Comparing accepted gaps in traffic flow for conducting left turn actions in different intersection scenarios – A driving simulator study

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Abstract

Automated vehicles (AVs) are required to interact predictably and intuitively with conventional road users to support traffic safety and efficiency. This might be achieved by implementing established interaction capabilities of manual drivers in AVs. When coordinating interactions, drivers anticipate the development of driving scenes and adapt own manoeuvres by selecting specific gaps in traffic flow (gap acceptance, GA) to provide adequate safety margins to surrounding road users. Therefore, the current driving simulator study aimed at deriving manual drivers' GA for conducting left turn manoeuvres at intersections as a basis for AVs' driving functions. Thus, two intersection scenarios including interaction vehicles (approach trajectories from the left vs. head-on trajectories from the ego-vehicle's perspective) encountering with two different speed levels (30 km/h vs. 50 km/h) were investigated by a within-subject design including $N = 28$ participants. The results revealed that smaller time gaps were selected at higher approach speeds and when the interaction vehicles encountered the intersection from the left of the ego-vehicle's perspective. The findings imply that there is no one unique time gap value for conducting turning manoeuvres. Rather, drivers seem to consider the speed of approaching vehicles and thus anticipate resulting safety margins to surrounding traffic participants as well as specific required temporal durations for conducting turning manoeuvres in different intersection scenarios. The revealed gaps could provide a basis for intuitive driving functions of AVs in such scenarios.

Introduction

Road traffic represents a social system requiring interactions between different traffic participants (Domeyer et al., 2020). Since there has been a steady increase of automated driving functions in recent years, facilitating for enhanced road safety, traffic efficiency, driving comfort and accessibility (ERTRAC, 2017), vehicles of different levels of automation will share the road in the near future (Litman, 2017). For this, transparent and efficient coordination of actions are required in mixed traffic, comprising conventional traffic participants and automated vehicles (AVs, i.e., SAE Level 3 or higher; SAE, 2018).

To prevent from breakdowns of interaction processes ensuring safe and efficient encounters, drivers are required to obtain adequate Situation Awareness (SA) of the driving environment (Endsley, 1995; Krems & Baumann, 2009). According to

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Endsley (1995), the concept is described as “knowing what is going on” (Endsley, 1995; p. 36) and comprises three levels: the perception of relevant elements of a situation, the integration and comprehension of their meaning as well as the prediction and anticipation of futures states of the respective situation (Endsley, 1995). The capabilities of predicting and anticipating future states of driving scenes and prospective movements of surrounding road users enable drivers for a proactive behaviour by adapting own manoeuvres and thus ensure smooth encounters (Endsley, 1995; Stahl et al., 2014). Due to potentially conflicting trajectories of the involved road users, coordinating and anticipating driving actions is highly important in intersection scenarios (Hancock et al., 1991; Wilbrink et al., 2018). Since these manoeuvres cause a higher mental load of drivers compared to straight driving, potentially leading to an increased accident rate (Hancock et al., 1989), automated turning actions might foster traffic safety and efficiency.

To support the involved traffic participants in achieving adequate SA, AVs’ driving behaviour needs to be transparent and predictable (Habibovic et al., 2018). Therefore, established and intuitive interaction capabilities should be implemented in AVs’ driving functions (Schieben et al., 2019) to provide a common ground when coordinating actions, comprising mutual knowledge and assumptions about interactions (Clark & Brennan, 1991). Specific parameters of manual driving might be derived and applied as a basic orientation for AVs’ driving functions. However, to provide intuitive and expectable interactions in mixed traffic, AVs are required to consider diverse influencing factors when conducting driving manoeuvres comparable to human drivers (Beggiato et al., 2018; Stange et al., 2022). Thus, potentially influencing factors and their particular impact on driving parameters need to be further investigated.

When coordinating actions, drivers mainly apply temporal and spatial thresholds to surrounding traffic participants (Gibson & Crooks, 1938; Hall, 1969; Summala, 2007). These thresholds describe drivers’ individual gap acceptance behaviour (GA; Summala, 2007). Previous research showed that drivers’ GA was influenced by various factors, such as the approach speed of encountering traffic (e.g., Hancock et al., 1991). A stable effect was reported for approach speed on GA, particularly resulting in smaller accepted time gaps when initiating driving manoeuvres during higher speeds of encountering traffic participants (e.g., Hancock et al., 1991; Petzoldt et al., 2017). The effect was shown for different approach speeds (e.g., Schleinitz et al., 2019), diverse encountering interaction partners (Hensch et al., 2021) and from various perspectives (e.g., for a pedestrians’ perspective see Beggiato et al., 2018; for a drivers’ perspective see Hensch et al., 2023). Besides situational factors, drivers might also consider infrastructural conditions and anticipate required manoeuvres and resulting temporal durations to provide sufficient thresholds of space and time to surrounding road users. Thus, different intersection scenarios and anticipated driving manoeuvres might have an impact on GA, since these scenarios are considered as highly relevant for coordinating actions (Wilbrink et al., 2018). For instance, Avsar et al. (2021) investigated accepted gaps in traffic flow in a driving simulator study. The authors reported more accepted gaps for left turn manoeuvres at intersections when the interaction vehicles approached the ego-vehicle’s perspective from the left compared to head-on approach trajectories of the interaction vehicles. In contrast,

Petzoldt et al. (2017) found no effect of intersection scenarios on drivers' GA for left turn manoeuvres in their test track study. Thus, it seems reasonable to investigate the influence of intersection scenarios and specifically anticipated manoeuvres on drivers' GA for left turn actions in closer detail.

Objectives of the study

The current study aimed at investigating manual drivers' accepted time gaps in traffic flow for conducting left turn manoeuvres at intersections. The quantified GA parameters could provide information about influencing factors on manoeuvring decisions for intuitive interactions. Therefore, the derived time gap values of manual drivers might be used as a basic orientation for AVs' driving functions in these scenarios, particularly as accepted time ranges for initiating automated turning manoeuvres, to support transparent and predictable interactions in mixed traffic. The influence of the approach speed of encountering interaction vehicles was manipulated (i.e., 30 km/h vs. 50 km/h) within the current study. Two different intersections, requiring left turn manoeuvres, were also considered in the study, since the coordination of actions between different traffic participants is particularly important in these scenarios.

Method

Research Design

The present driving simulator study investigated participants' GA in traffic flow for conducting left turn manoeuvres in two different intersection scenarios. A 2x2x2 within-subject design was applied. In particular, two approach speeds of the interaction vehicles (30 km/h vs. 50 km/h) and two intersection scenarios (Figure 1) were investigated. Each condition was repeated twice to stabilize the results. Participants' accepted gaps served as dependent variable.

Apparatus and Material

The study was conducted in a fixed-based driving simulator comprising a mock-up including adjustable seats, steering wheel, speedometer, brake, accelerator pedal for vehicle control, rear and side mirrors. The simulation of the urban environment including the investigated intersection scenarios was programmed in SILAB 7.0 (WIVW, 2021). The driving scenery was projected with a resolution of 7680x1600 pixels by three projectors at 180° field view. Participants' driving behaviour was logged with a sampling frequency of 60 Hz.

The simulation included eight urban T-intersections comprising two different scenarios (Figure 1), which were presented in a balanced order. Both implemented scenarios required the participants in the ego-vehicle to conduct left turn manoeuvres and thus crossing the path of the approaching interaction vehicle stream (i.e., exclusively passenger cars due to controlling for influencing factors, such as vehicles size on GA; Hancock et al., 1991). In scenario 1, the ego-vehicle was required to turn from a side road into a main road and the interaction vehicles approached from the left of the ego-vehicle's perspective (Figure 1a). Whereas, in scenario 2, the ego-vehicle was located on a main road and the interaction vehicles encountered the intersection with head-on

approach trajectories from the ego-vehicle's perspective (Figure 1b). Thus, different routes of the ego-vehicle were required despite conducting left turn manoeuvres in both scenarios. When approaching the intersections, the ego-vehicle always needed to give priority to the interaction vehicles demanding a full stop and a subsequent start from standstill. The interaction vehicles encountered the intersections with an approach speed of either 30 km/h or 50 km/h respectively, which was varied per intersection. The gaps within the approaching interaction vehicle stream increased ascendingly (i.e., one additional second per gap). When the oncoming vehicles approached with 30 km/h, gaps in traffic flow up to 10 seconds were presented and gaps up to 12 seconds were presented at 50 km/h approach speed. The maximum gaps were deduced from previous online studies of the authors that examined comparable scenarios (Hensch et al., 2021; Hensch et al., 2022). Road signs were placed at the intersections to remind participants of the instructed left turn manoeuvres. To provide a conventional driving experience and reduce the risk of simulator sickness, straight route parts were included in the simulation between the investigated intersection scenarios.

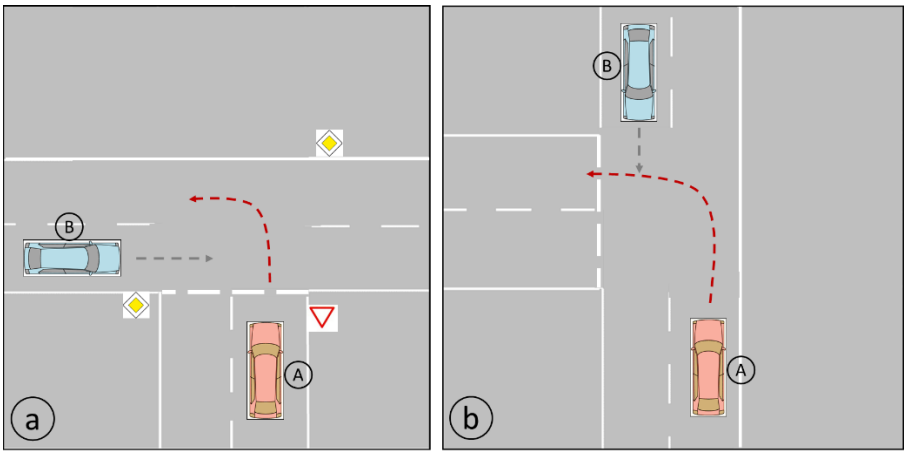

Figure 1. Intersection scenarios of the simulator drive requiring the ego-vehicle (A) for accepting gaps within traffic flow (B) and thus conducting left turn manoeuvres. a) Scenario 1: The ego-vehicle was required to turn from a side road into a main road while the interaction vehicles approached the intersection from the left of the ego-vehicle's perspective. b) Scenario 2: The ego-vehicle was located on a main road while the interaction vehicles encountered the intersection with head-on approach trajectories from the ego-vehicle's perspective.

Procedure

Since drivers' GA was investigated within the current study, holding a valid driver's licence was a precondition for participating to the study. At first, participants were welcomed, general information was provided and informed consent was obtained. Then, sociodemographic data were collected. In the subsequent simulator drive, participants' accepted gaps in traffic flow for conducting left turn manoeuvres at intersections were collected. The participants were instructed to conduct left turn manoeuvres at the smallest gaps they still perceived as comfortable. To familiarize the participants with the simulation environment and the vehicle guidance particularly

when conducting turning manoeuvres at intersection, a test drive was conducted. Afterwards, drivers' GA was collected in a drive that included eight urban intersection scenarios, presented in a balanced order. At the end, participants received a monetary compensation of €25 for contributing to the study.

Participants

Overall, $N = 41$ participants contributed to the study. However, $n = 12$ participants had to be excluded from data analysis due to simulator sickness. Moreover, $n = 1$ participant did not accept any of the presented gaps, which did not allow a calculation of mean accepted time gaps for conducting turning manoeuvres in traffic flow. All participants of the remaining sample of $n = 28$ participants ($M = 34$ years, $SD = 14.54$) held a valid driving licence ($M = 15.88$ years, $SD = 13.33$) and reported a mean annual mileage of $M = 12588.75$ km ($SD = 13654.77$).

Data preparation and analysis

Participants' mean accepted gaps in traffic flow when conducting left turn manoeuvres in the examined intersection scenarios were calculated according to Lobjois et al. (2013) and Petzoldt (2014), who applied comparable approaches when investigating pedestrians' gap selection during road crossing actions. Logistic regressions with binary outcomes (i.e., yes/no response for accepting a specific gap in traffic flow) were calculated to consider for varying decision patterns to accept or reject gaps, since participants not always showed a consistent decision behaviour (Petzoldt, 2014). Four individual regression models were calculated per participant (one per approach speed condition of 30 km/h vs. 50 km/h; one per intersection scenario namely scenario 1 vs. scenario 2, respectively). The individual regression models predicted the probability that a gap in traffic flow was accepted for conducting a turning manoeuvre (i.e., yes response for accepting a specific gap) for each participant. The respective transition points of the individual regression models (i.e., 50% probability of accepting a specific gap) were defined as the mean GA for each participant and per condition and were used for further analysis (Lobjois et al., 2013; Petzoldt, 2014). As an indicator of model fit, mean Nagelkerke's R^2 are reported for the calculated regression models (Nagelkerke, 1991).

Results

The calculated individual regression models for each participant per speed level of the approaching traffic (mean Nagelkerke's $R^2_{30\ km/h} = .92$; mean Nagelkerke's $R^2_{50\ km/h} = .96$) and per scenario (mean Nagelkerke's $R^2_{scenario\ 1} = .93$; mean Nagelkerke's $R^2_{scenario\ 2} = .95$) are plotted in Figure 2. In particular, participants accepted smaller gaps in traffic flow when conducting turning manoeuvres at higher speeds of approaching vehicles. This is also depicted in Figure 2 were the individual regression models are distributed closer towards the y-axis when the interaction vehicles approached the intersection with 50 km/h compared to 30 km/h. This difference can be also found when comparing the mean accepted time gaps ($M_{30km/h} = 6.13$s, $SD_{30km/h} = 1.56$; $M_{50km/h} = 5.60$s, $SD_{50km/h} = 1.14$; Figure 3). Moreover, smaller time gaps were accepted for conducting turning manoeuvres in scenario 1 compared to scenario 2, which is also displayed in Figure 2. In detail, the individual regression models of scenario 1 are somewhat distributed closer towards

the y-axis compared to the regression models of scenario 2. This difference is also shown when comparing the mean accepted time gap values for the scenarios ($M_{\text{scenario 1}}$ = 5.60s, $SD_{\text{scenario 1}}$ = 1.40; $M_{\text{scenario 2}}$ = 6.13s, $SD_{\text{scenario 2}}$ = 1.43; Figure 3). According to the 2 (approach speed) x 2 (scenario) repeated measures ANOVA, the differences in mean accepted time gaps were revealed to be statistically significant for both factors, approach speed ($F(1,27) = 17.80$, $p < .001$, $\eta^2_p = .397$) and scenario ($F(1,27) = 7.67$, $p = .009$, $\eta^2_p = .228$). Additionally, a significant interaction effect for approach speed x scenario was found ($F(1,27) = 11.80$, $p = .002$, $\eta^2_p = .304$).

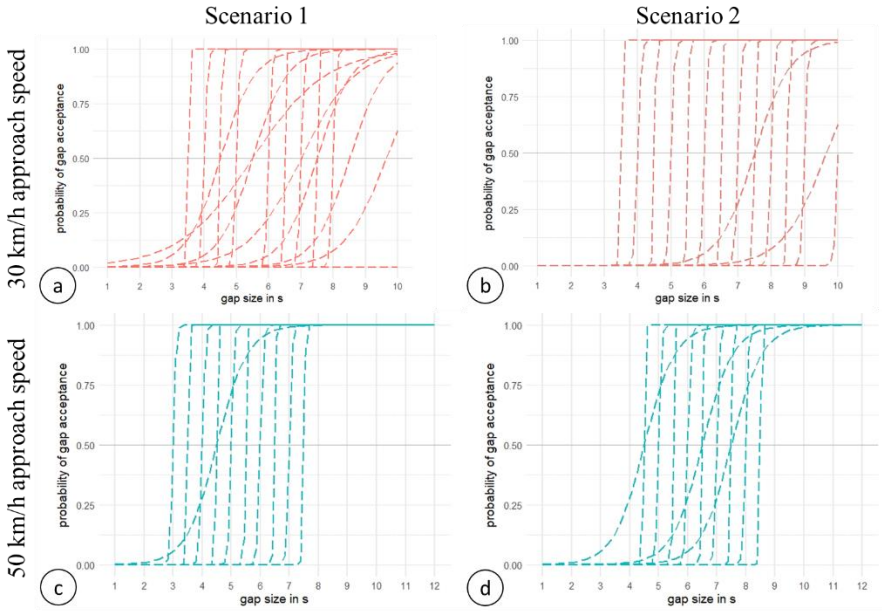

Figure 2. Individual regression models for participants' GA for a) scenario 1 and b) scenario 2 with an approach speed of 30 km/h of the interaction vehicles; and c) scenario 1 and d) scenario 2 with an approach speed of 50 km/h of the interaction vehicles. The individual regression models might overlap due to similar decision patterns of different participants (i.e., accepted and rejected gaps in traffic flow). The solid horizontal lines in the respective graphs highlight the transition points of the individual regression models (i.e., 50% probability of accepting a gap).

Discussion

The present driving simulator study aimed at investigating and quantifying manual drivers' GA when conducting left turn manoeuvres with approaching traffic in different intersection scenarios. The derived gaps could be used as a basic orientation for transparent and intuitive driving functions in AVs, specifically as accepted time ranges for initiating automated turning manoeuvres at intersections (for comparable approaches see Beggiato et al., 2018; Stange et al., 2022). The results showed that there is no one unique time gap value that is always considered as appropriate when conducting left turn manoeuvres at intersections. Rather, drivers' decisions for selecting a gap in traffic flow was influenced by the approach speed of the

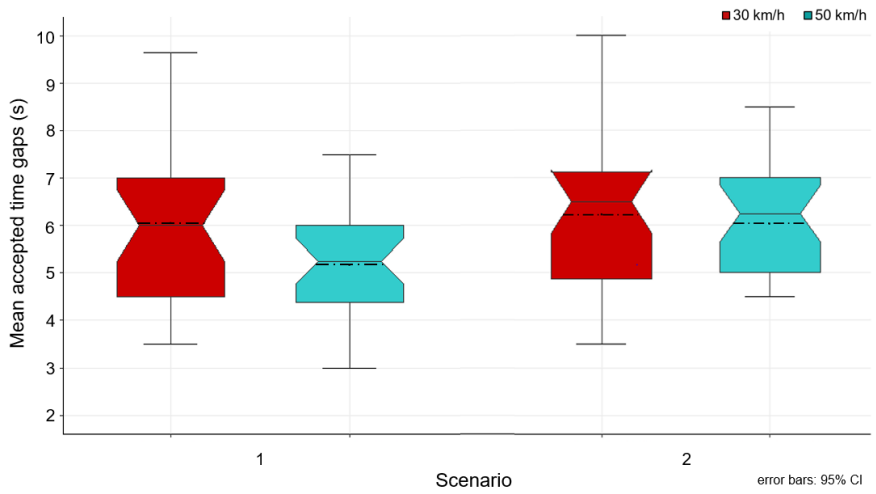

Figure 3. Boxplots of mean GA (in seconds) by investigated scenarios (1 = ego-vehicle required to turn from a side road into a main road while the interaction vehicles approached from the left of the ego-vehicle's perspective; 2 = ego-vehicle located on a main road while the interaction vehicles encountered with head-on approach trajectories from the ego-vehicle's perspective; see Figure 1) and approach speed of encountering vehicles. The boxes represent the mean 50% of GA values, the lower whiskers represent the minimum GA values, the upper whiskers the maximum GA values that were selected respectively. The solid line within the boxes displays the median value, the dashed line the mean value for the respective condition.

encountering vehicles. Moreover, GA differed between the investigated intersection scenarios.

The approach speed of the encountering interaction vehicles was shown to influence drivers' GA in traffic flow when conducting left turn manoeuvres at intersections. In particular, smaller time gaps were accepted at higher speeds of the approaching vehicles. The results corroborate previous studies that also reported smaller GA at higher speeds of encountering interaction partners (Hancock et al., 1991; Petzoldt et al., 2017). The findings might be explained by the approach that drivers rather rely on spatial distances when selecting gaps in traffic flow than on time-to-arrival estimates when initiating driving manoeuvres (Law et al., 1993). To provide an intuitive interaction behaviour in mixed traffic, the results imply that AVs need to consider the speed of the approaching traffic when selecting gaps in traffic flow for left turn manoeuvres (Hensch et al., 2023).

In addition, the intersection scenario itself also affected drivers' GA. In detail, smaller GA for conducting left turn manoeuvres was revealed when the interaction vehicles approached the ego-vehicle from the left (i.e., scenario 1) compared with head-on trajectories of the interaction vehicles (i.e., scenario 2). The findings are in line with Avsar et al. (2021). The authors reported more accepted gaps in intersection scenarios were the interaction vehicles encountered from the left of the ego-vehicle's perspective (comparable with scenario 1 of the current study) in contrast to intersection scenarios were the interaction traffic approached from the opposite

direction of the ego-vehicle's perspective (comparable with scenario 2 of the current study; Avsar et al., 2021). The results of the current study might be explained by larger distances for passing the encountering interaction vehicles in scenario 2 compared to scenario 1 (i.e., passing the potential point of collision to prevent accidents). Therefore, the findings indicate that drivers anticipate specific route distances and thus temporal durations that are required to execute prospective manoeuvres. Specifically, drivers seem to anticipate varieties in route distances and thus resulting differences considering temporal durations for passing the potential point of collision during turning manoeuvres at intersections with encountering interaction traffic. This could have influenced GA parameters to provide sufficient time and space to surrounding traffic participants (Gibson & Crooks, 1938; Summala, 2007). Thus, AVs should also be enabled to consider specific route distances and thus required manoeuvre durations for conducting driving actions when selecting gaps in traffic flow and therefore support smooth interactions with other road users. However, the results might be also explained by the observers' perspective on the approaching traffic (Petzoldt et al., 2017). This might have led to more accurate time-to-arrival estimates due to the viewing angle on the approaching interaction vehicles (i.e., from the left of the observers' perspective) resulting in smaller GA for scenario 1 and more conservative decisions in GA due to the frontal view in scenario 2 (Schiff & Oldak, 1990).

It should be mentioned that the current driving simulator study merely investigated left turn scenarios including interaction vehicles from one specific direction to achieve standardized conditions. To receive a comprehensive understanding of human drivers' interaction behaviour in road traffic, future studies should investigate further interaction partners and driving parameters besides GA (e.g., acceleration behaviour; Bellem et al., 2018). Additional factors, such as different age groups and their impact on the specific driving parameter of GA, should be also quantified in future driving simulator studies (as investigated for deceleration behaviour e.g., by de Haan et al., 2022). Moreover, perspectives of other road users, such as pedestrians during crossing actions, need to be considered to receive an extensive understanding of human users' interaction behaviour in road traffic (e.g., Beggiato et al., 2018).

Conclusion

For smooth interactions, drivers anticipate required temporal durations for their prospective manoeuvres and the development of driving scenes (Stahl et al., 2014). Coordinating actions is particularly relevant at intersections due to potentially conflicting trajectories of involved road users (Hancock et al., 1991; Wilbrink, 2018). Therefore, drivers adapt their own manoeuvres accordingly to provide sufficient safety margins to surrounding road users (Gibson & Crooks, 1938; Summala, 2007). To support intuitive encounters in mixed traffic, established interaction capabilities from manual drivers could be used as a basic orientation for AVs' driving functions (Beggiato et al., 2018; Stange et al., 2022). With regard to GA as one specific driving parameter, the results of the current driving simulator study imply that there is no one unique time gap value for conducting left turn manoeuvres at intersections in traffic flow. In fact, the speed of approaching interaction vehicles and the particular traffic scenario influenced drivers' accepted gaps. Drivers seem to consider infrastructural

conditions, contextual factors, anticipate particular manoeuvres and thus resulting routes as well as temporal durations when conducting driving actions. To support traffic safety and efficiency as well as the acceptance of AVs, this differentiated knowledge of experienced human drivers (Krems & Baumann, 2009) might be also implemented in AVs' driving functions to support intuitive interactions in mixed traffic.

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References

Avsar, H., Utesch, F., Wilbrink, M., Oehl, M., & Schießl, C. (2021). Efficient communication of automated vehicles and manually driven vehicles through an external human-machine interface (eHMI): Evaluation at T-junctions. In C. Stephanidis, M. Antona, & S. Ntoa, (Eds.), *HCI International 2021 - Posters. HCII 2021. Communications in Computer and Information Science, vol 1421* (pp. 224-232). Springer: Cham. https://doi.org/10.1007/978-3-030-78645-8_28.

Beggiato, M., Witzlack, C., Springer, S., & Krems, J.F. (2018). The right moment for braking as informal communication signal between automated vehicles and pedestrians in crossing situations. In N. Stanton (Ed.), *Advances in Human Aspects of Transportation. AHFE 2017. Advances in Intelligent Systems and Computing* (pp. 1072-1081). Springer: Cham. https://doi.org/10.1007/978-3-319-93885-1.

Bellem, H., Thiel, B., Schrauf, M., & Krems, J.F. (2018). Comfort in automated driving: An analysis of preferences for different automated driving styles and their dependence on personality traits. *Transportation Research Part F, 55*, 90-100.
https://doi.org/10.1016/j.trf.2018.02.036.

Clark, H.E., Perrone, J.A., & Isler, R.B. (2013). An illusory size-speed bias and railway crossing collisions. *Accident Analysis and Prevention, 55*, 226-231. https://doi. org/10.1016/j.aap.2013.02.037.

De Haan, T., Stuiver, A., Lorist, M.M., & de Waard, D. (2022). Other road users' adaptations to increase safety in response to older drivers' behaviour. *Transportation Research Part F, 84*, 277-286.
https://doi.org/10.1016/j.trf.2021.12.009.

Domeyer, J.E., Lee, J.D., & Toyoda, H. (2020). Vehicle automation-other road user communication and coordination: Theory and mechanisms. *IEEE Access, 8*, 19860-19872. https://doi.org/10.1109/ACCESS.2020.2969233.

Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Human Factors, 37*, 32-64.
https://doi.org/10.1518/001872095779049543.

European Road Transport Research Advisory Council (ERTRAC). (2017). *Automated driving roadmap.* Report of the ERTRAC working group "Connectivity and Automated Driving". https://www.ertrac.org/wp-content/uploads/2022/07/ERTRAC_Automated_Driving_2017.pdf

Gibson, J.J., & Crooks, L. E. (1938). A Theoretical Field-Analysis of Automobile-Driving. *The American Journal of Psychology, 51,* pp. 453-471. https://doi.org/10.2307/1416145.

Habibovic, A., Lundgren, V. M., Andersson, J., Klingegård, M., Lagström, T., Sirkka, A., Fagerlönn, J., Edgren, C., Fredriksson, R., Krupenia, S., Saluäär, D., & Larsson, P. (2018). Communicating intent of automated vehicles to pedestrians. *Frontiers in Psychology, 9,* 1336. https://doi.org/10.3389/fpsyg.2018.01336.

Hall, E.T. (1969). *The Hidden Dimension*. Doubleday: Anchor Books.

Hancock, P.A., Caird, J.K., & Shekhar, S. (1991). Factors influencing drivers' left turn decisions. *Proceedings of the Human Factors 35th Annual Meeting, 35*(15), 1139-1143. https://doi.org/https://doi.org/10.1177/154193129103501525.

Hancock, P.A., Wulf, G., Thom, D.R. & Fassnacht, P. (1989). Contrasting driver behavior during turns and straight driving. *Proceedings of the Human Factors 33rd Annual Meeting, 33(15),* 918-922. https://doi.org/10.1177/154193128903301504.

Hensch, A.-C., Beggiato, M., & Krems, J.F. (2022). Should I wait or should I go? - Deciphering implicit communication cues for cooperative interactions in left-turn scenarios. *IEEE International Conference on Computational Intelligence and Virtual Environments for Measurement Systems and Applications (IEEE CIVEMSA 2022),* 1-5. doi: 10.1109/CIVEMSA53371.2022.9853676.

Hensch, A.-C., Beggiato, M., & Krems, J.F. (2023). Drivers' gap acceptance during parking maneuvers as a basis for initiating driving actions in automated vehicles. *Transportation Research Part F, 92,* 133-142. https://doi.org/10.1016/j.trf.2022.11.008.

Hensch, A.-C., Beggiato, M., Schömann, M.X., & Krems, J. F. (2021). Different types, different speeds – The effect of interaction partners and encountering speeds at intersections on drivers ' gap acceptance as an implicit communication signal in automated driving. In H. Krömker (Ed.), *HCI in Mobility, Transport, and Automotive Systems. HCII 2021. Lecture Notes in Computer Science* (pp. 517-528). Springer: Cham. https://doi.org/10.1007/978-3-030-78358-7_36.

Krems, J.F., & Baumann, M.R. (2009). Driving and situation awareness: A cognitive model of memory-update processes. In M. Kurosu (Ed.), *Lecture Notes in Computer Science, vol. 5619 LNCS* (pp. 986-994). Springer: Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-02806-9_113.

Litman, T. (2017). *Autonomous Vehicle Implementation Predictions*. Victoria, British Columbia, Canada: Victoria Transport Policy Institute. https://www.vtpi.org/avip.pdf.

Lobjois, R., Benguigui, N., & Cavallo, V. (2013). The effects of age and traffic density on street-crossing behavior. *Accident Analysis & Prevention, 53,* 166-175, 2013. http://dx.doi.org/10.1016/j.aap.2012.12.028.

Law, D.J., Pellegrino, J.W., Mitchell, S.R., Fischer, S.C., McDonald, T.P., & Hunt, E.B. (1993). Perceptual and cognitive factors governing performance in comparative arrival-time judgments. *Journal of Experimental Psychology: Human Perception and Performance, 19,* 1183-1199. https://doi.org/10.1037/0096-1523.19.6.1183.

Nagelkerke, N.J.D. (1991). A note on a general definition of the coefficient of determination. *Biometrika, 78*, 691-692. https://doi.org/10.1093/biomet/78.3.691.

Petzoldt, T. (2014). On the relationship between pedestrian gap acceptance and time to arrival estimates. *Accident Analysis & Prevention, 72*, pp. 127-133. https://doi.org/10.1016/j.aap.2014.06.019.

Petzoldt, T., Schleinitz, K., Krems, J.F., & Gehlert, T. (2017). Drivers' gap acceptance in front of approaching bicycles – Effects of bicycle speed and bicycle type. *Safety Science, 92*, 283-289. https://doi.org/10.1016/j.ssci.2015.07.021.

SAE International's new standard J3016. (2018). *Levels of driving automation*. Warrendale, Pennsylvania, US: SAE International. https://doi.org/P141661.

Schieben, A., Wilbrink, M., Kettwich, C., Madigan, R., Louw, T., & Merat, N. (2019). Designing the interaction of automated vehicles with other traffic participants: Design considerations based on human needs and expectations. *Cognition, Technology and Work, 21*, 69-85. https://doi.org/10.1007/s10111-018-0521-z.

Schiff, W. & Oldak, R. (1990). Accuracy of judging time to arrival: effects of modality, trajectory, and gender. *Journal of Experimental Psychology. Human Perception and Performance, 16,* 303-316. doi: 10.1037//0096-1523.16.2.303.

Schleinitz, K., Petzoldt, T., & Gehlert, T. (2019). Drivers' gap acceptance and time to arrival judgements when confronted with approaching bicycles, e-bikes, and scooters. *Journal of Transportation Safety and Security, 12,* 3-16. https://doi.org/10.1080/19439962.2019.1591551.

Stahl, P., Donmez, B., & Jamieson, G. A. (2014). Anticipation in driving: The role of experience in the efficacy of pre-event conflict cues. *IEEE Transactions on Human- Machine Systems, 44*, 603-613. https://doi.org/10.1109/THMS.2014.2325558.

Stange, V., Goralzik, A., Ernst, S., Steimle, M., Maurer, M., & Vollrath, M. (2022). Please stop now, automated vehicle! – Passengers aim to avoid risk experiences in interactions with a crossing vulnerable road user at an urban junction. *Transportation Research Part F, 87,* 164-188. https://doi. org/10.1016/j.trf.2022.04.001.

Summala, H. (2007). Towards understanding motivational and emotional factors in driver behaviour: Comfort through satisficing. In P. C. Cacciabue (Ed.), *Modelling driver behaviour in automotive environments: Critical issues in driver interactions with intelligent transport systems* (pp. 189-207). Springer: London. https://doi.org/10.1007/978-1-84628-618-6.

Wilbrink, M., Schieben, A., Markowski, R., Weber, F., Gehb, T., Ruenz, J., Tango, F., Kaup, M., Willrodt, J.-H., Portouli, V., Merat, N., Madigan, R., Markkula, G., Romano, R., Fox, C., Althoff, M., Söntges, S., & Dietrich, A. (2018). *Designing cooperative interaction of automated vehicles with other road users in mixed traffic environments. InterACT D1.1 Definition of interACT use cases and scenarios*.

https://www.interact-roadautomation.eu/wp-content/uploads/interACT_WP1_D1.1_UseCases_Scenarios_1.1_approved_UploadWebsite.pdf

Würzburger Institut für Verkehrswissenschaften GmbH, WIVW (2021). *SILAB 7.0*. https://www.wivw.de.