, 7(5), pp.587-603.

Ariën, C., Jongen, E. M. M., Brijs, K., Brijs, T., Daniels, S. and Wets, G. (2013). A simulator study on the impact of traffic calming measures in urban areas on driving behavior and workload. *Accident Analysis & Prevention*.

Bella, F. (2007). Parameters for Evaluation of Speed Differential: Contribution Using Driving Simulator. *Transportation Research Record: Journal of the Transportation Research Board*, 2023, pp.37-43.

Bella, F. (2008). Driving simulator for speed research on two-lane rural roads. *Accident Analysis & Prevention*, 40, pp.1078–1087.

Bella, F. (2009). Can the driving simulators contribute to solving the critical issues in geometric design? *Proceeding of the 87th Annual Meeting of the Transportation Research Board*, Washington DC, USA.

Brown, C. M. (2001). New in-vehicle technologies: are lane departure warnings a good thing? *Proceeding of the SELF-ACE 2001 Conference – Ergonomics for changing work*, Montreal, Canada.

Calvi, A., Benedetto, A. and De Blasiis, M. R. (2012). A driving simulator study of driver performance on deceleration lanes. *Accident Analysis & Prevention*, 45, pp.195–203.

Charlton, S. G. (2004). Perceptual and attentional effects on drivers' speed selection at curves. *Accident Analysis and Prevention*, 36(5), pp.877–884.

Charlton, S. G. (2007). The role of attention in horizontal curves: A comparison of advance warning, delineation, and road marking treatments. *Accident Analysis & Prevention*, 39(5), pp.873–885.

Charlton, S. G., Alley, B. D., Baas, P. H., & Newman, J. E. (2002). *Human factors testing issues in road safety.* Handbook of human factors testing and evaluation (2nd ed., pp. 341–362). Charlton, S.G. and O'Brien, T.G.

Charlton, S. G. and Starkey, N. J. (2011). Driving without awareness: The effects of practice and automaticity on attention and driving. *Transportation Research Part F: Traffic Psychology and Behaviour*, 14(6), pp.456–471.

Comte, S. L. and Jamson, A. H. (2000). Traditional and innovative speed-reducing measures for curves: an investigation of driver behaviour using a driving simulator. *Safety Science*, 36(3), pp.137–150.

County Surveyor's Society – Department of Transport. (1994). *Village Speed Control Work Group – a summary. Traffic Advisory Leaflet 1/94*, United Kingdom.

CROW. (2004). *Aanbevelingen voor verkeersvoorzieningen binnen de bebouwde kom*, The Netherlands.

Department for Transport. (1993). *Gateways. Traffic Advisoty Leaflet 13/19*, United Kingdom.

Dixon, K., Zhu, H., Ogle, J., Brooks, J., Hein, C., Aklluir, P. and Crisler, M. *Determining Effective Roadway Design Treatments for Transitioning from Rural Areas to Urban Areas on State Highways*. No. FHWA-OR-RD-09-02. Oregon Department of Transportation Research Unit and Federal Highway Administration, USA, September 2008.

Domeyer, J. E., Cassavaugh, N. D. and Backs, R. W. (2013). The use of adaptation to reduce simulator sickness in driving assessment and research. *Accident Analysis & Prevention*, 53, pp.127–132.

Elvik, R. *The Power Model of the relationship between speed and road safety - Update and new analyses.* No. 1034/2009. Institute of Transport Economics, Sweden, October 2009.

Ewing, R. (1999). *Traffic Calming: State of the Practice.* Washington DC: Institute of Transportation Engineers, US Department of Transportation.

Federal Highway Administration. (2007). *Drivers' evaluation of the diverging diamond interchange*. No. FHWA-HRT-07-048. http://www.fhwa.dot.gov/publications/research/safety/07048/index.cfm.

Federal Highway Administration. (2009). *Traffic calming on main roads through tutal communities*. No. FHWA-HRT-08-067. http://www.fhwa.dot.gov/publications/research/safety/08067/index.cfm.

Forbes, G. J. *Speed Reduction Techniques for Rural High-to-Low Speed Transitions – A synthesis of highway practice.* Transportation Research Board, USA, 2011.

Galante, F., Mauriello, F., Montella, A., Pernetti, M., Aria, M. and D'Ambrosio, A. (2010). Traffic calming along rural highways crossing small urban communities: Driving simulator experiment. *Accident Analysis & Prevention*, 42(6), pp.1585–1594.

Hallmark, S. L., Peterson, E., Fitzsimmons, E., Hawkins, N., Resler, J. and Welch, T. *Evaluation of Gateway and Low-Cost Traffic-Calming Treatments for Major Routes in Small, Rural Communities*. Iowa Highway Research Board and Iowa Department of Transportation, USA, November 2007.

Harkey, D. L. and Zegeer, C. V. *PEDSAFE: Pedestrian Safety Guide and Countermeasure Selection System*. No. FHWA-SA-04-003. Federal Highway Administration, USA, September 2004.

Jamson, S. and Lai, F. (2011). Are novelty effects of road safety treatments observable in simulator experiments? *Proceeding of the 90th Annual Meeting of the Transportation Research Board*, Washington DC, USA.

Jamson, S., Lai, F. and Jamson, H. (2010). Driving simulators for robust comparisons: A case study evaluating road safety engineering treatments. *Accident Analysis & Prevention*, 42(3), pp.961–971.

Jenssen, G. D., Bjoerkli, C. A., Sakshaug, K. and Moen, T. (2007). Behavioural adaptation to adaptive front lighting systems (AFS): a six day driving simulator study. *Proceeding of the 14th World Conference on Intelligent Transport Systems*, Beijing, China.

Kemeny, A. and Panerai, F. (2003). Evaluating perception in driving simulation experiments. *Trends in Cognitive Sciences*, 7(1), pp.31–37.

Kircher, K. *Driver distraction – A review of the literature*. No. 594A. VTI, Sweden, 2007.

Lenné, M. G., Triggs, T. J. and Redman, J. R. (1997). Time of day variations in driving performance. *Accident Analysis & Prevention*, 29(4), pp.431–437.

Lewis-Evans, B. and Charlton, S. G. (2006). Explicit and implicit processes in behavioural adaptation to road width. *Accident Analysis & Prevention*, 38(3), pp.610–617.

Manser, M. and Creaser, J. (2011). Assessing driver behavioral adaptation to rural intersection driver support system. *Proceeding of the 6th International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, Lake Tahoe, California, USA.

Marchesini, P. and Weijermars, W. *The relationship between road safety and congestion on motorways.* No. R-2010-12. SWOV: The Netherlands, 2010.

Martens, M. H. and Fox, M. R. J. (2007). Do familiarity and expectations change perception? Drivers' glances and response to changes. *Transportation Research Part F: Traffic Psychology and Behaviour*, 10(6), pp.476–492.

Molino, J. A., Katz, B. J. and Hermosillo, M. B. (2010). Simulator evaluation of low cost safety improvements on rural, two-lane, undivided roads: nighttime delineation for curves; and traffic calming for small towns. *Proceeding of the 89th Annual Meeting of the Transportation Research Board*, Washington DC, USA.

Montella, A., Aria, M., D'Ambrosio, A., Galante, F., Mauriello, F. and Pernetti, M. (2011). Simulator evaluation of drivers' speed, deceleration and lateral position at rural intersections in relation to different perceptual cues. *Accident Analysis & Prevention*, 43(6), pp.2072–2084.

Nilsson, L. (1993). Behavioural research in an advanced driving simulator – Experiences of the VTI system. *Proceedings of the 37th Annual Meeting of Human Factors and Ergonomics Society*, Seattle, USA.

Rosey, F., Auberlet, J. M., Bertrand, J., Plainchault, P. (2008). Impact of perceptual treatments on lateral control during driving on crest vertical curves: a driving simulator study. *Accident Analysis & Prevention*, 40(4), pp.1513-1523.

Rudin-Bronw, C. M., Williamson, A. and Lenné, M. G. *Can driving simulation be used to predict changes in real-world crash risk?* No. 299. Monash University Accident Research Centre, Australia, December 2009.

Safetynet. (2009) *Speeding*. http://ec.europa.eu/transport/road_safety/specialist/knowledge/speed.

Shinar, D. (2007). *Traffic safety and human behavior* (1st ed.). Elsevier.

Taylor, M. and Wheeler, A. *Accident reductions resulting from village traffic calming.* Transport Research Laboratory Ltd, UK, 2000.

Thomas, L. J., Srinivasan, R., Decina, L. E. and Staplin, L. (2008). Safety Effects of Automated Speed Enforcement Programs: Critical Review of International Literature. *Transportation Research Record: Journal of the Transportation Research Board*, 2078, pp.117–126.