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Priority Rule Signalization under Two Visibility Conditions:

Driving Simulator Study on Speed and Lateral Position

Kristof Mollu[*,1], Mathijs Biesbrouck[1], Lotte Van Broeckhoven[1], Stijn Daniëls[1,2], Ali Pirdavani[1,3], Katrien Declercq[1], Giovanni Vanroelen[3], Kris Brijs[1], Tom Brijs[1]

1) Hasselt University
Transportation Research Institute (IMOB)
Agoralaan, BE-3590 Diepenbeek, Belgium
T: +32(0)11 26 91 24; F: +32(0)11 26 91 99
e-mail: {kristof.mollu, ali.pirdavani, katrien.declercq, kris.brijs, tom.brijs}@uhasselt.be; mathijs.biesbrouck@gmail.com; lottevanbroeckhoven@gmail.com

2) Vias Institute
Haachtsesteenweg 1405, BE-1130 Brussels, Belgium
e-mail: stijn.daniels@vias.be

3) Hasselt University
Faculty of Engineering Technology
Agoralaan, BE-3590 Diepenbeek, Belgium
e-mail: giovanni.vanroelen@uhasselt.be

** Corresponding author*

ABSTRACT

In literature, priority-controlled and right-hand priority intersections have rarely been compared on other elements than the number of right-of-way violations and collisions. This study investigates the effect on speed and lateral position of five priority rules under two visibility conditions at an intersection (without hierarchy between branches), which is, at this moment, a knowledge gap.

Fifty participants drove five different routes in a simulator and were exposed to the following manipulations: priority to the right rule applying and indicated (road sign and road sign with road marking), priority to the right rule applying but not indicated (no sign), priority to the right rule not applying and indicated (priority road and priority at next intersection), under good and bad visibility.

Results show a significant speed decrease for both situations where the priority to the right rule was indicated compared to situations with no priority to the right rule, especially when visibility was bad. Priority to the right signs with additional road marking resulted in lowest speed under both visibility conditions. For all priority rules, lateral position shifted more towards the middle of the road when visibility was bad.

Since speed was higher in case of priority roads or roads with priority at next intersection, it can be concluded that a higher level of control (priority-controlled intersections) does not necessarily result in a traffic safety improvement. Therefore, policy makers should take into account the results of this study and not generally change all the priority to the right intersections by priority-controlled intersections.

KEYWORDS

Driving simulator; priority rule signalization; intersection; speed; lateral position; visibility

1. INTRODUCTION

The car is one of the most used transportation modes in our daily life (European Environment Agency, 2015). Since the car occupies such prominent role in the movement patterns of almost everyone in the 21st century, clearly understandable rules are a necessary precondition for safe and fluent traffic. Intersections geometrically align and shape the road environment. Approaching an intersection is considered a complex task, requiring multitasking as an essential skill (Lemonnier, Brémond, & Baccino, 2015). According to Simon, Hermitte, & Page (2009), 43% of all road injury crashes in EU27 occur at intersections. Research also shows that the number of priority violations is higher at priority to the right intersections compared to priority-controlled intersections (De Ceunynck et al., 2013). Therefore, traffic safety at intersections has become a critical issue in the transportation system (Liu, Lu, Wang, Wang, & Zhang, 2014).

Still frequently, unsignalized intersections shape the landscape in most urban and rural areas. The general conclusion in literature is that motor vehicle injury fatality rates are consistently higher in rural areas than in urban areas (Zwerling et al., 2005). Zwerling et al. (2005) concluded that fatal crash incidence (i.e. number of fatal crashes per 100 million miles driven), injury fatality rate (i.e. number of fatal crashes per 1000 crashes with injuries) and crash injury rate (i.e. number of crashes with injury per 1000 crashes) was respectively 2.2, 3.0 and 1.1 times higher at rural roads compared to urban roads. Only the crash incidence density (i.e. number of all crashes per million miles driven) was 0.6 times lower. According to NHTSA (2015) traffic safety statistics the fatality rate per 100 million vehicle miles travelled was 2.5 times higher in rural areas than in urban areas (data of 2010). Geurts, Thomas, & Wets (2005) analyzed different characteristics of accident spots and identified 50 kph speed limit areas with intersections with traffic signs where no priority was given to be frequent crash locations (a set of items was categorized as frequent when the combination of items or accident characteristics was above 5% (here 5.6%)). Compared to inside urban areas, higher speed limits or delayed time for medical response in rural areas lead to higher mortality in rural crashes (Clark & Cushing, 1999; Eiksund, 2009; Jones & Bentham, 1995; Muelleman, Wadman, Tran, Ullrich, & Anderson, 2007). Zwerling et al. (2005) suggested that interventions to reduce speed (and increase seat belt usage) on rural roads may help to reduce disparity in fatal crash involvement rates. Due to the difference in characteristics of rural and urban intersections, there is no single preferred solution to reduce the number of crashes at intersections. Mobility experts have to take into account these surrounding factors when designing the road environment (Tay, 2015).

Most countries implement the priority to the right rule when yield road signs (e.g., stop signs) are absent (Elvik, Vaa, Erke, & Sorensen, 2009; European Commission, 2003; Liu et al., 2014). The Vienna Convention on Road Signs and Signals has, worldwide, 65 parties/countries involved and 35 countries have ratified it (UNECE, 2017). This convention recognizes that international uniformity of road signs, signals, symbols and road markings is necessary in order to facilitate international road traffic and to increase road safety (United Nations, 1968). The Vienna Convention also describes the priority signs and these are used in this paper.

Other factors besides the type of priority rule, such as the visibility at intersections, influence driving behavior. Roads with limited visual complexity induce longer eye fixations compared to visually complex urban roads (Chapman & Underwood, 1998). Shinar (2007) refers to several studies arguing that up to 90% of the information used for conducting the driving task consists of visual input. Furthermore, Vollrath, Briest, Schießl, Drewes, & Becker (2006) concludes that the lack of visual information is a direct accident cause in over

90% of all crashes at intersections. Graab, Donner, Chiellino, & Hoppe (2008) did an error analysis on 278 accidents and in slightly less than 20% of all accidents there was a visual impairment before the accident. In 52% of these accidents there were objects such as buildings, vegetation and parked or stationary vehicles. Thus, we can conclude that poor visibility (at intersections) correlates with the occurrence of crashes.

Speed is defined as an important risk factor in traffic safety. Higher speeds have been proven to increase the likelihood of getting involved in a crash (De Pauw, Daniëls, Brijs, Hermans, & Wets, 2014; Elvik et al., 2009). Furthermore, as kinetic energy in case of a crash at higher speed is more intense, severity will increase. Therefore, lower speeds at intersections are better for traffic safety. Observation of speed behavior has been widely studied but not that much attention has been paid to intersection-related settings (Montella et al., 2011). Some researchers have found speed-reducing effects of infrastructural (e.g. channelizing separator islands, gates, etc.) and perceptual (e.g. rumble strips, dragon teeth markings, colored intersection area, etc.) measures at intersections (Ariën et al., 2013; Godley, Fildes, & Brian, 2002; Gross, Jagannathan, & Hughes, 2009; Jamson, Lai, & Jamson, 2010; Katz, Molino, & Rakha, 2008; Macaulay et al., 2004; Montella et al., 2011; Thompson, Burris, & Carlson, 2006).

A review of fourteen studies conducted by Elvik et al. (2009) (described in De Ceunynck et al. (2013)) concludes that when priority to the right intersections are replaced by priority-controlled intersections, in general, the number of injury crashes drops by 3% only [95% confidence interval (CI) (−9, +3)]. However, the results are not unanimous. Some studies even indicate an increase in the number of crashes, and the crash severity is generally higher at priority-controlled intersections (De Ceunynck et al., 2013). De Ceunynck et al. (2013) referred to Casteels & Nuyttens (2009) and concluded that the crash severity is generally higher at priority-controlled intersections because of no yielding behavior and consequently higher approaching speeds. However, based on both references (Casteels & Nuyttens, 2009; De Ceunynck et al., 2013), it is not possible to conclude if this refers to intersections with the same speed limit.

According to De Ceunynck et al. (2013), priority-controlled and right-hand priority intersections have rarely been compared on other elements than the number of right-of-way violations. This study further extends previous work because it compares different types of priority regulation at intersections (described in the Vienna Convention) on speed behavior and lateral position which has not yet been done before. Thus, the main purpose of this study is not to investigate effects on yielding behavior but on speed and lateral position in function of five priority rules and under two intersection visibility conditions in a fully controlled environment. Which is, at this moment, an identified knowledge gap.

2. METHOD

2.1 Participants

For this study, a varied and realistic sample of Belgian drivers in terms of age and driving experience was recruited. In total, 50 participants volunteered for this study and all gave informed consent. None of the participants suffered from simulator sickness which according to some authors can be considered as an indicator of fidelity (Godley et al., 2002; McLane & Wierwille, 1975). Due to technical issues, the data for one participant could not be used for analysis. Hence, the final sample contained 49 participants (age 19 to 77 year; mean age = 39.73; *SD* = 18.31; 24 females). All participants had a car driving license for an average of 18.73 years (range 1 to 49 years; *SD* = 16.33). 40% of the participants drove more than 15,000 km a year, while the average in Belgium for 2015 was 15,151 km (Kwanten, 2016). All had (corrected to) good vision.

The ethical committee of Hasselt University approved the study protocol of this research.

2.2 Driving simulator

The experiment was conducted on a medium-fidelity fixed-base driving simulator (STISIM Drive 3) equipped with a force-feedback steering wheel, an instrumented dashboard, brake and accelerator pedals, direction indicators, and visual projection covering a 135 degree field of view supported by three tv screens (each with 1280 x 800 pixels resolution and 60 Hz refresh rate). Participants did not receive any kinesthetic feedback. To minimize the risk for simulator sickness, temperature in the driving simulator room was held below 21 °C (Fisher, Rizzo, Caired, & Lee, 2011, pp. 14–17).

Figure 1 STISIM Drive 3 driving simulator

2.3 Experimental scenarios

A linear mixed model with ‘priority rule’ (5 levels) and ‘visibility’ (2 levels) as fixed factors and person as random factor was used in five different scenarios for each participant. Every scenario (4.2 km long) contained four intersections with one of the priority rules of Figure 2 and was mainly straight except for some slightly curved parts (25°, only in the filler pieces). This design made it possible to investigate the effect on speed behavior and lateral position.

Figure 2 Explanation of the used traffic signs in the scenarios

					No traffic sign
Traffic sign (Vienna Convention)	**B3**	**A19^{a}**	**A18^{a}**	**A18^{a} with additional road marking on the ground (white A18 sign painted on the ground)**	/
Explanation	Priority road	Priority at next intersection, the horizontal line may be changed to clearly reflect local conditions	Intersection with priority to the right rule	Intersection with priority to the right rule	Intersection with priority to the right rule
Reference in text	*Priority road*	*Priority at next intersection*	*Priority to the right with sign*	*Priority to the right with sign + marking*	*Priority to the right (no sign)*

The road was a tertiary road which have a low to moderate traffic volume and link smaller settlements such as villages or hamlets (OSM, 2017b). Figure 3 gives an illustration of a real life tertiary road. The speed limit of this kind of roads is in a lot of countries, 50 kph (OSM, 2017a). Therefore, a maximum speed of 50 kph was used in the scenarios. This limit was indicated on the side of the road by means of one 50 kph speed limit zone sign, located 100 m after the starting position. A speed zone sign was used because regular speed signs should be repeated after every intersection and could reveal the presence of the intersection itself (speed limit zone configurations are typically used for a whole area to indicate the speed limit across a number of streets without repetition of signs after every intersection).

The position of the different priority signs was according to the Vienna Convention (United Nations, 1968). When a driver has priority, this should be indicated by a sign B3 (sign placed immediately after the intersection) or A19^a (sign placed just before the intersection) while a priority to the right sign (A18^a) should be placed just before the intersection. Whenever a priority sign was used, the B3 sign was placed 30 m following every intersection while A19^a and A18^a signs were placed 30 m prior to every intersection. It was guaranteed that every sign could be read from the same distance (i.e. 200 m before the sign; regardless the visibility). If an additional road marking was present (white A18^a sign painted on the road surface), this was done 10 m in advance to the intersection. As in reality, it could be possible that the presence of the different signs or the marking could be used by the driver to detect the location of an intersection.

Figure 3 Illustration of a real life tertiary road

Every scenario consisted of four intersections (with four branches) at 850 m, 1850 m, 2850 m and 3850 m (every intersection in a scenario had the same priority rule). While the environment surrounding the intersections was held constant, the order of the intersections was randomized across the five scenarios. Two intersections appeared under good visibility of the intersecting roadway vs. two intersections under bad visibility of the intersecting roadway. The good visibility condition implied no obstacles higher than 1.10 m present on the right side of the road in an area of 150 m in advance to the intersection (Rijkswaterstaat, 2015). According to Schermers, Dijkstra, Mesken, & de Baan (2013), this provides the driver with enough time to react to an opposite danger without increasing the risk of a crash. A hedgerow and a field of trees blocked the view of the right-side intersecting roads at the intersections with bad visibility. Every intersection had additional elements to make the surrounding environment as realistic as possible (pavement, houses, etc.). The road sections between the intersections functioned as filler pieces and were not analyzed. Throughout the entire scenario the road was wide enough for two lanes of 2m75 each. Driving lanes were not separated by means of road markings and there were no bicycle paths. In order to obtain comparable measurements within and between all participants, there was no traffic present in the direct vicinity of the intersection, while on the other sections, traffic was present. Weather conditions were sunny and dry.

2.4 Procedure

During the introductory part, all participants filled in a questionnaire with general information and demographic questions. Participants gave written informed consent. Subsequently, they received information on the functioning of the simulator. In order to allow participants to get acquainted to the simulator, they completed a warm up session during which they practiced in negotiating a few curves and crossing a couple of intersections. The same experimenter assisted the different participants and evaluated their behavior during this practice session.

The experiment itself consisted of five trips (each of 4.2 km, 5-6 minutes) with priority rule (5 levels) and visibility (2 levels) as manipulated conditions. All drives were randomized in order to cancel out potential order and learning effects. Participants drove at the right side of the road and were instructed to continuously follow the road, and to drive as they normally do. Participants were instructed that the entire scenario was located in a 50 kph zone. At the start of each drive, these instructions were repeated.

2.5 Data collection and analysis

Driving data was sampled in a time based manner to ensure that driving parameters would be at a constant time interval. For this experiment a constant time interval of 14 ms was used and the visual environment was presented at a 60 Hz refresh rate. The time frequency is usually set between 30 and 250 Hz (Fisher et al., 2011, pp. 20–22). A piecewise linear interpolation technique based on distance and an interpolation step of 0.5 m was used in MATLAB to conduct the zonal and point location based analysis. More detailed information on this interpolation technique can be found in Ariën et al. (2015).

Speed and lateral position were monitored during the entire trip. For all statistical analyses in SAS 9.4 TS level 1M3, the type I error (α) was set at .05. Based on the normal probability plots the assumption of normality was checked.

Speed

To verify there were no differences between the conditions at the start of the scenarios, a control analysis was conducted. For that purpose, for every scenario, an average speed for the whole control section (zonal section between 350 and 700 m from the starting point) was analyzed.

Furthermore, the average speed of the 49 participants before the intersection (zonal section of 50 m before the middle of the intersection) and at the intersection (point location exactly in the middle of the intersection) was calculated for the intersections with the same level of visibility and to be used in the analysis. A linear mixed model with ‘priority rule’ (5 levels) and ‘visibility’ (2 levels) as fixed factors and person as random factor was used.

Lateral position

As for speed behavior, an average lateral position was calculated in the control zone of the scenarios (zonal section between 350 and 700 m from the starting point) to test if there were differences.

To test whether depending on the priority rules and/or visibility, drivers drove more to the right or to the left at the intersection itself, a linear mixed model with ‘priority rule’ (5 levels) and ‘visibility’ (2 levels) as fixed factors and person as random factor was used. The reference location of this analysis was a point location in the exact middle of the crossing of the branches at every intersection since this point is the potential collision point.

3. RESULTS

3.1 Speed

Control zone

The linear mixed model analysis for the control zone (350 – 700 m) with ‘priority rule’ as fixed effect shows no significant effect of ‘priority rule’ ($F(4,45) = 1.68$, $p = 0.1711$) on average speed. This indicates there was no significant difference in average speed between the five scenarios (Priority road: $M = 50.43$ kph, $SE = .40$; Priority at next intersection: $M = 50.51$ kph, $SE = .44$; Priority to the right sign: $M = 50.38$ kph, $SE = .61$; Priority to the right sign + road marking: $M = 49.55$ kph, $SE = .51$; Priority to the right (no sign): $M = 50.13$ kph, $SE = .49$).

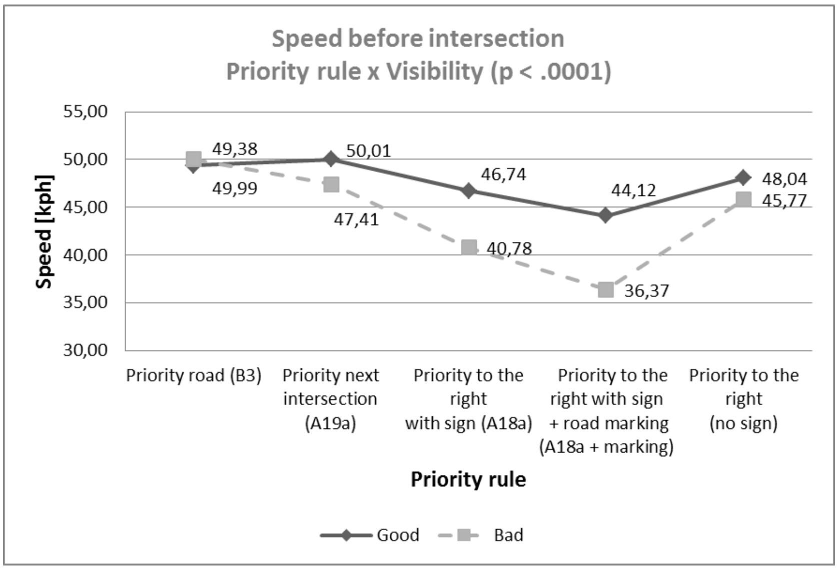
Before intersection (50 m)

The linear mixed model analysis with ‘priority rule’, ‘visibility’ and the interaction as fixed effects and person as random effect revealed highly significant main effects on average speed for ‘priority rule’ ($F(4, 45) = 21.51$, $p < .0001$), ‘visibility’ ($F(1, 48) = 45.64$, $p < .0001$) and for the interaction term ($F(4, 45) = 13.39$, $p < .0001$).

Since the interaction of ‘priority rule’ and ‘visibility’ was significant, all interpretations were done on the level of the interaction. The mean speed for all combinations of priority rule and visibility is presented in Figure 4. In order to further investigate the significant interaction between ‘priority rule’ and ‘visibility’, the five scenarios were compared two by two for each level of visibility (2*10 comparisons) and for each priority rule, both levels of visibility were compared (5 comparisons). To control the overall type I-error α of .05, these comparisons were done at a significance level of $\alpha/25 = 0.002$ each

(Bonferroni correction for multiple comparisons). The comparisons are in Table 1. Comparisons marked with an asterisk were significant at the 0.002 significance level.

Figure 4 Significant two-way interaction effect 'priority rule' x 'visibility' for the average speed in the zone of 50 m before the intersection



The analysis revealed that, except for a priority road and for the priority to the right without a sign, the mean speed in the zone of 50 m before the intersection was significantly different in function of visibility with mean speed being higher for good visibility compared to bad. For both visibility levels, the priority to the right rule explicitly signalized with a sign and a road surface marking resulted in significantly the lowest average speed in the zone of 50 m before the intersection. Only in case of good visibility, the average speed difference between the priority to the right rule explicitly signalized with a sign and a road surface marking and a priority to the right with a sign but without the marking was not significant. Regarding good visibility, half of the average speed differences between each priority rule were significant: difference between priority road and priority to the right with sign;

difference between priority road and priority to the right with sign + marking; difference between priority at next intersection and priority to the right with sign; difference between priority at next intersection and priority to the right with sign + marking; difference between priority to the right with sign + marking and priority to the right (no sign). All the priority rule average speed differences were significant for bad visibility, except for the average speed difference between priority at next intersection and priority to the right (no sign).

Table 1. Significant two-way interaction effect ‘priority rule’ x ‘visibility’ for the average speed in the zone of 50 m before the intersection: two by two comparisons

Differences of Least Squares Means										
Effect	**Priority**	**Visibility**	**Priority**	**Visibility**	**Estimate**	**Standard error**	**DF**	**t Value**	**Pr > |t|**	
priority*visibility	B3	Good	B3	Bad	-0.61	0.53	48	-1.14	.2612	
	A19[a]	Good	A19[a]	Bad	2.61	0.43	48	6.10	<.0001	*
	A18[a]	Good	A18[a]	Bad	5.96	1.08	48	5.51	<.0001	*
	A18[a] + marking	Good	A18[a] + marking	Bad	7.45	1.16	48	6.41	<.0001	*
	No sign	Good	No sign	Bad	2.27	0.86	48	2.64	.0111	
priority*visibility	B3	Good	A19[a]	Good	-0.62	0.60	48	-1.03	.3074	
	B3	Good	A18[a]	Good	2.65	0.72	48	3.69	.0006	*
	B3	Good	A18[a] + marking	Good	5.26	1.01	48	5.22	<.0001	*
	B3	Good	No sign	Good	1.35	0.71	48	1.89	.0646	
	A19[a]	Good	A18[a]	Good	3.27	0.73	48	4.47	<.0001	*
	A19[a]	Good	A18[a] + marking	Good	5.89	0.86	48	6.83	<.0001	*
	A19[a]	Good	No sign	Good	1.97	0.71	48	2.79	.0076	
	A18[a]	Good	A18[a] + marking	Good	2.62	0.88	48	2.99	.0044	
	A18[a]	Good	No sign	Good	-1.30	0.72	48	-1.81	.0766	
	A18[a] + marking	Good	No sign	Good	-3.92	0.82	48	-4.80	<.0001	*
priority*visibility	B3	Bad	A19[a]	Bad	2.59	0.78	48	3.30	.0018	*
	B3	Bad	A18[a]	Bad	9.21	1.24	48	7.41	<.0001	*
	B3	Bad	A18[a] + marking	Bad	13.32	1.43	48	9.32	<.0001	*
	B3	Bad	No sign	Bad	4.22	1.14	48	3.70	.0005	*
	A19[a]	Bad	A18[a]	Bad	6.63	1.26	48	5.27	<.0001	*
	A19[a]	Bad	A18[a] + marking	Bad	10.73	1.29	48	8.29	<.0001	*
	A19[a]	Bad	No sign	Bad	1.63	1.01	48	1.62	.1113	
	A18[a]	Bad	A18[a] + marking	Bad	4.11	1.03	48	3.97	.0002	*

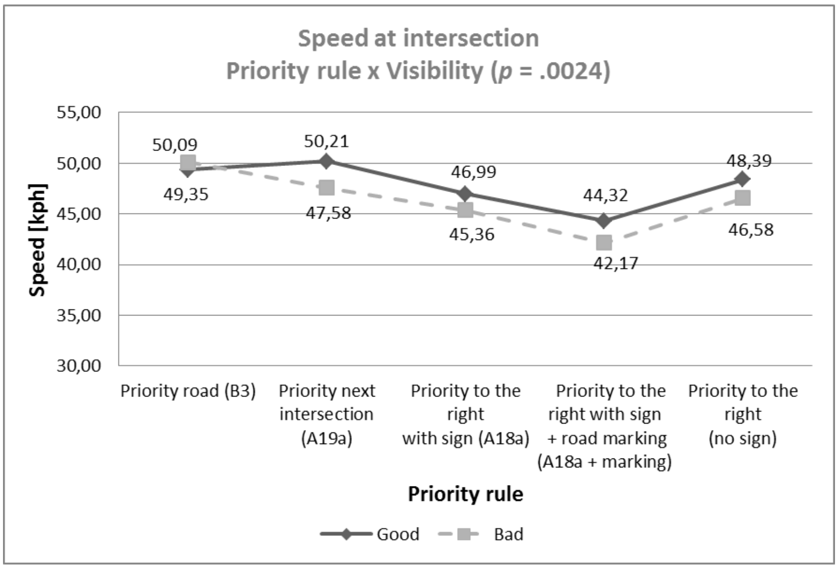
A18[a]	Bad	No sign	Bad	-4.99	1.30	48	-3.86	.0003	*
A18[a] + marking	Bad	No sign	Bad	-9.10	1.33	48	-6.82	<.0001	*

At intersection

Similar to the zone of 50 m before the intersection, the point analysis at the intersection itself revealed a highly significant main effect on average speed for both ‘priority rule’ ($F(4, 45) = 13.02$, $p < .0001$) and ‘visibility’ ($F(1,48) = 17.89$, $p = 0.0001$) and a significant interaction effect on average speed for ‘priority rule’ and ‘visibility’ ($F(4, 45) = 4.86$, $p = 0.0024$).

Since the interaction effect was significant, this was used to interpret the results. The mean speed for all combinations of ‘priority rule’ and ‘visibility’ is presented in Figure 5. Table 2 contains a more elaborate examination. Again we corrected for multiple comparisons by using a significance level of 0.002 for the pairwise comparisons.

Figure 5 Significant two-way interaction effect ‘priority rule’ x ‘visibility’ for the average speed at the intersection



Only the average speed difference for priority at next intersection was significant, indicating that average speed in the middle of the intersection was higher when visibility was good as compared to bad. The other average speed differences between good and bad visibility were not significant. Irrespective of visibility level, mean speed was significantly lower at the intersection when the priority to the right rule was explicitly signalized with a sign and a road marking, except when compared with the condition in which good visibility was combined with a priority to the right sign without a marking.

Table 2 Significant two-way interaction effect 'priority rule' x 'visibility' for the average at the intersection: two by two comparisons

Differences of Least Squares Means										
Effect	**Priority**	**Visibility**	**Priority**	**Visibility**	**Estimate**	**Standard error**	**DF**	**t Value**	**Pr > |t|**	
priority*visibility	B3	Good	B3	Bad	-0.74	0.56	48	-1.33	.1914	
	A19[a]	Good	A19[a]	Bad	2.64	0.45	48	5.88	<.0001	*
	A18[a]	Good	A18[a]	Bad	1.64	0.92	48	1.78	.0821	
	A18[a] + marking	Good	A18[a] + marking	Bad	2.15	0.74	48	2.93	.0052	
	No sign	Good	No sign	Bad	1.81	0.72	48	2.53	.0149	
priority*visibility	B3	Good	A19[a]	Good	-0.86	0.61	48	-1.42	.1621	
	B3	Good	A18[a]	Good	2.36	0.70	48	3.35	.0016	*
	B3	Good	A18[a] + marking	Good	5.03	1.07	48	4.71	<.0001	*
	B3	Good	No sign	Good	0.96	0.73	48	1.31	.1955	
	A19[a]	Good	A18[a]	Good	3.22	0.76	48	4.22	.0001	*
	A19[a]	Good	A18[a] + marking	Good	5.89	0.89	48	6.62	<.0001	*
	A19[a]	Good	No sign	Good	1.82	0.71	48	2.55	.0141	
	A18[a]	Good	A18[a] + marking	Good	2.67	0.97	48	2.75	.0084	
	A18[a]	Good	No sign	Good	-1.40	0.71	48	-1.97	.0548	
	A18[a] + marking	Good	No sign	Good	-4.07	0.82	48	-4.94	<.0001	*
priority*visibility	B3	Bad	A19[a]	Bad	2.51	0.69	48	3.62	.0007	*
	B3	Bad	A18[a]	Bad	4.73	1.09	48	4.35	<.0001	*
	B3	Bad	A18[a] + marking	Bad	7.92	1.09	48	7.25	<.0001	*
	B3	Bad	No sign	Bad	3.50	0.89	48	3.96	.0002	*
	A19[a]	Bad	A18[a]	Bad	2.22	0.98	48	2.27	.0279	
	A19[a]	Bad	A18[a] + marking	Bad	5.41	0.94	48	5.77	<.0001	*
	A19[a]	Bad	No sign	Bad	0.99	0.72	48	1.37	.1758	
	A18[a]	Bad	A18[a] + marking	Bad	3.19	0.91	48	3.48	.0011	*

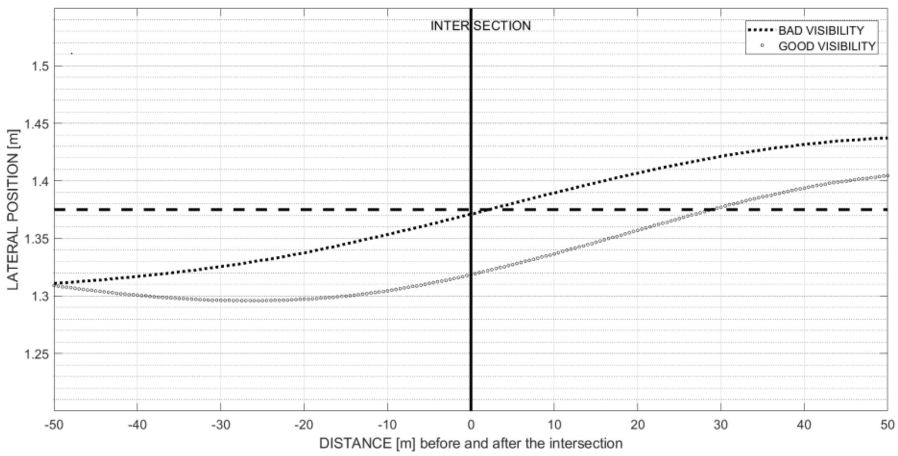
A18[a]	Bad	No sign	Bad	-1.23	0.93	48	-1.32	.1936	
A18[a] + marking	Bad	No sign	Bad	-4.41	0.95	48	-4.65	<.0001	*

3.2 Lateral position

Similar to the speed analysis in the control zone, there was no significant effect of ‘priority rule’ (F(4,45) = 1.49, p = 0.2213) on average lateral position. Thus there was no significant difference in average lateral position between the five scenarios (Priority road: M = 1.25 m, SE = .03; Priority at next intersection: M = 1.24 m, SE = .04; Priority to the right sign: M = 1.28 m, SE = .03; Priority to the right sign + road marking: M = 1.20 m, SE = .04; Priority to the right (no sign): M = 1.21 m, SE = .04).

For lateral position, there was only a significant main effect for ‘visibility’ at the intersection (F(1, 48) = 10.19, p = 0.0025). No significant main effect for ‘priority rule’ (F(4, 45) = 1.10, p = 0.3688) and no significant interaction effect (F(4, 45) = 1.84, p = 0.1374) on average lateral position was found. When visibility was bad, the lateral position shifted more to the left side (middle) of the driving lane (M = 1.37 m, SE = .03) compared to when visibility was good (M = 1.32 m, SE = .03). Figure 6 shows the mean lateral positon at the intersections (a car was in the middle of the lane when the lateral position was 1.375 m).

Figure 6 Mean lateral position at the intersections



4. DISCUSSION & CONCLUSION

Priority-controlled and right-hand priority intersections (signalized or not) have rarely been compared on other elements than the number of right-of-way violations and collisions. This study investigates the effect on speed and lateral position of five priority rules under two visibility conditions at an intersection. By using a Bonferroni correction for multiple comparisons, the results are very strict. The statistical tests were performed on speed and lateral position data at a control section (350 m long and started 350 m after the start of every scenario), before the intersection (50 m section before the intersection) and at the intersection (in the middle of the intersection).

4.1 Control zone

First, a control zone (350 m long and started 350 m after the start of every scenario) was analyzed. As expected, no significant difference in speed and lateral position was found among the five priority conditions. Furthermore, the speed was in every scenario more or less the same as the speed limit (50 kph). Drivers choose their speed on the basis of their perception of the appropriate speed for a road environment and their perception of their own speed (Edquist, Rudin-Brown, & Lenne, 2009). Therefore, we have an indication that the used speed limit of 50 kph and the scenario were realistic. On the other hand, before every trip, we instructed drivers that the entire scenario was located in a 50 kph zone and to drive as they normally do.

4.2 Speed

In general, this study showed that average speed would be lowest if the priority regulation was indicated by means of a traffic sign that indicates that drivers do not have always priority (indicated by a priority to the right sign (+ road marking)). In percentages, the speed differences (at the intersection) between priority regulated intersections and signalized priority to the right intersections vary between 5% to 13% (good visibility) and 5% to 19% (bad visibility). The priority to the right rule which was explicitly signalized with a sign and additional road marking, and the priority to the right rule which was explicitly signalized with a sign but no marking resulted in, respectively, the lowest and the second lowest average speed. The speed differences between priority to the right with a sign and priority to the right with a sign + road marking (both explicitly indicating the priority to the right rule) were not significant in case of good visibility while there was a difference when the visibility was bad. The same finding applies to the comparison of both signs indicating priority (priority road and priority at next intersection). Furthermore for these situations, speed before and at the intersection was significantly higher compared to the scenarios where giving priority was indicated.

In case of tertiary intersections with no hierarchy between the branches (as in this study), priority to the right can have a positive effect on speed. Therefore, policy makers and mobility experts should also consider the impact of the priority regulation on speed behavior to decide on which priority regulation should be used at an intersection. Furthermore, when a priority to the right intersection is used, it is advisable to always signalize this with a traffic sign (+ marking), especially when the visibility is bad.

The higher speeds in case of priority controlled intersection can lead, to a potentially more severe situation if a collision occurs, as speed and crash severity are highly correlated. When priority regulated intersections are compared to priority to the right intersections (not controlling for other characteristics like speed and traffic flow), twice as many road injury crashes occurred at priority regulated intersections (priority road or priority at next intersection) compared to priority to the right intersections [Dataset] (FOD Economie, AD Statistiek – Statistics Belgium, 2014). This might be explained by the fact that a higher level of priority control (priority road or priority at next intersection), most of the time, will be a result of a hierarchy between crossing roads while a lower level of control (priority to the right) implies, most of the time, no hierarchy between the roads. On the other hand also speed can have an impact in the accident risk at these intersections. However, the scientific literature is inconclusive about which type (priority-controlled or priority to the right rule intersection) should be preferred in which situation from a safety point of view (De Ceunynck et al., 2013). In general terms, the number of injury crashes will be lower when priority to the right intersections are replaced by priority-controlled intersections (Elvik et al., 2009). On the other hand, some studies indicate an increase in the number of crashes after a change in regulation (Vaa & Johannessen, 1978; Vodahl & Giæver, 1986; both cited in Elvik et al., 2009). Elvik et al. (2009) attributes this to the counterbalancing factor that driving speed on the primary road of priority-controlled intersections tends to be higher. This finding can be confirmed by the results of this study; we found in this study highest speed at priority controlled intersections (priority road and priority at next intersection).

The “Vision Zero principle” means that eventually no one will be killed or seriously injured within the road transport system (Johansson, 2009). Thus collisions can occur. Speed is one of the factors that affect the likelihood and the severity of crash. According to Haleem & Abdel-Aty (2010) there are various other geometric, traffic, and driver factors that affect crash injuries at three- and four-legged unsignalized intersections. Thus, it can be concluded that a higher level of control (priority-controlled intersections) does not necessarily result in an improvement in traffic safety. Furthermore, the speeding effect on tertiary roads can also have negative consequences for other road users like cyclists and pedestrians (if they have no separate infrastructure) and as suggested by the results, a signalized priority to the right intersection can be used for speed management purposes.

Despite the fact that not all the differences between good and bad visibility were significant, it can be concluded that visibility has an influence on mean speed. When visibility was good, the speed was generally higher compared to bad visibility (especially before the intersection). Since late detection is a basic driver error that leads to crashes (Rumar, 1990) we advise to indicate a priority to the right intersection always with a traffic sign (A18[a] sign or A18[a] sign + marking), especially when the visibility is bad.

4.3 Lateral position

It was expected that drivers moved to the center of the road (i.e. further from the intersection nearest leg) in case of priority to the right intersections and/or in case of bad visibility. A possible reason for this could be the fact that drivers tend to anticipate by shifting the potential collision point to the left when they approach an intersection. Montella et al. (2011) also observed moving trajectories towards the roadway center line at the intersection. As indicated by the results of the present study, drivers only swerved to the center of the road if visibility was bad and there was no influence of the priority regulation. By doing this, they can prevent a potential crash since there is more time to react (time-to-collision is higher). However, this can have a negative impact on head-on collisions. Bergmans et al. (2015) did an accident analysis of 12,488 collisions to investigate the traffic safety differences between priority-controlled intersections and priority to the right intersections. One of the conclusions of their study was that, regardless of other characteristics, the proportion of head-on collisions at priority to the right intersections (5.3%) was significantly higher than the proportion of head-on collisions at priority-controlled intersections (4.2%).

5. LIMITATIONS AND FURTHER RESEARCH

Driving simulators allow carefully controlled production and totally standardized reproduction of driving scenarios without exposing the participant to any (life threatening) risk when encountering a dangerous situation. The ease and accuracy of data collection is another advantage. Validity is essential in scientific research, so it is as well in the field of driving simulation. Although absolute validity is often difficult to obtain in driving simulators, several experiments show that driving simulators generally reach high relative validity (e.g. Bella, 2009; Godley, 1999; Törnros, 1998; Yan, Abdel-Aty, Radwan, Wang, & Chilakapati, 2008). Results are absolutely valid when, for example, the absolute magnitude of a speed impact in the simulator is comparable to the absolute magnitude in reality, while a driving simulator is relatively valid if the direction or relative magnitude of the effect is similar (Fisher et al., 2011). This research tried to simulate an environment that corresponds to participants' actual driving behavior in a real-life environment under different priority and intersection visibility conditions. Even if absolute validity is hard to obtain, we are therefore interested in this study in the relative differences in driving behavior (speed and lateral position) between the different tested conditions which for practical relevance provides new and useful insights.

Approaching vehicles at the intersections (from the left or right) were not implemented to obtain comparable measurement and to not influence the results. Communication between road users is important in traffic situations. Also, the speed of other approaching vehicles is an important factor for a driver's decision to give way (De Ceunynck et al., 2013; Janssen, Van Der Horst, Bakker, & Ten Broeke, 1988). Therefore, not implementing approaching vehicles at the branches of the intersection, could be regarded as a limitation of this experiment. However, participants were not instructed that there was no interaction with other traffic at the intersections and they came across opposing traffic in the rest of the scenario. Therefore, they could expect crossing traffic at the intersections (in reality there is also not always crossing traffic at an intersection; especially not at tertiary roads). The results also showed that participants anticipated at the intersections since there was an effect on speed and lateral position. By randomizing the scenario order of the five experimental trips between the participants, the eventual expectancy value of the fact that no vehicle was approaching was equal per route. Further research could investigate the influence of approaching vehicles and other road users (cyclists and pedestrians).

The field of view of the driving simulator was 135° which satisfies the prescribed minimum of 120° field of view for the correct estimation of longitudinal speed (Kemeny & Panerai, 2003). However, the closer participants approached the intersections, the more the field of view and intersection sight distance was reduced. Therefore, in case of a complete stop just before the intersection, it was no longer possible to scan 90° to the left and right to verify that the way was clear. This can be seen as a limitation of the study and further research should take into account a driving simulator with a larger field of view. Though, drivers have never came to a complete stop. According to Ariën et al. (2016) there are significant indications that fixed-base simulators are also adequate to examine geometric design issues (e.g. Ariën et al., 2014; Calvi, Benedetto, & De Blasiis, 2012; Charlton, 2007).

The experiment tried to create scenarios that were as realistic as possible and intersections without any hierarchy between the branches. Therefore, the characteristics of the road and the road environment of the intersection was chosen carefully. However, there was no post-questionnaire to test if participants experienced the scenarios as realistic and without any hierarchy between the branches. This can be seen as a small limitation of the study.

80% of drivers who enter priority to the right intersections look to the right by turning their head (Kulmala, 1990). To further investigate this, the implementation of an eye tracker could be promising.

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DECLARATION OF INTEREST

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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