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Improving clarity, cooperation and driver experience in lane change manoeuvres

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ABSTRACT

Many situations in traffic involve multiple road users and can only be solved by successful cooperation. However, 30% of cooperation in traffic fail, which indicates that there is potential for improvement (Benmimoun et al., 2004). In this study, lane change manoeuvres were examined as a typical cooperative situation. In order to improve cooperation, two ways of enhancing lane change manoeuvres were tested. Firstly, a head-up display was used to support the regular turn signal. Secondly, the meaning of regular turn signals has been revisited and enhanced semantics that distinguish between planning and starting a manoeuvre were proposed and assessed. A driving simulator study with N = 52 participants was carried out to investigate the effect of using an Augmented Reality Head-Up Display (AR-HUD) and the enhanced semantics on cooperation. Similarly, the effect on clarity and the general experience of the situation were explored. The results suggest that both approaches are promoting permissive behavior. In addition, other drivers are perceived more cooperatively. Lastly, the ambiguity in the lane change situation was reduced.

Introduction

For most situations in traffic formal rules unambiguously prescribe the adequate behavior of drivers. These rules apply to juridical determination of whose failure an accident was, but their effectiveness for preventing accidents may be limited. Granting a smooth ride for everyone and preventing accidents is probably more a matter of increasing situation awareness, unambiguous communication of intent and good will between drivers. One situation where this is tantamount is lane change maneuver on motor highways. If a driver on the right lane expresses intent to change to the left lane, a driver who occupies the left lane has priority, but may waive by reducing speed and creating a gap. In many situations such cooperative behavior of the occupying driver can be considered desirable as it is safe and prevents stress on a larger scale.

In previous studies we have identified three factors that promote permissive behavior in lane change situations. First, drivers are more likely to cooperate when costs for this cooperation are perceived low. An example for high cost is having to brake sharply because of a merging car really close to the own vehicle. Second, the urgency for the changing driver is taken into account. For instance, when the end-of-lane is approached, urgency is high. Third, cooperative behavior depends on how clearly the changing driver communicates this very intention. However, the only formal way for communication of lane changes is the turn signal and alarmingly our previous results suggest that the turn signal may not be as unambiguous as it may seem (Haar et al., 2019).

In the present study we first explored and implemented enhanced semantics of the turn signal in order to communicate information about the intention to other drivers more precisely. In a second condition we applied the same logic into an augmented reality (AR) head-up display. In a controlled experiment using a driving simulator the enhanced semantics and the AR implementations were put to a test whether they truly made cooperative behavior in lane change maneuvers more likely.

Cooperation between drivers

Successful cooperation between drivers, whether prescribed by rules or by good will, plays an important role in traffic. Facilitating cooperative behaviour in traffic is expected to have multiple positive effects. Benmimoun et al. (2004) identified comfort and safety as core needs that are of immense importance to road users. Their study about cooperative behaviour with more than 800 participants also revealed that 30% of all

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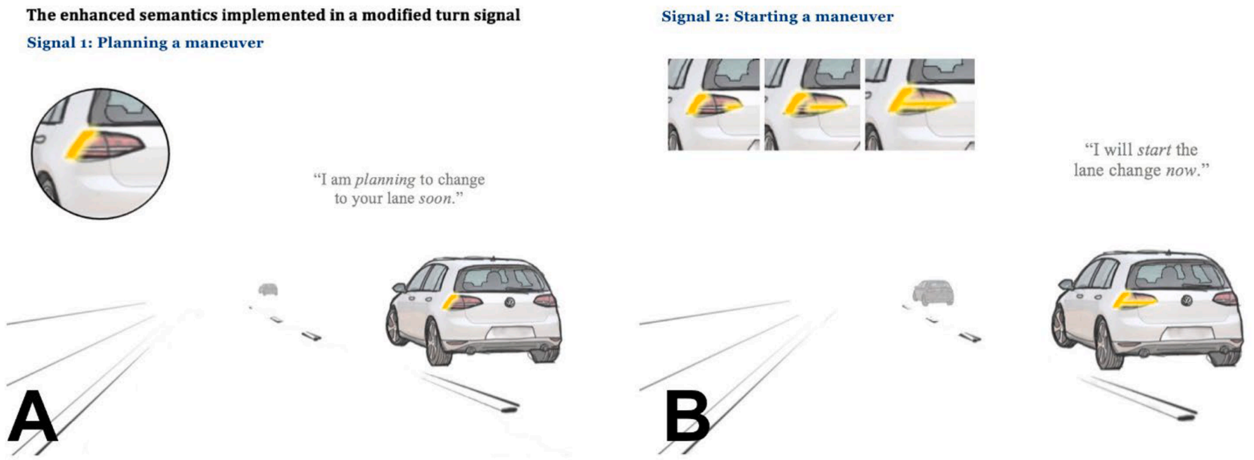

Fig. 1. Illustration of the *enhanced semantics* visualized in a turn signal.

cooperations in traffic fail. This emphasizes the huge potential for improvement in regard to cooperation in traffic. In addition, advancing developments in sensor technologies and vehicle-to-vehicle communication can provide the basis for new cooperative systems (Llatser et al., 2019). Eventually, that potential might be harnessed by the development of new advanced driver assistance systems (Fekete et al., 2015). Examples of such cooperative systems using traditional interfaces like the instrument cluster (Kraft et al., 2020), focused on heavy vehicles (Fank et al., 2021) and automated traffic (Zimmermann et al., 2014). Several advantages are expected if cooperation between road users can indeed be improved. First, successful cooperation between drivers is likely to increase safety by minimizing the number of accidents that occur due to misunderstandings. Second, it is expected that traffic is perceived as more comfortable when road users cooperate by e.g. opening a gap for a slower car or by changing to a slower lane when a faster car is approaching from behind. In line with this, Benmimoun et al. (2004) suggested that better cooperation would increase safety, comfort and efficiency of manoeuvres and would thereby have an impact on the way that drivers perceive and experience the driving task.

Lane change maneuvers

Ellinghaus (1986) conducted a survey among 2000 motorists and identified lane changes as one of the situations in traffic where cooperation is crucial. Sen et al. (2003) found that about 9% of all accidents are related to lane change situations. False assumptions of others' actions have been identified as the cause of 4.5% of all car accidents (National Highway Traffic Safety Administration, 2008). False assumptions can arise, when drivers do not (or cannot) communicate their intentions clearly, for example, when the requesting driver does not use the turn signal in an appropriate way.

The turn signal is the one and only legit channel for communicating intentions for lateral manoeuvres. According to the German road traffic regulations (StVO §7) every lane change has to be signalized clearly and early enough by using the turn signal (also see Leue, 2017). Importantly, however, a recent study by the Auto Club Europa (2008) with 394.000 drivers found that the turn signal was used incorrectly or too sparingly by many drivers. Besides the gross omission of using the turn signal, there may be more subtle shortcomings. Salvucci and Liu (2002) mentioned that road users differ in the way in which they make use of the turn signal. They suggested that drivers can be divided into two groups: the first group uses the turn signal on highways to communicate when they are waiting for a gap. The second group appears to use the turn signal to communicate the moment in which they are about to start a lane change. Even though the two styles require different responses from other traffic participants, both satisfy the requirements of the German road traffic regulations.

Besides the inherent ambiguity of the turn signal, communication can be hampered by additional issues. One example of these issues could also be the general visibility of the turn indicator itself, which is crucial for interaction and communication. If the signal itself cannot be perceived by the receiver, they cannot respond adequately. Also, the information richness that can be conveyed with a simple lighting device of a car remains limited. Rich information about the intention of a driver or the consequences of these intentions cannot be conveyed and this could lead to insufficient limited situational awareness of drivers. Given these issues it is crucial that new technological solutions are explored to improve communication about (intended) lane changes. One of the promising technologies in this respect are head-up displays (HUD). These displays can show rich information in the drivers' field of view and therewith increase their situational awareness. For instance, drivers can be supplied with visual information without taking their eyes off the road and thereby lower accident probability (Cohen and Hirsig, 1990; Fadden et al., 2016). It was suggested that this increased situational awareness can even be increased as augmented reality content is shown in HUD (AR-HUD), which provides the illusion that the digital content is attached to the objects in real world.

In the present study we will explore the effectiveness of turn signals with enhanced semantics. Furthermore, we investigate the benefit of an AR-HUD to improve situation awareness and salience.

Design of enhanced turn signals

The current turn signal has not been changed since its serial introduction in 1939 and has an information capacity of two bit: left or right, on or off. This limited design allows only to communicate two messages: the intention to turn and the direction. However, as Salvucci and Liu (2002) suggest, drivers may use the turn signal to signal a request or the intention to change lane. The current two-bit turn signal cannot distinguish request and intention, which can lead to misunderstandings.

In the present study, we enhanced the semantics and integrated an advanced Head Up Display. To enhance the semantics, we first extended the capacity of the turn signal by one bit to distinguish between request and intention. The planning of a maneuver was communicated by a flashing yellow bar on the side of the backlight (Signal 1 in Fig. 1). As the driver of the car starts the lane change this signal is extended by an animated yellow light moving into the direction of the lane change and the former flashing lights becomes permanent (Signal 2 in Fig. 1). This design resulted from two pilot studies using a low-fi simulator with 25 participants. The differentiation between both signals could be realized

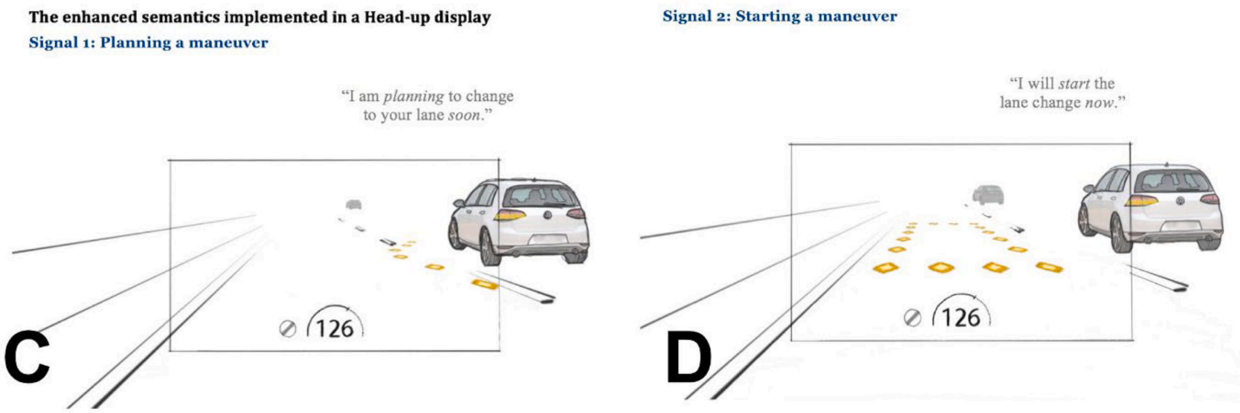

Fig. 2. Illustration of the *enhanced semantics* visualized in an AR-HUD.

without adding complexity to the drivers' task. Drivers would activate their turn signal as usual to communicate the planning phase. This shows Signal 1, and when the car detects a steering angle larger than a certain threshold Signal 2 could be activated automatically.

Second, we aimed at improving situational awareness and salience using a C*ontact-analogue augmented reality* HUD (AR-HUD). This technology creates the impression that digital information is embedded in the analog world and therefore real-world objects can be augmented with digital information. Zimmermann et al. (2014) evaluated a system to assist drivers during automated lane changes using an AR-HUD and found that participants judged the usage of this technology in interactive scenarios as positive. With those benefits in mind, we designed an AR-HUD concept that would support the driver in manually driven lane-change scenarios and that we extended with the developed enhanced semantics that distinguishes between request and intention. Instead of being manually triggered by the driver, such systems can be based on vehicle-to-vehicle communication or on a intention recognition system. This would have the benefit to be technologically independent from other drivers. Such technologies are worked on rigidly and could be used for the practical implementation.

Fig. 2 illustrates the AR-HUD concept we used to inform the responding driver, that was developed in a pilot study with 24 participants. The planning of the maneuver by the merging driver is communicated by a yellow-dashed line in the AR-HUD from individual objects next to the merging car (Signal 1 in Fig. 2). This line performs a pulsing animation in the direction of the lane change synchronized with the regular turn indicator. As the merging driver starts the lane change maneuver, the line moves to the target lane and forms a square in the size of the merging car. This square is positioned centrally in the target lane parallel to the merging car and keeps this parallel position until the merging maneuver is finished.

Research questions

In this study we assessed whether the enhanced semantics and AR-HUD integration individually promote cooperative behavior in lane change maneuvers to an extent that justifies real-world implementation. We expected that both innovations would separately encourage cooperative behavior in comparison to the current turn signals. Furthermore, we explored how the combination of enhanced semantics with AR-HUD implementation would perform in comparison. It is possible that the combined design performs approximately equal to the sum of both separate effects (independence), better than the sum (synergy) or worse (ceiling effects).

Table 1
Overview of the four conditions that each driver completed (see Figs. 1 & 2 for the visualizations of the conditions (A–D).

Visualization	Condition name	Semantics	AR-HUD
A	*Baseline turn signal*	Current semantics	Disabled
A and B	*Enhanced turn signal*	Enhanced semantics	Disabled
C	*Baseline AR-HUD*	Current semantics	Enabled
C and D	*Enhanced AR-HUD*	Enhanced semantics	Enabled

Method

Participants

A sample size of 48 or more participants was desired to realize complete counterbalancing so that every possible randomized orders of conditions was experienced by one participant. After removing one participant from the data set due to simulator sickness a total of N = 52 remained (n = 24 female) with an average age of 42 (SD = 4.2). All of the participants were employees of the Volkswagen Group and no selection based on factors such as gender, age, driving experience or others was applied. Upon completion of the study, the participants received a small gift to compensate for the time that they spent to participate. All participants were German and all questionnaires and instructions were provided in German.

Experimental design

This study was designed to allow for both, between-participant and within-participant comparisons. The independent variables (Table 1) were whether an AR-HUD was used (disabled or enabled) and whether the enhanced semantics were applied (current semantics or enhanced semantics). The dependent variable was the number of successful lane changes, which was indicated by whether or not a participant allowed the merging car to change lanes (objective), and by evaluating the participants' perception of the situation measured by questionnaires (subjective).

Measures

The questionnaire assessed the quality of the lane changes in terms of comfort, efficiency, safety subjectively rated by the participant (cf. Benmimoun et al., 2004). It also included ratings of how clear the intentions and the timing of the other drivers were (Zimmermann et al., 2014; Zimmermann et al., 2015). The participants gave their ratings on a 7-point Likert-scale that ranged from *"I fully disagree"* to *"I fully agree"*, and were invited to write down a more detailed description of how they

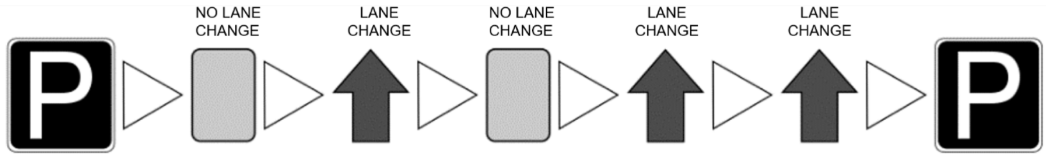

Fig. 3. The order of situations. The dark arrows represent the situations in which the other car attempted a lane change manoeuvre. The grey block represents similar situations where no lane change was attempted.

had perceived the lane change.

The *objective measurement* of cooperative behavior consisted of the number of lane changes in which the participants slowed down to let the other car in. The more often a participant allowed a lane change, the more cooperative that behavior was regarded.

Scenario

In the scenario, participants were driving on the left lane of a two-lane highway and were confronted with a number of situations in which another car attempted to change to the driver's lane. We specifically used two lanes to create a better comparability between the cooperative behavior of the participants. In total, there were five encounters in which the participant passed by a slower car. In three out of those five encounters, the car set the turn signal to change to the participant's lane. In the other two situations the car did not attempt a lane change, in order to minimize predictability and hence socially desirable outcome. An overview of the order in which those situations occurred can be seen in Fig. 3. It took the drivers five to six minutes to complete the whole scenario.

Materials

The fixed-base driving simulator at the research facilities of the Volkswagen Group used in this experiment, was equipped with three projectors for a 180° front view. The interior mock-up, which was used to simulate a realistic cockpit, had side-mirrors and a rear-mirror aiming on three LCD screens, providing a realistic back-view. The steering of the simulation was realized by using an original manufacture steering wheel and pedals, built into the interior mock-up.

Procedure

At the beginning of the study, the experimenter instructed the participants about the possible side effects of using a fixed-base simulator and informed them that they were free to cancel the experiment at any time without any further consequences. After doing so, they were provided with a short introduction to the experiment and filled in a demographic questionnaire. Then, the participants were invited to get used to the simulator by accelerating, braking, steering and changing lanes in a test scenario. Once the participants were all set, the experimenter started the first condition. Upon completion of the first condition, the experimenter asked the participants to fill in the first questionnaire on a tablet and told them that they could ask questions at any time. Then, the three other conditions were tested in the same manner (driving and then filling in a questionnaire about the drive). After the fourth questionnaire had been filled in, the participants were invited to ask open questions about the study and to leave remarks if desired.

Data analysis

Observations were gathered in a fully within-subject design, which makes it possible to examine the effects on population level and participant level. For the subjective and objective outcome variables a two-factorial linear multi-level model (LMM) was construed, including the manipulations *AR-HUD*, *enhanced semantics* and an interaction term.

Table 2
The regression model for predicting questionnaire ratings and cooperative behavior.

Model terms	*Population-Level effects* expected population means	*Participant-level variation* standard deviation
1 (Intercept)	Reference rating when *no AR-HUD* is used and when the *current semantics* are applied	Participant variation in reference rating when *no AR-HUD* is used and when the *current semantics* are applied (β_0)
AR-HUD	Difference between using an AR-HUD and *not using an AR-HUD* (when the *current semantics* are applied)	Participant variation in difference between using an AR-HUD and *not using an AR-HUD* (when the *current semantics* are applied) (β_{HUD})
EnhancedSemantics	Difference between *enhanced semantics* and *current semantics* (when *no AR-HUD* is used)	Participant variation in difference between *enhanced semantics* and *current semantics* (when *no AR-HUD* is used) (β_{Sem})
EnhancedSemantics: AR-HUD	Interaction effect of using the *enhanced semantics* and an AR-HUD	

Treatment contrasts were used, such that effects denote the difference towards the *no AR-HUD / current semantics* reference condition.

For *feeling of cooperation* and the *allowed lane change*, logistic regression was used. By exponentiation one receives odds[1], which has a more intuitive interpretation. For all other estimations, the subjective rating of cooperativeness and the clarity of the situation, a normally distributed error term was assumed. The model parameters and their interpretation are given in Table 2.

Since we employed a full within-subject design with repeated measures, the manipulation effects can be estimated on the population level, as well as participant level. The participant level estimates are summarized as standard deviation of variation around the population-level mean. Low variation indicates that the population level effect is highly typical for each and every participant.

In accordance with the research questions, which capitalize on quantification of benefits, the regression analysis is based on interpretation of parameter estimates and their level of certainty (in contrast to null hypothesis significance testing with p-values). Models were formulated, estimated and interpreted according to the Bayesian paradigm. The level of certainty is expressed by Bayesian credibility intervals.[2]

Each parameter of interest will be reported in the same three-step fashion: First, the point estimate gives the most likely magnitude of

[1] An odds of 2:1 means that when an opponent bets 2€ on cooperation to happen, putting €1 against is a rational choice, perhaps, because two in three past events were cooperative.

[2] The uncertainty of an estimate in Bayesian statistics is routinely expressed as 95% *credibility intervals*, which have the intuitive interpretation that many researchers attribute to frequentist confidence intervals: "*There is 95% chance that the true value lies between these limits.*" Hoekstra, Morey, Rouder, and Wagenmakers (2014); Smaldino and McElreath (2016)

Fig. 4. Driving simulator of the Volkswagen Group used in the study.

Table 3
The coefficients table of the second model predicting how often the participant allowed a lane change on a logistic scale. The values in brackets are the odds (exp(log(odds))). The participant-level effects regarding the interaction effect have been excluded, because they caused oversaturation of the model.

	Population-Level			Participant-level variation
	log (odds)	*Lower 2.5%*	*Upper 2.5%*	σ
Intercept [No AR-HUD / Current semantics]	0.92 (2.51)	0.39 (1.48)	1.49 (4.4)	1.33
AR-HUD	0.94 (2.56)	0.31 (1.36)	1.67 (5.31)	0.62
Enhanced semantics	0.45 (1.57)	−0.14 (0.87)	1.08 (2.95)	0.64
AR-HUD:Enhanced semantics	−0.61 (0.54)	−1.48 (0.23)	0.19 (1.21)	–*

effect on population level. Second, the 95% credibility interval indicates the level of certainty. Third, the standard deviation of participant-level effects represents individual variation around the population-level effect. When variation is small, the population level effect is highly representative for any individual, whereas large variation indicates that unobserved impact factors play a significant role.

Results

Below, we first report the results regarding the subjective and objective measurements of cooperation. Next, the clarity of communication results are presented.

Observed permissive behavior

The first research question aimed to investigate in how far cooperation and the perception of cooperation were affected by the use of an AR-HUD and/or the enhanced semantics. To answer this question, the objective and subjective measurements are reported. Fig. 4 suggests that AR-HUD and enhanced semantics promote both, permissive behavior and perceived cooperation.

As a baseline, the odds of permissive behavior are exp$(0.92) = 2.51$ to 1 with a regular turn signal and no AR-HUD (Table 3), but with a striking variation between participants ($\sigma = 1.33$[3]). Using an AR-HUD increased the proportion of permissive events by factor exp$(0.94) = 2.56$. This effect size carries considerable uncertainty, but it is almost certainly positive. At the same time, there is only moderate variation between participants. The left plot in Fig. 5 suggests that enhanced semantics promotes permissive behaviour. This is supported by the model, where presence of enhanced semantics increased permissive behaviour by factor exp$(0.45) = 1.57$. Yet, there remains considerable uncertainty whether the effect is truly positive, and there is relatively more participant-level variation. Finally, the interaction effect is negative by tendency, which means that the combination of AR-HUD and enhanced semantics yields less than the sum of both effects, which indicates a ceiling effect.

Perceived cooperation

The right bar chart in Fig. 5 suggests that the number of times in which a lane change was perceived as a cooperation was much higher when a combination of AR-HUD and the enhanced semantics was used. Similarly, it seems that using only the enhanced semantics or only an AR-HUD led to an increased feeling of cooperation. In general, there appeared to be a positive trend.

In line with this result, Table 4 shows that once an AR-HUD was used, the proportion of lane changes that were described as cooperative increased by factor exp$(0.80) = 2.23$ with a considerable certainty that the effect is positive. Moreover, the model suggest that the enhanced semantics had a considerable certain positive effect on the number of times that a lane changed was perceived as cooperative (exp$(1.01) = 2.75$). Lastly, using an AR-HUD and the enhanced semantics together seems to have a synergy effect due to the positive leaning but rather uncertain interaction effect.

[3] Note that participant-level variation can only be assessed on the linear predictor scale.

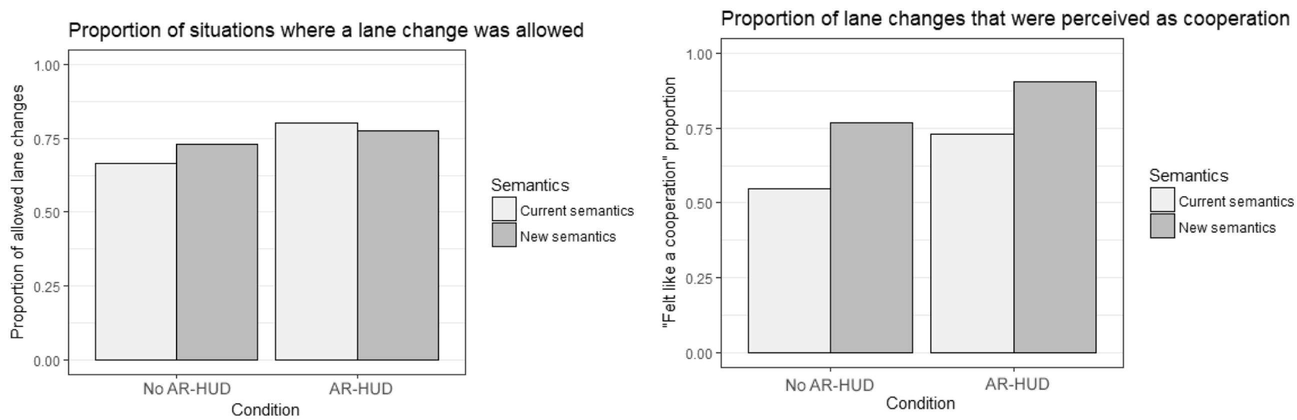

Fig. 5. Left: The observed number of total lane changes of all participants with/without using an AR-HUD and the *enhanced semantics*. Right: Bar chart depicting the number of times in which the participants reported that a lane change felt like a cooperation.

Table 4
The coefficients table of Model 1 that predicts the feeling of cooperation during lane changes on a logistic scale. The gray values in brackets are the odds (exp(log (odds))). The participant-level effects of this model have been excluded, because they caused oversaturation of the model.

	Population-Level			Participant-level Effects
	log *(odds)*	*Lower 2.5%*	*Upper 2.5%*	σ
Intercept [No AR-HUD / Current semantics]	0.21 (1.23)	−0.32 (0.73)	0.75 (2.12)	–
AR-HUD	0.80 (2.23)	0 (1)	1.62 (5.05)	–
Enhanced semantics	1.01 (2.75)	0.19 (1.21)	1.87 (6.49)	–
AR-HUD:Enhanced semantics	0.29 (1.34)	−0.99 (0.37)	1.66 (5.26)	–

Table 5
The coefficients table of a model that predicts perceived amount of cooperation in own behavior. On a scale from −3 to 3.

	Population-Level			Participant-level Effects
	μ	*Lower 2.5%*	*Upper 2.5%*	σ
Intercept[No AR-HUD / Current semantics]	0.80	0.54	1.06	0.53
AR-HUD	0.34	0.03	0.64	0.26
Enhanced semantics	0.32	0.01	0.62	0.32
AR-HUD:Enhanced semantics	−0.17	−0.57	0.24	–

Perception of own cooperativeness

The boxplot in Fig. 5 provides the impression that the participants always perceived their own behavior as cooperative with no regard to whether an AR-HUD, the enhanced semantics or neither was used (most of the values are above 0). Furthermore, there appear to be no interaction effects. Therefore, the reporting of the results will focus on the main effects.

The model estimates (see Table 5) that the baseline for the degree to which the participants perceived their own behavior as cooperative was 0.8, with a rather high certainty (95% CI [0.54, 1.06]). However, the variation of the baseline scores is quite large ($\sigma_0 = 0.53$), with strong variation between participants. A similar effect was observed regarding the AR-HUD visualizations. Using only the AR-HUD led to a slight increase of considerable certainty. However, the AR-HUD's effect varies strongly depending on the participant ($\sigma_{HUD} = 0.26$).

Quite similar to the effect of the AR-HUD, the enhanced semantics increased the ratings slightly with a considerable certainty. However, this effect also varies strongly between participants. Lastly, whereas using a combination of AR-HUD and enhanced semantics appears to have a slight negative effect, but the 95% credibility interval is very broad, ranging from and includes a high fraction of positive and negative values, which prevents to draw certain conclusions about the effectiveness of this combination. Similar effects could be found regarding the perception of the partner's cooperativeness (Appendix A).

Clarity of the other driver's timing

The left boxplot in Fig. 6 suggests that the other driver's timing was rather unclear when the regular turn signal and no AR-HUD was used. It also gives the impression that a combination of AR-HUD and the enhanced semantics leads to a very strong increase in clarity of timing. Similarly, enabling an AR-HUD appears to lead to a strong increase in clarity of timing and using the enhanced semantics seems to trigger a slight increase. Moreover, there seem to be no interaction effects. Thus, only the main effects will be described (Fig. 7).

All of the visual inspections above are supported by the effects estimated by the model (Table 6). The participants rated the clarity of the baseline situation negatively. The estimate of this intercept is predicted by this model with a high certainty and rather small variation between participants. The model estimates that the clarity of the other's timing is getting much clearer when an AR-HUD is used, which effect is predicted with a considerable certainty. This AR-HUD's effect varied also only slightly between participants (see Fig. A1).

An even stronger and more certain increase is observed when the enhanced semantics are introduced. Comparable to the effect of the AR-HUD, the effect of the enhanced semantics also varies only moderately between participants.

Clarity of the other driver's intentions

The right boxplot in Fig. 6 indicates that the intentions of the other driver are neither clear nor unclear when a regular turn signal and no AR-HUD are used. The visualization also suggests that using an AR-HUD, the enhanced semantics or a combination of both leads to a strong increase in clarity of the other driver's intentions. The graph indicates a ceiling effect when the enhanced semantics and the AR-HUD are combined.

In line with those observations, the estimations in Table 7 reveal that the clarity of the partner's intentions was rated as being neither very clear nor very unclear when a regular turn signal and no AR-HUD was

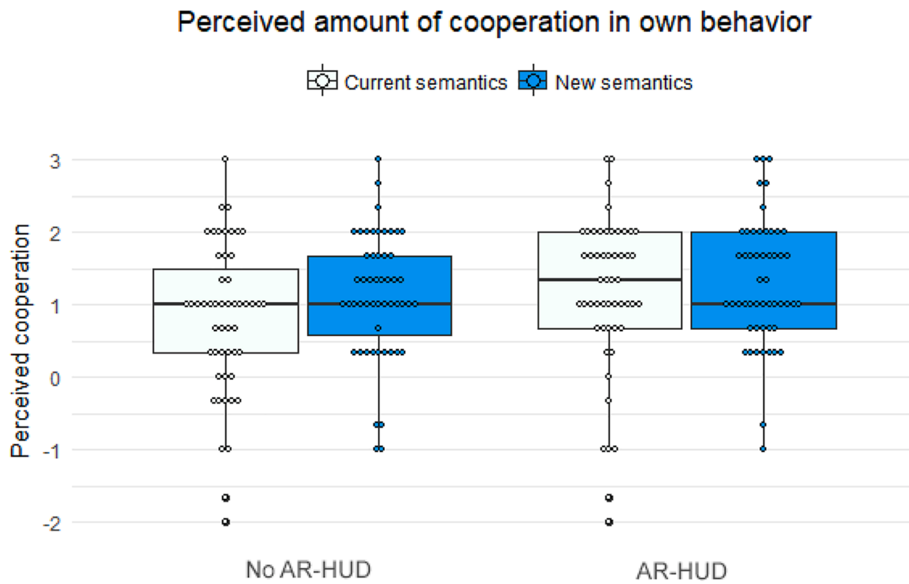

Fig. 6. Boxplot of the amount of cooperation that the participants perceived in their own behavior.

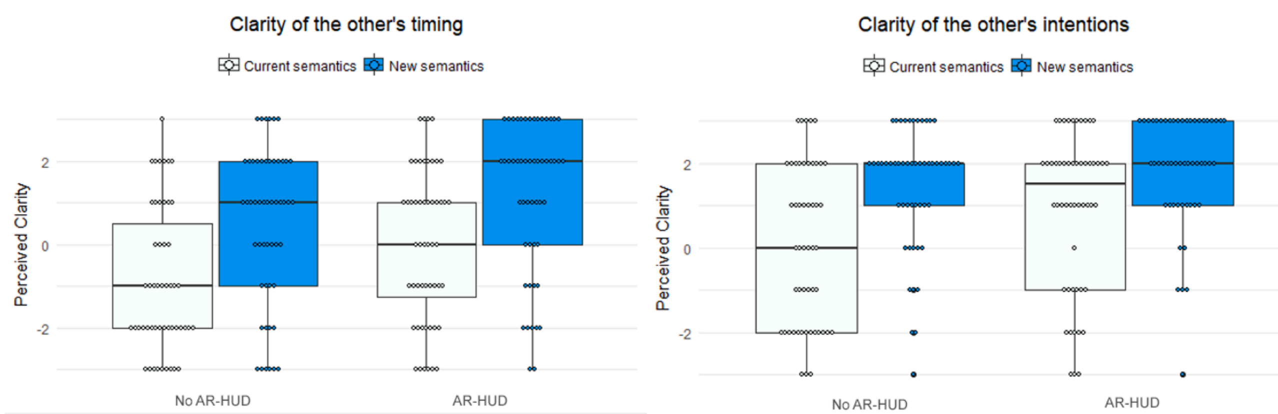

Fig. 7. Left: Boxplot that depicts how clear it was when exactly the other driver started the lane change. Right: Boxplot that shows how clear the intentions of the other driver were to the participant.

Table 6
The coefficients table of a model that predicts the clarity of the other's timing. On a scale from −3 to 3.

	Population-Level			Participant-level Effects
	μ	Lower 2.5%	Upper 2.5%	σ
Intercept [No AR-HUD / Current semantics]	−0.91	−1.39	−0.43	0.45
AR-HUD	0.88	0.19	1.58	0.56
Enhanced semantics	1.38	0.72	2.08	0.50
AR-HUD:Enhanced semantics	−0.19	−1.11	0.75	–

Table 7
The coefficients table of a model that predicts the clarity of the other's intentions.

	Population-Level			Participant-level Effects
	μ	Lower 2.5%	Upper 2.5%	σ
Intercept [No AR-HUD / Current semantics]	0.05	-0.40	0.50	0.45
AR-HUD	0.88	0.26	1.49	0.39
Enhanced semantics	1.39	0.79	2	0.34
AR-HUD:Enhanced semantics	−0.44	−1.30	0.44	–

used. The credibility interval is also centered above the zero is rather small, which gives this estimate a considerable certainty. In addition, the variation between participants is also only moderately. The clarity of intention ratings increased strongly and moderately certain when an AR-HUD was used. The variation of this effect between participants is rather small when compared to the effect size (see Table A1).

Once again, the enhanced semantics had an even stronger positive effect than the AR-HUD and increased the clarity of intention ratings with a highly certain positive effect. The effect size is four times as large as the variation ($\sigma_{Sem} = 0.34$), which indicates that the effect of the enhanced semantics varies only very slightly between the participants.

The negative interaction estimate supports the observation, that we have to deal with a ceiling effect as the enhanced semantics and the AR-HUD are combined. However, the credibility interval is rather broad and also contains a large proportion of positive values.

Discussion

This study was conducted to assess the potential benefits of next generation turn signals. Two novel design approaches were examined separately and in combination: one allowed the driver to distinguish request and intention of the merging car by providing enhanced semantic information through an adjusted turn-signal display and the other involved an augmented reality head-up displays (AR-HUD). The results lend broad support for the beneficial effects of these displays in terms of the observed number of lane changes, the perception of the situation as a cooperation, and the degree to which the participants rated their own and their partners behavior as cooperative.

The observed number of lane changes indicated that using an AR-HUD can successfully stimulate cooperative behavior in drivers. In line with this, there were indications that using the enhanced semantics display – enabling drivers to distinguish between requesting a gap or indicating start of the maneuver – stimulated permissive behavior as well.

When it comes to the perception of the situation, similar observations can be made. In the *enhanced semantics* condition, participants interpreted the lane change situations as far more cooperative. Analogously, using an AR-HUD increased the degree to which the lane change maneuvers themselves were perceived as a cooperation between the participant and the other driver. In addition, participants were asked to contrast the amount of cooperativeness in their own and their partner's behavior. Interestingly, in the current semantics/no AR-HUD condition, the participants rated themselves as more cooperative than the other driver. This is in line with the well-known cognitive bias of illusory superiority, where the own behavior and capabilities are regarded as being superior to others (Hoorens, 1995). When the enhanced semantics were used, the other driver was perceived as more cooperative, almost drastically. In fact, the ratings climbed from "the behavior is rather uncooperative than cooperative" to about the self-reported level of cooperativeness. Thus, the enhanced semantics facilitated a more balanced perception of cooperativeness between the involved drivers.

AR-HUD visualizations also led to higher levels of perceived cooperativeness of other drivers, although to a lower degree. There does not seem to be a direct link between improved visualization and attribution of cooperativeness. Perhaps, this effect can be explained by one type of emotional carry-over that has been found to occur in subjective ratings, the so-called fluency of processing effect (Forster et al., 2013; Winkielman et al., 2003). Classic indicators are abstract signals. The extrapolation of consequences (the situation that results from the maneuver) remains as a cognitive task to the receiver of the message. The AR-HUD visualization in part takes over this task from the driver, reducing cognitive effort. The fluency of processing theory states that reducing cognitive effort creates a positive affective state and it has been shown that this effect robustly carries over to other judgements (Forster et al., 2013; Winkielman et al., 2003). It can be speculated that perceiving other drivers as more benign can reduce negative emotions, stress and aggressive behavior in traffic on a larger scale.

Some of these results need to be interpreted with care due to limitations of the study. Firstly, the participants received an introduction into the meaning of the enhanced semantics prior to the first trial. This might have had an influence on the results because the participants might have felt obligated to rate the presented concepts in a socially desirable way or their ratings might have been affected subconsciously to fit the participant's interpretation of what the experiment's purpose might be (Fisher and Katz, 2000; Orne, 2009). To minimize this effect, the introduction was phrased in an objective way in order to avoid any form of judgment in the choice of words and had the main goal of explaining the logic behind the enhanced semantics. However this effect needs to be kept in mind while interpreting the results.

Secondly, the study was conducted in a simulator and not in the field. This might have led to a less realistic experience than a study in a real environment might have provided. Driving simulations can never fully replicate the experience of driving a car on the road with all external factors and "test tracks offer a very depleted and inflexible driving environment" (Carsten and Jamson, 2011). However, there is a huge body of research that shows that results that are obtained in fixed-base driving simulators lead to valid results when tested in the field (Reimer and Mehler, 2011; Shechtman et al., 2009).

The situation that was simulated in this study required modeling the behavior of other drivers that interact with the participant. Haar et al. (2016) described cooperative maneuvers as complex situations that involve reciprocal processes and require multiple drivers to interact. Therefore, the behavior of the computer-controlled driver has an impact on the way that the participant behaves. Subsequently, unrealistic behavior of the simulated driver might lead to behavior that is not representative of how the participant would usually react to a situation. For instance, it occurred that the computer-controlled drivers did not change lanes when the gap that the participant opened was not big enough. Even though this was something that some of the participants commented on after the experiment, some of them also reported that they had experienced similar behavior with real drivers.

As long as human drivers control cars, promoting efficient communication between drivers is crucial for safety, efficiency and comfort in traffic. Given the current trend towards higher levels of automation in automotive traffic, it seems almost inevitable that fully automated individual traffic is preceded by a transition phase of "mixed traffic", with all possible levels of automation being on the road at once. Only when all traffic is operating fully autonomously, the use of human-readable turn signals might be obsolete. However, fully autonomous cars will still get in contact with other road users like pedestrians and cyclists. Even in times of fully autonomic automobility, the communication of intentions must be human-readable. Thus, future research should explore how the enhanced semantics can be used to improve external communication of cars with other road users.

This paper suggests four more interesting topics for future research: First, it indicates the need to explore in how far the enhanced semantics display can reduce ambiguity in other situations than lane change situations. For example, at roundabouts there is ambiguity about which of the exits any car is taking, as well as an ample opportunity for cooperative behavior. Second, the practicability of using the enhanced semantics in the real world needs to be researched. Doing so, the following five constraints and requirements should be kept in mind: (1) the enhanced semantics must be intuitive, i.e. not require more than a simple instruction, (2) any enhanced semantics must not contradict existing semantics, (3) any sets of enhanced semantics must be consistent, (4) enhanced semantics and visualizations must be simple enough to work in crowded situations and (5) at best there should be a cost efficient upgrade path for older cars. This also includes to uncover how long people would need to effectively relearn the semantics of a turn signal and would thereby give a better indication of how realistic an introduction of this change in semantics would be. Also, individual differences between drivers in how they deal with the proposed adjustments could be an important topic to further investigate in order to provide practicality. An example for this could be differences in personalities and driving styles. It could be that drivers with a more aggressive driving style could ignore the gained benefits of the presented functions, which could even lead to further complications of a complex situations. Third, it would be interesting to see if the semantics are still working when the planning phase is skipped and the maneuver is started instantly or how people would react to a unusual long exposure to a planning phase. Fourth, even when it is shown that the system proposed in this paper provides a positive effect at an individual level, the question remains if such a system would be beneficial for traffic in general. Traffic simulations should be used to investigate the effects of such cooperative system on the traffic flow and other efficiency measures.

Conclusion

The present study showed that collaborative lane change manoeuvres can be enhanced in two ways: by using an augmented reality head-up display and by providing separate information on intention and action via the turn signal. Both approaches appeared beneficial for strengthening cooperative behavior and helping participants to tell when exactly another driver wants to initiate a lane change and what another driver is planning to do. At the same time, the lane change situations were perceived as safer, more efficient and more comfortable. A remarkable finding was that other drivers were generally perceived as being less cooperative when a regular turn signal was used and that the use of the enhanced semantics display created the impression that other road users were behaving more cooperatively.

All in all, the present findings suggest that the regular turn signal as we know it today might become a relic of the past. Its capability of communicating intentions clearly should be questioned and supporting technologies and revised semantics should be investigated. In the end, this study questions well-established standards and demonstrates the ability of new technologies to enhance the way in which road users interact with each other.

CRediT authorship contribution statement

A. Haar: Conceptualization, Methodology, Software, Writing – original draft, Formal analysis, Visualization. **A.B. Haeske:** Data curation, Software, Writing – original draft, Formal analysis, Visualization. **A. Kleen:** Conceptualization, Methodology, Supervision, Investigation, Writing – review & editing. **M. Schmettow:** Supervision, Methodology, Formal analysis, Writing – review & editing. **W.B. Verwey:** Supervision, Methodology, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

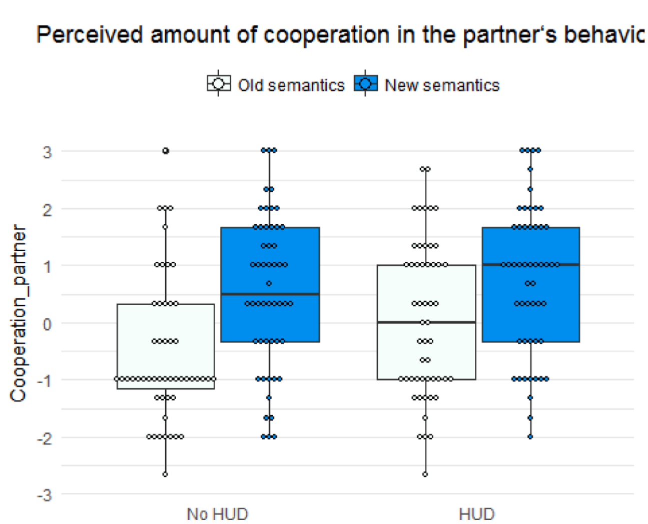

Fig. A1. The coefficients table of a model that predicts perceived amount of cooperation in the partner's behavior.

Table A1
The coefficients table of a model that predicts perceived amount of cooperation in the partner's behavior.

		Fixed Effects		Participant-level Effects
	μ	*Lower 2.5%*	*Upper 2.5%*	*σ*
Intercept [No AR-HUD / Current semantics]	−0.55	−0.90	−0.19	0.51
AR-HUD	0.59	0.10	1.05	0.46
Enhanced semantics	1.09	0.64	1.57	0.40
AR-HUD:Enhanced semantics	−0.38	−1.04	0.26	–

References

Auto Club Europa, 2008. Reviere Der Blinkmuffel. Tech. Rep., p. 2008

Benmimoun, A., Neunzig, D., Maag, C., 2004. *Effizienzsteigerung durch professionelles/ partnerschaftliches Verhalten im Straßenverkehr*. FAT-Schriftenreihe Nr. 181. Frankfurt/Main: Forschungsvereinigung Automobiltechnik e.V.

Carsten, O., Jamson, A.H., 2011. In: Handbook of Traffic Psychology. Elsevier, pp. 87–96. https://doi.org/10.1016/B978-0-12-381984-0.10007-4.

Cohen, A., Hirsig, R., 1990. Zur Bedeutung des fovealen Sehens für die Informationsaufnahme bei hoher Beanspruchung. In: Derkum, H. (Ed.), Sicht und Sicherheit im Strassenverkehr. Köln, Verl. TÜV Rheinland.

Ellinghaus, D., 1986. *Rücksichtslosigkeit und Partnerschaft: Eine sozialpsychologische Untersuchung über den Umgang unter Kraftfahrern im Straßenverkehr. Uniroyal Verkehrsuntersuchungen.* IFAPLAN, Köln.

Fadden, S., Ververs, P.M., Wickens, C.D., 2016. Costs and benefits of head-up display use: a meta-analytic approach. Proceed. Hum. Fact. Ergon. Soc. Ann. Meet. 42 (1), 16–20. https://doi.org/10.1177/154193129804200105.

Fank, J., Knies, C., Diermeyer, F., 2021. After You! Design and Evaluation of a Human Machine Interface for Cooperative Truck Overtaking Maneuvers on Freeways. In: *13th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. Published. https://doi.org/10.1145/3409118.3475139.

Fekete, S., Vollrath, M., Huemer, A.K., Salchow, C., 2015. Interaktionen im Straßenverkehr: Kooperation und Konflikt. In Der Fahrer im 21. Jahrhundert: Fahrer, Fahrerunterstützung und Bedienbarkeit (pp. 325–338). Düsseldorf: VDI Verlag.

Fisher, R.J., Katz, J.E., 2000. Social-desirability bias and the validity of self-reported values. Psychol. Market. 17 (2), 105–120.

Forster, M., Leder, H., Ansorge, U., 2013. It felt fluent, and I liked it: Subjective feeling of fluency rather than objective fluency determines liking. Emotion 13 (2), 280–289.

Haar, A., Kleen, A., Albrecht, L., Schmettow, M., Verwey, W.B., 2016. Intentionen wahrnehmen und Umfeld verstehen: kognitive Prozesse in der Interaktion mit anderen Verkehrsteilnehmern. In *VDI Berichte - Fahrerassistenzsysteme und automatisiertes Fahren*.

Haar, A., Kleen, A., Schmettow, M., Verwey, W.B., 2019. Improving cooperation in traffic - Novel HMI approaches to enhance driver-driver interactions. In: de Waard, D., Brookhuis, K., Coelho, D., Fairclough, S., Manzey, D., Naumann, A., Onnasch, L., Röttger, S., Toffetti, A., Wiczorek, R. (Eds.), Proceedings of the Human Factors and Ergonomics Society Europe Chapter 2018 Annual Conference.

Hoekstra, R., Morey, R.D., Rouder, J.N., Wagenmakers, E.-J., 2014. Robust misinterpretation of confidence intervals. Psychon. Bull. Rev. 21 (5), 1157–1164. https://doi.org/10.3758/s13423-013-0572-3.

Hoorens, V., 1995. Self-favoring biases, self-presentation, and the self-other asymmetry in social comparison. J. Pers. 63 (4), 793–817. https://doi.org/10.1111/j.1467-6494.1995.tb00317.x.

Kraft, A.-K., Maag, C., Baumann, M., 2020. Comparing dynamic and static illustration of an HMI for cooperative driving. Accid. Anal. Prev. 144, 105682. https://doi.org/10.1016/j.aap.2020.105682.

Llatser, I., Michalke, T., Dolgov, M., Wildschutte, F., Fuchs, H., 2019. Cooperative Automated Driving Use Cases for 5G V2X Communication. In: 2019 IEEE 2nd 5G World Forum (5GWF). Published. https://doi.org/10.1109/5gwf.2019.8911628.

Leue, A. (Ed.), 2017. *StVO Straßenverkehrs-Ordnung: Textausgabe mit Erläuterungen, Allgemeiner Verwaltungsvorschrift zur Straßenverkehrs-Ordnung, verkehrsrechtlichen Bestimmungen des Bundes-Immissionsschutzgesetzes, Fernreiseverordnung sowie ausgewählten Ausnahmeverordnungen* (25., neu bearbeitete Auflage, Stand: Oktober 2017). C.F. Müller, Heidelberg, Heidelberg.

National Highway Traffic Safety Administration, 2008. *National Motor Vehicle Crahs Causation Survey: Report to Congress* (No. DOT HS 811 059). United States.

Orne, M.T., 2009. Demand Characteristics and the Concept of Quasi-Controls1. In: Rosenthal, R., Rosnow, R.L. (Eds.), Artifacts in Behavioral Research. Oxford University Press, pp. 110–137. https://doi.org/10.1093/acprof:oso/9780195385540.003.0005.

Reimer, B., Mehler, B., 2011. The impact of cognitive workload on physiological arousal in young adult drivers: a field study and simulation validation. Ergonomics 54 (10), 932–942.

Salvucci, D.D., Liu, A., 2002. The time course of a lane change: Driver control and eye-movement behavior. Transp. Res. Part F 5 (2), 123–132. https://doi.org/10.1016/S1369-8478(02)00011-6.

Sen, B., Smith, J.D., Najm, W.G., 2003. Analysis of lane change crashes, No. HS-809 571. United States.

Smaldino, P.E., McElreath, R., 2016. The natural selection of bad science. R. Soc. Open Sci. 3 (9), 160384. https://doi.org/10.1098/rsos.160384.

Shechtman, O., Classen, S., Awadzi, K., Mann, W., 2009. Comparison of driving errors between on-the-road and simulated driving assessment: a validation study. Traffic Inj. Prev. 10 (4), 379–385.

Winkielman, P., Schwarz, N., Fazendeiro, T., Reber, R., 2003. The hedonic marking of processing fluency: Implications for evaluative judgment. Affective processes in cognition and emotion, The psychology of evaluation, pp. 189–217.

Zimmermann, M., Bauer, S., Lutteken, N., Rothkirch, I.M., Bengler, K.J., 2014. Acting together by mutual control: Evaluation of a multimodal interaction concept for cooperative driving. In W.W. Smari, G.C. Fox (Eds.), The 2014 International Conference on Collaboration Technologies and Systems (CTS 2014) (pp. 227–235). Bloomington: IEEE. 10.1109/CTS.2014.6867569.

Zimmermann, M., Fahrmeier, L., Bengler, K.J., (Eds.), 2015. A Roland for an Oliver? Subjective perception of cooperation during conditionally automated driving.