Faculteit Industriële Ingenieurswetenschappen

master in de industriële wetenschappen: bouwkunde

Masterthesis

The impact of perceptual road edge marking on driving behaviour in horizontal curve: a driving simulator

Siwagorn Bunjong

Scriptie ingediend tot het behalen van de graad van master in de industriële wetenschappen: bouwkunde

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Glossary

A	Clothoid parameter
ACC	Acceleration
ANOVA	Analysis of Variance
AWV	Agentschap Wegen en Verkeer
BAC	Blood alcohol content
DCC	Deceleration
EU	European Union
g	Gram
h	Hour
IMOB	Institute for Mobility
IQR	interquartile range
km	Kilometre
l	Litre
L	Length of clothoid
m	Meter
M	Mean
R	Radius
RE	Solid red edge line
RWE	Red-white pattern edge line
s	Second
SS	Simulation sickness
SSQ	Simulation sickness questionnaire
STI	Systems Technology Inc.
WHO	World Health Organization

Abstract in English

Horizontal curves have been a significant safety concern on roads for years, often resulting in a high incidence of crashes. According to a European Road Safety Observatory report, 53% of all road crashes in the European Union occurred on rural roads in 2020, mainly due to misjudging when navigating these curves. This study aims to explore innovative and low-cost solutions to this issue, such as implementing continuous red and red-white patterns on edge road markings. The objective is to evaluate the impact of red-white patterns and solid red edge lines on driving behaviour, including speed, lateral position, and acceleration before and during horizontal curves.

The various road markings were tested in a driving simulator using STISIM software. Fifty volunteers, comprising 35 men and 15 women aged between 20 and 75, participated in the study. The simulation road was designed according to the Flanders road agency (AWV) guidelines. The simulation tested twelve horizontal curves, including left and right turns, with 125 m and 350 m radii.

The results were analysed using the repeated measures Analysis of Variance (ANOVA), a within-subjects design. The study found that using low-cost edge road markings can help reduce driving speeds around curves and improve driver behaviour and control, ultimately enhancing road safety. These results indicate that road authorities should consider implementing these markings in dangerous curves.

Abstract in het Nederlands

Horizontale bochten zijn al jarenlang een groot veiligheidsprobleem op de weginfrastructuur, vaak leidend tot een hoog aantal ongevallen. Volgens een rapport van het European Road Safety Observatory vonden in 2020 53% van alle verkeersongevallen in de Europese Unie plaats op landelijke wegen, voornamelijk als gevolg van verkeerde inschattingen van bochten. Daarom onderzoekt deze studie de impact van innovatieve kost effectieve oplossing voor dit probleem, meer bepaald het implementeren van volle rode en rood-witte patronen lijnen op randwegmarkeringen, in vergelijking met de standaardwegmarkeringen die in Vlaanderen gebruikt worden.

De verschillende wegmarkeringen werden getest in een rijsimulator met behulp van STISIM-software. Vijftig vrijwilligers, waarvan 35 mannen en 15 vrouwen in de leeftijd van 20 tot 75 jaar, namen deel aan het onderzoek. De wegen waren ontwerpen volgens de richtlijnen van Agentschap Wegen en Verkeer. Twaalf horizontale bochten, waaronder linker- en rechterbochten met boogstraal van 125 m en 350 m, werden in deze studie onderzocht.

De resultaten werden geanalyseerd met behulp van *repeated measures ANOVA, een within-subjects design.* Uit de resultaten blijkt dat het gebruik van kost effectieve randwegmarkeringen kan helpen om de rijsnelheden in bochten te verminderen en het rijgedrag van bestuurders te verbeteren, zodat hierdoor de verkeersveiligheid wordt verhoogd.

1 Introduction

Horizontal curves in rural areas have been a significant road safety concern for many years. More than 25 per cent of fatal crashes were associated with a horizontal curve, and the risk was 1.5-4 times higher than in straight sections. About 75 per cent of curve-related fatal crashes involved running off the roadway and striking an object or overturning [1, 2]. These crashes were mainly caused by human error, as well as by the geometric design of the road and poor vehicle maintenance. These crashes could have been prevented by changing the geometric design of the horizontal curve, such as increasing the shoulders' width or placing barriers along the curve. However, these interventions were not always possible due to limited available space, and they could have been costly projects for what they returned. Therefore, a cost-effective approach to reduce rural crashes on horizontal curves, such as signage and pavement markings, should have been implemented. To understand the impact of these countermeasures on reducing crashes in rural areas, they should first be tested on drivers' behaviour through a driving simulator.

This driving simulator study analysed the effect of two low-cost road marking countermeasures, including a red-white pattern edge line and a solid red edge line, combined with a vertical warning sign on driving behaviour. This countermeasure was inspired by a typical racetrack where the curve is visible to drivers before entering. These measures were analysed before and during the horizontal curves with 125 m and 350 m radii. The two low-cost road markings were compared to a control condition based on the Flemish Road and Traffic Agency (AWV) guidelines. Each condition was analysed for left and right turning for each radius, resulting in 12 horizontal curves for this research. The driving speed, lateral positioning, and acceleration were measured during the test to analyse the driving behaviour and were analysed using the repeated measures ANOVA within-subject method.

The main objective of this research was to investigate the impact of red-white pattern (RWE) and solid red edge lines (RE) on speed, lateral position, and acceleration in and during horizontal curves. The following hypotheses were formulated for this experiment:

- The RWE stimulated drivers to slow down while approaching a dangerous curve.
- Both treatments encouraged drivers to decelerate early before the curve.
- Both treatments warned drivers to stay away from the edge road marking.

2 Literature review

To gain a better understanding of the topic of this thesis, this chapter details the research questions. The chapter starts by pinpointing the search areas for the problem and the concept of human reaction on the road and ends with the theoretical hypotheses of this research.

Section 2.1 defines the scope of the topic of this thesis, which will focus on fatalities in rural areas and existing countermeasure interventions and guidelines to design a safe roadway. Section 2.2 describes the possibilities and the concept of testing the interaction with human subjects to increase safety on the horizontal curves of the road. Learning human interactions of drivers on the road can be a guideline to pinpoint the areas of improvement and how to translate them into objective data. Section 2.3 highlights the research gap found in past research and the possibility of debate about driving simulation. Finally, in section 2.4, the theoretical hypotheses of this research will be detailed to fill up the gaps in the current study.

2.1 Road safety

Road safety is one of the critical factors considered when designing a roadway. According to the World Health Organization (WHO), approximately 1.19 million people worldwide are lost each year due to road traffic crashes, and 20-50 million extra people suffer non-fatal injuries, often leading to disability. These road traffic injuries caused considerable economic losses to individuals, their families, and the nation. The report states that road traffic death rates are highest in low- and middle-income countries and lowest in the European Region. However, people with lower socioeconomic backgrounds were more likely to be involved in road traffic crashes [3].

In Europe, the European Road Safety Observatory report states that in 2020, 53% of all road fatalities in the European Union (EU) occurred on roads outside urban areas [4, 5], contrasting with 40% within urban areas [4]. Another 7% of traffic crashes occurred on motorways and off-road regions.

According to the statistics reports of the Flemish federal government showed that in 2022, there were almost 38,000 road crashes occurred in Belgium, of which 62% of all crashes in Belgium occur in Flanders [6], which comes to approximately 23,560 road crashes. The European Road Safety Observatory further noted that the proportion of fatalities on roads outside urban areas in total fatalities tended to be high in Northern Europe. The proportion of traffic crashes outside urban areas in the total number of crashes per country in the EU27 is shown in Figure 1.

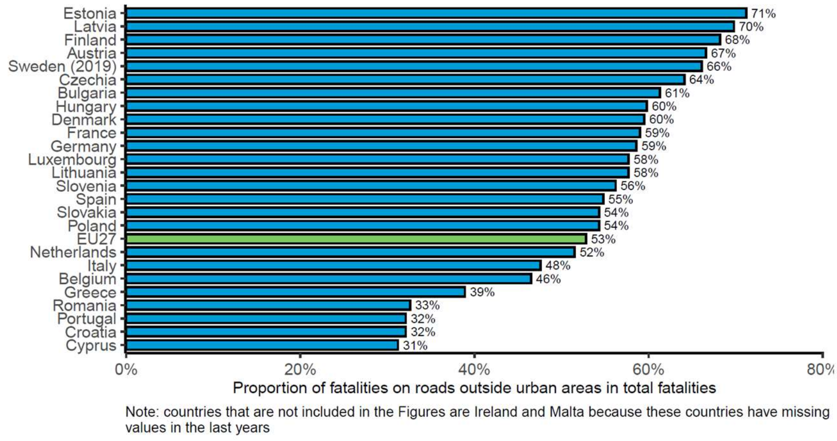


Figure 1: Fatalities rate on roads outside urban in Europe

The European Road Safety Observatory further noted that 46% of road fatalities in Belgium were in rural areas [5]. This rate was relatively lower than in neighbouring countries like the Netherlands (52%), Germany (59%), France (59%), and Luxembourg (58%). This was a critical safety issue in different parts of the world, as crashes on horizontal curves are a big concern in all countries [7-10]. The most common type of crash on curves was single-vehicle crashes (run-off-road), particularly in rural areas where these crashes could account for up to 76 per cent of curve-related fatalities [11].

2.2 Risk factors and causes of vehicle crashes

According to the Vias Institute report [12], the primary source of vehicle crashes came from three main categories: human factors, infrastructure design and defections of the vehicle. According to the report, 80-90% of fatalities came from human factors. The main factors that influence the behaviour of the driver are speed, usage of alcohol or drugs, distraction and tiredness.

2.2.1 Inappropriate speed

There was a link between vehicle speed and the risk of fatal crashes. Inappropriate speed could be the source of vehicle crashes or a higher risk of fatal crashes. This had to do with the longer reaction time for the driver at high vehicle speeds. Reaction time is how long a driver needs to react to unexpected events, such as reaching the brake to lower the speed or stop the vehicle. A higher speed increased not only the distance during the reaction time but also the braking distance of the car as well. As a consequence, the risk of frontal crashes was higher.

Several studies [13-16] confirmed an exponential relation between initial speed and the number of crashes, as shown in Figure 1. The higher the initial speed, the higher the risk of many crashes would be in an exponential way. Driving at a lower initial speed could decrease the risk of crashes.

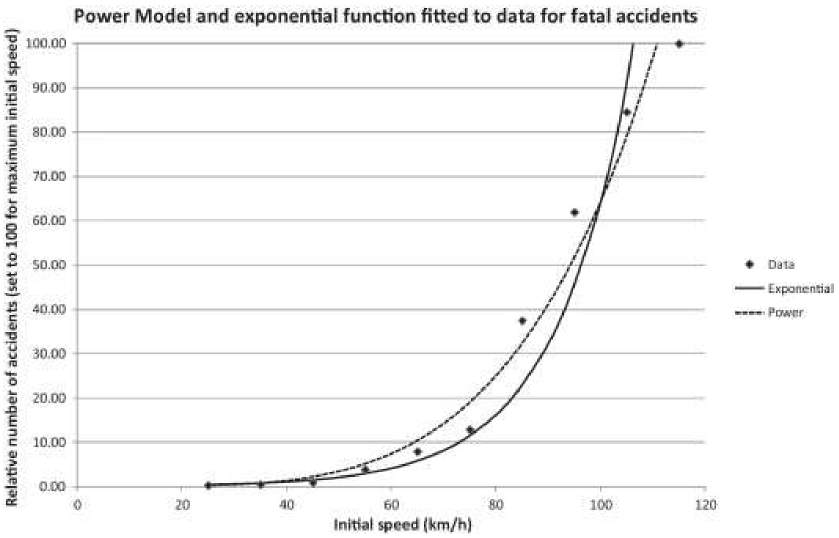


Figure 2: Power Model and exponential function fitted to the crash data

However, speed is the primary factor in vehicle crashes, not the only factor. In general, approximately 10-15% of all crashes were caused by inappropriate speed on the road [17].

2.2.2 Usage of alcohol or drugs

Driving a vehicle under the influence of alcohol was one of the essential primary factors of vehicle crashes. However, there was a small percentage that used the car while drunk; alcohol is involved in vehicle crashes most of the time. According to the Vias Institute, nearly 47,000 drivers were tested positive and fined for driving while under the influence of alcohol in 2022. A European survey also showed that 7% of vehicle crashes in Belgium involve alcohol usage [18]. Driving under the influence of alcohol is a traffic crime in all European countries, but the limit of alcohol usage varies from country to country. In most countries, including Belgium, the legal limit is a blood alcohol content (BAC) of 0.2-0.5 g/l. Alcohol consumption has several adverse effects on driving ability: concentration decreases, reaction speed decreases, speed fluctuations and some form of drowsiness may occur. Drivers often thought they were still perfectly capable of driving even though they had been drinking.

On the other hand, driving under the influence of drugs is considered, in general, a potential risk for vehicle crashes due to the delay of perception and reaction time. A study by Schulze et al. estimated that about 2% of vehicle crashes involve drug usage [19].

2.2.3 Distraction and sleepiness

Driving a vehicle on the road requires a lot of focus and attention to ensure safety while travelling from one location to another. Ranney [20] estimated that 25-30% of drivers spend their rides with other activities, distracting them from focusing on the road. There were many causes of distraction, such as mobile phones, billboards, passengers, built-in entertainment systems, etc. A distracted driver is not paying attention to traffic and may not perceive an obstacle in time to react, and the consequences cause potential vehicle crashes. Distraction was a primary factor in the risk of vehicle crashes.

Similarly, tiredness or sleepiness behind the wheel was a big issue for road safety. According to a report by Riguella and Goldenbeld [21], 20-25% of vehicle crashes in Europe are caused by tiredness or sleepiness. Tiredness is a lack of attention due to decreased ability and motivation to act. This could be physical and mental aspects. Typically, seniors and people in poor health conditions get tired faster than average or younger people.

2.2.4 Surface friction or grip

In contrast with the infrastructure design, the grip between vehicles and the road was the primary factor for crashes. A high-quality road type offers better grip, which, in dangerous situations, notably results in a shorter braking distance. However, friction is easily influenced by weather conditions. According to the report of Leblud et al. [22], wet road conditions led to lower friction and, consequently, a longer stop distance for a vehicle, while dryer road surfaces provided better grip, as shown in Figure 3.

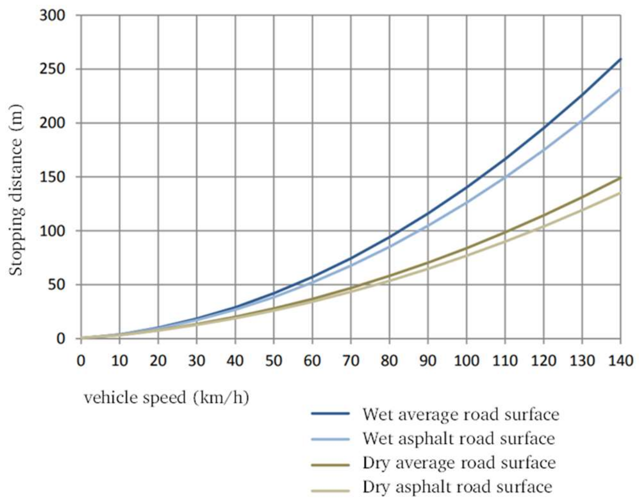


Figure 3: Braking distance on type of road surface

According to the EU report [5], most of the single-vehicle fatalities reported in 2022 in the European Union occurred in dry weather and daylight on rural roads. This indicated that drivers often experienced difficulties controlling lateral positions rather than struggling with road perception and pavement grip.

2.2.5 Poor maintenance vehicles

The Vias Institute suggested that there was also a slight percentage chance that older or poorly maintained vehicles can lead to vehicle crashes as well. However, according to the Hermitte et al. report [23], inspecting every part of the vehicle to determine the risk of failing parts is tricky. To minimise the risk of vehicle crashes due to defective vehicles, the drivers in Belgium are obligated to get inspections at least once a year.

2.3 Countermeasures

The previous section explained the possible risk of vehicle crashes. This section applied the potential interventions to minimise vehicle crashes. Several studies have shown two categories of intervention: Design-assisted intervention and low-cost interventions.

2.3.1 Design aspect intervention

The Vias Institute report [12] suggested that upgrading shoulders would significantly impact the safety of passengers in the vehicle. Studies by Alari and Usami [24] also indicated that there shouldn’t be any obstacle near the shoulder to increase road safety. By increasing the shoulder when a vehicle deviates from the road, the shoulder allows the driver to correct it without causing any crashes. Studies by Jurewicz et al. [25] and Levett [26] suggested that the risk of vehicle crashes could be significantly reduced by up to 69% by implementing the shoulder. However, there were concerns about increasing the shoulder width in infrastructure; building the shoulder was only sometimes possible due to the available geographical space. Mecheri et al. [27] were concerned that there might be a new style of driving through the corner called corner cutting. Corner cutting is when the driver intentionally uses the shoulder to travel faster through the corner, which was not designed for this reason.

Another solution in design intervention was increasing curve widening. A curve widening is a widened section inside the carriageway in a horizontal curve. The existing sharp curves would mainly be added to improve safety through the curve. According to Charles et al. study [28], curve widening significantly impacted road safety. They expected this intervention would reduce the crash rate by up to 21 per cent. However, widening the space of the shoulder could reduce crashes by as much as 33 per cent. The challenging part of proceeding with this intervention is the geographic space and budget to build on.

2.3.2 Low-cost intervention

As previous sections were told, the leading cause of many traffic crashes on rural roads was human behaviour due to lack of attention. Low-cost interventions, including speed limits, road design, marking, and safe infrastructure management, could be implemented to increase road safety for a reasonable investment budget. Most of these interventions were unrestricted to the geographic space used to build the road. It is a cost-effective intervention for maximal safety on road safety. A low-cost intervention shared the same concept as self-explanation roads. Self-explaining roads are designed to naturally guide drivers through the road elements such as signs, markings, road surfaces, lighting, and speed management. The goal was to encourage drivers to follow the road's design and purpose instinctively and reduce unsafe driving manoeuvres. [29, 30]. Albin et al. report [31] recommended implementing low-cost interventions to enhance road safety. These include profiled road markings, delineators, advance warning signs, dynamic curve warning systems, and roadside barriers. Figure 4 and Figure 5 show an example of low-cost interventions.

Figure 4: Roadside barriers, chevron signs and speed limit sign

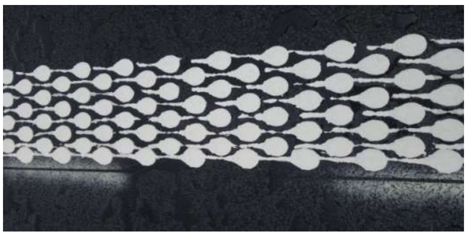


Figure 5: Profiled dot marking

A study by Garach et al. [32] involved experimenting with widening road markings as a low-cost intervention on rural roads. The study surveyed 185 participants who watched 14 pre-recorded videos of a vehicle driving in real scenarios on both wide and narrow road markings in Spain. The results showed that almost half of the participants perceived a higher speed with wide markings than narrow markings. This perception made the drivers feel like the road was narrowing, which could potentially lead them to lower their speed and drive more safely.

2.4 Driving simulators

To test a new innovative intervention on the road, it would likely be tested in driving simulators first before applying it on a small scale in real scenarios. With driving simulators, the research could be tested on a small research budget for a short period and could also secure the safety of the drivers during the experiment. Most of the studies have shown that using driving experiments is a better way to understand the driving behaviour behind the wheel [27, 33-38].

A driving simulator was used in a study by Babic et al. [38] to analyse low-cost road markings in horizontal curves to increase road safety. The research tested two types of road markings, including red median and horizontal warning signs on dangerous horizontal curves with radii of 175 m on a two-way rural road. Dangerous horizontal curves with radii less than 200 m present an increased road crash risk due to inappropriate speed and underestimating the sharpness of the curve [2, 38-41]. This research aimed to warn drivers from the farthest possible distance before the curve to slow down the driving speed and improve driving control along the curve. The total length of the scenarios was almost 15 km long, including ten identical curves of radii 175 m for both the left and right curves. All the curves had a total length of 210 m, a deflection angle of 90° for each curve, and a transition of 50 m. Each curve had a different combination of interventions, including a red median on the curves, horizontal warning signs on the pavement surface and standard vertical warning signs of curvature ahead. The scenarios were tested in a randomised order to prevent the prediction of what was coming next. The driving scenarios consisted of a two-way road in a rural area with 3.5 m wide road lanes and 15 cm wide for both centre line and edge road markings. In the experimental intervention, the red median started 50 m before the curve until the end of the curve. The median was 50 cm wide with a 15 cm solid white road marking on both sides. There were five dangerous curve warning signs for the horizontal warning sign in white road markings. The first sign started at 205 m before the curve, and the last sign was set at 100 m before the curve. The size of each horizontal warning sign was 25% more than the previous sign. A total of 47 participants between 22 and 66 years old were tested in this study. From the driving simulator, 11 data points were collected for each curve, including longitudinal speed, lateral movement, and acceleration/deceleration. Five data points are located before the curve, five data points in the curve, and one point after the curve. The study showed that both road marking interventions decreased the driving speed by 5 km/h compared to scenarios without road marking treatments (only vertical warning signs). The study also highlighted that the speed reduction from 300 m before the curve until the start of the curve for scenarios with vertical warning signs only was much higher, 30.60%, than the two experimental treatments, which is a 26.27% speed reduction for red median and 25.78% for horizontal warning signs. This is due to the relatively low perception of traffic signs, as drivers may not notice many warning signs [42, 43]. Consequently, the control condition's deceleration was more abrupt than the treatments. Regarding the lateral movement during the curve, the vehicle drove closer to the centre line in the control condition and horizontal warning signs. While on the red median, the car moved closer to the edge of the road marking.

Awan et al. [41] conducted a similar study on road marking treatments and investigated the impact of two different road marking treatments on driver behaviour during horizontal curves, using a driving simulator as the experimental platform. These treatments included the implementation of optical circles placed before the curve and a herringbone pattern running along the curve itself. The idea behind this experiment was to influence driving speeds by manipulating drivers' perceptions, creating an illusion of high-speed driving, a concept known as perceptual pavement markings [35, 44, 45].

Such markings were intended to enhance drivers' attention and prompt them to reduce speed before entering the curves. The study was based on real-life scenarios from Hoogstraten and Maaseik in Belgium, with 3.2 m and 2.8 m as lane widths. Each scenario consisted of an 18 km road with 12 horizontal curves, and it was tested for optical circles and herringbone treatments. The optical circles treatment spanned a length of 90 m, with the diameter of the circles gradually increasing from 1.4 m to 2.3 m at 10 m intervals. The optical circles concluded at 91 m and 107 m before the curve in both scenarios. On the other hand, the herringbone pattern reduced lane width to 2.5 m at the beginning of the curve, gradually expanding to the maximum lane width at the midpoint of the curve and then decreasing once again. The herringbone pattern treatments started at approximately 40-50 m before the curve and extended 30 m beyond it. The experiment involved 49 participants aged 19 to 54, each of whom experienced the two scenarios of Hoogstraten and Maaseik in the driving simulator. The driving simulator recorded 11 data points for each curve, including longitudinal speed, lateral movement, and acceleration/deceleration. Four data points were collected before the curve, five within the curve, and two after the curve. The results indicated that the optical circles effectively contributed to a safe reduction in speed before entering the curve compared to the herringbone pattern. Additionally, the herringbone markings provided a comfortable driving experience through the curve by controlling the vehicle's lateral position. This study sheds light on the potential of different road marking treatments to influence driver behaviour and safety when navigating horizontal curves.

In another study led by Babic et al. [37], a driving simulator was used to evaluate the effectiveness of various chevron sign designs as low-cost treatments for assisting drivers in navigating horizontal curves. The objective was to understand how these signs influenced driver behaviour and which designs attracted the most attention for safe navigation through the curve. The chevron signs featured various colour combinations, such as white backgrounds with red arrows, fluorescent green backgrounds with red arrows, white backgrounds with black arrows, yellow backgrounds with black arrows, and black backgrounds with white arrows. The research occurred on a rural two-lane road with 3.5 m wide lanes in Croatia, including ten identical curves. The speed limit on a rural road in Croatia is 90 km/h. Each curve consisted of 50 m transition curves with a 110 m length curve and a 150 m radius of curvature. In between the curves, there was a straight section of 800 m. Four chevron signs and a dangerous curve warning sign were placed on each curve, with the dangerous curve warning sign positioned 150 m before the curve. The study involved 60 participants aged 19 to 33. Two parameters were measured to analyse driver behaviour: longitudinal speed and lateral movement. Six measuring points were collected for each curve: three points before and three points during the curve. The results indicated that the chevron signs had an impact on driving speed. A fluorescent background with red arrows reduced speed from the speed limit to 83.46 km/h, while a white background with a red arrow reduced to 84.56 km/h and a black arrow to 84.08 km/h. However, all chevron designs caused a slight shift in the lateral movement towards the edge line. The study suggested that fluorescent, red, or white colours were more effective at capturing drivers' attention on the road. It also proposed utilising colour combinations to indicate the sharpness of horizontal curves but cautioned that doing so could confuse drivers and lead to increased speeds while navigating the curves.

2.5 Research gap

The literature review revealed extensive research on the effects of various road markings implemented before and during curves on drivers' behaviour. Most studies focused on different variations of median centreline and herringbone markings, while others examined the use of coloured median or chevron signs in combination with a vertical warning sign. However, there is limited research on the impact of edge line markings as a cost-effective intervention. This study assesses the effects of two types of low-cost edge road marking treatments on drivers' behaviour before and during sharp and shallow horizontal curves. The two road marking treatments to be analysed are a red-white pattern line and a solid red line. The red-white pattern line aims to create an illusion for drivers, encouraging them to slow down during the curve automatically. The solid red edge line is also implemented to determine if it enhances curve visibility. The primary objective of this research is to improve road safety in horizontal curves, thus necessitating the analysis of these treatments in the context of both sharp and shallow curves.

2.6 Theoretical hypotheses

This research project focuses on analysing the effects of two low-cost road marking techniques on driver behaviour before and during horizontal curves with two distinct radii (sharp and shallow). An extensive review of the existing literature informs the hypotheses of this study. These hypotheses are described in the following sections.

2.6.1 Speed

Speed of driving speed is defined as the distance or position the vehicle travelled divided by time. Elvik [16] has demonstrated the relationship between speed and crash risk. Lowering the speed before entering the curve potentially reduces the risk of crashes. As hypotheses for this research, the treatments would stimulate drivers to slow down while approaching a dangerous curve. Moreover, the RWE would most encourage drivers to reduce their driving speed.

2.6.2 Acceleration or deceleration

Acceleration or deceleration is the rate at which a vehicle or other vehicle can increase or decrease its speed. Acceleration has a direct link to speed. When a car decelerated abruptly, the risk of a crash also increased. As hypotheses for this research, both treatments encourage drivers to decelerate early before the curve and, therefore, a moderate deceleration, corresponding to a lower risk of crashes due to complete vehicle control.

2.6.3 Lateral position

The lateral position is the distance between the vehicle's centre and the road's centre line. This factor represents one of the driver's behaviour risks, whether a frontal crash or running off the road causes the crash. The higher the lateral position, the closer the vehicle will be to the edge of the road. When the car is closer to the edge of the road, the risk of run-off-road crashes will increase. As hypotheses for this research, the treatments would encourage drivers to avoid the edge line to reduce run-off tracks.

3 Methodology

To test these hypotheses, 12 curves with two different curve types (six dangerous and six shallow curves) were created in the driving simulator software STISIM Drive, produced by Systems Technology Inc. (STI). In this chapter, the scenarios design for the driving simulator will be explained in detail. The chapter starts with the design of the experimental route, participants, the setup of the driving simulator, and the protocol used during the test of this research.

Section 3.1 explained different aspects of designing the route for the driving simulator in detail, including the requirement of developing a horizontal curve from AWV, trajectories of the driving simulator and road markings treatment design. Section 3.2 described the participants participating in this research and the side effects of driving simulation. Section 3.3 described the set-up of the driving simulator, and section 3.4 explained the protocol of the participants in this research. Section 3.5 described the location of measuring points, and section 4.1 explained the necessary steps before starting statical analysis: detecting outliers to ensure the result is reliable for this research.

3.1 Scenarios design

The scenarios of these curves were created in a region of Flanders in Belgium. Therefore, the traffic law of this research will also follow the traffic law of Flanders, as shown in Figure 6.

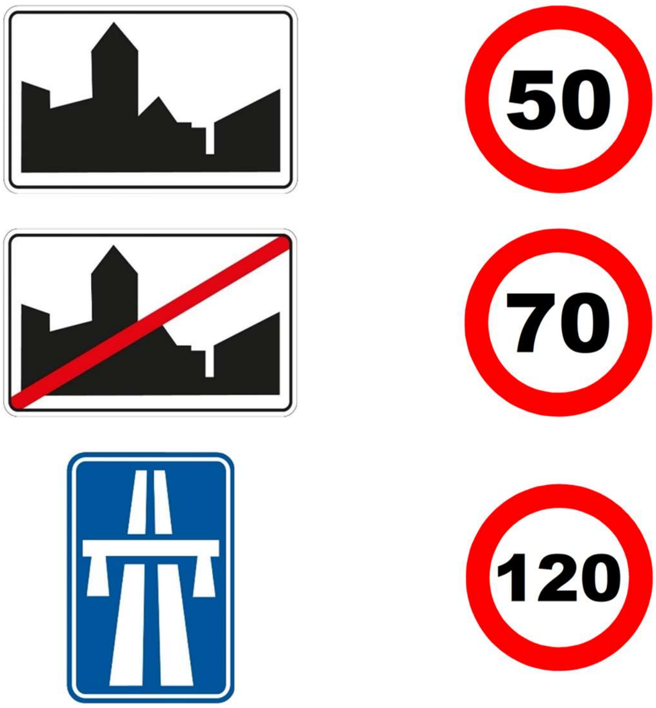


Figure 6: Speed limits in Flanders

In urban areas, the speed limit is 50km/h, while in rural areas, the speed limit is up to 70 km/h. Additionally, the speed limit is 120 km/h on the highway [46]. Since the experiment scenarios were created in a rural area with a two-way road, the maximum speed limit would be 70 km/h.

In the literature review, several previous studies have indicated that curves with a radius less than 200 m are considered the most dangerous. The crashes on these horizontal curves include running off the road, frontal collisions, and collisions with objects at the roadside. Therefore, it was determined that a sharp curve would have a radius of 175 m for the experiment, while a gentle curve would have a radius of 350 m. However, due to the lack of realistic feel in the driving simulator of the curve, the radius of 175 m was not sharp enough and had to be reduced to 125 m to increase the sharpness of the curve feeling. As a result, the curve with a radius of 125 m was considered a sharp and dangerous curve. In comparison, with a radius of 350 m, it was regarded as a gentle curve and is used to analyse further the impact of drivers' behaviour on road marking treatments. The design of horizontal curves followed the guidelines of designing the infrastructure according to AWV.

3.1.1 Guideline AWV

According to the guideline *"Vademecum weginfrastructuur deel Vlaamse hoofdwegen"*, the visibility of drivers is an essential aspect that needs to be considered when designing a road section [47]. Requirements from visibility determine the dimensioning of many design elements.

A driver was required to have visibility of the road to control the vehicle's lateral position and respond safely and comfortably to events that occurred ahead. "Safely" refers to drivers identifying and reacting to unexpected events on the road in time, such as stationary vehicles and objects on the road. "Comfortably" refers to drivers identifying and being able to perform necessary manoeuvres in time and being comfortable with unexpected events on the road. To analyse the impact of the treatments on drivers' behaviours, only the minimum requirements to design the road were necessary for this research, which meant safety requirements were applied in this study.

To design the horizontal curve, the following elements had to be determined: the horizontal straight section, horizontal curve section, and transition curve. Design speed was the primary factor in determining the dimensions of these design elements.

Horizontal straight section

The horizontal straight section or straight section is a straight section that connects two curves. The designed speed of the road determined the length of the straight section. AWV had a table with suggestions for the minimal and maximal lengths of the straight section in Table 1.

Table 1: Minimum and maximum length of the horizontal straight section

Design speed (km/h)	Minimal length (m)		Maximal length (m)
	between rectified curves	between opposing curves	
90	360	180	1800
70	280	140	1400
50	200	100	1000
30	120	60	600

For this research, the designed speed was chosen to be 70 km/h to be safe on the curve in both the left and right direction, and the straight section had a minimum of 280 m length between the two curves in the simulator.

Transition curve

The transition curve is a gradual transition between a horizontal straight and a horizontal curve or between two horizontal curve sections. The transition curve provides drivers with the opportunity for smooth steering deflection and keeps lateral vehicle force manageable.

The trajectory of the transition curve is identical to the clothoid, also known as the Euler spiral. Therefore, the Euler spiral theory is applied [47]. This curve was the trajectory traversed if the vehicle's speed and the steering wheel were constant. This created a smooth transition between the two design components. The clothoid was characterised by the clothoid parameter A. The clothoid is a spiral whose radius of curve R is inversely proportional to its length counted from the zero point (where R = infinity). The following formula represents the calculation of the transition curve.

$$A^2 = R_x * L_x \tag{1}$$

Wherein:

A: clothoid parameter (m)

R_x: radius of clothoid at point x (m)

L_x: length of clothoid between point x and zero point (R = infinity) (m)

In the meantime, AWV has established the minimum requirements for the clothoid parameter A. For a curve with a radius of 125 m, A should be 41.67, and for a radii 350 m, A should be 95. Additionally, the length of the transition curve L should be 14 m for a radius of 125 m and 26 m for a radius of 350 m.

Horizontal curve section

The horizontal curve section is a circular curve with a given radius. The horizontal curve had several functions, such as connecting roads in different directions, providing a variety of road scenes to increase concentration while driving, and improving visibility downstream. The most important parameters when designing a horizontal curve were the length of the curve (the arc length) and the radius of the curve (the curve radius).

A minimum arc length based on three driving seconds was prescribed to recognise the horizontal arc as an independent element. In Table 2, AWV prescribes the minimum circular curve length.

Table 2: Minimal circular curve length

Design speed (km/h)	Minimal arc length (m)
90	75
70	60
50	40
30	25

As other studies have experimented, the deflection angle of the curve was 90° [38, 48]. This was a good angle from which to start the curve and would also be used in this research. Therefore, the arc length would be 183 m for the radii 125 m and 524 m for the radii 350 m, which was clearly above the minimum requirement of an arc length.

3.1.2 Scenarios

For this research, four different driving routes were created. Each route consisted of a randomised order of 12 scenarios with horizontal curves, six curves with a radius of 125 m and six curves with a radius of 350 m. As mentioned in the guideline of AWV, the curve with a radius of 125 m had a length of 183 m and a transition section of 14 m. The curve with a radius of 350 m had a length of 524 m and a transition section of 26 m. Of the 12 scenarios, every four scenarios had a different condition of road marking treatments in combination with a vertical warning sign. The conditions are control condition (solid white edge line), red-white pattern condition (red-white pattern edge line) and red condition (solid red edge line). A vertical warning sign of dangerous curves is placed 150 m before each curve. The road marking treatments started 100 m before the curve began and went until the end of the curve.

The road section consisted of a two-way rural road with 3.5 m wide lanes with 30 cm of shoulder and 15 cm white centreline and edge lines. The centreline was a dashed line of 2.5 m long and had a distance of 10 m between two dashed lines. However, 150 m before the curve, the dashed line changed to 1 m long with a distance of 1.5 m between the two lines until the start of the transition curve. From that point until the end of the transition curve, the centreline was a single solid line. After the transition curve, the centreline was a dashed line again with a length of 1 m for each line until 150 m after the curve, and the centreline changed back to a dashed line with 2.5 m long. The dimensions for the road markings were designed according to the regulations prescribed by AWV [49]. Figure 7 shows the dimensions of the centreline.

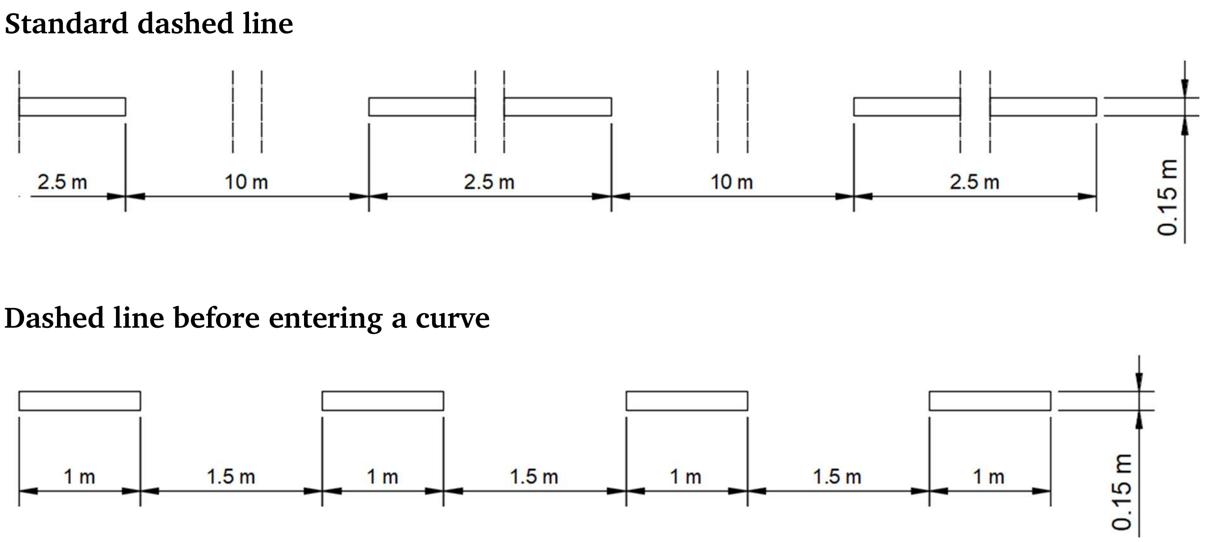


Figure 7: Dimension of dashed centreline

The layout of each route consisted of 6 combinations of 2 horizontal curves with a filler section. A filler section was a section that aimed to change the scenery during the test drive to keep the route interesting for the participants of this research. Filler sections of this research were urban city areas, a couple of houses, tunnels, hills, intersections or an overpass.

Each route had a total length of approximately 15 km, which could correspond to a 15-minute test drive in a rural area. In the beginning, there was a vertical speed limit sign to ensure which driving speed the participants could be ridden on the road, as shown in Figure 8. On every route, some vehicles came from opposite directions to the test driver. However, no traffic was moving from the opposite direction around the curve area to ensure that the driver's behaviours were not influenced by the traffic along the curve. Besides the two-way road, the environment consisted of trees throughout the entire route with filler sections. To ensure the sudden finishing of the route, there was a traffic light at the end of every road, as shown in Figure 9. The participants could slow their speed to almost entirely stop, and the test route would end.

Figure 8: Start scene of the simulator

Figure 9: End scene of the simulator

3.1.3 Road marking treatments

Based on the previous studies in the literature review section and the concept of perceptual markings, the road marking treatments were implemented with two different experimental low-cost road markings, especially edge markings in this study, which are red-white dashed pattern lines and solid red lines before and along the horizontal curve. This section describes both treatments in detail.

The red-white dashed pattern line resembled the red and white checkered line. However, the dimensions of those red and white parts differed depending on the distance to the curve. The red-white line is 10 m long for both colours and reduced gradually to 1.5 m long. This treatment aimed to create an illusion of driving too fast by alternating red and white colours. Therefore, it is hoped that the drivers would slow down automatically before entering the curve. Four zones were created for this treatment to reduce the pattern gradually, as shown in Figure 10.

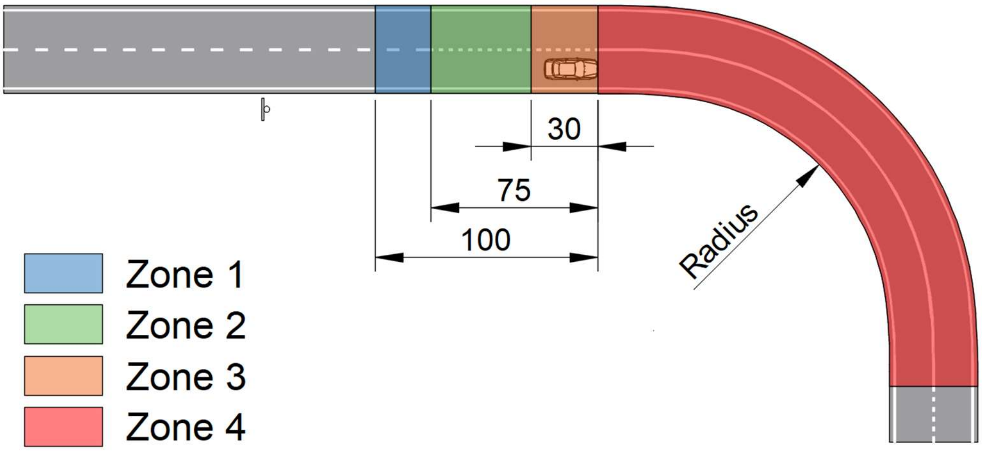


Figure 10: Overview of red-white marking zones

The first zone started at 100 m before the curve and ended at 75 m before the curve. In this zone, the red-white marking had a width of 15 cm and was 10 m long for each colour. The second zone began at 75 m and ended at 30 m before the curve. The red-white marking changed to 6 m for each colour. The third zone started 30 m before the curve until the beginning of the transition curve. The red-white marking altered the length to 3 m. The fourth zone markings were from this point until the end of the transition curve. The red-white marking reduced the length again to 1.5 m for each colour. Figure 11 shows the design of each zone with dimensions.

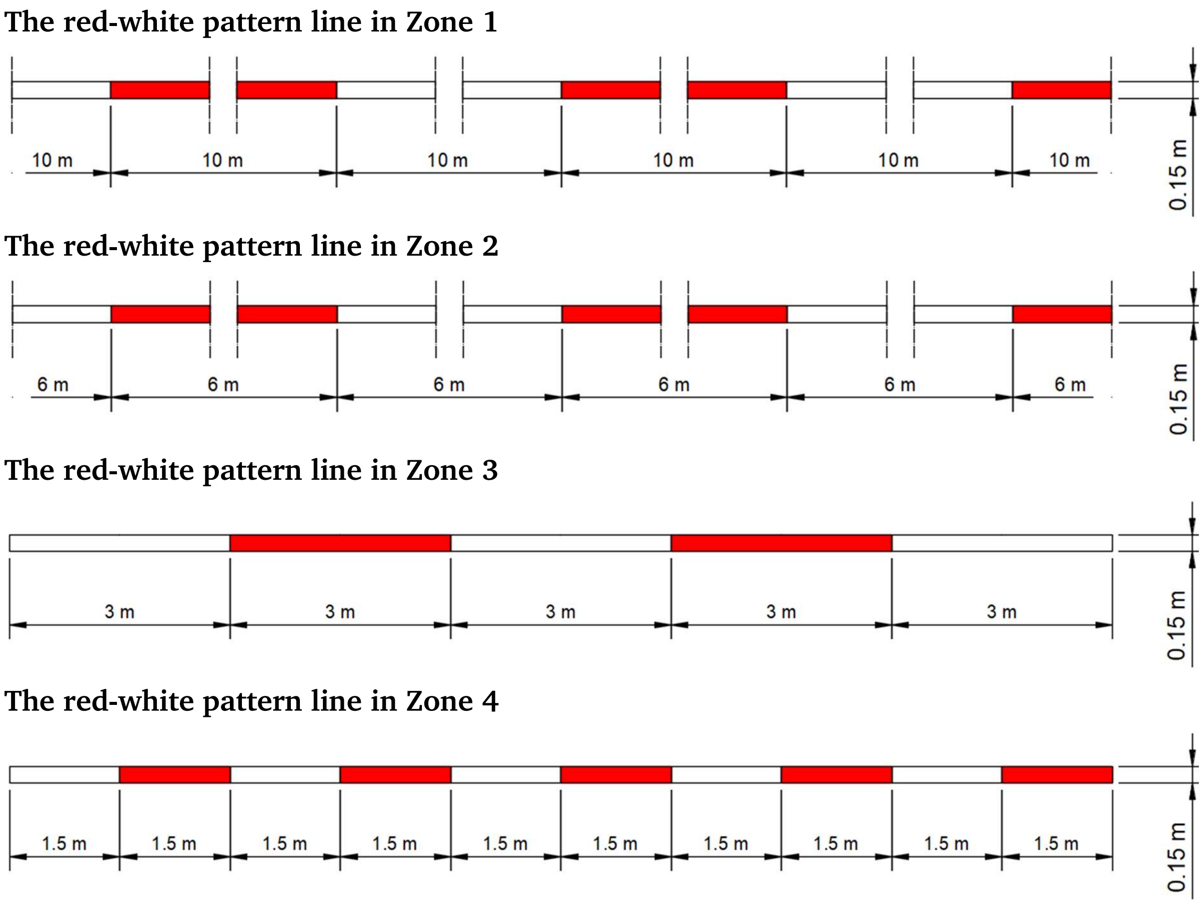


Figure 11: Dimension of red-white pattern edge line

On the other hand, the solid red line had the same dimension as the white line in the control condition. However, during the simulation, the white edge line changed colour to red at 100 m before the horizontal curve and ended at the end of the transition curve. Figure 12 shows the differences between the red and white edge lines (control conditions).

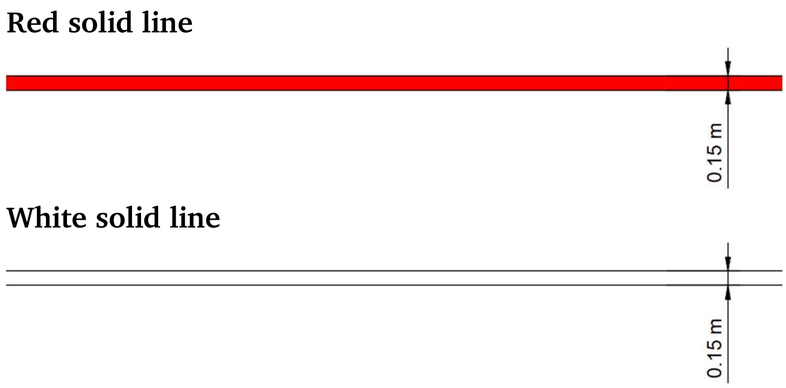
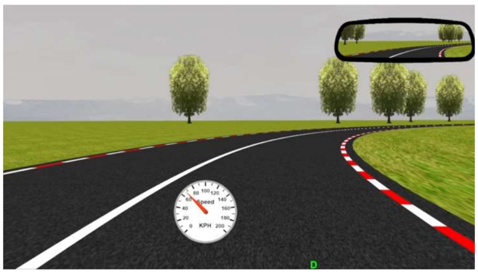
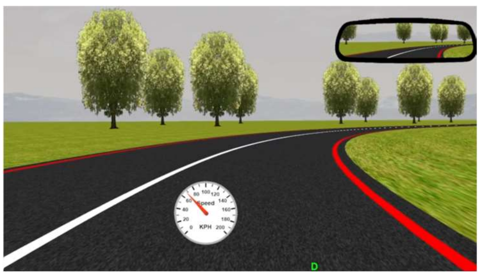
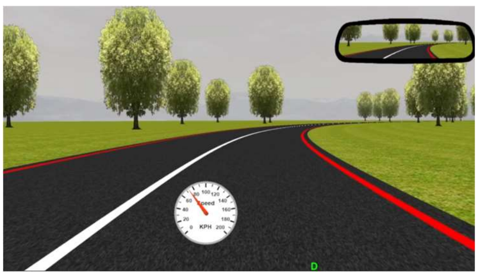


Figure 12: Dimension of solid edge lines

These designs of road marking treatments were the result of an iterative process in the driving simulator to ensure that the participants noticed the changes in perceptual road markings during the test. Table 3 shows drivers' perspectives in simulation with all road marking conditions and two different radii curves for the left curves. This is also identical to the right-direction curve.

Table 3: Preview of road marking during the right curve in a driving simulator

	Radius 125 m	Radius 350 m
Control condition		
Red-white pattern		
Solid red line		

3.2 Participants

For this research, 52 volunteers with a valid driving licence type B or similar participated. The test participants were recruited through announcements on several social media platforms, flyers, and word of mouth. The recruiting flyers can be found in Appendix A. The volunteers were between 20 and 75 years, with a mean age of 34 years, and the driving experience between 1 year and 56 years, with a mean experience of 15 years. Every volunteer gave their informed consent based on the research protocol approved by the Ethics Committee of Hasselt University. However, two participants were excluded due to being affected by simulation sickness. Therefore, the data from the driving simulator were collected from 50 participants, consisting of 15 female and 34 male drivers. According to the participation report, 51% of the participants used an automatic transmission vehicle as a daily driver, and 67.3% drove between less than 5,000 and 14,999 km.

3.2.1 Simulation sickness

Simulation sickness (SS) is similar to motion sickness; the difference is that the physical and mental feelings from SS are usually less severe. Only a minority of a proportion of people are exposed to SS [50]. Several studies [50-52] reported symptoms similar to motion sickness, such as headache, dry mouth, drowsiness, disorientation, dizziness, nausea and vomiting. The studies highlighted that in fixed-based simulators, the SS is related to elements of the visual experience. There are several theories about SS, and the most well-known is cue conflict theory.

The Cue Conflict Theory is used to explain the development of simulator sickness. This occurs when the sensory systems expect one thing in the simulator but experience something different. This created an internal conflict that could not be resolved, ultimately leading to symptoms similar to motion sickness. For instance, the feeling of acceleration and deceleration may differ between the simulated vehicle and the physical vehicle [53, 54].

According to Brooks et al. [52], SS could occur rapidly and persist until the simulation ends. Therefore, the participants' data exposed to simulation sickness are considered invalid and could significantly impact the research project. Several studies recommended considering aspects to keep the level of SS low, such as room temperature, amount of turns, traffic flow and duration of the simulation. Kennedy et al. [55] found an almost linear relationship between the duration of a simulator and SS and concluded that a safe maximum duration is approximately one hour.

3.3 Set up

The experiment occurred at the Institute for Mobility (IMOB) of Hasselt University. The institute itself provided the set-up of the driving simulator. This driving simulator operating system that participants utilised consists of two primary components: a driving unit and three monitors, as shown in Figure 13.

Figure 13: Fixed-based driving simulator in IMOB

The driving unit was the actual interior of a Peugeot vehicle with all the tools and functions of a typical average vehicle, such as pedals, a driver's seat, a dashboard, a manual transition gearbox, and a steering wheel. The monitors were 48-inch OLED TV displays with dimensions of 107.1 x 61.8 cm and integrated audio speakers. Two of these screens were placed at a 45° angle. This was to ensure the realistic feeling of driving in the simulator. The resolution of these screens was 3840 x 2160 pixels with a refresh rate of 100 Hz. These components were connected and integrated with STISIM Drive software. The performance measurement system of STISIM could register 67 different output parameters. The output parameters of driver behaviour for this research were driving speed, lateral position and acceleration, which were standard output parameters for this type of research [32-35, 37, 38].

3.4 Protocol

In this study, all participants adhered to a detailed and standardised driving simulator protocol according to the University Hasselt to ensure the reliability and validity of the collected data. This protocol took a total of around one hour per participant. It consisted of specific guidelines and steps that each participant followed throughout the experimental phase, including consent forms, pretest questionnaires, warm-up sessions, two experimental sessions, and posttest questionnaires. The documents for this protocol can be found in Appendices B through E. After recruiting volunteers through various channels, participants were invited to IMOB in Hasselt at specific timeslots. Every participant read the consent form carefully, agreed with the purpose of the research, and filled out the pretest questionnaires before starting the driving simulators. The pretest questionnaires aim to identify participants by identifying their gender, date of birth, driving license, driving experiences, and average sleep duration. Afterwards, the participants familiarised themselves with the driving simulator set-up during the warm-up session.

During this session, they drove a 2 km long route, and no data were collected. The warm-up route began by entering and exiting the urban area, followed by two 90° curves with a 175 m radius in both directions. After the warm-up session, the participants were informed that they should drive as they used to in real life. They followed the Belgian traffic laws, specifically traffic laws in Flanders, before starting the experiment. Figure 14 shows the participants' driving during the simulation.

Figure 14: Simulator during the test

Each participant completed two routes from two different studies in a randomised order. One study was intended for a fellow researcher’s master’s thesis. For this research, the route was also chosen randomly from four designed routes for each participant. Between those two sessions, a 10-minute break was provided to minimise the risk of simulation sickness. At the end of the experiment, the participants were asked to fill out posttest questionnaires about their experience using the driving simulator and the implemented edge road marking treatments.

3.5 Measuring points

After the participants completed the driving simulations, various output parameters were collected from STISIM Drive software. These parameters included longitudinal speed (km/h), lateral position (m), and acceleration and deceleration (m/s^2) to analyse the driving behaviour of the participants before and during horizontal curves for all road marking treatments. Seven measuring points were collected from each curve for this research to compare the impact of edge road marking treatments on the behaviours. Two measuring points were located at 250m and 150m before the curve, and five measuring points were located within the horizontal curve. The measuring points within the curve were situated at the start of entering the transition curve, the end of the entering transition curve, the middle of the curve, the beginning of the exiting transition curve, and the end of the exiting transition curve. In total, there were 84 measuring observation points per participant for each output parameter. For clarification, Figure 15 illustrated the location of the seven measuring points for each curve.

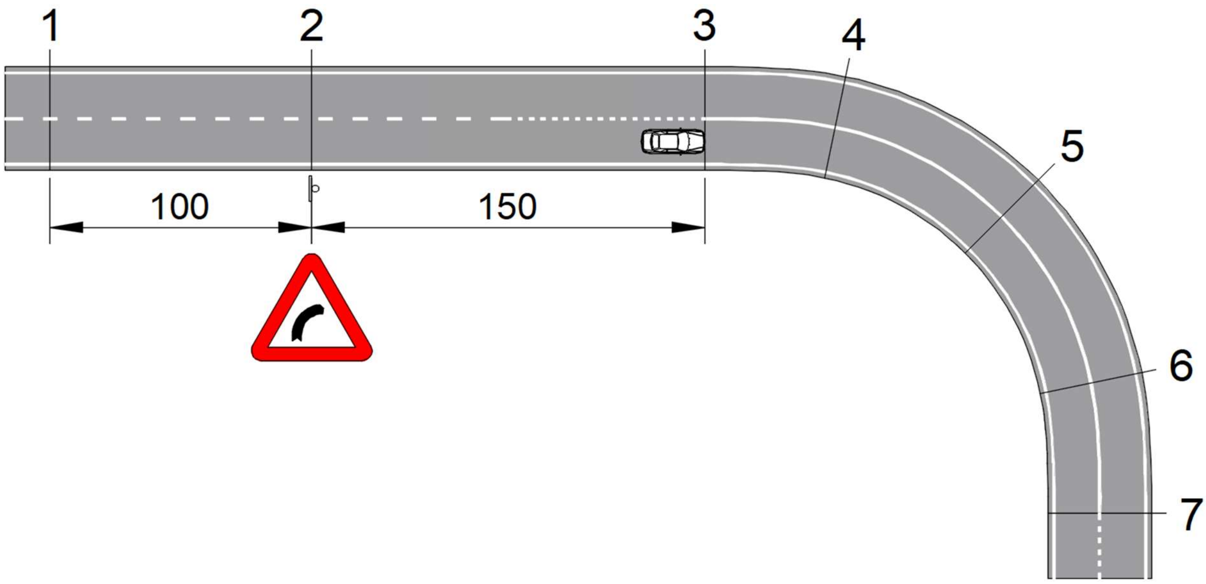


Figure 15: Measuring points of a horizontal curve

To analyse and compare the driving behaviours in response to different road marking treatments, a repeated measures Analysis of Variance (ANOVA) within-subjects was used on various output parameters. Using this technique made it possible to evaluate the significance of the mean differences for each independent variable, such as measuring points, across multiple scenarios involving dependent variables like the lateral positioning of the vehicle. This approach identified the significance of differences across all possible pairings of independent variables for every dependent variable. It was crucial to recognise that the sequence in which dependent variables were listed matters, as each variable acts as a tier within the hierarchy of the preceding variable. The longitudinal speed, lateral position, acceleration, and deceleration were dependent variables in this research. The independent variables consisted of parameters that were used to create horizontal curves for testing, such as the radius of the curve, curve directions, road marking conditions, and measuring points. All variables were tested for all participants using ANOVA tests.

3.6 Outliers

To conduct a reliable analysis for this research, it was crucial to identify any outliers in the collected data from the participants. An outlier is a data point that significantly differs from the rest. SPSS utilised Tukey's method to detect outliers that are visible on boxplots. This method used the interquartile range (IQR) to filter out large or small numbers. When the data deviated by more than 1.5 times but less than three times from the interquartile range, SPSS flags it as an outlier. However, there was a concern that this approach may be inaccurate and lead to the loss of valuable data for the research project [56, 57]. As a result, extreme outliers, which were data points that were three times greater or lower than IQR, were excluded from this research.

Each value indicated whether a participant was an outlier or not. According to Qinaat et al. [58], if a participant's data comprised 15% or more outliers of the total collected data, they would be excluded from the research. Consequently, three participants were excluded as extreme outliers from this research. This means the data collected from 47 participants was analysed further in this research. This corresponds to 3,948 collected data for each output parameter.

4 Research results

Forty-seven participants completed the driving simulator without any issues. This corresponded to 11,844 collected data, with 3,948 data for each output parameter. In this chapter, the results of the driving simulator are explained from the perspective of speed, acceleration/deceleration, and lateral position using repeated measures ANOVA within the subjects.

Section 4.2 described the result of speed between the treatments. Additionally, section 4.3 described the result of acceleration and deceleration, and section 4.4 described the result of lateral position of the vehicle.

4.1 Speed

To estimate the significance of speed differences between the factors, the p-values should be less than 0.05. Table 4 displays the results of the repeated measures ANOVA within-subjects for the Greenhouse-Geisser test. The results significantly impacted the Curve radius ($F_{1,\,000}$ = 12.805; p < 0.001), Conditions ($F_{1,\,961}$ = 5.863; p = 0.004), and Measuring points ($F_{2,\,131}$ = 43.341, p < 0.001). This implies that the driving speed was significantly influenced regardless of any other factors for various curve radii, three road marking conditions, and seven measuring points. Additionally, the two-way interaction effects of Curve direction * Measuring point ($F_{2,\,819}$ = 9.243; p < 0.001), Curve radius * Measuring point ($F_{2,\,268}$ = 47.858; p < 0.001), and Condition * Measuring point ($F_{2,\,428}$ = 5.162; p = 0.004) were also significant. These results demonstrated that speed varied significantly between the two curve radii, three road marking conditions, and seven measuring points. Moreover, the three-way interaction effect for the factor Curve direction * Curve radius * Measuring point ($F_{4,\,891}$ = 1.276; p < 0.001) was also significant. This indicates that speed significantly differed between the road marking conditions along the curves for the two curve radii.

Table 4: Analysis of speed: ANOVA within-subject test for Greenhouse-Geisser

Effect	df	F	P
Curve direction	1, 000	0.052	0.821
Curve radius	1, 000	12.805	**< 0.001**
Condition	1, 961	5.863	**0.004**
Measuring points	2, 131	43.341	**< 0.001**
Curve direction * Curve radius	1, 000	2.185	0.146
Curve direction * Condition	1, 991	0.512	0.6
Curve radius * Condition	1, 965	0.671	0.511
Curve direction * Curve radius * Condition	1, 798	0.532	0.571
Curve direction * Measuring point	2, 819	9.243	**< 0.001**
Curve radius * Measuring point	2, 268	47.858	**< 0.001**
Curve direction * Curve radius * Measuring point	2, 428	5.162	**0.004**
Condition * Measuring point	4, 891	5.438	**< 0.001**
Curve direction * Condition * Measuring point	5, 627	1.276	0.271
Curve radius * Condition * Measuring point	4, 196	1.563	0.183

The descriptive statistics and pairwise comparisons for the implemented conditions used in this research can be found in Table 2. Both the speed in the red-white pattern edge line (RWE) and the solid red edge line (RE) treatments showed a significant difference compared to the control condition (solid white edge line). The RE treatment also demonstrated a significant difference in driving speed compared to the RWE condition.

Table 5: Descriptive statistics: mean and pairwise comparison of speed

Condition	Control	RWE	RE
Mean speed (km/h)	65.77	65.29	64.92
Pairwise comparison (p-values)			
Control	1	**< 0.001**	**< 0.001**
RWE		1	**0.005**
RE			1

The graph in Figure 16 displayed the mean speed for curve directions at each measuring point. The speed from 250 m before the curve (measuring point 1) to the end of the beginning transition curve (measuring point 4) decreased at almost the same rate for both directions. Furthermore, the overall speed patterns for both directions were remarkably similar, indicating insignificant differences.

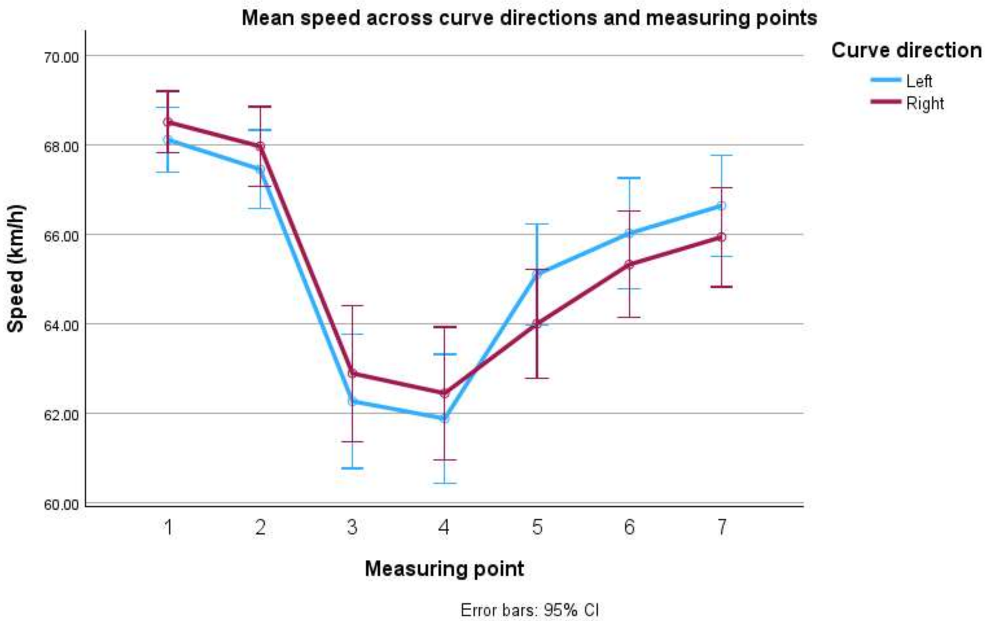


Figure 16: Average speed across curve directions and measurement points

The graph in Figure 17 the mean driving speed for different curve radii was shown at each measuring point before and during the curve. The figure indicated that the driver's average speed at the beginning of a curve (measuring point 3) with a radius of 125 m is 5 km/h lower than at a curve with a radius of 350 m. This difference in speed was consistent throughout the entire segment until exiting the curve (measuring point 7). These results encompassed all curves, conditions, and both directions.

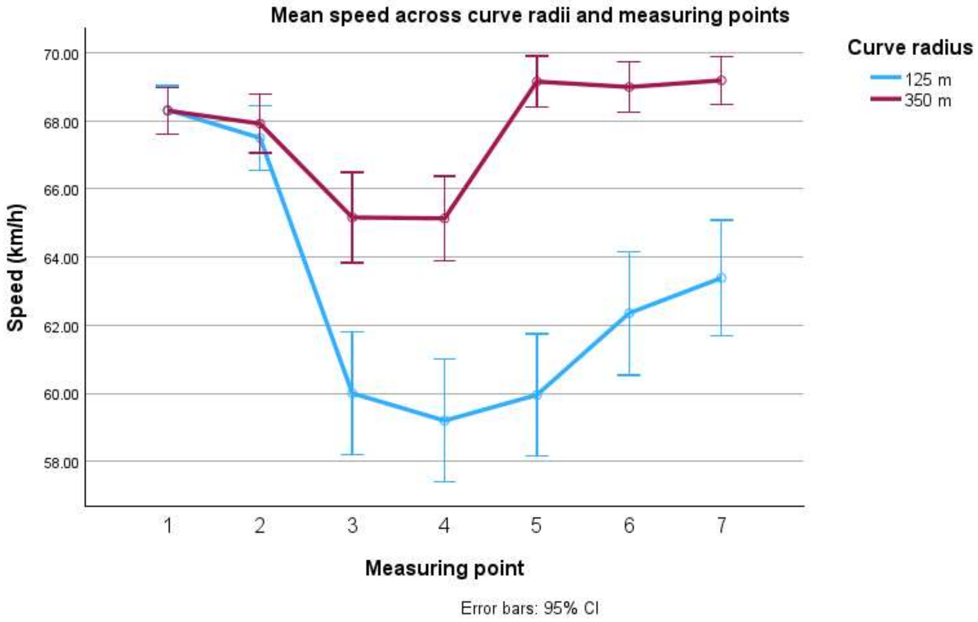


Figure 17: Average speed across curve radii and measuring points

In Figure 18, the graph displayed the average driving speed for three conditions at each measuring point before and during the curve. The results indicated that both treatments (RWE and RE) led to a lower mean speed than the control condition at the start of the curve (measuring point 3) and at the end of the transition curve (measuring point 4). Specifically, at the beginning of the curve, the speed for the RE condition was 0.29 km/h slower, and for the RWE condition, it was 0.85 km/h slower compared to the control condition. However, for all conditions, the speed reached its lowest point at the end of the beginning of the transition curve, with speeds of 61.71 km/h for RWE, 62.24 km/h for RE, and 62.55 km/h for the control condition. Additionally, from that measuring point, the speed for RE gradually increased until the end of the curve compared to the RWE and control conditions.

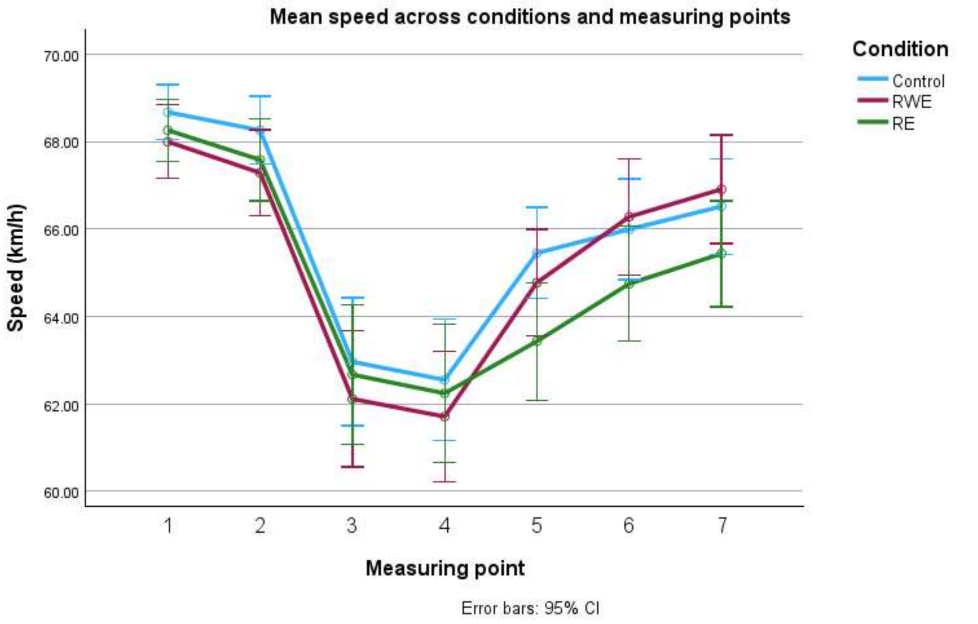


Figure 18: Average speed across conditions and measuring points

4.2 Acceleration and deceleration

To evaluate the significance of acceleration (ACC) and deceleration (DCC), the p-values should be less than 0.05. According to Table 6, the repeated measures ANOVA within-subject results for the Greenhouse-Geisser test indicated that both curve radius and measuring points significantly impacted acceleration and deceleration. This showed that the seven measuring points ($F_{3,\ 032}$ = 57.073; p < 0.001) and the two curve radii ($F_{1,\ 000}$ = 4.126; p = 0.048) significantly affected the differences in acceleration. However, the curve direction ($F_{1,\ 000}$ = 0.056; p = 0.815) and conditions factors ($F_{0,\ 086}$ = 0.575; p = 0.564) were insignificant, suggesting that the differences in ACC and DCC were not noticeably different across different conditions and curve directions. Moreover, the two-way interaction effects of Curve radius * Measuring points ($F_{2,\ 894}$ = 56.537; p < 0.001) and Condition * Measuring points ($F_{7,\ 027}$ = 2.900; p = 0.006) were also significant. These results implied that lateral positioning varied significantly across the three road marking conditions and the seven designated measuring points. The three-way interaction effect for the factor Curve direction * Curve radius * Measuring points ($F_{3,\ 393}$ = 2.742; p = 0.039) was also significant.

Table 6: Analysis of acceleration: ANOVA within-subject test for Greenhouse-Geisser

Effect	df	F	P
Curve direction	1, 000	0.056	0.815
Curve radius	1, 000	4.126	**0.048**
Condition	0, 086	0.575	0.564
Measuring points	3, 032	57.073	**< 0.001**
Curve direction * Curve radius	1, 000	0.302	0.585
Curve direction * Condition	1, 955	0.528	0.587
Curve radius * Condition	1, 979	0.508	0.601
Curve direction * Curve radius * Condition	1, 902	0.346	0.698
Curve direction * Measuring points	3, 918	0.890	0.469
Curve radius * Measuring points	2, 894	56.537	**< 0.001**
Curve direction * Curve radius * Measuring points	3, 393	2.742	**0.039**
Condition * Measuring points	7, 027	2.900	**0.006**
Curve direction * Condition * Measuring points	7, 373	0.562	0.795
Curve radius * Condition * Measuring points	6, 308	2.261	0.035

The descriptive statistics and pairwise comparisons of ACC and DCC for the road marking conditions used in this research are presented in Table 7. The acceleration in the RWE conditions was the highest compared to the other conditions. According to the pairwise comparisons, each condition did not show any significant differences.

Table 7: Descriptive statistics: mean and pairwise comparison of acceleration

Condition	Control	RWE	RE
Mean acceleration (m/s^2)	0.0062	0.0173	0.0091
Pairwise comparison (p-values)			
Control	1	0.134	0.382
RWE		1	0.216
RE			1

The graph in Figure 19 illustrated the average acceleration between curve directions at each measuring point. The horizontal axis displayed the different measuring points before and during the horizontal curve, while the vertical axis indicated the average acceleration of the vehicle on the road. A positive acceleration value represented acceleration, and a negative value represented deceleration. From 250m before the curve (measuring point 1) to the beginning of the transition curve (measuring point 3), drivers decelerated at almost the same rate for both directions. From that point until the end of the curve (measuring point 7), there was constant acceleration at nearly the same rate. It was also important to note that the drivers decelerated more gently before the curve on the left than on the right. Additionally, the overall speed patterns for both directions are remarkably similar, indicating insignificant differences.

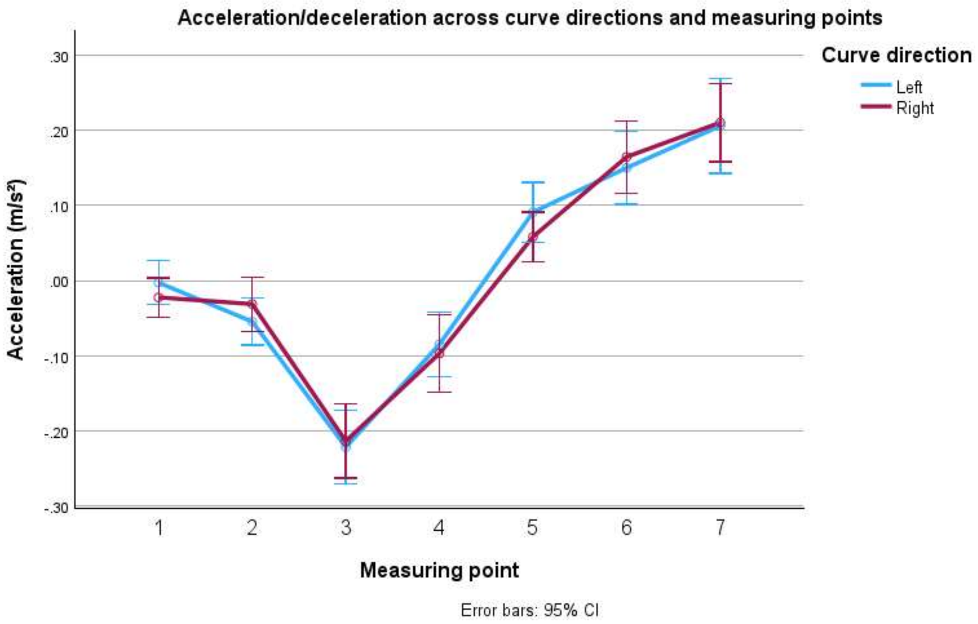


Figure 19: Average acceleration/deceleration across curve directions and measuring points

A graph Figure 20 illustrated the average acceleration and deceleration between the curve radii and the measuring points was presented in Figure 20. Analysis of the figure reveals that drivers begin active deceleration 150 meters before reaching the curve (measuring point 2). The figure illustrated that drivers decelerated more abruptly before the start of the curve on the sharp curve (radius 125 m). Upon reaching the curve's start (measuring point 3), they experienced their most significant deceleration for both radii (M_{ACC} = -0.33 m/s^2 for radius 125 m and M_{ACC} = -0.11 m/s^2 for radius 350 m). However, as they reach the middle of the curve (measuring point 5), drivers experience a significant increase in speed in curves with a radius of 125 m, reaching their highest speed (M_{ACC} = 0.36 m/s^2) as they exited the curve. In contrast, the average speed for drivers in curves with a radius of 350 m remained close to zero, indicating no change in speed from the initial slowdown before entering the curve until exiting the curve.

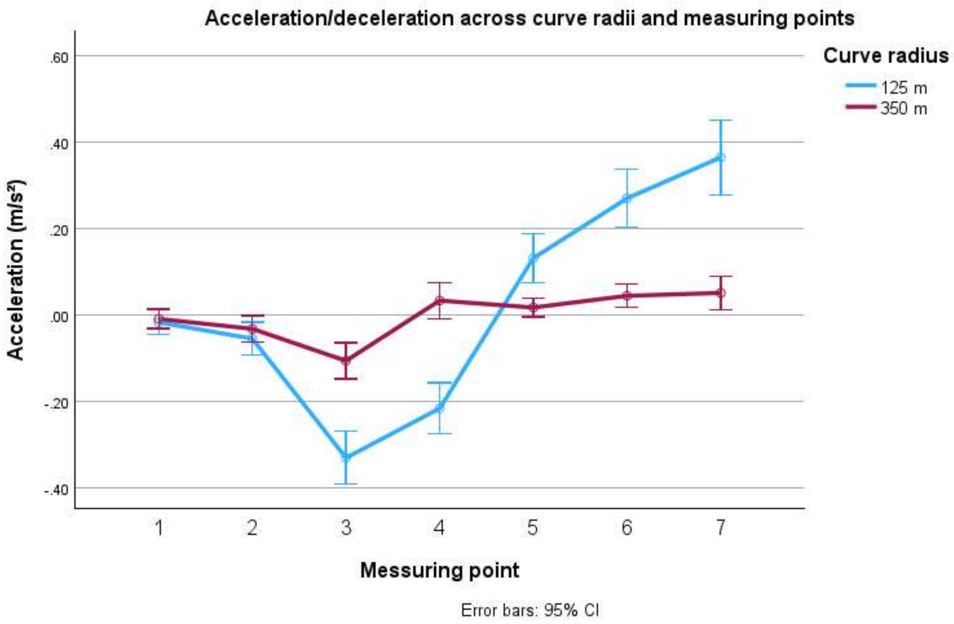


Figure 20: Average acceleration/deceleration across curve radii and measuring points

In Figure 21, the graph displayed the average acceleration for three conditions at each measuring point. The results indicated that drivers decelerated at a similar rate for all conditions from 150 m before the curve (measuring point 2) to the beginning of the transition curve (measuring point 3). However, it was worth noting that the DCC in the RWE condition is slightly gentler before entering the curve than in other conditions. Additionally, the overall speed patterns for both directions were remarkably similar, indicating insignificant differences.

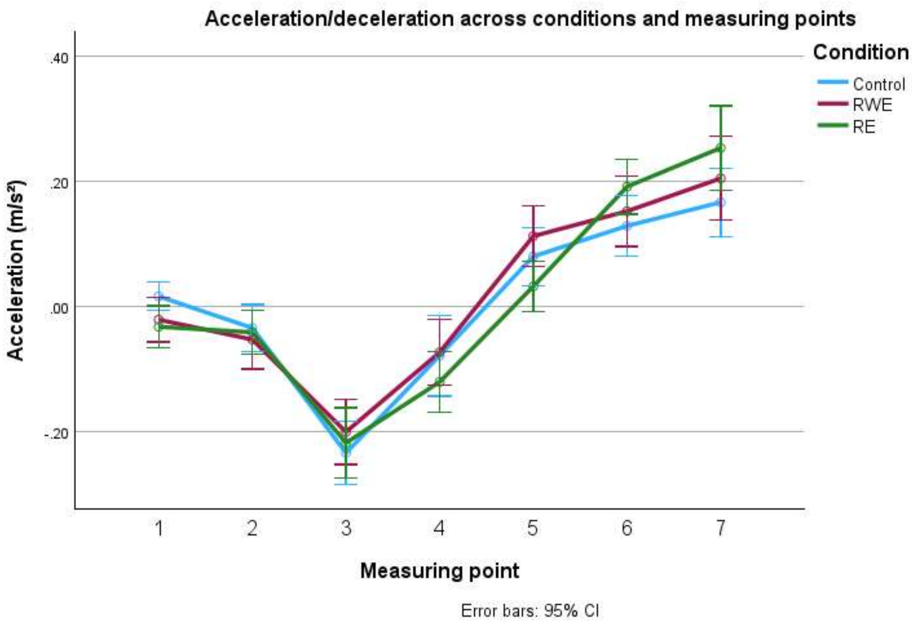


Figure 21: Average acceleration/deceleration across conditions and measuring points

4.3 Lateral position

To assess the importance of the lateral positioning of vehicles, the p-values should be less than 0.05. According to Table 8, the results of the repeated measures ANOVA within-subject for the Greenhouse-Geisser test showed that all factors, including Curve direction ($F_{1,\,000}$= 12.038; p = 0.001), Curve radius ($F_{1,\,000}$ = 8.536; p = 0.005), Conditions ($F_{1,\,998}$ = 5.018; p = 0.009), and Measuring points ($F_{2,\,728}$ = 7.081; p < 0.001), significantly affected the lateral position. This meant that the overall variations in lateral positioning were significantly influenced regardless of other factors. Additionally, the two-way interaction effects of Curve direction * Curve radius ($F_{1,\,000}$ = 54.942; p < 0.001), Curve direction * Measuring points ($F_{2,\,763}$ = 54.022; p < 0.001), Curve radius * Measuring points ($F_{3,\,370}$ = 4.262; p = 0.005) and Condition * Measuring points ($F_{5,\,212}$ = 4.797; p < 0.001) were also significant. These results indicated that lateral positioning varied significantly between the two curve radii, three road marking conditions, and seven measuring points. The three-way interaction effect for the factor Curve direction * Curve radius * Condition ($F_{1,\,940}$ = 14.966; p < 0.001), Curve direction * Curve radius * Measuring points ($F_{2,\,897}$ = 20.062; p < 0.001), and Curve direction * Condition * Measuring points ($F_{5,\,745}$= 2.285; p = 0.390) were also significant.

Table 8: Analysis of lateral position: ANOVA within-subject test for Greenhouse-Geisser

Effect	df	F	P
Curve direction	1, 000	12.038	**0.001**
Curve radius	1, 000	8.536	**0.005**
Condition	1, 998	5.018	**0.009**
Measuring points	2, 728	7.081	**< 0.001**
Curve direction * Curve radius	1, 000	54.942	**< 0.001**
Curve direction * Condition	1, 783	2.250	0.118
Curve radius * Condition	1, 800	2.185	0.124
Curve direction * Curve radius * Condition	1, 940	14.966	**< 0.001**
Curve direction * Measuring points	2, 763	54.022	**< 0.001**
Curve radius * Measuring points	3, 370	4.262	**0.005**
Curve direction * Curve radius * Measuring points	2, 897	20.062	**< 0.001**
Condition * Measuring points	5, 212	4.797	**< 0.001**
Curve direction * Condition * Measuring points	7, 451	7.468	**< 0.001**
Curve radius * Condition * Measuring points	5, 745	2.285	0.390

The descriptive statistics and pairwise comparisons of lateral positioning for the road marking conditions used in this research are presented in Table 9. The RE treatment resulted in a significant difference in lateral positioning compared to the RWE and control conditions. Furthermore, the vehicle's position under the RE condition was, on average, closest to the centerline. However, the difference between the RWE and control conditions is insignificant.

Table 9: Descriptive statistics: mean and pairwise comparison of lateral position

Condition	Control	RWE	RE
Mean lateral position (m)	1.99	1.98	1.95
Pairwise comparison (p-values)			
Control	1	0.355	**< 0.001**
RWE		1	**< 0.001**
RE			1

Figure 22 showed the average lateral position for left and right curve directions. The horizontal axis displayed the different measuring points before and during the horizontal curve. In contrast, the vertical axis indicated the distance between the vehicle's centre and the road's centreline on the right lane side. A greater lateral position implied that the car was farther from the centreline and closer to the edge of the road. On a left curve, the lateral position initially moved towards the right side of the lane at the start of the transition curve (measuring point 3), then leaned towards the centreline at the beginning of the exiting transition curve (measuring point 5). Conversely, on a right curve, the lateral position was the opposite of the left curve, being closer to the centreline at the start of the curve and leaning toward the edge road marking at the exit of the curve.

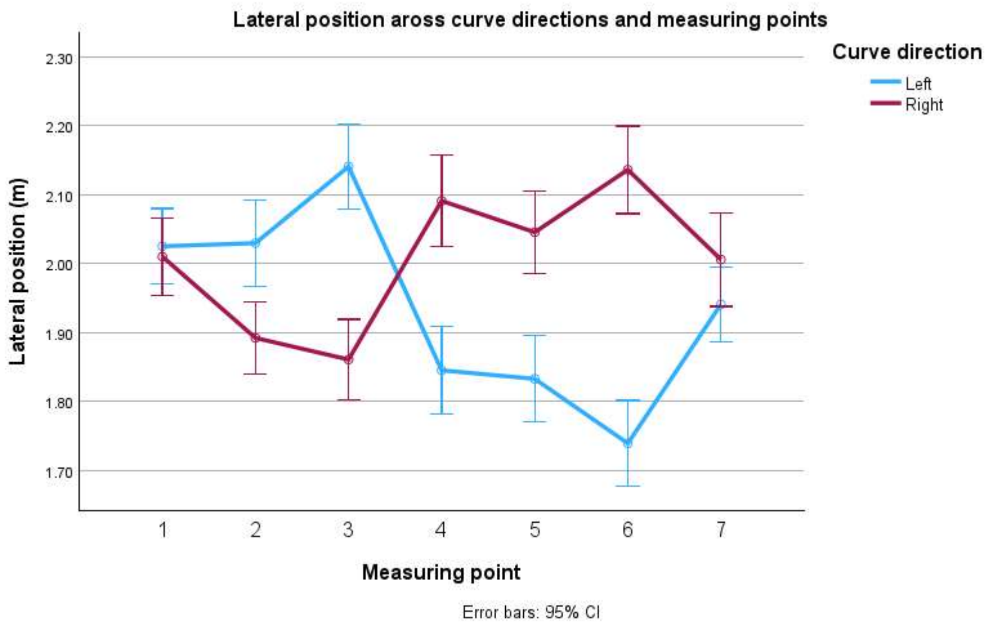


Figure 22: Average lateral position across curve directions and measuring points

Furthermore, Figure 23 illustrated the average lateral position at various curve radii at each measuring point. The graph showed that the lateral position for both radii fluctuated between 2 m and 1.90 m. The larger curve radius (350 m) fluctuated between 2.03 m and 1.96 m, while the smaller curve radius (125 m) fluctuated between 2.01 m and 1.90 m. Specifically, the lateral position on the smaller curve radius tended to be closer to the road's centreline than the larger one. Particularly at the start of the exit transition curve (measuring point 6), there was a 0.07 m contrast between the two curve radii, where the lateral position for the larger curve radius was 1.97 m and for the smaller curve radius was 1.90 m.

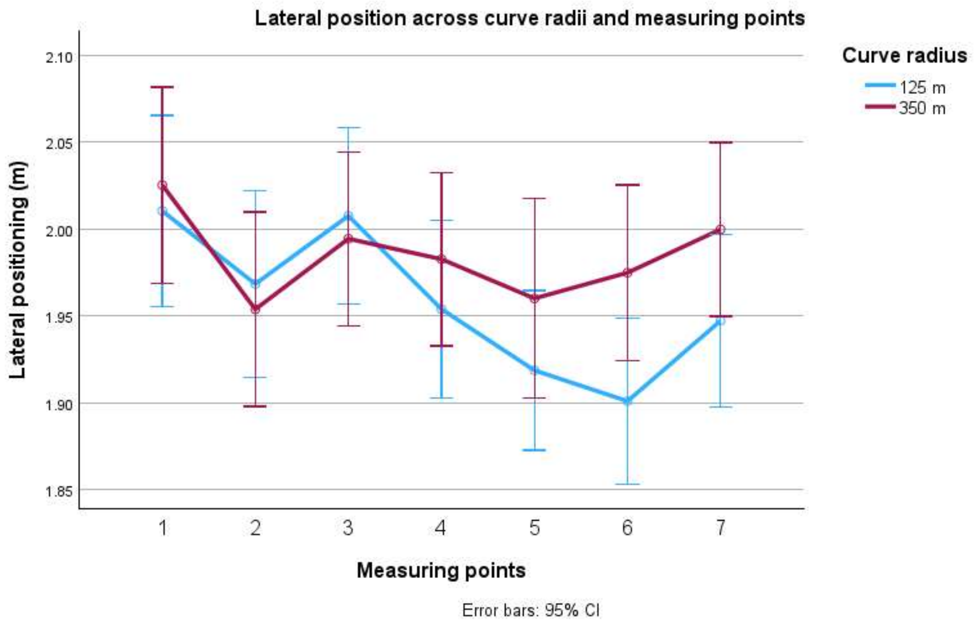


Figure 23: Average lateral position across curve radii and measuring points

Figure 24 demonstrated the average lateral position at each measuring point under various conditions. The graph indicated that the lateral position for all conditions fluctuated between 2.02 m and 1.92 m. In the control condition, the lateral position ranged from 2.01 m to 1.96 m, while in the RWE condition, it ranged from 2.06 m to 1.92 m, and in the RE condition, it ranged from 1.98 m to 1.90 m. Notably, the lateral position in the RE condition tended to stay towards the centreline compared to the control conditions. Additionally, the lateral position in the RWE condition generally tended to be slightly closer to the road's centreline.

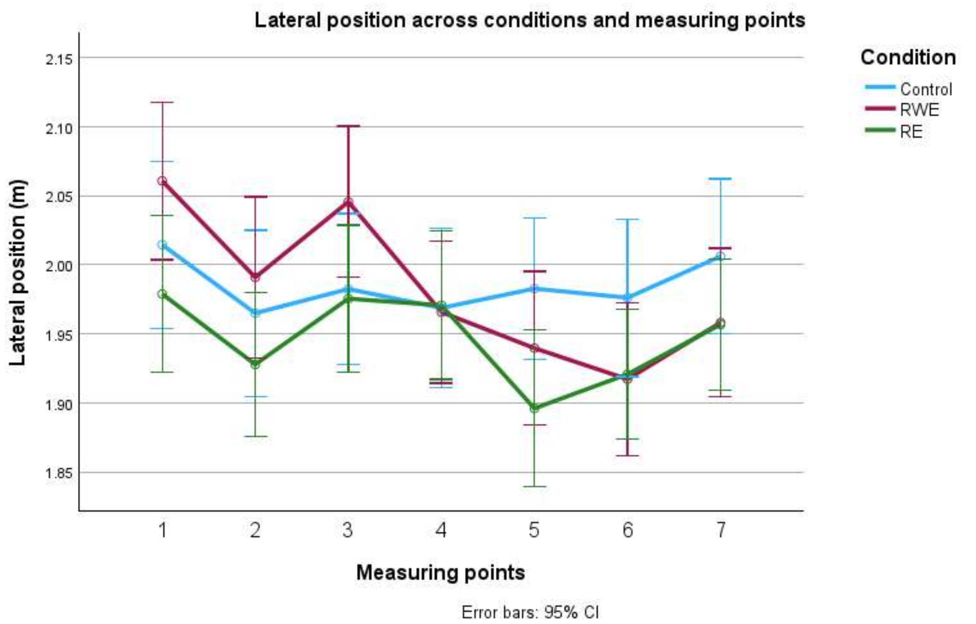


Figure 24: Average lateral position across conditions and measuring points

5 Discussions

The statistical analysis indicated that the road marking treatments put in place had a favourable impact on driving behaviour both before and during the horizontal curves. This chapter delved deeper into the results, focusing on their effects and comparing them to previous studies. The discussion will follow the same sequence as the results, starting with driving speed in section 5.1, then examining acceleration and deceleration in section 5.2 and concluding with exploring lateral position in section 5.3.

5.1 Driving speed

The findings revealed that road markings such as RWE and RE reduced the driving speed before and during the curve. However, there were no significant variations in driving speed between left and right turns. This suggested that the conditions decrease the speed independently of the curve directions, as confirmed by Babic et al. [38].

The study found that the average speed on curves with a small radius of 125 m is 5 km/h lower than on curves with a radius of 350 m due to the sharper geometry of the horizontal curve. In addition, both road marking treatments resulted in a decrease in driving speed.

Both experimental treatments resulted in a lower mean speed at each measuring point than the control condition. In the RWE treatment, the average speed was lowest at the beginning of the curve. However, when exiting the curve, the speed was slightly higher than in the control condition by 0.39 km/h. It is possible that drivers noticed the treatment at the start of the curve and slowed down. Conversely, they may have felt comfortable on the curve and could fully control the vehicle, which led to a rapid increase in speed for the rest of the curve. On the other hand, for the RE treatment, the mean speed was 1.08 km/h at the end of the curve. It can be assumed that the RE encouraged drivers to increase their speed gradually during the curve.

Before the curve, the drivers rode close to the allowed maximum speed of 70 km/h for all conditions. However, the result showed they slowed down slightly when seeing the vertical warning sign 150 m before the curve. The driver slowed down continuously after passing the vertical sign while approaching the horizontal curve. However, there are no significant differences between the conditions. This may be due to low attention paid to road markings and vertical sign changes, which aligns with the findings of Babic et al. [42] and Costa et al. [43]. The results of earlier research revealed that drivers tend to fixate their eyes and attention on the place they are heading towards. For example, when drivers drove on a straight section, they focused more on the distant horizon and less on the sides of the road [59, 60]. However, when drivers navigated a curve, they tended to shift their focus more towards the sides of the road, particularly the edge road marking [27].

5.2 Acceleration and deceleration

The study's findings show that drivers slow down at a similar rate on treated sections as on regular roads before approaching a curve, regardless of the curve's direction. This suggests that the treatments did not help drivers slow down more gradually than regular road conditions. The hypothesis that both treatments encourage drivers to decelerate early before the curve and achieve a moderate deceleration was false.

However, the results revealed that drivers decelerated and accelerated more abruptly on a smaller horizontal curve (radius 125 m) than on a larger curve (radius 350 m). This finding suggests that the geometric design of the road, such as the curve's radius, could influence acceleration and deceleration.

5.3 Lateral positioning

The results of the lateral movement study showed that 150 meters before the curve, participants deviated toward the centreline of the road, regardless of the conditions. This behaviour was attributed to participants perceiving vertical warning signs as obstacles near the road, prompting the drivers to move toward the centreline before returning to their initial position at the start of the curve. During the horizontal curve, drivers maintained a consistent lateral position about 2 meters from the centreline in the control condition. However, the RWE treatment led vehicles to move closer to the centreline throughout the entire curve, reaching a maximum lateral position of 1.92 meters to the right of the centreline at the beginning of the exit transition curve. In contrast, the RE treatments did not significantly alter the initial lateral position, indicating a consistent and close proximity to the centreline.

The findings suggested that the treatments effectively warned and encouraged drivers to stay closer to the centreline to avoid running off the road. However, it was necessary to note that moving closer to the centreline increased the risk of frontal crashes, but the lateral movement caused by the treatments was marginal. Therefore, the movement toward the centreline induced by the RWE treatment can be considered safe. In comparison with a similar study [38], Barbic highlighted that vehicles tended to move closer to the edge of the road marking due to the implemented red median, which aligned with the similar lateral movement of the car toward the implemented edge road marking. This finding suggested that drivers tended to move away from the implemented treatments.

6 Future research

The study provided valuable insights into the impact of innovative road markings as low-cost interventions on drivers' behaviour on horizontal curves. However, it also had some limitations that could be addressed in future research. The fixed-base simulator used in the study did not fully recreate the feeling of realistic driving, as it could not simulate the centripetal force experienced during the horizontal curves. Additionally, the simulator had the interior of an actual vehicle. Still, it could not fully replicate the actual driving experience because participants could not see the vehicle's front end and, therefore, could not accurately estimate its width during the simulation. For future research, it may be beneficial to consider using a setup similar to that used by Babic et al. [38], who utilised an actual vehicle and a seamless projector to create a more realistic driving experience.

Moreover, Mollenhauer [54] found that incorporating motion-modified driver behaviour could better replicate real-world responses, as several studies have shown positive results from adding motion cueing [61-63]. In a study by Curry et al. [62], they compared their fixed-based simulator to their motion-based simulation. After performing similar driving tasks for the same duration, the motion-based simulator participants reported lower simulation sickness questionnaire (SSQ) scores, indicating a lower risk of simulation sickness.

Other limitations of this research are also the sample size and the age range of the participants. Fifty volunteers participated, which was considered a larger sample size compared to similar previous simulation studies [2, 27, 33-38, 41, 44, 45, 48, 58]. However, a more extensive and diverse sample of participants could provide a more comprehensive understanding of the effects of different experimental conditions, as some statistical results were insignificant. Although the age range of the participants in these studies varied from 20 to 75 years, it covers a broad range of ages. Nonetheless, the number of test participants decreased with age, so the effectiveness of the treatment should also be tested on an older population. It was worth noting that older participants might have more difficulty with the driving simulator due to simulation sickness than younger participants [52].

While conducting the research, no vehicles travelled in the opposite direction during the curves, which helped assess the treatments' impact. This approach has been utilised in several previous studies [2, 38]. However, it was necessary to note that the results, driver behaviour and the treatments' effectiveness could be influenced to some extent by the presence of other vehicles travelling in the opposite direction during the curve. Therefore, it is suggested that future studies explore the effects of the interventions with active traffic in the opposite direction.

7 Conclusion

The study investigated the impact of two low-cost edge road marking methods on driver behaviour in horizontal curves with small (125 m) and significant (350 m) radii. The road marking interventions tested were red-white pattern edge lines, solid red lines, and a vertical warning sign positioned 150 meters before the curve. These interventions prompted drivers to reduce their speed at the transition section of the curve. Drivers decreased their speed at a rate similar to the control condition (i.e., only with a vertical warning sign) before the curve began. They continued to slow down until the vehicle gradually passed the transition curve. The proposed road markings reduced speed slightly more than the control condition. The red-white edge line treatment reduced the speed the most out of the three conditions in the transition curve, but the effect faded away when vehicles reached the middle of the curve. On the other hand, the solid red line treatments moderated the speed throughout the horizontal curve. Additionally, drivers reduced their speed more when encountering a sharp curve. The experimental treatments did not significantly impact the vehicle's acceleration and deceleration. Moreover, in the red-white edge line condition, the lateral movement of the car tended to move towards the centre of the road along the curve. In contrast, in the solid red line condition, the lateral movement stayed similar, closer to the road's centreline, and tended to lean towards the centreline at the end of a sharp curve. This treatment is recommended as a countermeasure for horizontal curves where run-off tracks are concerned.

In summary, the study shows that solid red edge lines and red-white pattern edge lines decrease speed compared to control conditions before and during horizontal curves, indicating that drivers exhibit better control when navigating through the curves and that these markings positively impact road safety. Although both types of road markings enhanced drivers' behaviour, further research is necessary to comprehend the combined effects of these treatments. Based on the results, the study suggests that road authorities and policymakers thoughtfully choose potentially hazardous curves and consider implementing these low-cost interventions.

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Appendix A: Recruiting flyer

RIJSIMULATIE

INSTITUUT VOOR MOBILITEIT
UHASSELT

MASTERPROEF OP HET VEILIGHEID VAN AUTOBESTUURDERS

Wist je dat 62% van alle ongevallen in België in 2022 vonden plaats in het Vlaamse Gewest?

HET DOEL VAN ONDERZOEK

Het onderzoek gaat over de impact van kost besparende interventies op het rijgedrag van bestuurders, met als doel de veiligheid van bestuurders te verbeteren.
Dit allemaal uitgevoerd via een simulatie.

WAT MOET JE DOEN

- **2 ritten** in een auto simulatie rijden zoals je dagelijks op de weg zou rijden
- **15 minuten per rit**

OVER MIJ

Industriële bouwkundig masterstudent van universiteit Hasselt en KU Leuven, die de veiligheid van autobestuurders willen verbeteren.

GRATIS **INSCHRIJVEN**

SCAN ME

LOCATIE

(ma-vr) 9-18 u

9-30 APRIL 2024

IN MAASTRICHTERSTRAAT 100, 3500 HASSELT

VOOR MEER INFO CONTACTEER MIJ!

siwagorn.bunjong@student.uhasselt.be

DRIVING SIMULATION

MASTER THESIS ABOUT LOW-COST INTERVENTIONS

Did you know that 62% of all accidents in Belgium in 2022 occurred in the Flemish Region?

PURPOSE OF RESEARCH

The research is about the impact of low-cost interventions on driver behaviour, intending to improve driver safety.
All this will be conducted through a simulation.

WHAT YOU HAVE TO DO

- Drive **2 rides** in a car simulation as you would on the road every day
- **15 minutes per ride**

ABOUT ME

Master's student of Civil engineering from Hasselt University and KU Leuven, who want to improve the safety of drivers.

FREE **ENTRY FEE**

SCAN ME

LOCATION

(mon-fri)
9-18 h

9-30 APRIL 2024

IN MAASTRICHTERSTRAAT 100, 3500 HASSELT

imob INSTITUUT VOOR MOBILITEIT
UHASSELT

FOR MORE INFO CONTACT ME!

siwagorn.bunjong@student.uhasselt.be

Appendix B: Consent form for participants

Informatie- en toestemmingsformulier voor de deelnemer

IMOB INSTITUUT VOOR MOBILITEIT UHASSELT

Titel van het onderzoek:
De impact van low-cost interventies op het rijgedrag

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Onderzoek locatie
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Witte Kazerne
Maastrichterstraat 100
Hasselt, België
tel. +32 11 26 91 11

1 Informatiebrochure

U wordt uitgenodigd om vrijwillig deel te nemen aan een onderzoek met betrekking tot het bestuderen van **de impact van de low-cost interventies op het rijgedrag** in een rijsimulator. Vooraleer u toestemming geeft om aan dit onderzoek deel te nemen, is het belangrijk dat u dit formulier leest en ondertekent.

In dit informatieformulier worden de inhoud van het onderzoek, de voordelen, risico's en ongemakken gepaard gaande met het onderzoek beschreven. Ook de voor u beschikbare alternatieven en het recht om op elk ogenblik de studie te verlaten, zijn hieronder beschreven. U hebt het recht om op elk ogenblik vragen te stellen over de mogelijke en/of bekende risico's die deze studie inhoudt.

1.1 Doel en omschrijving van het onderzoek

Deze studie wordt uitgevoerd in opdracht van het instituut voor mobiliteit (IMOB) en kadert binnen de masterproef van de opleiding Industriële ingenieurswetenschappen aan de Universiteit Hasselt en de Katholieke Universiteit Leuven. De studie omvat de ontwikkeling van nieuwe technologische interventies om de veiligheid van de weggebruikers op de weg te verbeteren met behulp van een rijsimulator. Deze rijsimulator zal door IMOB beschikbaar gesteld worden.

Volgens de statistieken van de verkeersveiligheid vinden er gemiddeld 38.000 verkeersongevallen per jaar plaats in België, waarvan 20% buiten de rijbaan. Bijkomend blijkt uit verschillende studies dat horizontale bochten verantwoordelijk zijn voor een aanzienlijk hoog aantal van deze ongevallen. Met als voorname reden het hebben van een verkeerde perceptie die kan leiden tot onveilig rijgedrag.

Deze foutieve waarneming vindt meestal plaats wanneer een bestuurder de geometrie van de weg of veranderingen in de rijomgeving, met name gebogen segmenten, niet voldoende of te laat opmerkt. Eveneens kan een verkeerde inschatting van de snelheid hier ook voor zorgen. Daarom willen we met dit onderzoek een oplossing ontwikkelen voor deze problematiek. Zodat de algehele veiligheid voor de weggebruiker in een bocht verbeterd wordt.

De mogelijke oplossing die we in dit onderzoek zullen onderzoeken, is het implementeren van low-cost interventies. Deze interventies vereisen relatief lage kosten, maar kunnen daarentegen wel voor een aanzienlijke verbetering in de veiligheid van de weggebruikers zorgen. Deze interventies kunnen bijvoorbeeld het plaatsen van waarschuwingsborden, wegmarkeringen, snelheidsdrempels enzovoort omvatten bij gevaarlijke situaties.

In dit onderzoek wordt de relatie tussen een bepaald type low-cost interventie en het rijgedrag onderzocht door middel van het uitvoeren van rijsimulaties. Op die manier kunnen we de impact van innovatieve interventies op het rijgedrag van automobilisten bestuderen. Tevens kunnen we de effectiviteit van de voorgestelde interventies evalueren in termen van het verminderen van ongevallen en het verbeteren van de verkeersveiligheid op de weg.

1.2 Rijsimulatoronderzoek

Het rijsimulatoronderzoek vindt plaats in de ‘kleine rijsimulator’ van het Instituut voor Mobiliteit (IMOB). Deze simulator omvat een design met o.a. dashboard, stuur, pedalen en zetels van een auto, om een zo realistisch mogelijke rijervaring te creëren.

U wordt gevraagd om enkele korte ritten af te leggen met een totale duurtijd van 45 minuten, waarin u rijdt zoals u gewoonlijk zou rijden. Voor het aanvangen van uw eerste rit in de simulator krijgt u enkele vragen over uw rijervaring met een voertuig. Vervolgens vragen we u om na elke rit een formulier in te vullen over uw rijervaring tijdens de rit en 5 minuten te rusten. Na het rijden van **alle** ritten krijgt u ten slotte enkele vragen over de verschillende verkeerssituaties die u in de simulator heeft ervaren. In totaal duurt dit contactmoment ongeveer 1 uur en 30 minuten. Gedurende de gehele tijd van de studie bent u in staat om te communiceren met de onderzoeker en kan u deze steeds zien.

Door de gegevens uit de subjectieve beoordelingen en de data verkregen door de rijsimulator (die uw rijprestaties zoals rijstrookpositie, voertuigcontrole enz. kan meten) te verwerken en vergelijken kunnen we de relatie tussen de toegepaste wegmarkeringen en het rijgedrag vaststellen.

1.3 Overzicht inclusief- en exclusiecriteria

Om deel te nemen aan dit onderzoek, dient u aan volgende voorwaarden te voldoen:
- U heeft geen overmatig alcoholgebruik (maximum 2 consumpties per dag)
- U gebruikt enkele vorm van drugs
- U heeft geen infectieziekte (bijvoorbeeld: griep, COVID-19, verkoudheid, tandontsteking etc.)
- U bent niet zwanger
- U spreekt Nederlands of Engels
- U hebt een officieel adres in Vlaanderen of in België.
- U beschikt over een definitief of voorlopig rijbewijs B met minstens 20 uur rijles.
- U hebt afgelopen nacht voldoende slaap gehad.

1.4 Duur van het onderzoek

Het onderzoek duurt ongeveer 1 uur en 30 minuten.

1.5 Simulatieziekte

Bij het rijsimulatoronderzoek bestaat er een kleine kans op rijsimulatorziekte. De symptomen zijn vergelijkbaar met wagenziekte; enkele voorbeelden zijn: vermoeidheid, hoofdpijn, moeite met scherp zien, suf gevoel, zweten, misselijkheid, droge mond en moeite met concentreren. Wanneer u merkt dat u last krijg van rijsimulatorziekte wordt het experiment direct gepauzeerd en wordt er bekeken of er nog verder gereden kan worden. Op basis van onze vorige ervaringen met rijsimulatoronderzoek en wetenschappelijke literatuur, passen we een aantal maatregelen toe die de kans op ziek worden verkleinen. Indien u toch symptomen hebt, wordt het afgeraden om het eerstvolgende uur (en zolang de symptomen aanwezig zijn), zelf een wagen te besturen.

1.6 Opdrachtgevers van het onderzoek

De opdrachtgever van het onderzoek is het Instituut voor Mobiliteit (IMOB) en dit kadert in een masterproef van de opleiding Industriële Ingenieurswetenschappen aan de Universiteit Hasselt en de Katholieke Universiteit Leuven.

1.7 Vrijwillige deelname

U neemt <u>geheel vrijwillig</u> deel aan deze studie en u heeft het <u>recht te weigeren er aan deel te nemen</u>. Indien u aanvaardt deel te nemen, zal u deze informatiefolder ontvangen en zal u gevraagd worden het aangehechte toestemmingsformulier te ondertekenen. U kunt weigeren om deel te nemen of u kunt <u>op elk ogenblik tijdens het onderzoek stoppen</u>, zelfs nadat u het toestemmingsformulier ondertekend heeft. U hoeft geen reden te geven voor het intrekken van uw toestemming tot deelname. Het intrekken van uw toestemming zal geen enkel nadeel of verlies van voordelen met zich meebrengen.

Teneinde u toe te laten om een geïnformeerde beslissing te nemen aangaande uw deelname aan dit onderzoek, worden in dit document uw rechten en verplichtingen beschreven (indien u beslist om deel te nemen). Indien u niet zeker bent deze uitleg begrepen te hebben, aarzel niet u tot de onderzoeker te richten. Al uw vragen zullen beantwoord worden.

1.8 Verantwoordelijkheden van de deelnemer

Dit zijn uw verantwoordelijkheden als u beslist deel te nemen aan het onderzoek:

- Stel uw vragen indien u die heeft.
- Informeer de onderzoeker indien u van mening verandert aangaande uw deelname aan dit onderzoek.
- Indien u beslist om deel te nemen aan dit onderzoek bent u verplicht het toestemmingsformulier te tekenen.

1.9 Basis van deelname en terugtrekking uit het onderzoek

Indien u eerst toestemming geeft om deel te nemen en vervolgens toch van mening verandert, bent u vrij uw toestemming in te trekken en uw deelname op elk ogenblik stop te zetten. Dit heeft geen enkel nadelig gevolg voor u.

1.10 Voordelen

In principe is er <u>geen rechtstreeks voordeel</u> voor de deelnemers. Door deel te nemen aan dit onderzoek draagt u echter een steentje bij aan de wetenschap. Nadat het onderzoek is afgelopen, ontvangt u een samenvatting van de resultaten van de studie. U dient er echter rekening mee te houden dat het onderzoek over langere tijd loopt, waardoor er enige tijd tussen uw deelname en rapportage van uw resultaten kan zitten.

1.11 Kosten en vergoeding

Deze studie zal voor u geen bijkomende kosten met zich meebrengen. Alle kosten die voortvloeien uit uw deelname aan het onderzoek zijn voor rekening van de onderzoeker of de opdrachtgever. Kosten die geen verband houden met de studie doch deel zijn van uw behandeling, blijven ten laste van u en uw ziekenfonds en/of verzekeraar.

1.12 Vertrouwelijkheid, privacy en data gebruik

Er zal geen gevoelige data verzameld of verwerkt worden voor deze studie. Alle informatie die tijdens deze studie verzameld wordt, zal strikt vertrouwelijk behandeld worden en zal enkel met uw goedkeuring bekend gemaakt worden of indien vereist door de wetgeving. Deze studie volgt strikt de **Algemene verordening gegevensbescherming** - AVG (Engels: General Data Protection Regulation - GDPR) zoals vereist door de Europese wetgeving.

Vertrouwelijkheid zal gegarandeerd worden door middel van een deelnemersnummer. Uw naam zal in geen enkel document opgenomen worden, m.u.v. een lijst waarin ook uw deelnemersnummer vermeld staat. Wanneer de studie afgelopen is, zal deze lijst enkel bewaard worden aan de Universiteit Hasselt.

Informatie die zou toestaan om u als persoon te identificeren zal niet buiten het onderzoeksteam doorgegeven worden. Uw persoonlijke data zal bewaard worden aan de Universiteit Hasselt en enkel de gepseudonimiseerde (gecodeerde) data zal toegankelijk zijn voor onze internationale partners. Het onderzoeksteam zal ook toegang hebben tot de gepseudonimiseerde informatie en zal de verzamelde data in haar onderzoeksrapporten en andere publicaties tijdens en na afloop van het project gebruiken. De informatie verkregen tijdens deze studie kan gebruikt worden voor verdere analyses, wetenschappelijke publicaties of onderwijs, tijdens of na afloop van het project. Uw identiteit zal ook niet bekend gemaakt worden in de informatie die gebruikt wordt voor publicatie of onderwijs. **Volgens Europese open datawetgeving, kan een deel van de volledig geanonimiseerde data beschikbaar gemaakt worden na afloop van het project.** U kan uw persoonlijk data op elk moment opvragen tijdens of na het project.
U heeft het **recht om toegang te verkrijgen** tot uw persoonlijke data, een **elektronische kopie** te verkrijgen, **aan te passen** of op te vragen, of de data die verzameld is tijdens het project te **verwijderen**.

Uw persoonlijke data zal worden **gecodeerd** en opgeslagen op een dataserver geïnstalleerd op de Universiteit Hasselt. **Deze data zal voor maximum 10 jaar opgeslagen worden**. Deze server is geïnstalleerd op een **beveiligde locatie** en voldoet aan alle **databeveiligingsreglementen**.
Deze en andere aspecten van dataopslag en beveiliging zijn verwerkt in een databesturingsplan (Engels: Data Management Plan).
Een **databeveiligingsofficier** aangesteld door Universiteit Hasselt zal toezicht houden over de correcte toepassing van legale procedures gerelateerd aan AVG binnen dit project. Vragen betreffende het beheer van uw gegevens kan u stellen aan de functionaris voor de gegevensbescherming van het UZA via email: dpo@uhasselt.be.

Wanneer u vindt dat uw rechten met betrekking tot uw persoonsgegevens onvoldoende worden gerespecteerd, kan u steeds terecht bij de functionaris voor de gegevensbescherming die desgevallend de nodige maatregelen zal treffen. U hebt ook het recht om een klacht in te dienen bij de Belgische Gegevensbeschermingsautoriteit:
https://www.gegevnsbeschermingsautoriteit.be/burger.

Meer informatie kan u nalezen op https://www.uhasselt.be/nl/gebruiksvoorwaarden-privacy.

1.13 Commissie voor ethiek

Dit onderzoek werd goedgekeurd door de Sociaal-Maatschappelijke Ethische Commissie van de Universiteit Hasselt op datum van **16/05/2024**. De ethische comités hebben als taak de personen die aan klinische studies deelnemen te beschermen. Ze controleren of uw rechten als patiënt en als deelnemer aan een studie gerespecteerd worden, of – uitgaande van de huidige kennis – de balans tussen risico's en voordelen gunstig is voor de deelnemers, of de studie wetenschappelijk relevant en ethisch verantwoord is. U dient het positief advies van de ethische comités in geen geval te beschouwen als een aansporing om deel te nemen aan deze studie. Indien u besluit deel te nemen aan het onderzoek, dient u het bijbehorende toestemmingsformulier te ondertekenen en bij ons in te leveren.

1.14 Contactpersonen

Indien u vragen heeft over het onderzoek of uw rechten als deelnemer, nu, tijdens of na uw deelname, dan kan u steeds contact opnemen met:

Prof. dr. ir. Ali Pirdavani
Kantoor H-B107
Agoralaan Gebouw H
3590 Diepenbeek, België
ali.pirdavani@uhasselt.be

Siwagorn Bunjong
siwagorn.bunjong@student.uhasselt.be

Lucas Delbare
lucas.delbare@student.uhasselt.be

Indien nodig, kan u ook contact opnemen met de verantwoordelijke op gebied van data bescherming (Engels: Data Protection Officer) van de Universiteit Hasselt via volgend e-mail adres: privacy@uhasselt.be.

2 Toestemmingsformulier

<u>Deel enkel bestemd voor de deelnemer of de wettelijke vertegenwoordig(st)er</u>

Hierbij bevestig ik, ondergetekende:

_______________________________ *(naam + voornaam)* dat ik over de studie ben ingelicht en een kopie van het Informatie- en toestemmingsformulier ontvangen heb.

Ik heb de informatie gelezen en begrepen. De onderzoeker heeft mij voldoende informatie gegeven met betrekking tot het doel van het opzet van het onderzoek, de voorwaarden en de duur ervan en de mogelijke risico dit onderzoek voor mij kunnen inhouden. Bovendien werd mij voldoende tijd gegeven om de informatie te overwegen en om vragen te stellen, waarop ik bevredigende antwoorden gekregen heb. In verband hiermee verklaar ik het volgende:

- Ik heb begrepen dat ik mijn deelname aan deze studie op elk ogenblik mag stopzetten, zonder dat dit mij enig nadeel kan berokkenen;
- Ik ga akkoord met de verzameling, de verwerking en het gebruik van mijn gegevens, zoals beschreven in het informatieblad voor de deelnemer (de rijgegevens worden in versleutelde vorm digitaal opgeslagen en enkel de betrokken onderzoekers hebben toegang tot deze gegevens);
- Ik ga akkoord met de anonieme overdracht en de anonieme verwerking van mijn gegevens in andere landen dan België;
- Ik ga akkoord met het gebruik door de opdrachtgever van deze gecodeerde gegevens voor andere onderzoeks¬doeleinden;
- Ik stem geheel vrijwillig toe om deel te nemen aan deze studie;
- Ik in de rijsimulator zal rijden zoals ik normaal ook rijd in het verkeer.

Handtekening deelnemer (of wettelijk vertegenwoordig(st)er):

Naam: _________________________
(hoofdletters)

Datum: ________________________

<u>Deel enkel bestemd voor het onderzoeksteam</u>

Ik, ondergetekende, (student Industriële Ingenieurswetenschappen), bevestig hierbij dat ik,

_____________________________________ *(naam + voornaam)* heb ingelicht en dat hij (zij) zijn (haar) toestemming heeft gegeven om deel te nemen aan de studie.

Handtekening:

Naam: _____________________

(hoofdletters)

Datum: ____________________

(ondertekening door een lid van het onderzoeksteam is de regel – indien hiervan afgeweken wordt motivering bijvoegen)

Appendix C: Instructions for participating

De impact van low-cost interventies op het rijgedrag

Instructies voor de deelnemer

Deel 1: voorbereiding

Toestemmingsformulier

Voordat het experiment van start gaat, wordt van u verwacht dat u het informatie- en toestemmingsformulier doorneemt en ondertekent. Dit formulier bevat belangrijke informatie over het experiment, inclusief het doel ervan, de procedures die zullen worden gevolgd, mogelijke risico's en uw rechten als deelnemer. Door het formulier te ondertekenen, geeft u aan dat u deze informatie hebt begrepen en akkoord gaat met de deelname aan het experiment.

De rijsimulator

Zo dadelijk neemt u plaats in onze **kleine rijsimulator**. Deze simulator is geconfigureerd met het dashboard van een auto.

Het voertuig dat u in de simulator bestuurt beschikt over een **automatische versnellingsbak**. Dat betekent dat u enkel gebruik moet maken van het rempedaal en het gaspedaal.

De simulator is ook uitgerust met een stuurhendel om de richtingaanwijzers te bedienen. Het is dan ook de bedoeling om in het scenario zo realistisch mogelijk te rijden: dat houdt ook het gebruik van de richtingaanwijzers in.

De simulator projecteert tot slot ook een eenvoudige instrumentencluster. Die kunt u zien vooraan op het scherm.

De stoel van de simulator is tevens verstelbaar om uw ritten zo comfortabel mogelijk te maken. Maak hiervoor gebruik van de hendels.

Simulatorziekte

In het informatie- en toestemmingsformulier werd reeds vermeld dat er, bij het rijden in de simulator, steeds de kans op simulatorziekte bestaat. De symptomen van simulatorziekte zijn vergelijkbaar met die van wagenziekte. Enkele voorbeelden van deze symptomen zijn vermoeidheid, hoofdpijn, een suf gevoel, moeite hebben met scherp zien, zweten, misselijkheid, een droge mond en moeite hebben met concentreren.

Als u merkt dat u last krijgt van simulatorziekte, geef dit dan onmiddellijk aan (iets zeggen, hand opsteken, …). Het experiment wordt dan onmiddellijk stopgezet. Nadien wordt bekeken of u nog verder kunt meedoen aan het experiment en uw rit kan hervatten of herstarten.

Deel 2: Oefenrit

Allereerst krijgt u voor de aanvang van de eerste rit een vragenreeks voorgeschoteld over uw algemene rijervaring en uw gegevens.

Vervolgens zal de eerste rit die u uitvoert in de simulator een **oefenrit zijn**. Tijdens deze rit krijgt u de kans om de simulator uitproberen en te gewennen aan de besturing. Met name leert u hoe u het gas geven en remmen moet doseren en hoe gevoelig het sturen in de simulator is.

Fouten die u maakt in dit oefenscenario tellen niet mee voor de metingen: het scenario is enkel bedoeld als training voor de volgende scenario's.

Deel 3: traject 1

In dit scenario wordt een gewone autorit gesimuleerd op een landelijke weg, waarbij u onderweg enkele nieuwe low-cost interventies zal tegenkomen. De bedoeling is dat u gedurende het volledige traject zoals u normaal gezien ook zou rijden en dat u zich aan de verkeersregels houdt.

Na afloop van de rit krijgt u een pauze van 5 minuten om naar het toilet te gaan, frisse lucht te scheppen en/of iets te drinken. Gedurende pauze ontvang u een nieuwe vragenlijst die betrekking heeft op uw rijervaring van deze rit.

Deel 4: traject 2

In dit tweede scenario rijdt u opnieuw door enkele verkeerssituaties op een landelijke weg, waarbij u onderweg enkele andere nieuwe low-cost interventies zal tegenkomen. Net als voorheen wordt van u verwacht dat u gedurende dit traject normaal rijdt, rekening houdend met de huidige verkeersregels.

Nadat dit tweede traject is afgerond, ontvangt u opnieuw een vragenlijst over uw rijervaring van deze rit en over de verschillende verkeerssituaties die u tijdens deze en vorige rit hebt ervaren.

Appendix D: Pretest-questionnaires

Voorafgaande vragenlijst

Beste deelnemer,

Hartelijk dank dat u wilt deelnemen aan ons onderzoek.
Voordat u wordt opgehaald door de onderzoeker, vragen wij u vriendelijk om deze vragenlijst in te vullen. Het invullen duurt maximaal 5 minuten. Mocht u vragen onduidelijk vinden, kunt u deze tijdelijk open laten staan en zal de onderzoeker deze later met u bespreken.

Wij waarderen uw medewerking enorm.
Met vriendelijke groeten,

Siwagorn Bunjong en Lucas Delbare
Masterstudenten bouwkunde
Universiteit Hasselt en KU Leuven

* Verplichte vraag

1. Naam (voornaam + achternaam) *

   ____

2. Unieke deelnemer ID

   ____

3. Geboortedatum *

   ____

   Voorbeeld: 7 januari 2019

4. Woonplaats (Postcode + gemeente)

   ____

5. Geslacht *

Markeer slechts één ovaal.

- Man
- Vrouw
- Zeg ik liever niet
- Anders: ____________________

6. Hoogst voltooide opleiding (met diploma)

Markeer slechts één ovaal.

- Lager onderwijs
- Lager middelbaar onderwijs
- Hoger middelbaar onderwijs
- Hoger onderwijs, niet universitair onderwijs
- Hoger onderwijs, universitair onderwijs
- Anders: ____________________

7. Wat is uw beroep?

Markeer slechts één ovaal.

- Bediende
- Arbeider
- Zelfstandige
- Student
- Niet beroepsmatig actief
- Anders: ____________________

8. Welke type rijbewijs bezit u? *

Vink alle toepasselijke opties aan.

- [ ] Rijbewijs A
- [ ] Rijbewijs B
- [ ] Rijbewijs C
- [ ] Rijbewijs D
- [ ] Theoretisch rijbewijs
- [ ] Anders: ____________________

9. Hoelang heeft u al uw rijbewijs? (in aantal jaren)

____

10. Hoeveel kilometer rijdt u gemiddeld per jaar als bestuurder? *

Markeer slechts één ovaal.

- ( ) minder dan 5 000 km
- ( ) 5 000 tot 9 999 km
- ( ) 10 000 tot 14 999 km
- ( ) 15 000 tot 19 999 km
- ( ) 20 000 tot 25 000 km
- ( ) meer dan 25 000 km

11. Rijdt u meestal handgeschakeld of met automatische versnelling?

Markeer slechts één ovaal.

- ( ) Handmatig
- ( ) Automatisch

12. Hoe goed is uw nachtrust van de afgelopen 3 dagen?

Markeer slechts één ovaal.

	1	2	3	4	5	
Zeer	◯	◯	◯	◯	◯	Uitstekend

13. Hoeveel uur slaapt u gemiddeld? (in aantal uren)

____

Appendix E: Posttest-questionnaires

Vragenlijst na de test

Beste deelnemer,

Hartelijk dank voor uw deelname aan ons onderzoek.
Voordat u het onderzoekcentrum verlaat, vragen wij u nog vriendelijk om onderstaande vragenlijst in te vullen. Het invullen van deze vragenlijst zal maximaal 5 minuten duren. Indien er vragen onduidelijk zouden zijn, kan u deze tijdelijk open laten en zal de onderzoeker deze toelichten.

Wij waarderen uw medewerking enorm.
Met vriendelijke groeten,

Siwagorn Bunjong en Lucas Delbare
Masterstudenten bouwkunde
Universiteit Hasselt en KU Leuven

* Verplichte vraag

1. Naam (voornaam + achternaam) *

____

2. Unieke deelnemer ID *

____

3. Hoe was uw ervaring met de rijsimulator? *

Vink alle toepasselijke opties aan.

- [ ] Uitstekend
- [ ] Goed
- [ ] Niet goed niet slecht
- [ ] Slecht
- [ ] Zeer slecht

4. Hoe nauw sluit rijden in de simulator aan op het rijden in de realiteit? *

Markeer slechts één ovaal.

- Uitstekend
- Goed
- Niet goed niet slecht
- Slecht
- Zeer slecht

5. Had u een realistische ervaring van de snelheid die u reed in de simulatie? *

Markeer slechts één ovaal.

- Uitstekend
- Goed
- Niet goed niet slecht
- Slecht
- Zeer slecht

6. Wat denkt u dat het doel van deze studie is?

7. Ervaarde u duizeligheid of misselijkheid tijdens het rijden in de simulator? *

Markeer slechts één ovaal.

- Duizeligheid
- Misselijkheid
- Geen van beide

8. Hoe goed kon u de markering van rode drakentanden zien op het wegdek voor de bocht? *

Markeer slechts één ovaal.

- Uitstekend
- Goed
- Niet goed niet slecht
- Slecht
- Zeer slecht

9. Hoe goed kon u de rood/witte mediaan zien op het wegdek tijdens de bocht? *

Markeer slechts één ovaal.

- Uitstekend
- Goed
- Niet goed niet slecht
- Slecht
- Zeer slecht

10. Hoe goed kon u de rood/witte randmarkering zien op het wegdek tijdens de bocht? *

Markeer slechts één ovaal.

- Uitstekend
- Goed
- Niet goed niet slecht
- Slecht
- Zeer slecht

11. Hoe goed kon u de rode randmarkering zien op het wegdek tijdens de bocht? *

Markeer slechts één ovaal.

- Uitstekend
- Goed
- Niet goed niet slecht
- Slecht
- Zeer slecht

12. Hoe zou u de effectiviteit van de interventie met rode drakentanden op uw snelheid en positie op het wegdek beoordelen? *

Markeer slechts één ovaal.

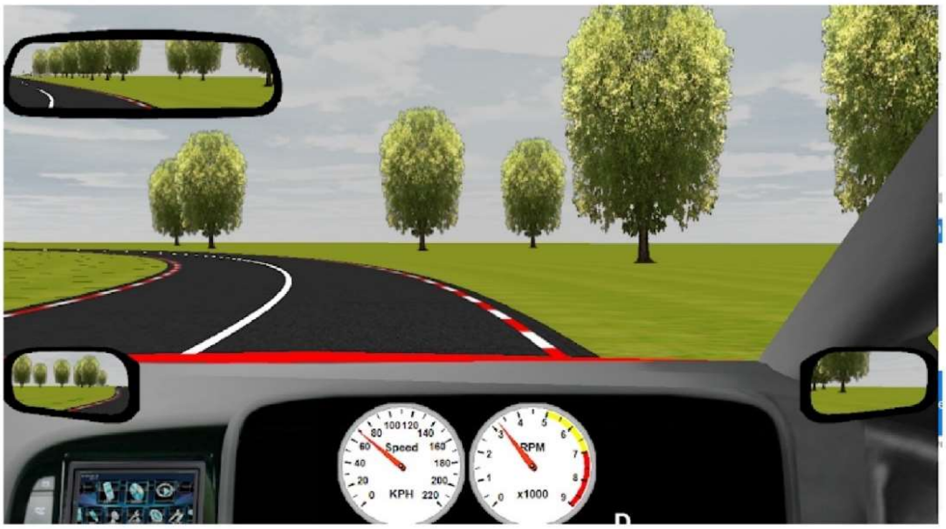
	1	2	3	4	5	
Hele	◯	◯	◯	◯	◯	Zeer effectief

13. Hoe zou u de effectiviteit van de interventie met een rood/witte mediaan op uw snelheid en positie op het wegdek beoordelen? *

Markeer slechts één ovaal.

	1	2	3	4	5	
Hele	◯	◯	◯	◯	◯	Zeer effectief

14. Hoe zou u de effectiviteit van de interventie met een rood/witte randmarkering op uw snelheid en positie op het wegdek beoordelen? *



Markeer slechts één ovaal.

	1	2	3	4	5	
Hele	◯	◯	◯	◯	◯	Zeer effectief

15. Hoe zou u de effectiviteit van de interventie met een rode randmarkering op uw snelheid en positie op het wegdek beoordelen? *

Markeer slechts één ovaal.

	1	2	3	4	5	
Hele	◯	◯	◯	◯	◯	Zeer effectief

16. Indien u nog vragen of opmerkingen heeft over het onderzoek, kan u deze hier onder noteren.