How do different road curvature profiles incite different curve entry styles?

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Final Bachelor Project, Cognitive Robotics, 3mE, Delft University of Technology

January 7, 2019

Abstract

In order to design a haptic feedback controller that adapts to the driver instead of a 'one size fits all' driver system, a study on the effect of how different road curvature profiles incite different curve entry styles was conducted. This study was conducted at the Human Machine Interaction lab in the faculty of Aerospace Engineering of the Delft University of Technology. A driving simulator test with 24 different drivers was conducted, both male and female, of different ages, and with different amounts of driving experience. Drivers show prepositioning behavior, commonly towards the outer curve, independent of the curve direction. Driver classification distributions imply curve cutting behavior correlates stronger to velocity than road curvature. Curve entry position and extreme lateral offset values for all tested conditions have shown to be significant using ANOVA-testing ($p < 0.01$).

1 Introduction

If all vehicles on the road would be replaced with autonomous vehicles (AV) it would lead to huge improvements in the efficiency of road use and reduce the frequency and intensity of traffic jams (Stern et al., 2018). It also would eliminate human error from traffic situations and enable more efficient forms of road design. The future potential of AVs is significant, however the current state of the art AVs are unable to handle all possible traffic situations. This means if a state of the art AV finds itself in a driving situation outside of its range of control the driver has to take over control and manage the situation to the best of his capabilities. Research has shown humans do not perform well when having to asses traffic situations in a split second (Nyholm and Smids, 2016). When a disengaged driver has to take over control in such a scenario it is unlikely the driver will be able to perform at his best. Using vehicles that are only partially autonomous instead of using full AVs would result in the user remaining an active participant in traffic while still providing some comfort. Although such systems are currently available they are not personalized, meaning they give the same assistance to every user without taking the users individual driving style into account. Since not all people drive alike, these systems are not yet considered user friendly. To create a solution the Delft University of Technology department of Cognitive Robotics is creating a self learning advanced Driver Assistance System (aDAS). For the development of personalized aDAS more data is needed on driver behavior in and around road curves.

It is common practice when studying driving behavior to classify driver styles, model behavior and assess created models. Data is either gathered through experiments in simulators or in vehicles equipped with sensors. The study by Duanfeng et al. (2017) is an example of the latter where data is gathered on a Chinese freeway. The data was used to classify driver styles and create a driver model which actively monitors and warns drivers when danger of sideslips and rollovers increases in curves. With different studies providing various models a method for evaluating and comparing driver models was introduced by Barendswaard et al. (2018). Previous study regarding driving behavior in curves at the Delft University of Technology has been conducted using simulations.

This paper demonstrates a study that investigates the correlation between curvature profiles and curve entry styles for two common velocities. Different people show different driving behavior. In order to design certain types of advanced Driver Assistance Systems these differences have to be taken into account. Feedback in such a system has to be tuned to specific user demand. In order to classify drivers and model realistic driver behavior in and around curves data is gathered on constant speed situations. The results will aid in personalizing of the advanced Driver Assistance System currently in development by the Delft University of Technology department of Cognitive Robotics. This plays a crucial part in the acceptance of such systems in everyday life. For example, aggressive drivers will be annoyed when a driver assistance system breaks earlier than they expected, while more cautious drivers will experience a late stop as unsafe. This research will contribute to this personalization by collecting data on driving behavior, specifically the relation between road curvature, velocity and vehicle prepositioning.

In order to collect data on driving behavior and the relation between road curvature and vehicle prepositioning an empirical experiment will be conducted. Test subjects will drive specifically designed roads in a driving simulator provided by the Delft University of Technology. Conditions using constant velocity will be evaluated for different combinations of curvature and velocity based on realistic road design. The main type of output metric will be the lateral offset of the simulated vehicle. Prepositioning and in curve driver behavior will be analyzed, in order to classify driver styles. The influence of factors like driver style and experience will also be examined.

In this paper the following research question will be answered:

How does road curvature influence vehicle prepositioning in constant speed situations?

In order to answer the research question the following subquestions will be answered:

- *How do drivers position their vehicle at curve entry for different combinations of speed, curvature and curve sequence?*
- *What is the influence of different combinations of speed and curvature on vehicle preposition time?*
- *Are drivers consistent in their driver style for the different tested conditions?*
- *How does driver style correspond to vehicle prepositioning?*
- *What is the influence of driver experience on vehicle positioning at curve entry?*

The outline of the paper is as follows: In section 2, the method of the experiment is explained. Section 3 shows the results of the experiment. The lateral error on straight sections, the lateral position at curve entry position, the peak lateral offset, the prepositioning time, the lateral error in curves, driver classification and the impact of driving experience on driving behavior are all treated in this section. Figure 1 shows the definitions used throughout the paper, note that prepositioning time in seconds is related to velocity and distance.

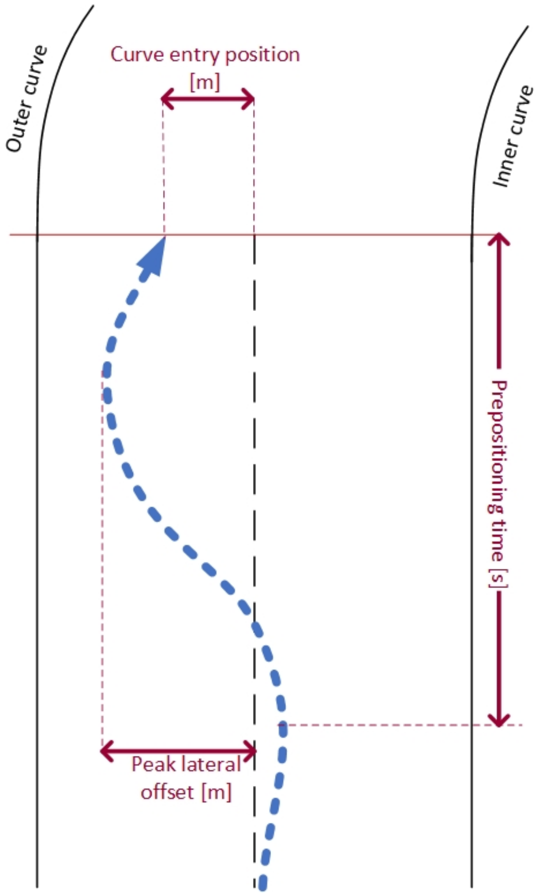

Figure 1: Definitions used throughout the paper visualized on the road

In the result section the research questions are also answered. In section 4 the major findings of the study are summarized and limitations discussed, finally the conclusion is stated and recommendations for further research are given.

2 Method

In order to answer the research question and subquestions, the following method was used:

Simulator set up

The simulator of the Human Machine Interaction lab was used for data gathering. It is located inside the faculty of Aerospace Engineering at the Delft University of Technology. The simulator has a fixed base and can be used for both car and airplane simulations. The car side of the simulator uses a control-loaded steering wheel (FCS), a control loaded accelerator pedal, a passive spring loaded brake pedal, a NISSAN adjustable car seat and a 12 inch LCD panel display. The simulator uses a three-sided projection screen and 3 HD resolution DLP projectors to cover a 180 degree field of view (Postema, 2018).

Road design

A condition for the simulator is made to consist of a road with 21 clothoidal curves. See Appendix A for a detailed explanation of different curve types and road design. This allows for 20 straight sections between curves. These 20 straight sections consist of 5 sections per curve sequence (Left-Left, Left-Right, Right-Left and Right-Right). This is because the small previous unpublished exploratory study conducted by S. Barendswaard (Personal communication, October 2018) implied drivers behave differently when driving between different sequences of curves. The total curve sequence is different per condition and always patternless to avoid some sort of precognitive effect on the measurements. The exploratory study also indicated postpositioning can take drivers up to 5 seconds to complete and prepositioning can start 15 seconds before curve entry. For these to not overlap straight sections between curves have been made to take 25 seconds. Note that the exploratory study was very small, therefore the interval was chosen to be 25 instead of 20 seconds.

The conditions are driven with constant velocity and all curves in a condition have the same absolute curvature. Tests are done with two commonly found velocities in the Netherlands, 50 km/h and 80 km/h. For each of these velocities there are two conditions with different curvatures, making for a total of four conditions. The chosen curvatures are based on multiple factors, most notably realistic road design as taught at the faculty of Civil Engineering of the Delft University of Technology and a desire for partial overlap with a previous unpublished final bachelor project study. The first curve radius is 204 meters, this is the minimum radius corresponding with road design for 80 km/h assuming a road tilt of 10%. This radius was also used in a previous study which allows for comparing results. The second curve radius is chosen to be larger, since it needs to be suited for both velocities. The second radius is 350 meters, which corresponds to minimum curvature for 100 km/h assuming similar road tilt. Curve length is optimized through use of the extended tangent point (see Gruppelaar et al. (2018)). This is the furthest drivers can see into a given road curve and is not only dependant on road curvature, but also the angle of the curve, lane width and lateral vehicle offset. The length of the curves is chosen to be minimal but for the extended tangent point to always be within the curve for drivers at curve entry, this is shown in Figure 2.

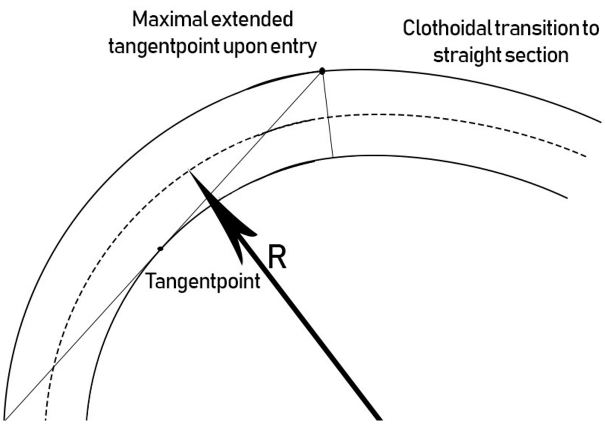

Figure 2: Maximum Extended Tangent Point

Experimental procedure

Twenty-four test subjects were tested. Test subjects were requested to drive a total of four conditions in the simulator. The simulator provides data output for subjects lateral position and lateral acceleration. Using four conditions allows for testing combinations of two different speeds and two different curvatures. Testing took approximately 10 to 12 minutes per condition, with small breaks in between. Total time per subject was approximately one hour. In this hour a consent form had to be filled in as well. This form is shown in Appendix B. All the subjects completed all the conditions without symptoms of motion sickness, as shown in Figure 1 of Appendix C. This briefing was sent to all participants before the experiment.

Metrics

In order to get the results, the following metrics were used and analyzed:

- Lateral position
- Lateral acceleration
- Driving experience
- Driver style classification table according to Spacek (2005):

Category	Name	Definition
1	Rough curve cutting	Start on outside, cutting inside, ending on the outside
2	Curve cutting	Start on outside, cutting inside, ending on the inside
3	Mild curve cutting	Inside of the curve all the time
4	Mild under-turning	Outside of the curve all the time
5	Under-turning	Start on inside, end on outside
6	Rough under-turning	Start on inside, going to the outside, then ending on the inside

Figure 3: Driver style classification (Spacek, 2005)

Dependent variables

Using a function provided by Sarah Barendswaard prepositioning time was calculated by analyzing the change in the derivative of the lateral position on the straight sections. Driver style classification by lateral jerk analysis, with jerk being the derivative of lateral acceleration, as described in Murphey et al. (2009) was done with the signal energy of the total jerk signal per subject:

$$E = \sum_{n=n1}^{n2} |x[n]|^2 \tag{1}$$

Data processing

After every condition a data log, recorded at 100Hz, from the simulator is saved on the computer. These log files are read and evaluated using MATLAB in order to store all the data in a single structure file. Different scripts subtract the significant data such as lateral position and lateral acceleration. This data is then stored in vectors with lengths depending on the total time of the driven condition. Since people tend to misjudge the car's position in the simulator, the data is corrected for lateral position bias. This is done by subtracting the average value from all data points. After this, the data is divided in eight different sections per condition. Four sections regarding the straight sections between different curve sequences, and four sections regarding these four different kinds of curves.

Firstly, the lateral offset in the straight sections is plotted over time. To make the plots easier to compare, the offset in the curved sections is plotted over distance. A second program analyzes the lateral position of the car at both curve entry point and the moment of maximum lateral offset. This program makes distributions out of these different lateral positions. Subsequently another program looks at the prepositioning time. This program analyzes the driven straight sections and shows the time needed to prepare for the curve. This is the point where the driver evades from their own neutral position.

After analyzing this data for all subjects two driver classification files were made in order to assign driver style in two different ways. The first program analyzes the driver style in terms of curve cutting, while the second program examines the lateral jerk. The influence of different conditions on driver behavior is investigated. This knowledge is also used to compare the curve entry styles of different driver classes. In order to look for difference between experienced and inexperienced drivers, these programs were also ran for selected groups of four drivers:

- A group consisting of four people with 39, 40, 40 and 42 years of driving experience
- A group of four people that did not have a driving license. Three of them were currently taking driving lessons.

Several programs have been made utilizing previously made MATLAB functions provided by S. Barendswaard, in order to have the same type of output.

Hypothesis

The following things are expected:

- An increase of curvature will cause drivers to preposition further to the outer curve. This way drivers will follow a path with smaller curvature than the actual road curvature.
- Driver style will be a reliable indication for prepositioning behavior.
- Drivers will be consistent in their style.

3 Results

The results gathered from the experiments have been plotted into figures. These figures are shown in Appendix D and will be discussed one by one in this section.

Lateral offset on straight sections

In Figure 14 of appendix D lateral offset is shown on straight sections. The subplots represent sections between different curve sequences. Here 'RL 80 km/h' shows driver positioning following a right curve preceding a left curve at a velocity of 80 km/h. In the subplots the curves with a radius of 350 meters are shown in green and those with a radius of 204 meters are shown in red. The marked areas again show the standard deviation of the measurements. The notable trends in these subplots are as follows:

1. For all combinations of velocity and curvature drivers show prepositioning behavior. Prepositioning seems to commonly be towards the outer curve.
2. All subplots show drivers reach a peak lateral offset shortly before the end of the straight section. People start steering into the curve before the curve actually starts. The consistency over different conditions indicates this is an important property of prepositioning behavior.
3. For the smaller curve radius, the red lines, people preposition further towards the outer curve when compared to the larger curve radius.

4. All plots appear to be a mirrored version of their exact directional opposites. At a velocity of 80 km/h the straight section plot between two left curves is an approximate mirrored version of the plot between two right curves. Similarly the 80 km/h LR plot is an approximate mirrored version of the 80 km/h RL plot. This is also the case for the 50 km/h plots. This strongly implies people consistently take the same approach to curves regardless of curve direction. This would also indicate the results of the previous exploratory study by S. Barendswaard were influenced by some precognitive effect, since the curve sequence was too predictable for test subjects.

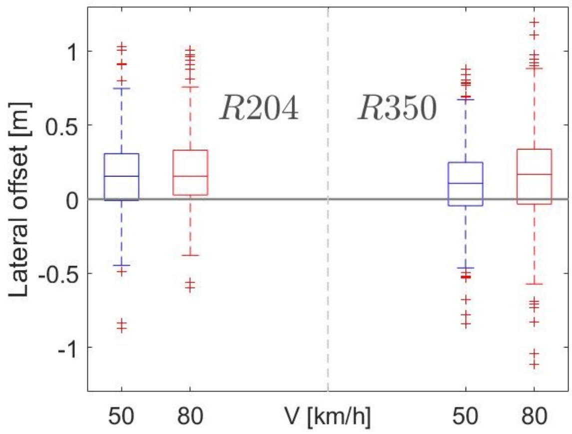

Figure 4: Box plot of the lateral offset at curve entry

Curve entry position

In Figure 15 of appendix D vehicle positioning is shown at curve entry for all measured curves per condition. In these plots a positive lateral offset indicates an offset towards the outer curve. The vertical lines represent the average lateral offset and the marked domains surrounding these lines indicate the area plus and minus one standard deviation. These plots show three notable trends:

1. For all conditions the average lateral offset is a positive value. This implies people, on average, do have a tendency to preposition their vehicles towards the outer curve.

2. The average lateral offset for both velocities is larger for the smaller curve radius. This implies for tighter curves people preposition more in a curve cutting manner.

3. The standard deviation is larger for the larger velocity, which implies human behavior varies more at larger velocities.

These results are also plotted in Figure 4. The box plot shows people will preposition more when driving with higher velocities. Figure 4 shows that on a smaller radius people preposition more compared to the larger radius and people preposition more on higher velocities compared to lower velocities. The results showing lateral offset on straight sections showed drivers commonly start steering into the curve before curve entry. This greatly influences the data in this figure. Peak lateral offset is suggested as a more suitable metric to gain insights in driver behavior. ANOVA testing of the curve entry position values for all conditions show significant differences with ($p < 0.01$).

Peak lateral offset during prepositioning

In the box plot shown in Figure 5 the average peak lateral offset at straight sections is shown. In Figure 14 of appendix D it is shown that people preposition before curve entry and steer into the curve before the curve starts. The peak lateral position during prepositioning for all subjects is just before the curve. Therefore the peak lateral offset might be a property better suited for determining preposition behavior compared to the offset in curve entry point. ANOVA testing shows the differences in peak lateral offset to be significant with ($p < 0.01$).

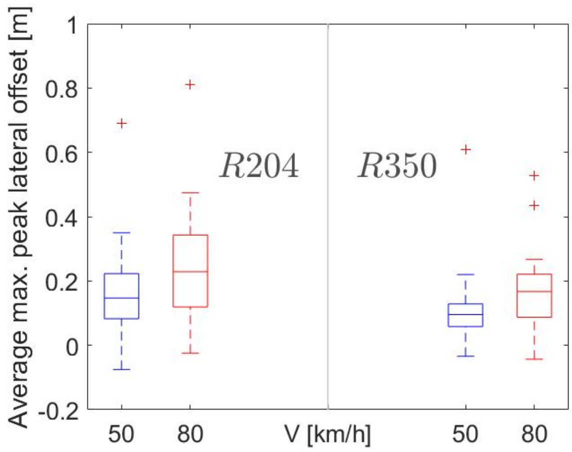

Figure 5: Box plot of the average peak lateral offset

Figure 5 gives important insights regarding the effect of curvature and velocity on prepositioning behavior. The figure shows that both curvature and velocity have an effect on prepositioning behavior. Both the conditions with 80 km/h show more prepositioning compared to 50 km/h in same radius curves. Both velocities also show more prepositioning when the radius becomes smaller.

Prepositioning time

Figure 6 shows a spread with values from roughly 1 to 20 seconds prepositioning time. Although there is a wide spread, a trend can be seen that values for the smaller radius are higher and that the values for a low velocity are higher. This can be explained by the fact that the corners with the small radius were more difficult to take and thus required more attention.

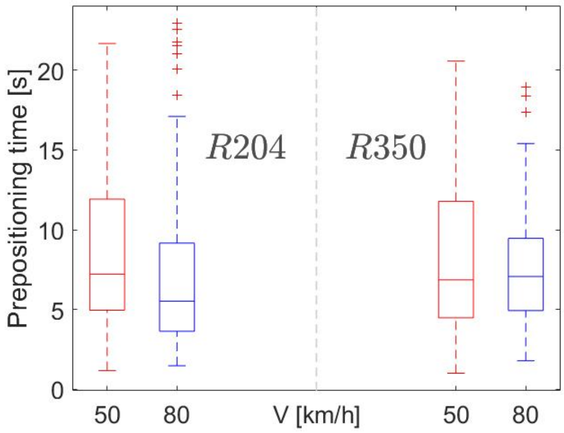

Figure 6: Preposition time for all test subjects

Lateral offset in curves

In Figure 16 of Appendix D the lateral offset in curves is plotted on the bottom for all tight curves and on the top for the wider curves. Here 'curve RL 204m' corresponds to all left curves with a radius of 204 meters preceded by a right curve in the simulations. Here positive values represent a lateral offset to the right side of the road. In all eight subplots the lateral offset has been plotted for both velocities, red representing a velocity of 50 km/h and green representing a velocity of 80 km/h. The marked areas surrounding the individual lines correspond with their standard deviations. The subplots on top show the road curvature profile plotted versus the distance for visual reference. Two notable trends are visible in these plots:

1. For the plots on the bottom row representing lateral offset in 204 meter radius curves, the two plotted velocities show a significant difference in measured lateral offset. For the larger velocity, plotted in green, it is visible how people cut corners more when compared to the red plots. In the left curves people drive on the left side of the road and in the right curves people drive on the right side of the road.

2. For the plots on the top row representing lateral offset in 350 meter radius curves, the two velocities result in extremely similar plots. This similarity is unexpected. It could either imply driving patterns in wide curves are not dependent on velocity, or imply these combinations of curvature and velocities are not optimally suited for answering the research question.

Driver Classification

As mentioned in the Method section two ways of defining driver style are used in this study. The first, as explained in Spacek (2005), assigns different driver styles based on in-curve vehicle positioning and range from 1: rough curve cutting, to 6: rough underturning. Table 1 outlines the different categories of this method. The second method, according to Murphey et al. (2009), is to classify by analyzing the lateral jerk of the vehicle, using equation 1 (see section 2).

In Figure 17 and Figure 18 of appendix D histograms of driver style per condition per curve are presented for both curve cutting and jerk analysis respectively. Both figures reveal a notable trend:

- Although road curvature seems to have a slight effect on driving behaviour, the driver classification distributions imply driver behavior correlates strongly to velocity.

This trend is also clearly visible in Figure 7.

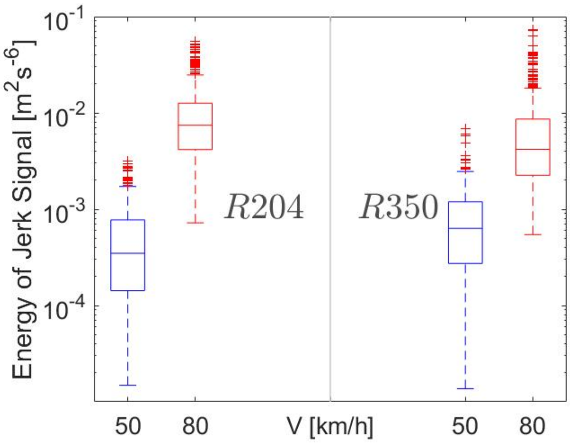

Figure 7: Box plot of the energy of the jerk signal

Even without driver influence the lateral jerk should be higher in case of a higher velocity. Lateral acceleration relates to the forward velocity in the following way: $a_{lat} = v^2/R$. This means average jerk in a curve entered with 80 km/h will naturally be $\frac{(80/50)^2}{50/80} = 4.096$ times as high as in a curve entered with 50 km/h. However, the difference in jerk in the test results is significantly higher, meaning velocity has influence on the driving behaviour.

The curve entry position and prepositioning time for each class, classified by curve cutting, are analyzed in appendix D in Figure 19 and 20 respectively. The same is done in Figure 21 and 22. From these box plots no trend can be detected regarding differences in either curve entry position or prepositioning time between different driver styles for both classification methods. No clear correlation can be found between the results of both methods. This is confirmed in Figure 23. This means the methods are independent and can be treated as such.

Influence of Driver Experience

In order to check if driver experience has an influence on prepositioning behavior two groups of four drivers were more closely examined. The groups are as described in section 2, Method. Figures 24, 25, 26 and 27 in appendix D show prepositioning behavior of the experienced driver group in blue and the inexperienced driver group in yellow. These figures show that experienced drivers will, under any and all conditions, preposition further toward the outer curve and start steering into the curve before it begins. This behavior is barely if at all present for subjects with minimum driving experience. Data on the peak lateral offset for experience is visible in Figure 8. Positive values indicate offsets towards the outer curve.

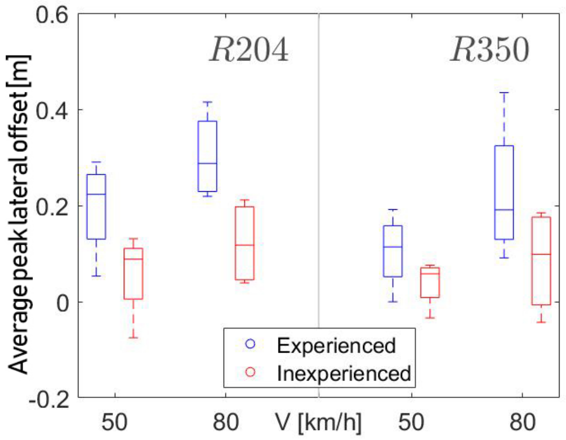

Figure 8: Box plots of the average peak lateral offset in two different groups

Figure 8 shows that experienced drivers tend to preposition more towards the outer curve. A reason for this might be that experienced drivers anticipate more on the coming road, which is an important skill most new drivers have not mastered yet.

The preposition time for the experienced and inexperienced groups is plotted in Figure 9. The variation for prepositioning time is large for the experienced drivers at low velocities. This can be explained due to the fact that the tested group was very small.

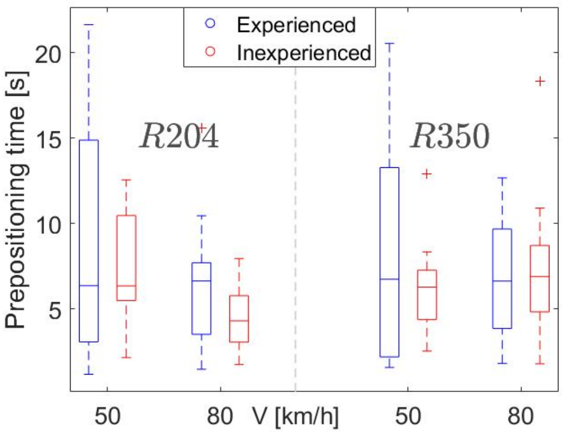

Figure 9: Preposition time for experienced and inexperienced subjects

These box plots show the following effect of experience:

1. Inexperienced drivers react later to upcoming curve, resulting in a shorter preposition time.

2. For experienced drivers the prepositioning time shows more variance.

3. For lower speeds the prepositioning time also shows more variance.

Answers to subquestions

With this information the following answers were found to the questions proposed in section 1:

- Drivers, on average, enter curves on the side of the road corresponding to the outer curve. This implies curve cutting is very common behavior. The lateral offset in this direction increases for greater curve radii when velocity is kept constant. Standard deviations indicate behavior varies more for higher velocities.

- Prepositioning time is influenced by both speed and curvature. Prepositioning time increases for smaller curve radii because these curves are harder to navigate. Prepositioning time decreases for higher speeds.

- Drivers are not consistent in their driving style for different conditions. Based on both driver classification methods, driver style is mainly influenced by velocity.

- No notable trend was found between different driver styles and both curve entry position and prepositioning time.

- Driver experience plays a major part in vehicle prepositioning. Results also indicated the largest difference existed for the peak offset, where drivers with around 40 years of experience showed larger peak offsets for every single condition. Curve entry data was less indicative of the difference, since experienced drivers started steering into curves before they started, while inexperienced drivers showed less of this behavior. Analysis of the prepositioning time indicated behavior of experienced drivers varies more. This further emphasizes aDAS need personalizing as opposed to a 'one size fits all' approach.

4 Discussion

This study has shown multiple major findings.

- For all combinations of velocity and curvature drivers significantly show prepositioning behavior. Prepositioning commonly occurs towards the outside of the upcoming curve.
- Drivers start steering into the curve before the curve actually starts. This behavior is significantly more visible for experienced drivers, but even inexperienced drivers do so in a less extreme fashion.
- Drivers consistently take the same approach to curves regardless of curve direction or curve sequence.
- Driver classification distributions implied curve cutting behavior correlates stronger to velocity than road curvature.
- People tend to cut the curve more as the curve radius gets smaller.

This means that prepositioning is always present and tending to the wide curve. But in-curve behavior is different. Curve cutting behavior is more dependent on velocity than on curvature. However, this study also has limitations in findings.

- In the wide curve, similar results were found for both 50 and 80 km/h. This might imply the tested curvature is too large for the tested velocities.
- The size of the tested group might be too small to find clear differences in driver classification styles and the influence of experience.

Conclusion

The effect of road curvature and driver experience on curve prepositioning was researched. The main research question was: *How does road curvature influence vehicle prepositioning in constant speed situations?* The hypothesis stating that drivers tend to preposition further to the outer curve in order to follow a path with a smaller curvature than the actual road curvature was confirmed. Results showed the majority of drivers do so. Driver classification was expected to be a good indication for preposition behavior, but consistency between different conditions was lacking. One of the most important findings is that velocity and driver experience are the most important factors for prepositioning behavior. This information can prove to be very important in the development of aDAS by the Delft University of Technology department of Cognitive Robotics.

Recommendations

This study gives important new knowledge in researching how drivers act in and in between curves. However the velocities used when testing were set and constant, which might give unrealistic results as results show the influence of velocity on prepositioning and in-curve behavior. This is especially important since one of the major findings was that velocity has a large impact on driving behavior. The use of a simulator might also be a point that can be improved. The simulator used in this experiment was fixed base and did not give G-force feedback. The simulator was unable to simulate road cant, but road design assumed a cant of 10%. Test subjects stated it was difficult to determine the position of the vehicle on the virtual road due to the absence of essential reference points. The use of a real car on a real road or circuit with advanced measuring systems might give results that are more realistic. A larger test group is also advised because having more data will give smaller standard deviations of results.

For further research the use of free speed is advised because of the impact of velocity on results. If constant speed is chosen we suggest using higher velocities. Fifty kilometers per hour is shown to be too slow, especially in curvatures with a large radius.

Acknowledgements

This study was conducted with collaboration of many people. Firstly, we would like to thank Sarah Barendswaard and David Abbink for their help and supervision of the project. We would like to thank them for giving important insights and supplying us with literature and useful MATLAB programs.
Secondly, we would like to thank all volunteers that have driven our driving simulator experiment. Thirdly, a word of thanks for Harold Thung, Rene van Paassen, Dirk van Baelen, Sarah Barendswaard and all other

people of the HMI-lab that helped us out when we encountered errors in the lab that we could not solve ourselves.

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A Curvature styles

Curvature profiles can be separated into a few categories. The most simple profile is a circular, fixed radius arc. This type is demonstrated in Figure 10.

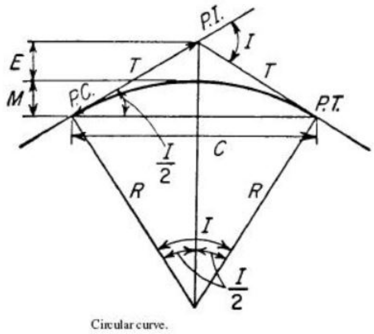

Figure 10: Circular curve, from (Singh, 2018)

This is mostly used as a building block for other, more complex curves. Compound and reverse curves are respectively homogeneous and heterogeneous combination of these circular curves as shown in Figure 11.

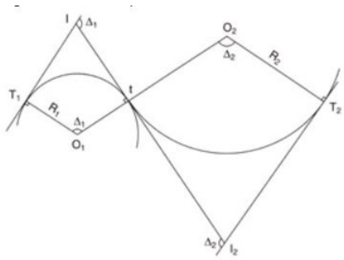

Figure 11: Reversed compounded curves , from (Breach, 2018)

These types however, are rarely used in actual road design. More regularly used are transition curves. These profiles have a variable radius along the path of the curve, and are used to smoothen the lateral acceleration profile of a vehicle. Different types include lemniscate (see Figure 12) and clothoid arcs (see Figure 13).

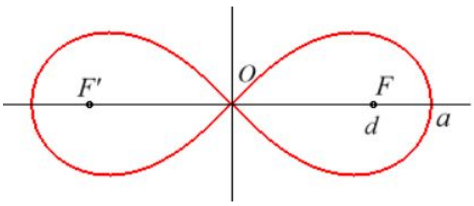

Figure 12: Lemniscate curves , from (Ferréol, 2017)

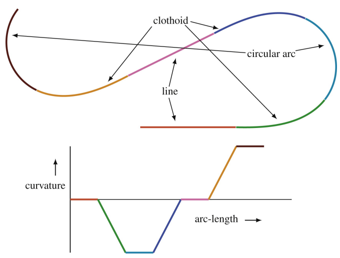

Figure 13: Clothoid curves , from (McCrae and Singh, 2009)

Lemniscate trajectories are used when the deflection angle of the curve is very large (e.g. a cloverleaf intersection), thus not applicable to this research. Clothoid arcs however, are used in the transition area between the straight section to the circular part of a road, and are the type of curvature profile used in this experiment.

B Consent form

Consent form for Driving Simulator Experiment

By filling in this consent form, I declare that I join this experiment voluntarily and may decide to quit at any time without further consequences.
This consent form is only used for this project. None of this data will be used for other purposes than this project. The driving simulator experiment is organized by: Bart Schelfaut, Jim Sluijter, Luuk van Breugel, and Lourens Zuiker. It is under supervision of David Abbink and Sarah Barendswaard

About you

1. **Name**: ____________________
2. **Age**: ____________________
3. **Gender**: ☐ Male ☐ Female
4. **Do you have a drivers license?**
   - ☐ Yes, for ______ years.
   - ☐ No.
   - ☐ I am taking lessons.
5. **Have you participated in a driving simulator experiment before?** ☐ Yes ☐ No

How do you consider your own behaviour on the road?

6. **Driving style** Calm ☐—☐—☐—☐—☐ Aggressive

Thank you for filling in this questionnaire. By signing, I agree that I join this experiment voluntarily. The data will be completely anonymous. To make a connection between point 6 and the data there will be a number added to this document by the organizer.

Date: ____________ Signature: ____________

C Experiment briefing

Experiment briefing

How do different road curvature profiles incite different Curve-Entry styles?

This experiment contributes to the development of an advanced Driver Assistance System. In order to design this system, different kinds of driving behaviour have to be classified. The goal of this experiment is to examine the relation between the curvature profile of a road and the positioning of the driver at the start and end of this curve.

Experimental Setup

The experiment will take place in the driving simulator of the Human-Machine Interaction Laboratory at the faculty of Aerospace Engineering. While you drive you will only be controlling the steering wheel, which gives mechanical feedback to mimic a real life situation. The experiment is done in constant speed situations, which means that the accelerator and brake pedals do not need to be used. The seat is adjustable.

Experimental Procedure

You will take four runs in total. In these runs you will navigate circuits with two different curve radii: 204m and 350m. Both these radii will be tested at 50km/h and 80km/h. After each run you will be checked for any signs of motion sickness according to the MISC scale in Table 1.

Symptoms		Score
No Problems		0
Some discomfort, no specific symptoms		1
Dizzines, warm, headache, stomach awareness, sweating...	Vague	2
	Little	3
	Rather	4
	Severe	5
Nausea	Vague	6
	Little	7
	Rather	8
	Severe	9
	Retching	10
Vomiting		11

Figure 1: MISC Scale

Your Rights

Participation in this experiment is completely voluntary. You're allowed to pause or terminate the experiment at any point. By signing the consent form and participating in the experiment you approve that the collected data may be used.

D Results

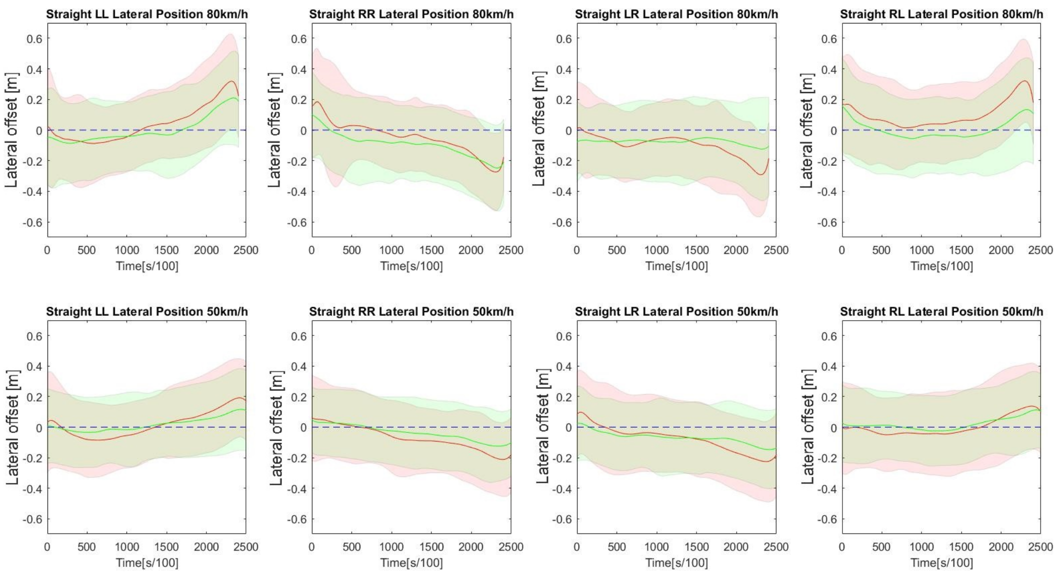

Figure 14: Lateral offset on straight sections

In the subplots the curves with a radius of 350 meter are shown in green and those with a radius of 204 meter are shown in red.

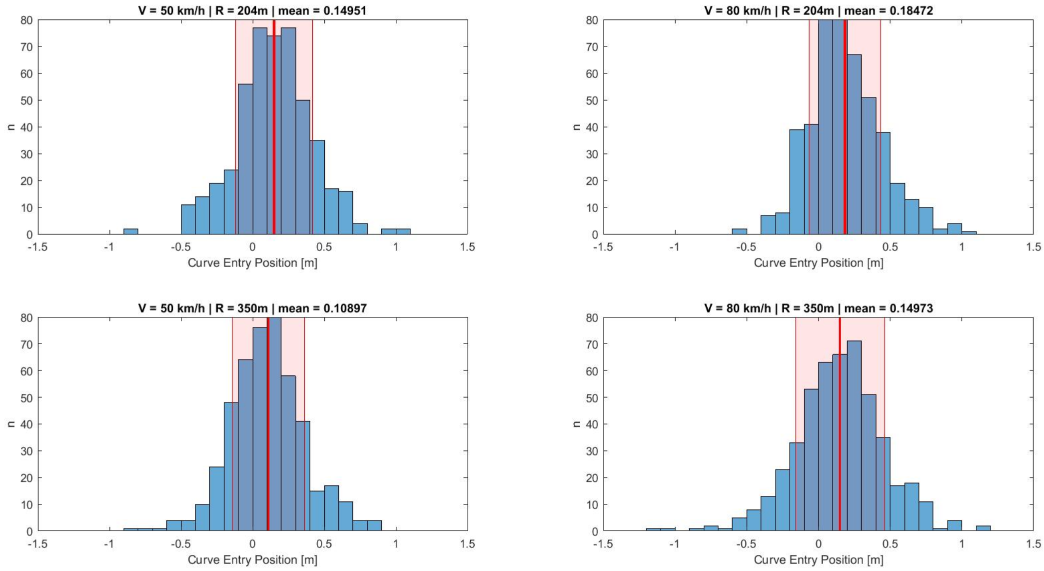

Figure 15: Vehicle positioning at curve entry for all conditions

Figure 15 shows the entry position at curves. In this figure a positive lateral difference error means a point on the road on the opposite side of the curve, e.g. the driver chooses to make the radius as big as possible. The red zone indicates the area plus and minus one standard deviation.

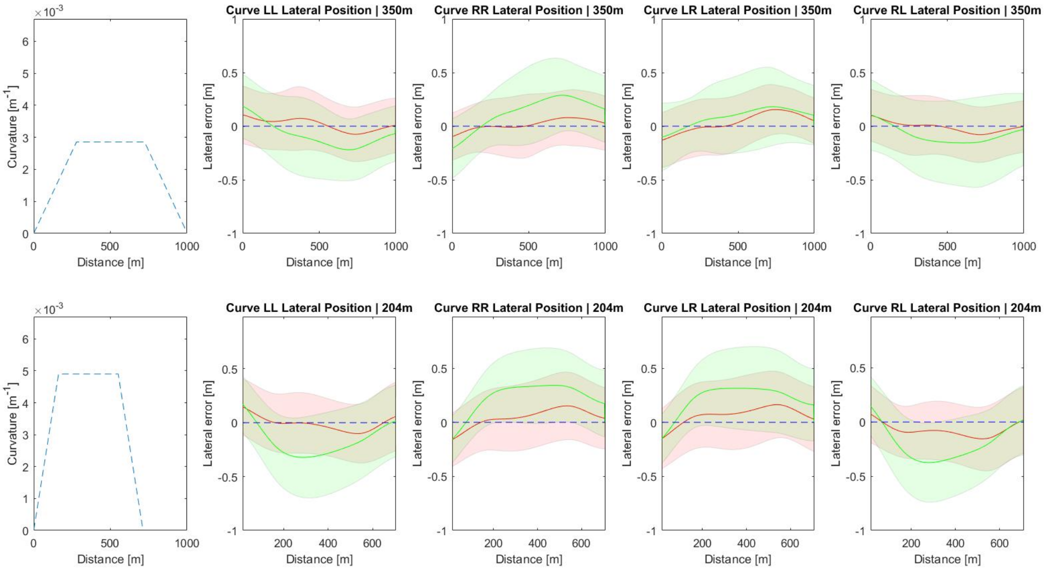

Figure 16: Lateral error in the curves

Figure 16 shows the lateral error in curves. Red lines represent 50 kilometers per hour and green lines represent 80 kilometers per hour.

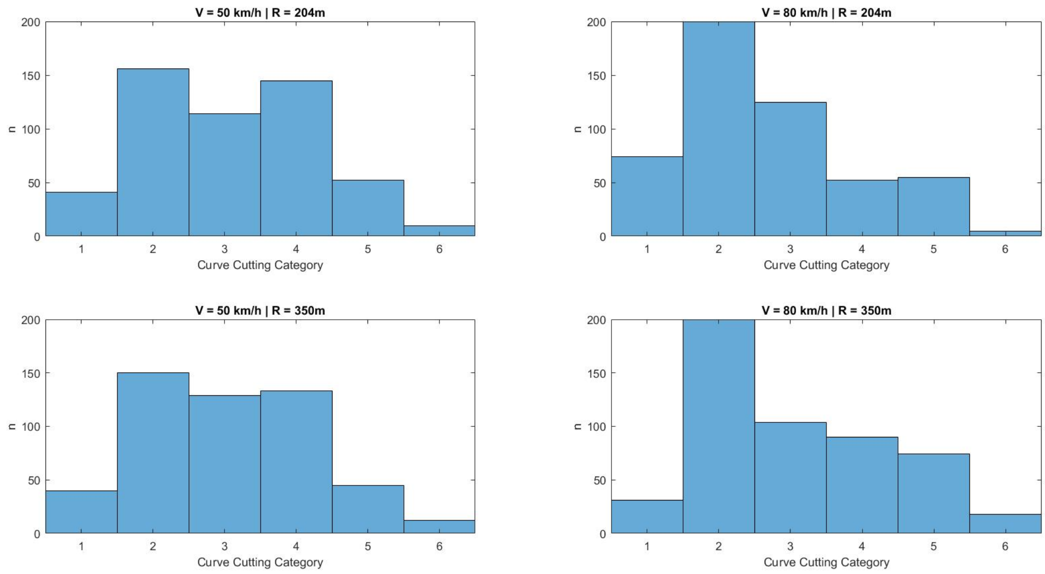

Figure 17: Curve cutting classification

Figure 17 shows the category of curve cutting in different scenarios. Different categories are shown in Table 1.

Category	Name	Definition
1	Rough curve cutting	Start on outside, cutting inside, ending on the outside
2	Curve cutting	Start on outside, cutting inside, ending on the inside
3	Mild curve cutting	Inside of the curve all the time
4	Mild under-turning	Outside of the curve all the time
5	Under-turning	Start on inside, end on outside
6	Rough under-turning	Start on inside, going to the outside, then ending on the inside

Table 1: Definitions of different curve cutting categories (Spacek, 2005)

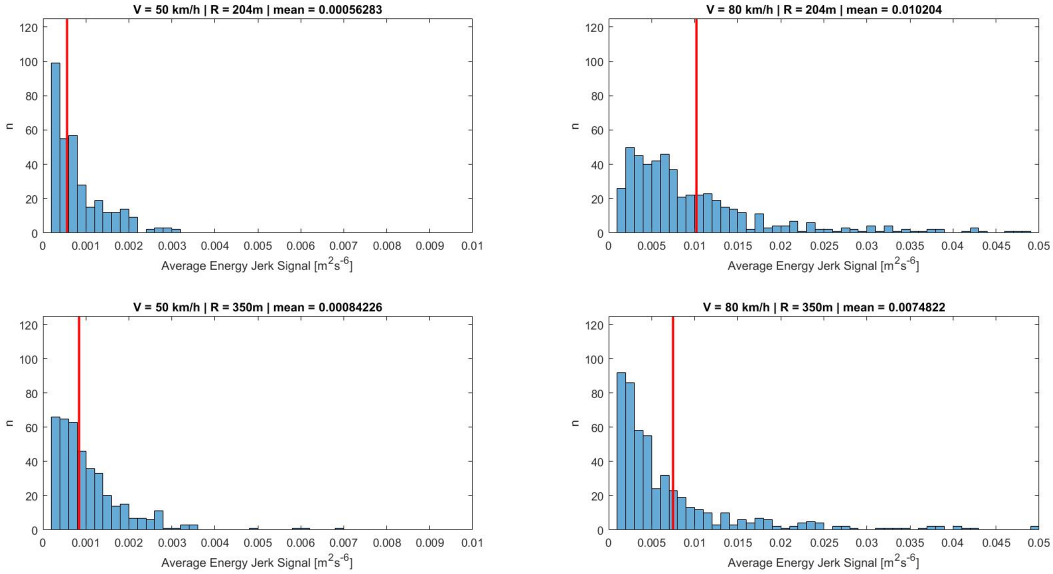

Figure 18: Measured average energy of the jerk signal

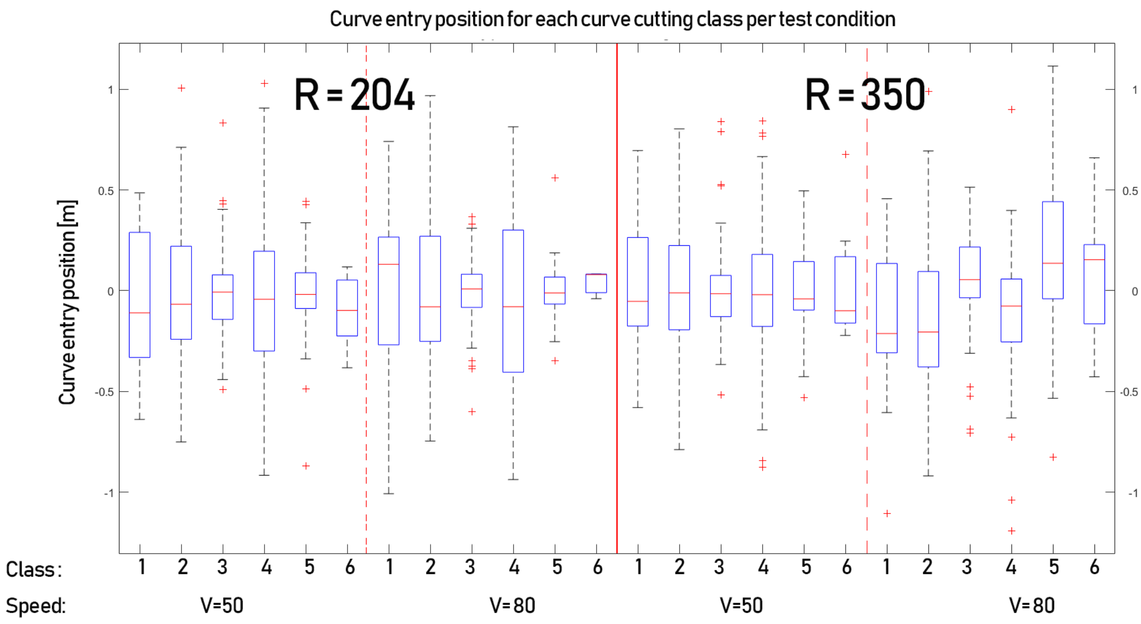

Figure 19: The distributions of curve entry position per classified driver style for each condition (curve cutting method).

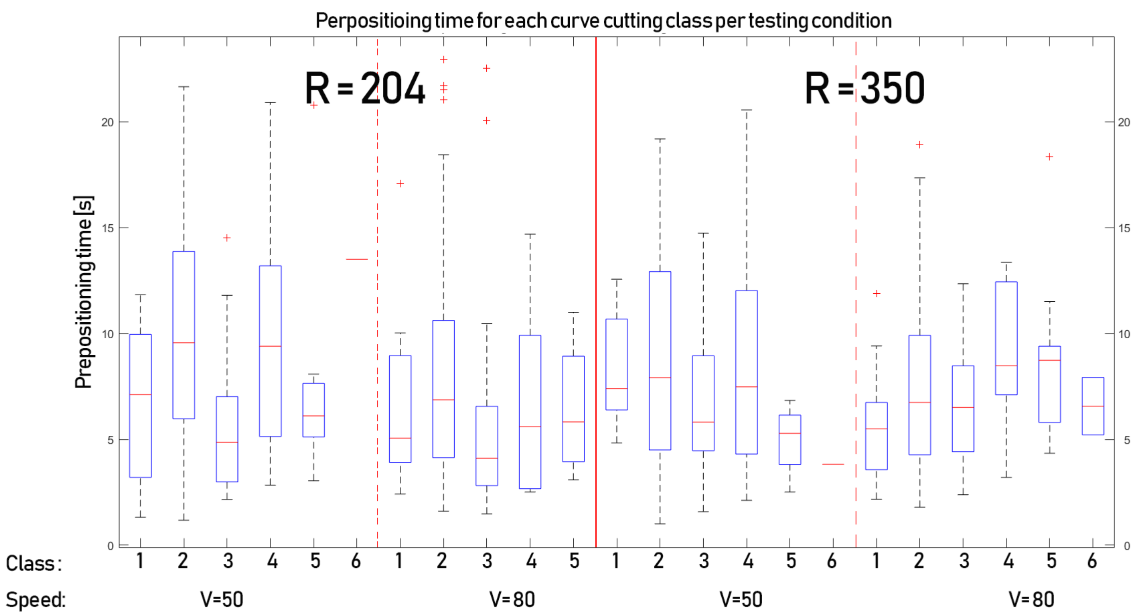

Figure 20: The distributions of prepositioning time per classified driver style for each condition (curve cutting method).

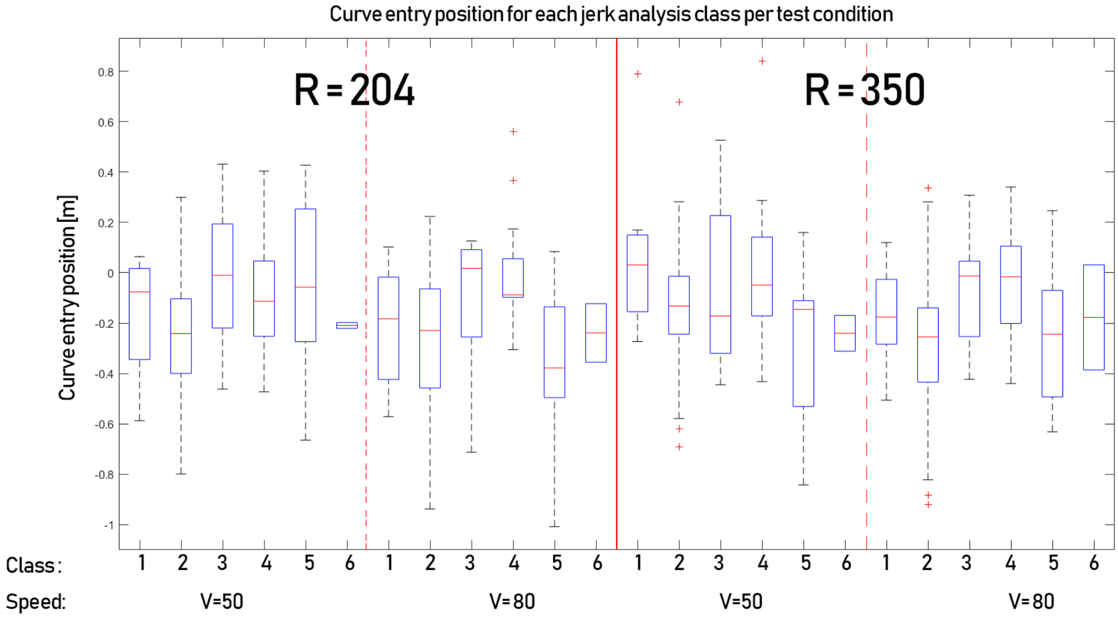

Figure 21: The distributions of curve entry position per classified driver style for each condition (jerk analysis method).

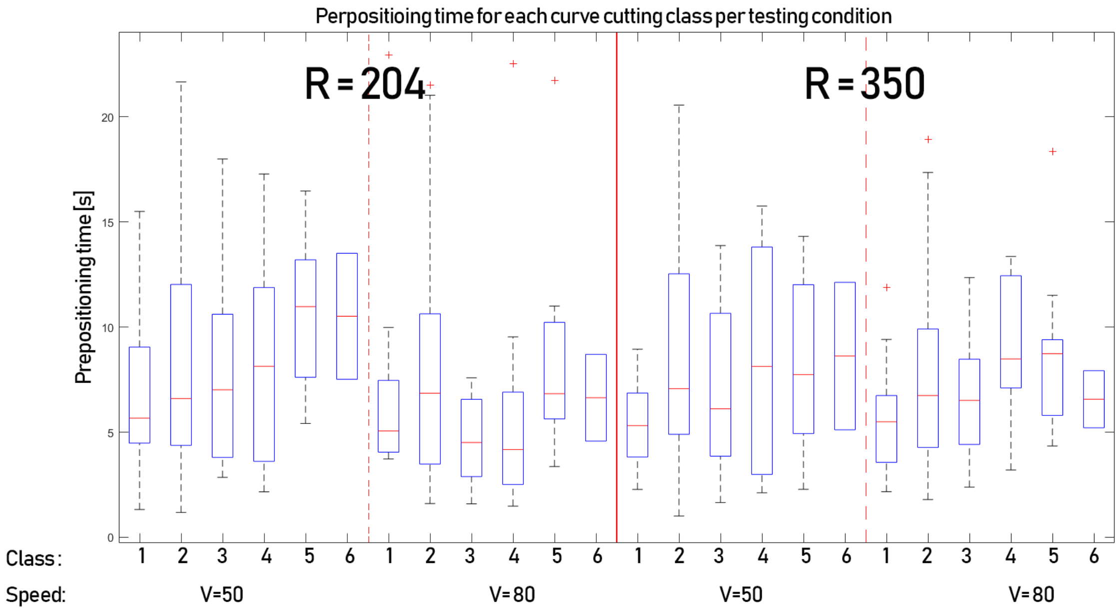

Figure 22: The distributions of prepositioning time per classified driver style for each condition (jerk analysis method).

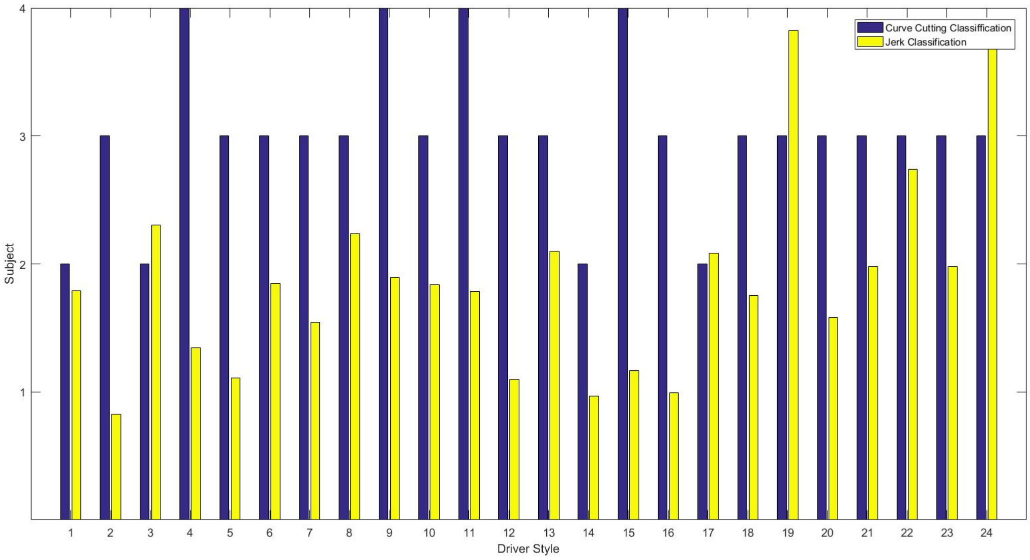

Figure 23: Comparison of Curve Cutting Classification and Jerk Classification.

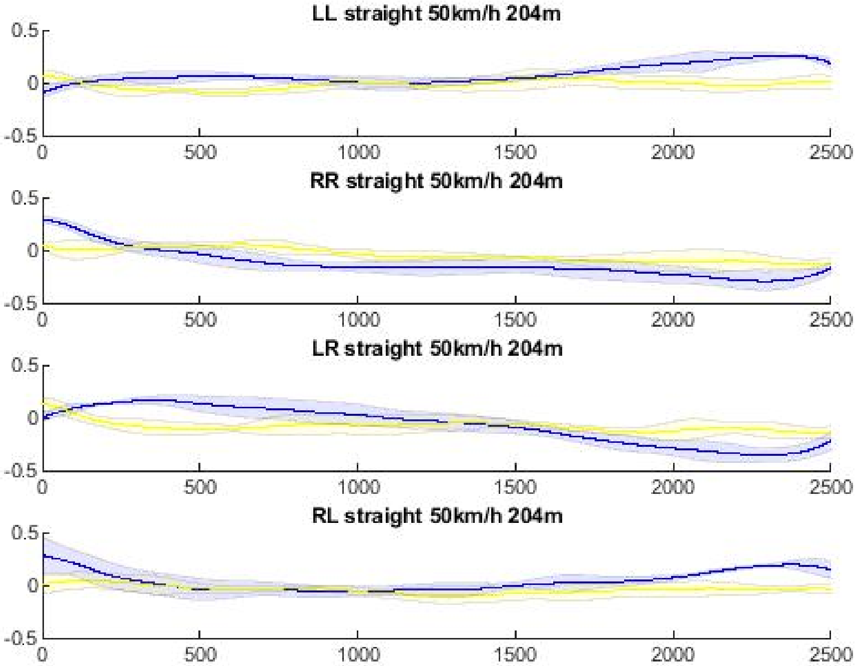

Figure 24: Lateral offset on straight sections showing an experienced group (in blue) and an inexperienced group (in yellow), at 50 km/h in between 204m radii curves

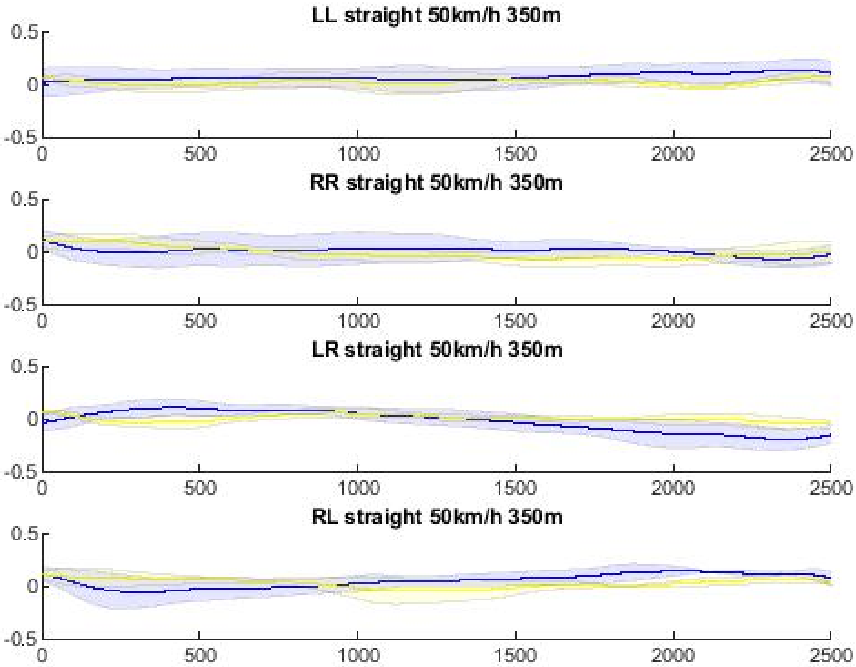

Figure 25: Lateral offset on straight sections showing an experienced group (in blue) and an inexperienced group (in yellow), at 50 km/h in between 350m radii curves

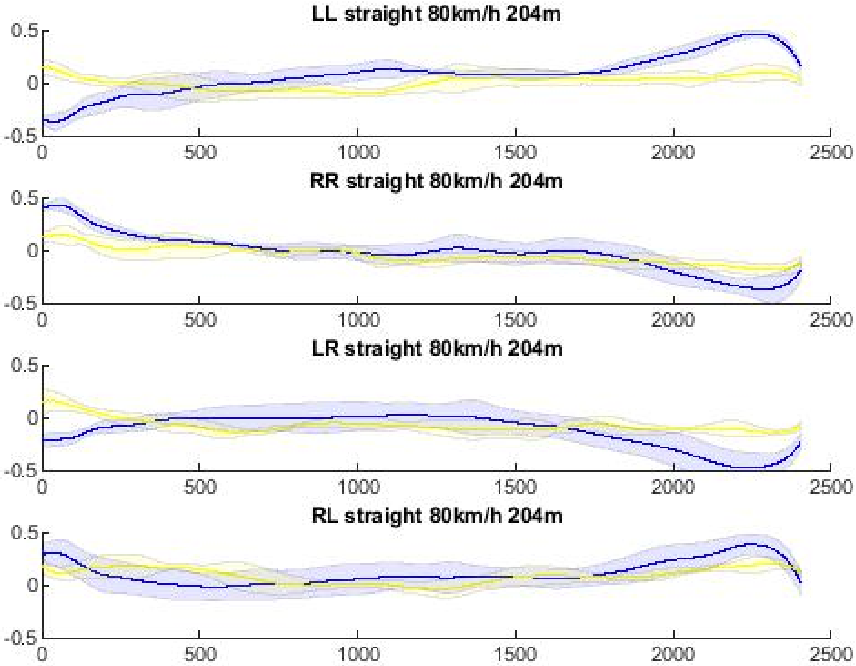

Figure 26: Lateral offset on straight sections showing an experienced group (in blue) and an inexperienced group (in yellow), at 80 km/h in between 204m radii curves

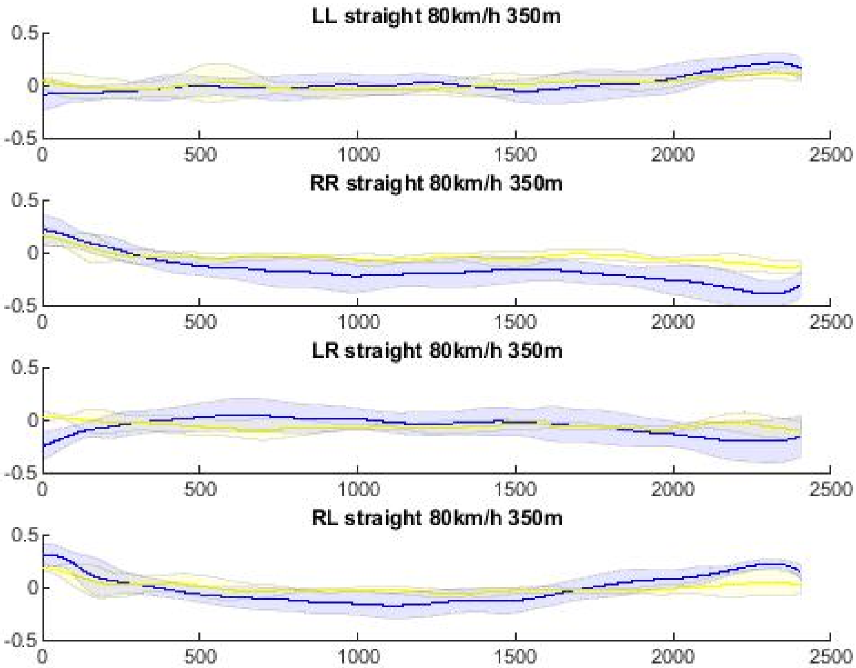

Figure 27: Lateral offset on straight sections showing an experienced group (in blue) and an inexperienced group (in yellow), at 80 km/h in between 350m radii curves