Investigation of Herringbone pattern and Optical Circles for Safe Driving Behaviour at Curves Using Driving Simulator

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ABSTRACT

Horizontal curves have 1.5 to 4 times higher probability of accidental occurrence than tangent sections. Majority of these accidents are caused due to human error. Therefore, human behaviour at the curve needs to be corrected. In this study, two different road marking treatments, 1) optical circles and 2) herringbone pattern, were used to influence drivers' behaviour while entering the curve on a two-lane rural road section. The road section is selected from the Belgian Road Network and a driving simulator is used to perform experiments. Both treatments were found to reduce speed before entering the curve. However, speed reduction was more gradual when optical circles were used. Herringbone pattern had more influence on lateral position than optical circles by forcing drivers to maintain a safe distance with the on-coming traffic on the adjacent lane. The study concluded that among other low-cost speed reducing methods, optical circles is an effective tool to reduce speed and increase drivers' attention. Moreover, Herringbone pattern can be used to reduce accidents in the curve where the main cause of the accident is the lateral position.

Keywords: Driving Simulator, Driving Behaviour at curves, optical circles, Herringbone pattern.

1 INTRODUCTION

Safety is a very important aspect of road design to be considered, especially in case of rural roads. On rural roads, certain behaviour is expected from the driver which is communicated through various clues. Knowledge of drivers' perception of these clues is important as failure to comprehend these will result in unsafe situations. A road design can be considered as self-explaining when it is able to evoke the required behaviour from the drivers without the help of road signs (Theeuwes and Godthelp 1995). With few additional road markings, a road can be made self-explanatory.

Previous research shows that probability of occurrence of a fatal accident in curves is 1.5 to 4 times higher than that for tangent sections (Alexei et al. 2005) which makes safety a major concern in designing horizontal curves especially in rural areas. Radius of a curve is directly proportional to the design speed of the road (AASHTO 2011) and in some situations, it is require to be increased for enhancing road safety. Solutions other than changes in geometric design are required if geometry of the curves cannot be modified due to factors such as lack of available space etc. This is also the case with the two locations selected from two-lane rural highways in the Belgian road network.

2 LITERATURE REVIEW

Several pavement markings have been studied previously to make roads self-explaining at different sections of the road. To ensure safe driving through the dangerous section, speed reduction before entering the danger zone and maintaining the appropriate lane position is important. Charlton (2007) used various combinations of pavement markings and warning signs in a driving simulator study and found that herringbone pattern used with signboards increased the separation gap between the two opposing lanes of traffic and influences driver to follow the path that provides maximum available radius through the curve, which implies appropriate lateral position. Ariën et al. (2012) studied transverse rumble strips and herringbone pattern in a driving simulator and found that transverse rumble strips were more effective than herringbone pattern in reducing speed. Kerman et al. (1982) proposed a reduction in approach speed to reduce speed at curves. This is because speed choice at curves is highly dependent on approach speed and geometry of the curve.

Some configurations of pavement markings are presumed to manipulate speed perception of the drivers by creating an illusion of high speed (called perceptual pavement markings). Kitamura and Yotsutsuji (2015) studied effects of sequential transverse and lateral markings on perceived speed on a single-lane straight road on drivers' behaviour using driving simulator. Different configurations of transverse markings along with roadside poles were created in which spacing between transverse markings and poles was decreasing gradually. Results indicated that perceived speed was higher than actual vehicle speeds. In this study, optical circles (created on the same principle as of optical bars) and herringbone pattern (used by Charlton (2007)) were applied on the two horizontal curves selected from Belgian road network using the similar methodology as explain in Ariën et al. (2017).

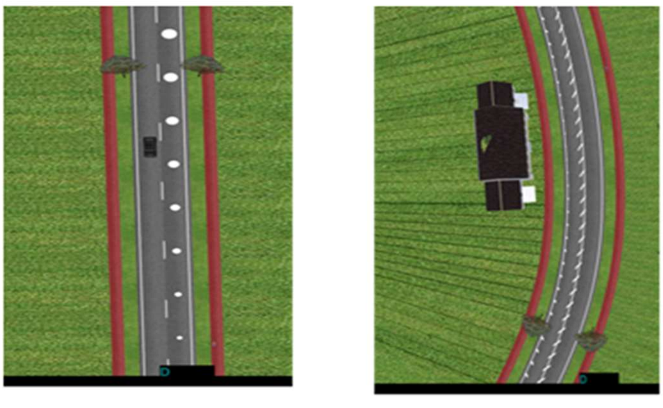
3 METHODOLOGY

The driving simulator at the Hasselt University, Transportation Research Institute (IMOB) is a fixed base medium fidelity simulator consisting of a mock up car (Ford Mondeo) with a seamless, curved screen placed at front of the vehicle. A synchronized image of 4200 by 1050 pixels quality is presented by three projectors at 60Hz refresh rate with 180^0 wide vision. Data from the driving simulator was collected at the frame rate. Two horizontal curves (named as Hoogstraat and Masseik in this paper) selected from Belgian road network on a two-way rural road were created in STISIM Drive Version 3. Lane width on the Hoogstraat and Masseik was 3.2m and 2.8m respectively. Both of these were transitional curves and their lengths and radii are given in Table 1. Pavement markings i.e. optical circles and herringbone pattern were applied on both of these curves. Effects of these markings were studied by comparing both curves with a control scenario in which no treatment was applied. As a result, six road sections (three sections for each curve) were created. These road sections were arranged in a randomized order to make two 18km long scenarios. The entire driving duration for both test scenarios was approximately 30 minutes.

Table 1: Curve lengths and their radii

Sr. No	Curve Radius (m)		Curve Length(m)	
	Hoogstraat	**Masseik**	**Hoogstraat**	**Masseik**
1	170	169	17.21	51.13
2	94	92	28.92	18.80
3	161	97	45.76	21.28
4	219	688	38.15	25.27

Optical circles segment was 90 meters long with a centre-to-centre distance of 10 meters between circles and was placed approximately 100 meters before the start of the curve. The diameter of circles increased gradually from 1.4m to 2.3m with an increment of 0.1m (Figure 1(a)). The illusion of increased speed is created by the concept of forced perspective illusion (Endler et al. 2010). Optical circles in this study are designed on the similar principal of previous studies (Godley et al. 2000, Galante et al. 2010, Montella et al. 2011). Reason to choose circles over square and eclipse is that circles require less area than squares and eclipse (Hussain 2017).



(a) Optical Circles (b) Herringbone Pattern

Figure 1: (a) Top view of optical circles, (b) Top view of Herringbone Pattern,

Herringbone pattern used by Charlton (2007) was modified according to the road width of the roads considered in this study. Width for the drivers to drive on both road sections was kept 2.5 meters at the start of the curve. This width gradually increases to the maximum lane width in the middle of the curve and then starts to reduce again. The inclination of herringbone strips was kept along the direction of the travel. Top view of herringbone pattern is shown in Figure 1 (b). The experimentation in this study was approved by the Ethical Committee of the University of Hasselt. 49 participants (14 female, 35 male) volunteered in this study with age range between 19-54 years with mean age of 26.08 years. After detecting outliers, data for 43 participants were considered in the analysis. Driving behaviour parameters considered in this study are longitudinal speed, mean acceleration/deceleration and mean lateral position. Effects of pavement markings (optical circles and herringbones) are computed and compared for both curves on 11 points (along the longitudinal axis) selected for the analysis. Description of these points is provided in Figure 2. For lateral position values obtained from the driving simulator, the central median was considered as benchmark. Positive values indicate that driver is on the right side of the median.

4 RESULTS

Due to the difference in lane width of the two roads, both curves are analysed individually by applying MANOVA statistical test to study overall effects of independent variables (road marking, points, two-way interaction between road marking and points) on dependent variables (speed, acceleration and lateral position) and repeated measures ANOVA to study the with-in subject effect of independent variables on each dependent variable individually. Table 2 and Table 3 present the analysis for Hoogstraat and Masseik respectively. Road markings and points were found to have overall significant effect including the two – way interaction between them (Wilks' Lambda $p < 0.05$). Effects of markings are explained on all three dependent variables in this section.

Table 2 Statistical analysis results for the curve Hoogstraat

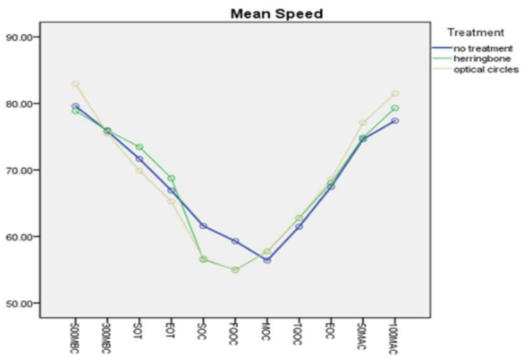
MANOVA results for Hoogstraat (Wilks' Lambda)						
Independent factor		**F value**			**p-value**	
Road Markings		206.048			.000	
Points		6.636			.000	
Road Marking * Points		2.077			.000	
Test of With-in Subject Effects (Greenhouse-Geisser)						
Independent Factor	**Speed**		**Acceleration/ Deceleration**		**Lateral Position**	
	F value	***p*-value**	**F value**	***p*-value**	**F value**	***p*-value**
Road Markings	.185	.815	6.342	.003	.634	.488
Points	112.909	.000	91.303	.000	55.238	.000
Road Markings * Points	5.899	.000	2.108	.015	5.375	.001

Table 3 Statistical analysis results for the curve Masseik

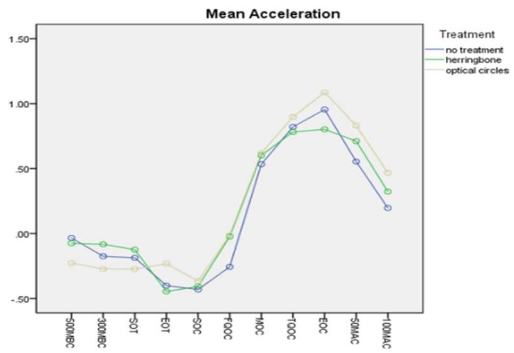
MANOVA results for Masseik (Wilks' Lambda)						
Independent factor		**F value**			**p-value**	
Road Markings		10.568			.000	
Points		6.636114.454			.000	
Road Marking * Points		2.279			.000	
Test of With-in Subject Effects (Greenhouse-Geisser)						
Independent Factor	**Speed**		**Acceleration/ Deceleration**		**Lateral Position**	
	F value	***p*-value**	**F value**	***p*-value**	**F value**	***p*-value**
Road Markings	6.265	.002	5.734	.005	12.955	.000
Points	119.579	.000	78.543	.000	45.798	.000
Road Markings * Points	3.730	.001	3.195	.000	5.463	.000

4.1 Mean Speed

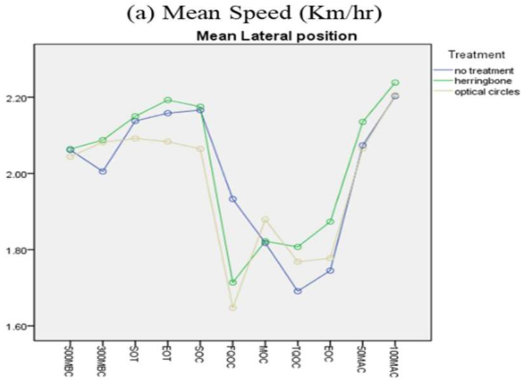
Figure 2a and 3a show three speed profiles across the 11 points for all three conditions for the curves Hoogstraat and Masseik respectively. For Hoogstraat, independent variables points and the two-way interaction were found significant (Greenhouse-Geisser ***p-value***<0.05, Table 2) whereas road markings turned out to be insignificant for speed (Greenhouse-Geisser ***p-value***=0.815, Table 2). For Masseik, all three independent variables had significant effect on speed (Greenhouse-Geisser ***p-value***<0.05, Table 3). Drivers started to reduce their speed from the point '500MBC' for all three conditions for both curves. The reason for this is that the curve was made visible approx. 500 meters upstream and a warning sign was placed 500m before the curve. Speed decrease before start of the curve was maximum for optical circles. This was expected as the objective of surface treatments is to reduce the speed of the driver before entering the curve.



(a) Mean Speed (Km/hr)



(b) Mean acceleration (m/s²)



(c) Lateral Position (m)

Points	
500MBC	500 meters before curve
300MBC	300 meters before curve
SOT	Start of treatment
EOT	End of treatment
SOC	Start of Curve
FQOC	1/4th of the curve
MOC	Middle of the curve
TQOC	3/4th of the curve
EOC	End of the curve
50MAC	50 meters after curve
100MAC	100 meters after curve

Figure 2: a) Mean Speed, b) mean acceleration/deceleration, c) lateral position for Hoogstraat, description of 11 data points

4.2 Mean Acceleration

Table 2 and 3 show that all three independent variables were significant for acceleration at both curves (Greenhouse-Geisser ***p-value***<0.05). Figure 2b and 3b show the plots of mean acceleration values for all three treatment conditions across the 11 points. In case of Hoogstraat, the acceleration in the optical circles case drops from '500MBC' to the minimum value at 'SOT'. The decrease in the acceleration was gradual, which also correspond to a second order (much smoother) change in speed for optical circles case compared herringbone and control cases. Increase in acceleration through the curve was largest for the herringbone treatment. This is because, for the herringbone treatment, drivers did not have to focus on correcting their lateral position and only required to focus on speed and acceleration. From this, we can assume that optical circles had a positive influence on speed and acceleration as they were able to reduce speed gradually. Speed did reduce for control and herringbone pattern but acceleration values suggest that speed before entering the curve was not decreased gradually rather abruptly.

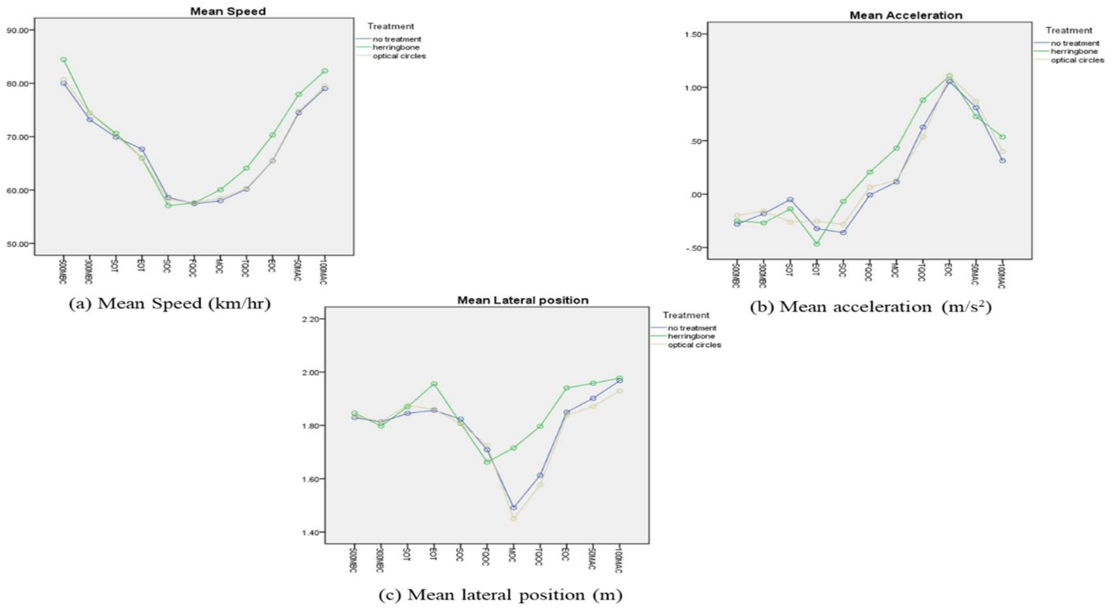


Figure 2: a) Mean speed, b) mean acceleration/deceleration , c) mean lateral position for Masseik

4.3 Mean Lateral Position

For Hoogstraat, Table 2 shows that points and the two-way interaction between points and road marking are significant (Greenhouse-Geisser ***p*-value** < 0.05) for the lateral position of the drivers. For Masseik, Table 3 shows that all three independent variables were significant for the lateral position (Greenhouse-Geisser ***p-value*** < 0.05). Lateral position values for Masseik were found to be lower than they were in case of Hoogstraat due to narrower lane width. For both curves, drivers started to adjust their lateral position from the 'SOT' point, which is approx. 300 meters before the start of the curve, by shifting towards the right edge of the lane when herringbones were applied. For herringbone strip, drivers lateral position through the curve was approximately in the middle of the lane. However, for the control case, drivers were found to drive more towards the left edge of the lane through the curve. This might be considered unsafe as this can increase the risk of head-on collision with the traffic on the opposing lane.

5 DISCUSSION

In order to ensure safe driving through the curve, speed reduction should take place before drivers enter the curve as speed reduction in the curve can cause skidding of the vehicle which increases the probability of accident occurrence. Based on speed difference values between the points 'EOT' and 'SOC' for both curves, it can be inferred that both road marking treatments were able to reduce the speed of the drivers before entering the curve. Based on the concept of relative validity of the driving simulators, it can be assumed that the magnitude of the change in speed might be different in reality if same treatments are applied before and at the curve but would be in the same direction i.e. speed will decrease.

For optical circles, acceleration values decreased uniformly because the optical circles were applied 100m before the curve. Acceleration values for herringbone and control condition decreased sharply before the point 'SOC'. This shows that optical circles were effective in safe reduction of speed before entering the curve. Though mean acceleration magnitude for all conditions was less than the recommended rate of -0.85m/s2 (Lamm and Choueiri 1987), it can be assumed that variations can be expected in real life. For herringbone pattern, acceleration values started to increase after the point 'SOC'. This is because drivers' lateral position was controlled by the herringbone strips. As a result, drivers were comfortable to drive at higher speeds through the curve. For the lateral position, herringbones pattern's influence was significant in the curve for both Hoogstraat and Masseik. The reason for this is the path drivers have to follow along the herringbone pattern is created in a way that the radius of the driver's trajectory is increased. In case of optical circles and no treatment, drivers were found driving towards the inner edge of the lane which might increase the risk of head-on collision with the traffic in the adjacent lane hence, can be considered unsafe. Ariën et al. (2017) found that for speed reduction, transverse rumble strips were effective than the reverse herringbone pattern whereas for lateral position, the treatments did not had significant effect. In our study speed reduced for both treatments but acceleration values suggest that optical circles will cause a safe reduction in speed before the curve. Herringbone pattern was found to influence the lateral position of the drivers before and through the curve. This may be due to the appropriate design of the herringbone strips followed in our study.

6 CONCLUSION AND FUTURE RESEARCH

Results obtained for driving behaviour parameters show that both optical circles and herringbones had positive effects on driving behaviour. The optical circles caused safe speed reduction before entering the curve which makes them a more suitable option than herringbone pattern. However, for lateral position, herringbone pattern made drivers follow a safe path along the curve. This shows that herringbone pattern can significantly reduce the number of accidents on the curves where accidents occur mostly due to faulty lateral position of the drivers. Hence, it can be concluded that at curve sections where speed reduction is required, optical circles are better option whereas herringbone pattern is useful when lateral position needs to be controlled. Real world implementation of both treatments with before and after studies can allow policy makers to study the long term effects of both treatments. Moreover, comparison of different perceptual treatments at curves among themselves and with transverse rumble strips using a driving simulator may also be investigated in future.

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