I also care in manual driving - Influence of type, position and quantity of oncoming vehicles on manual driving behaviour in curves on rural roads

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Abstract

There is not yet sufficient knowledge on how people want to be driven in a highly automated vehicle. Many studies suggest that automated vehicles should drive like a human driver, e.g. moving to the right edge of the lane when meeting oncoming traffic. To generate naturally looking trajectory behaviour, more detailed studies on manual driving are necessary. This is a driving simulator study investigating different oncoming traffic scenarios in curves. Fourty-six participants experienced three different oncoming traffic scenarios either on a 3.00 m or on a 3.50 m lane width in manual driving. Results show that participants react to oncoming traffic by veering to the right edge of the lane. We also found that the type of oncoming vehicles influences manual driving behaviour. Trucks lead to significantly greater reactions and hence to more lateral distance between the ego and the oncoming vehicle. From this study on manual driving, we recommend an adaptive autonomous driving style which adjusts its trajectory behaviour on type and position of oncoming vehicles. Thus, our results help to design an accepted and trusted trajectory behaviour for highly automated vehicles.

State of knowledge

Sensory and algorithmic developments enable an increasing implementation of automation in the automotive sector. Ergonomic studies on highly automated driving are essential aspects for later acceptance and use of highly automated vehicles (Banks, 2015; Elbanhawi et al., 2015). In addition to studies on driving task transfer or out-of-the-loop issues, there is not yet sufficient knowledge on how people want to be driven in a highly automated vehicle (Gasser, 2013; Radlmayr & Bengler, 2015). First insights show that preferences regarding the perception and rating of driving styles are widely spread. Many prefer their own or a very similar driving style and reject other driving styles that include e.g. very high acceleration and deceleration rates or small longitudinal and lateral distances to other road users (Festner et al., 2016; Griesche et al., 2016; Dettmann et al., 2021). Studies show that swift, anticipatory, safe and seemingly natural driving styles are prioritized (Bellem et al., 2016; Hartwich et al.; 2015; Dettmann et al., 2021). In the literature, trajectory behaviour as one part of the driving style is mostly implemented as a lane-centric

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position of the vehicle in the lane. From a technical point of view this is a justifiable and logical conclusion, but drivers show quite different preferences, especially in curves and in case of oncoming traffic (Bellem et al., 2017; Lex et al., 2017). In manual driving situations without oncoming traffic, participants drive close to the centre of the lane on straights (Schlag & Voigt, 2015; Rosey et al., 2009). In curves, participants show a different driving behaviour and move closer to the road centre in left turns and closer to the roadside in right turns (Rossner & Bullinger, 2018). Several studies report a tendency to cut the curve by hitting the apex, especially for left turns (Bella, 2005; Bella, 2013; Spacek, 2005). When meeting oncoming traffic in manual driving, participants increase their lateral safety distance by moving to the right edge of the lane, both on straights (Schlag & Voigt, 2015; Rossey et al., 2009; Triggs, 1997) as well as in left and right curves (Lex et al., 2017; Schlag & Voigt, 2015). When meeting heavy traffic, participants' reactions are even greater (Spacek, 2005; Dijksterhuis, 2012; Mecheri et al., 2017; Schlag und Voigt, 2015; Rosey et al., 2009; Räsänen, 2005). With the appearance of oncoming traffic in left curves, two manual driving strategies overlay: to hit the apex and to avoid short lateral distances to the oncoming traffic. Therefore, left curves are going to be the main focus of this study. In summary, the implementation of this natural driving behaviour into an automated driving style includes high potential to improve the driving experience in an automated car. Previous studies (Rossner & Bullinger 2018, Rossner & Bullinger 2019, Rossner & Bullinger 2020a, Rossner & Bullinger 2020b; Rossner et al. 2021) show that reactive trajectory behaviour in highly automated driving leads to significantly higher acceptance, trust and subjectively experienced driving performance on straights and in curves. In order to implement adaptive trajectories that modify trajectory behaviour on different lane widths and adjust their behaviour on type and position of oncoming vehicles, it seems most relevant to investigate manual trajectory behaviour in more detail. The aim of this study is to gain more knowledge on manual driving to implement better reactive trajectories that include less negative side effects and lead to a better driving experience. The results of the study will help to design an accepted and trustfully trajectory behaviour for highly automated vehicles.

Method and variables

A fixed-based driving simulator (Fig. 1) was used to conduct a mixed-design experiment. Forty-six participants experienced three different oncoming traffic scenarios either on a 3.00 m or on a 3.50 m lane width in manual driving.

Table 1. Participant characteristics

	Number	*Age*		*Driving licence holding (years)*		*Mileage last five years (km)*	
	N	*M*	*SD*	*M*	*SD*	*M*	*SD*
Female	13	35.2	6.9	17.3	6.9	60,300	57,000
Male	33	33.9	7.7	15.7	7.8	98,300	69,900
Total	46	34.3	7.4	16.2	7.5	87,500	68,100

Figure 1. Driving simulator with instructor centre (left) and a participant (right)

All participants were at least 25 years old and had a minimum driving experience of 2.000 km last year and 10.000 km over the last five years (see Table 1 for details). On the simulated rural road straight and curve sections were showed in alternation, so after each curve a straight section followed. The curves had a radius of 450 m and a length of 250 m. The test track consisted of 7 right and 19 left curves with none, one or two oncoming vehicles. Left curves with oncoming traffic lead to more safety critical situations and were therefore implemented in a higher number. For the same reason, two oncoming vehicles only occurred in left curves. Oncoming traffic was balanced to minimize sequence and habituation effects. The speed of the oncoming traffic was set at 80 km/h and represented either by a car or a truck. Participants were instructed to drive 100 km/h, but should feel free to reduce speed. However, all curves could be safely passed at 100 km/h (Vetters, 2012). Higher speeds of the ego vehicle were excluded by an activated limiter function at 100 km/h within the driving simulation. Consequently, the ego vehicle encountered the oncoming traffic at the apex of the curve with a very high probability (Fig. 2). Driving data, e.g. velocity or lateral position, was recorded throughout the whole experiment.

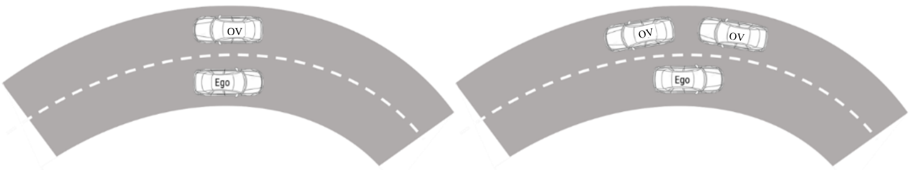

Figure 2. Ego vehicle ecountering oncoming traffic (OV) at the apex of the curve.

Results

Script-based data monitoring discovered zero invalid data recording cases, which needed to be excluded for further analysis. Each curve was splitted into 10 equal parts of 25 m. Driving data were averaged for each section (S). The analysis focused on the lateral behaviour of the ego vehicle in each sector in dependence of oncoming traffic, curve type and lane width. Lateral distance as main dependent variable was measured form the centre of the ego vehicle to the road side (Fig. 3). Left and right curves are reported separately in the following sections.

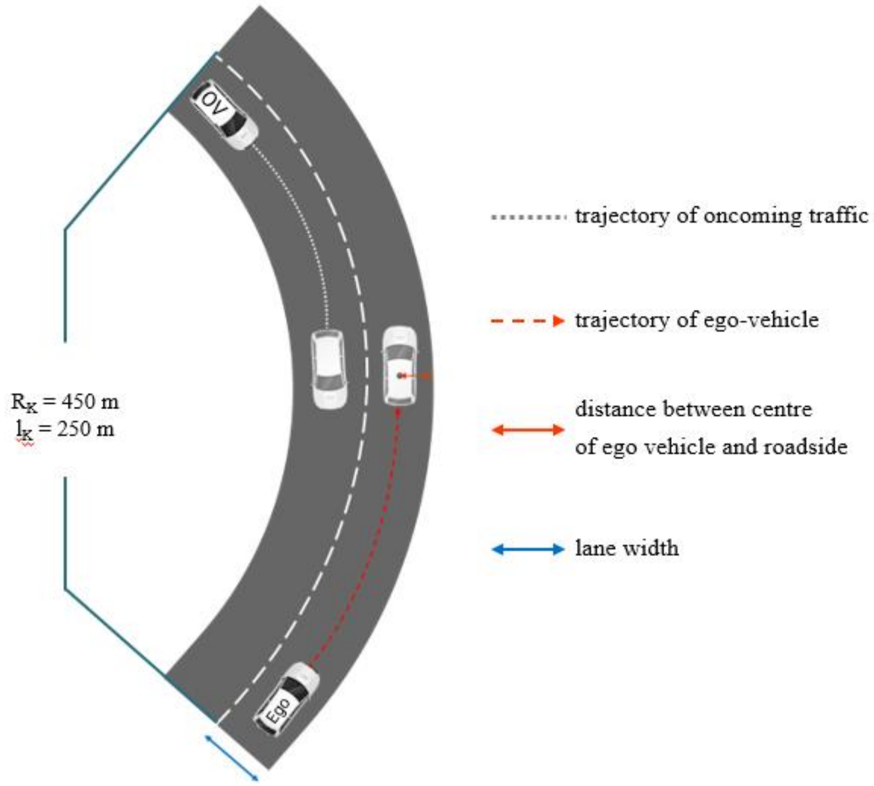

Figure 3. Measures in oncoming traffic scenario. OV = Oncoming vehicle, Ego = Ego vehicle.

Left curves

Without oncoming traffic, a similar behaviour for both lane widths can be observed. Participants enter the curve with a lateral shift to the road side. This represents a typical curve cutting manoeuvre. When passing the curve, participants increase the lateral distance to the roadside and reduce the distance to the road centre until section 9. In section 10, the opposite behaviour is shown, because participants prepared to drive out of the curve into the straight section. With oncoming traffic, a different behaviour can be determined. Between section 2 and 8 on about 150 m driven, a relocation of the trajectory in reaction to the oncoming traffic is performed. Lateral position differs most in section 5, which is the planned meeting point with the oncoming vehicles. On the lane width condition 3.00 m, lateral position without oncoming traffic differs 0.45 m from the truck and 0.27 m from the car scenario. On the lane width condition 3.50 m, participants show smaller reactions. The differences in lateral position without oncoming traffic is 0.37 m to trucks and 0.21 m to cars.

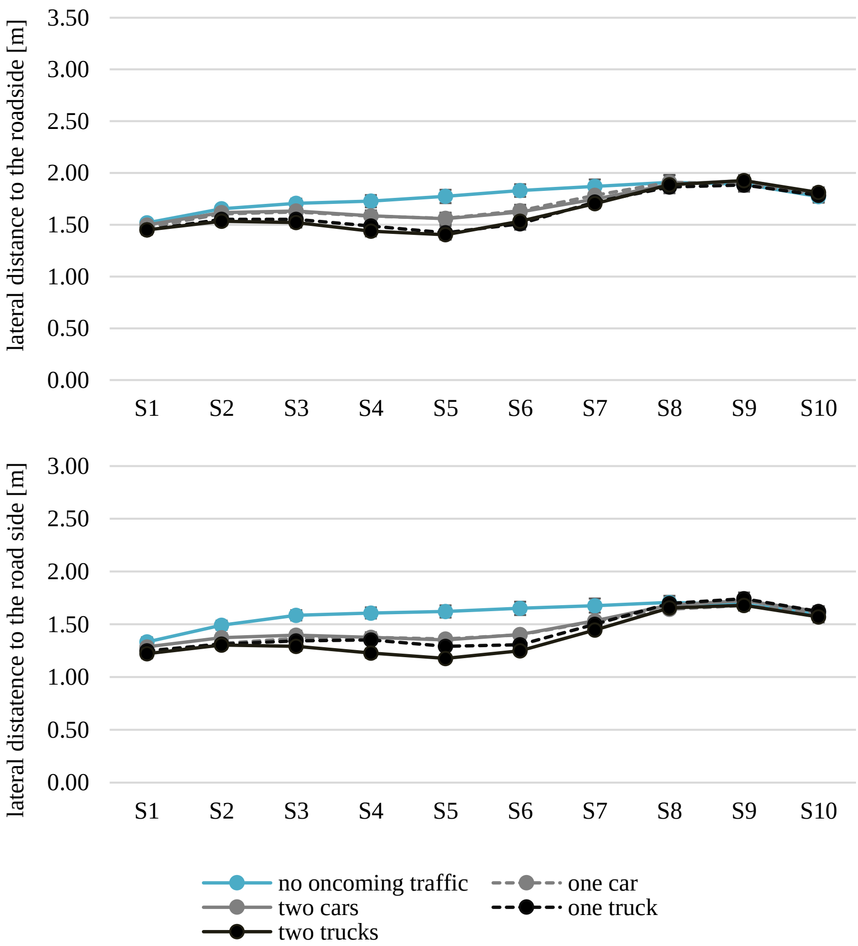

Figure 4. Mean values of lateral distance to the road side for each section in left curves

In addition, it was examined whether the between-subject factor lane width has an influence on the participant's driving behaviour. Using the rmANOVA with between-subject factor, the the lane width can be verified as an influencing factor ($F (1, 44) = 17.17$, $p < .001$, $\eta_p^2 = .28$). A post-hoc analysis according to Bonferroni also showed that the lane behaviour in the curve without oncoming traffic differed significantly from all other traffic situations ($p < .001$). The situation of oncoming traffic with one car dif-fered significantly from the scenario with two oncoming trucks ($p <.001$). The situa-tion with two oncoming cars in comparison to one oncoming truck ($p = .01$) and two oncoming trucks ($p < .001$) have significantly larger distances to the roadside. All oncoming traffic situations compared with one oncoming truck showed no significant difference ($p = .29$).

Right curves

Without oncoming traffic, a similar behaviour for both lane widths can be observed. Participants entre the curve with a lateral shift to the road centre. Again, this represents a typical curve cutting manoeuvre When passing the curve, test participants decrease the lateral distance to the roadside und increase the distance to the road centre until Section 8. In section 9 and 10, the opposite behaviour is conducted, because participants prepared to drive out of the curve into the straight section.

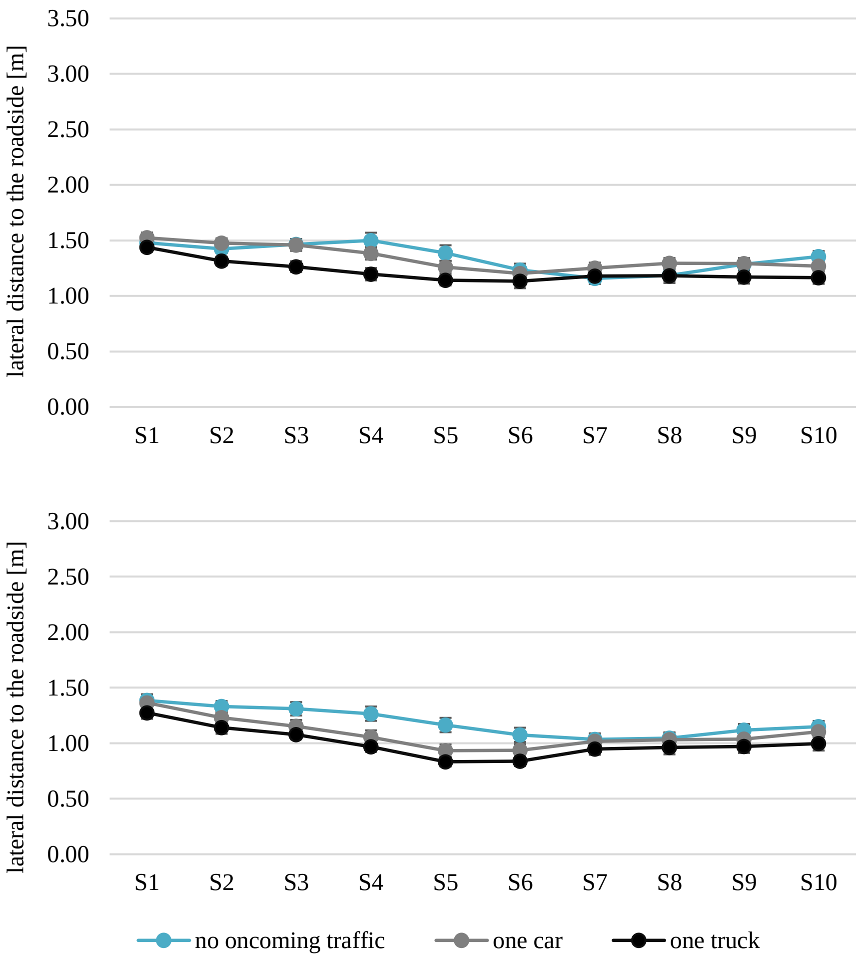

Figure 5. Mean values of lateral distance to the road side for each section in right curves

With oncoming traffic, a different behaviour can be determined. Between section 2 and 7 on about 125 m driven, a relocation of the trajectory because of the oncoming traffic is performed. As seen in left curves, lateral position differs most in section 4 respectively 5, which is the planned meeting point with the oncoming vehicles. On the lane width condition 3.00 m, lateral position without oncoming traffic differs 0.33 m from the truck and 0.23 m from the car scenario. On the lane width condition 3.50 m, participants show smaller reactions. The differences in lateral position without oncoming traffic is 0.25 m to trucks and 0.13 m to cars.

As for the left curves, the factors oncoming traffic ($F(2, 88) = 29.92$, $p < .001$, $\eta_p^2 = .41$) and the position in the curve ($F(3.76, 166.11) = 25.18$, $p < .001$, $\eta_p^2 = .36$) were identified as significant main effects. The lane width also led to significantly different lateral distances ($F(1, 44) = 25.17$, $p < .001$, $\eta_p^2 = .36$). The post-hoc analysis according to Bonferroni showed that the type of oncoming traffic differs for each one (no oncoming traffic vs. car $p < .05$, no oncoming traffic vs. truck $p < .001$, car vs. truck $p < .001$).

Conclusion and outlook

The aim of this study was to gain more knowledge on manual driving to implement better reactive trajectories that include less negative side effects, e.g. passing oncoming traffic with too small distances to the OV or to the road side, and that lead to a better driving experience. The use of manual drivers' trajectories as basis for implementing highly automated driving trajectories shows high potential to increase perceived safety on straights and curves (Rossner & Bullinger 2019; Rossner & Bullinger 2020a; Rossner & Bullinger 2020b; Rossner et al. 2021). Results of the study show in left curves without oncoming traffic, that participants gradually increase the lateral distance to the roadside. This indicates that the participants try to reduce the curve radius and minimize centrifugal forces that would potentially occur in a real world driving environment (Spacek 2005; Schlag & Voigt, 2015). Participants then show the opposite lateral behavior in right curves, but the strategy of passing the curve follows the same scheme. When considering the oncoming traffic situations, a distinction can be made with regard to the type of oncoming traffic. In both curve types and on both lane widths, significant differences in lateral position are found comparing none oncoming traffic, oncoming cars and oncoming trucks. When meeting a car, the lateral safety distance should be increased by moving about 0.20 m to the roadside based on the trajectory without oncoming traffic. If the oncoming vehicle is a truck, the safety distance should be increased by about 0.35 m to the roadside based on the trajectory without oncoming traffic. In contrast to this, the number of oncoming vehicles has no significant effect on the reaction of the participants. It is found that the car situations (one car vs. two cars) and truck situations (one truck vs. two trucks) do not differ significantly from one another. These results amplify the need of adaptive trajectories for highly automated vehicles to generate a positive driving experience and, therefore, higher acceptance rates of highly automated vehicles (Siebert, 2013; Hartwich et al., 2015). In all use cases, a safe driving performace has to be guaranteed during the whole drive. The overall safety Finally, the limitations of studies in fixed-based driving simulators depict the transfer of the results to real world driving situations. Bella (2009) arguments that specific use cases can be researched and various parameters (e.g. speed, lateral distance, angle of the brake pedal) can be recorded in driving simulator studies. Of course, no movement forces are perceptible, but the visual impression has a great influence on the perception of the oncoming traffic situations and the perceived lateral distances. Curves with a radius of 450 m and a length of 250 m can be passed safely with 100 km/h, so that the absence of movement forces is not that important. Nevertheless, it is very recommeded to conduct a similar study in a real world environment. The results also cover only a small part of the existing use cases. Other factors, such as meeting oncoming traffic at the beginning respectively the end of the curve, curves with additional horizontal course or the influence of additional traffic on the ego vehicle's lane are further topics to be investigated.

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Reference

Banks, V.A., & Stanton, N.A. (2015). Keep the driver in control: Automating automobiles of the future. *Applied Ergonomics*, *53B*, 389-395. https://doi.org/10.1016/j.apergo.2015.06.020

Bella, F. (2005). Speeds and Lateral Placements on Two-Lane Rural Roads: Analysis at the Driving Simulator. In 13th International Conference "Road Safety on Four Continents".

Bella, F. (2009). Can Driving Simulators Contribute to Solving Critical Issues in Geometric Design? *Transportation Research Record*: Journal of the Transportation Research Board, 2138, 120–126. https://doi.org/10.3141/2138-16.

Bella, F. (2013). Driver perception of roadside configurations on two-lane rural roads: Ef-fects on speed and lateral placement. *Accident Analysis and Prevention, 50*, 251–262. https://doi.org/10.1016/j.aap.2012.04.015.

Bellem, H., Schönenberg, T., Krems, J.F., & Schrauf, M. (2016). Objective metrics of comfort: Developing a driving style for highly automated vehicles. *Transportation Research Part F: Traffic Psychology and Behaviour*, *41*, 45-54 .

Bellem, H., Klüver, M., Schrauf, M., Schöner, H.-P., Hecht, H. & Krems, J.F. (2017). Can We Study Autonomous Driving Comfort in Moving-Base Driving Simulators? A Validation Study. *Human Factors, 59*, 442–456. doi:10.1177/0018720816682647.

Dettmann, A., Hartwich, F., Roßner, P., Beggiato, M., Felbel, K., Krems, J., & Bullinger, A.C. (2021). Comfort or not? Automated Driving Style and User Characteristics Causing Human Discomfort in Automated Driving. *International Journal of Human–Computer Interaction*, *4*, 331–339. https://doi.org/10.1080/10447318.2020.1860518.

Dijksterhuis, C., Stuiver, A., Mulder, B., Brookhuis, K.A. & de Waard, D (2012).: An adaptive driver support system: user experiences and driving performance in a simulator. *Human Factors, 54*, 772–785. https://doi.org/10.1177/0018720811430502.

Elbanhawi, M., Simic, M., & Jazar, R. (2015). In the Passenger Seat: Investigating Ride Comfort Measures in Autonomous Cars. *IEEE Intelligent Transportation Systems Magazine, 7(3)*, 4–17. https://doi.org/ 10.1109/MITS.2015. 2405571.

Festner, M., Baumann, H., & Schramm, D. (2016). Der Einfluss fahrfremder Tätigkeiten und Manöverlängsdynamik auf die Komfort- und Sicherheitswahrnehmung beim hochautomatisier-ten Fahren. 32nd VDI/VW- Gemeinschaftstagung Fahrerassistenz und automatisiertes Fahren, Wolfsburg.

Gasser, T.M. (2013). Herausforderung automatischen Fahrens und Forschungs-schwerpunkte. 6. Tagung Fahrerassistenz, München.

Griesche, S., Nicolay, E., Assmann, D., Dotzauer, M., & Käthner, D.:(2016). "Should my car drive as I do? What kind of driving style do drivers prefer for the design of automated driving func-tions?" Contribution to 17th Braunschweiger Symposium Automatisierungssysteme, Assis-tenzsysteme und eingebettete Systeme für Transportmittel (AAET), ITS automotive nord e.V., pp. 185-204, ISBN 978-3-937655-37-6.

Hartwich, F., Beggiato, M., Dettmann, A., & Krems, J.F.(2015). Drive me comfortable: Custom-ized automated driving styles for younger and older drivers. 8. VDI-Tagung „Der Fahrer im 21. Jahrhundert".

Köhler, B. (2017). *Auswirkungen der Wahrnehmung von Markierungskonstellationen auf das Fahrverhalten in Arbeitsstellen auf Bundesautobahnen*. Dissertation, Karlsruher Instituts für Technologie. Karlsruhe, Germany.

Leutzbach, W., Maier, W. & Döhler, M. (1981): Untersuchung des Spurverhaltens von Kraftfahrzeugen auf Landstraßen durch Verfolgungsfahrten. Forschungsgesellschaft für Straßen und Verkehrswesen. Straße und Autobahn, Heft 8.

Lex, C., Schabauer, M., Semmer, M., Magosi, Z., Eichberger, A., Koglbauer I., Holzinger, J. & Schlömicher, T. (2017). Objektive Erfassung und subjektive Bewertung menschlicher Trajek-toriewahl in einer Naturalistic Driving Study. VDI-Berichte Nr. 2311, pp. 177-192.

Mecheri, S., Rosey, F., & Lobjois, R. (2017). The effects of lane width, shoulder width, and road cross-sectional reallocation on drivers' behavioral adaptations. *Accident Analysis and Prevention, 104*, 65–73. https://doi.org/10.1016/j.aap.2017.04.019.

Radlmayr, J., & Bengler, K. (2015) Literaturanalyse und Methodenauswahl zur Gestaltung von Systemen zum hochautomatisierten Fahren. FAT-Schriftenreihe, vol. 276. VDA, Berlin.

Räsänen, M. (2005). Effects of a rumble strip barrier line on lane keeping in a curve. *Accident Analysis and Prevention, 37*, 575–581. https://doi.org/10.1016/j.aap.2005.02.001.

Rosey, F., Auberlet, J.-M., Moisan, O. & Dupré, G. (2009). Impact of Narrower Lane Width: Comparison Between Fixed-Base Simulator and Real Data.

Transportation Research Record: Journal of the Transportation. Research Board, 2138(1), 112–119. https://doi.org/10.3141/2138-15.

Rossner, P. & Bullinger, A.C.: Drive me naturally: Design and evaluation of trajectories for highly automated driving manoeuvres on rural roads. Technology for an Ageing Society, Postersession Human Factors and Ergonomics Society Europe Chapter 2018 Annual Conference, Berlin (2018). https://www.hfes-europe.org/posters-2018/

Rossner P. & Bullinger A.C. (2019) Do You Shift or Not? Influence of Trajectory Behaviour on Perceived Safety During Automated Driving on Rural Roads. In: Krömker H. (eds) HCI in Mobility, Transport, and Automotive Systems. HCII 2019. Lecture Notes in Computer Science, vol 11596. Springer, Cham.

Rossner P. & Bullinger A.C. (2020a). Does driving experience matter? Influence of trajectory behaviour on drivers' trust, acceptance and perceived safety in automated driving. Understanding Human Behaviour in Complex Systems, In D. de Waard, A. Toffetti, L. Pietrantoni, T. Franke, J-F. Petiot, C. Dumas, A. Botzer, L. Onnasch, I. Milleville, and F. Mars (2020). Proceedings of the Human Factors and Ergonomics Society Europe Chapter 2019 Annual Conference, pp 73-84. https://www.hfes-europe.org/understanding-human-behaviour-complex-systems/ ISSN 2333-4959.

Rossner P. & Bullinger A.C. (2020b) I Care Who and Where You Are – Influence of Type, Position and Quantity of Oncoming Vehicles on Perceived Safety During Automated Driving on Rural Roads. In Krömker H. (Ed.) HCI in Mobility, Transport, and Automotive Sys-tems. Driving Behavior, Urban and Smart Mobility. HCII 2020. Lecture Notes in Computer Science, vol 12213. Springer, Cham. https://doi.org/10.1007/978-3-030-50537-0_6.

Rossner, Friedrich, & Bullinger (2021). Hitting the Apex Highly Automated? – Influence of Trajectory Behaviour on Perceived Safety in Curves. In: HCI International 2021 - Late Breaking Papers: HCI Applications in Health, Transport, and Industry: 23rd HCI International Conference, HCII 2021, Virtual Event, July 24–29 2021, Proceedings, pp. 322–331. https://doi.org/10.1007/978-3-030-90966-6_23.

Schlag, B., & Voigt, J. (2015) Auswirkungen von Querschnittsgestaltung und längsgerichteten Markierungen auf das Fahrverhalten auf Landstrassen. Berichte der Bundesanstalt für Straßenwesen. Unterreihe Verkehrstechnik, (249).

Siebert, F., Oehl, M., Höger, R., & Pfister, H.R. (2013). Discomfort in Automated Driving – The Disco-Scale. In: Proceedings of HCI International 2013, Communications in Computer and Information Science, vol. 374, pp. 337-341, Las Vegas, USA.

Spacek, P. (1999). Fahrverhalten und Unfälle in Kurven - Fahrverhalten in Kurvenbereichen (Straßenverkehrstechnik, Bd. 2). Zürich: VSS. Available at https://books.google.de/books?id=rCD1HgAACAAJ.

Spacek, P. (2005). Track Behavior in Curve Areas: Attempt at Typology. *Journal of Transportation Engineering, 131*, 669–676. https://doi.org/10. 1061/(ASCE)0733-947X(2005)131:9(669).

Triggs, T.J. (1997). The Effect of Approaching Vehicles on the Lateral Position of Cars Travelling on a Twolane Rural Road. *Australian Psychologist, 32(3)*, 159–163. https://doi.org/10.1080/00050069708257375.

Vetters, A. (2012). Die neuen "Richtlinien für die Anlage von Landstraßen" RAL - Stand 2012. Zugriff am 28.10.2019. Verfügbar unter http://www.vsvi-mv.de/fileadmin/Medienpool/Seminarunterlagen/Seminare_2012/Vortrag_1_-_neue_RAL_Frau_Vetters.pdf.

Voß, G. & Schwalm, M. (2017). Bedeutung kompensativer Fahrerstrategien im Kontext automatisierter Fahrfunktionen. Berichte der Bundesanstalt für Straßenwesen, *Fahrzeugtechnik Heft F 118*, ISBN 978-3-95606-327-5.