APPLYING THE RESPONSE CODE OF PRACTICE FOR EVALUATION OF DRIVER ASSISTANCE SYSTEMS: HOW THE AGE OF THE DRIVER INFLUENCES PERCEPTION OF STEERING TORQUE SIGNALS

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ABSTRACT: This paper describes the effects of additional steering torque as a haptic signal on the driver-vehicle interaction. Its use for lane departure warning and lane keeping systems is conceivable, for example. For proper signal design with regard to the controllability of driver assistance systems required by the RESPONSE Code of Practice, these signals should be tested on potentially weaker driver groups. This requirement is taken into account here and therefore both learner drivers and older drivers were tested in this real vehicle study on test track. The analyses compare the effect of the signals among these subpopulations with the effect on middle-aged drivers. A total of 30 drivers were investigated and metrics of the driver and vehicle reaction were examined. The results do not indicate that age influences reaction and perception. Neither the reaction times nor the strength of the reactions differ significantly between the age groups.

1 Haptic signals and their use for driver assistance systems

The stark increase in information and assistance features in vehicles has brought with it a constant increase in the number of acoustic and visual signals. The driver's haptic channel is used comparatively little for the transfer of information even though very fast information preparation was proven in many studies. For example, it has been shown that, in comparison with acoustic feedback, haptic information (vibration of the handwheel) to support lane keeping leads to faster correction by the driver when the car is about to leave the lane [1]. Due to the faster correction, a lower maximum deviation of the vehicle from the centre of the lane can be observed (figure 1, left).

Figure 1 on the right shows, however, that signals of different modality lead to the same deviations on average. A closer analysis of the reactions to the applied steering torque clearly shows the weak points of haptic signals: Some test persons interpreted the signals incorrectly and responded by steering in the opposite direction (figure 1, right: Incorrect Strategy). In this case, the consequence is large lateral deviations [2]. This problem underlines how important a good ergonomic design of the haptic signal is.

Unfortunately in almost all of the known studies exclusively developed signal characteristics and scenarios were investigated. This makes it virtually impossible to make a general statement on design recommendations of haptic signals. A systematic investigation of signal characteristics like amplitude or gradient and of situation features like the current steering torque or the steering activity in the initial situation has been missing so far. Before using additional torque for driver assistance systems (e.g. lane departure warning), haptic signals in the vehicle need to be investigated systematically. In addition to signal design parameters, situational and usage contexts need to be taken into consideration in particular.

This paper therefore looks at the effects of directed additional steering torques in the form of haptic signals in the steering. Unlike vibrations, this type of haptic feedback contains direction information and, at the same time, shows effects on the vehicle movements. In the study presented here, the signals were investigated driving straight ahead. Results on the effect of different driving manoeuvres on the driver-vehicle interaction are presented in [3].

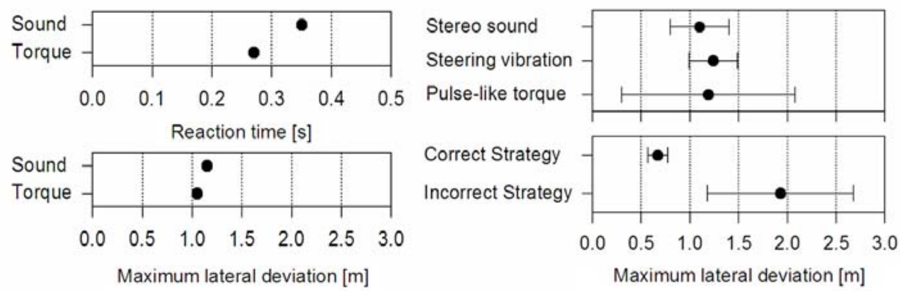

Fig.1. On the left, the comparison of acoustic (sound) and haptic warning (torque) modality according to [1]. At the top right, the comparison of acoustic warning (sound) with two haptic signals (vibration/torque) mod. according to [2]. At the bottom right, distribution of the reaction to pulse-like torque of correct and incorrect steering strategy of test persons.

2 RESPONSE Code of Practice: Controllability of ADAS

In addition to generally understanding the relationships of vehicle and driver reactions when additional steering torque is applied, the maximum allowable interventions should be defined before such signals are used. Therefore it should be ensured that the driver is not distracted from driving by the application of such an additional steering torque and is always able to control the vehicle safely. This central aspect of controllability is covered by the RESPONSE Code of Practice [4]. This agreement of different OEMs defines a process for the design and the assessment of driver assistance systems. Controllability is defined in the Code of Practice as the “likelihood that the driver can cope with driving situations including ADAS-assisted driving, system limits and system failures” [4, p5].

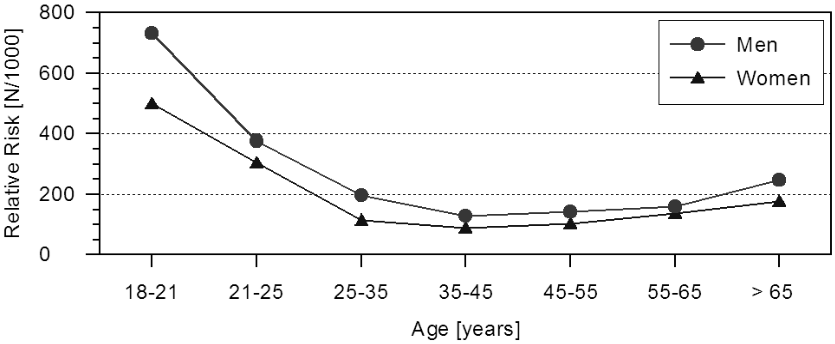

Fig.2. Driving performance-related risk of causing an accident, car accidents for 1000 persons every 1 million kilometres driven, [8; p43].

The Code of Practice proposes alternative approaches to test this aspect. One suggested possibility is testing at least 20 “naïve” test persons. This suggestion is taken into account in this investigation and the effects of the torque signals on normal drivers are looked at. Furthermore potential subpopulations at less or more risk should be taken into consideration according to the Code of Practice. Accident analyses [5; 6] show that the risk of causing an accident is above average, on the one hand, among people over 65 years of age and, on the other, among young drivers under 25 years of age. Figure 2 shows the risk of causing an accident related to age. Among older drivers, the reasons include deterioration in vision, motor functions and the ability to process information although considerable individual differences can be observed [7; 8; 9]. As a rule, older drivers are able to compensate for many of these performance reductions by adjusting their driving style [7, 10]. The reasons for increased accident responsibility among drivers include a lack of driving experience and a high level of risk taking [11; 12]. Younger and older drivers have therefore been considered as driver groups with potential risk in this study.

3 Questions

The study aims to describe the driver’s perception of and reactions to additional steering torque signals. This should provide design recommendations for haptic signals that are transmitted via the handwheel. These results are relevant for the configuration of further steering assistance functions, for example, lane keeping systems or yaw moment compensation [13].

With regard to guaranteeing the controllability of interventions via additional steering torque signals, test situations need to be found that allow useful determination of reasonable interventions and their validation with normal drivers. One central aspect in this study is the investigation of potentially weaker driver groups. If it is shown that the applied torque signals lead to other results among potentially weaker driver groups like new drivers with little driving experience and elderly drivers than with middle-aged drivers, these groups should be given special attention in further investigations. To this end, subpopulations of different ages are confronted with additional steering torque signals of different amplitudes. The effects on the driver and vehicle are then recorded. This study thus makes a contribution to the test design in the investigation of steering system faults as part of the guidelines from the RESPONSE Code of Practice [4].

4 Test design

4.1 Driving scenario

In previous internal investigations into the reaction of drivers to steering torque signals, corners in particular were looked at in addition to the application while driving straight [13]. These driving scenarios have been further developed for this investigation. A bottleneck was selected here as a worst case scenario for driving straight ahead and was simulated using a 2.5m wide track marked with traffic cones. This bottleneck represents, for example, lanes becoming narrower at motorway road works and its size is based on the minimum requirements from road-building guidelines [14]. Since the width of the vehicle used is 1.82m, the bottleneck only allows very small deviations from the lane guidance. The driver therefore needs to be able to correct errors very quickly and precisely.

In addition, torque signals on curves of different radii and during the dynamic manoeuvre “single lane change” were carried out in compliance with the guidelines from the ISO standard [15]. These measurements are not covered here. See [3] for the comparison of the driving manoeuvres. The driving situations were performed in an oval in a fixed order (figure 3). The driving speed was set at a constant 80km/h using a cruise control system. The task for the driver was to drive through the four scenarios without hitting the cones or leaving the lane in the curves. While driving through the scenarios an additional steering torque was applied. This force resulted in a movement of the handwheel the driver had to cope with.

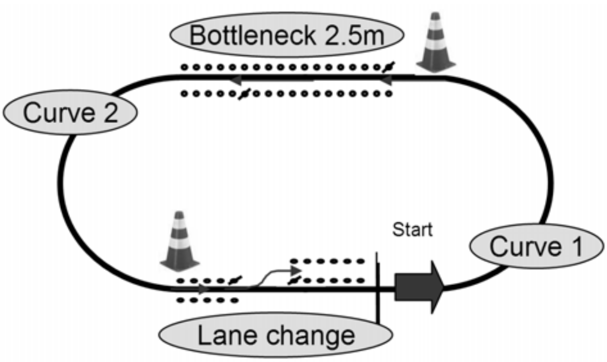

Fig.3. Realised driving situations on the test course.

4.2 Variation of additional steering torques

Additional moments with four different amplitudes are set within the different driving situations. As regards, the amplitude levels, 0<A<B<C applies. The additional signals with amplitude 0 were integrated in the procedure to provide a baseline measurement. No additional torque was applied, a measurement was

simply triggered in the respective situation. All depicted torque signals were repeated three times and randomly distributed to the right and left. The order was completely random among the test persons.

The torque signals were held up to approx. 2s after triggering. The reduction is very slow so that the driver is not confronted again with a fast change in torque. The test persons are asked for an assessment immediately after completion of the steering torque signal. The effects of the additional moment were assessed with the aid of the disturbance assessment scale [16] (figure 4). Five categories are distinguished on the scale. The test persons made the assessment in a two-stage procedure using a scale with a total of 11 stages.

4.3 System setup and investigated sample population

A VW Passat B6 equipped with measuring instruments was used for the test. In the test vehicle, it was possible to apply additional steering torques using modified control unit software for the electromechanical power steering. The investigator accompanied the tests in the front passenger seat and triggered the additional torque signals invisibly for the test persons during the test drive.

As the evaluation of the torque signals was to be made by normal drivers, participants were sought who had no experience in the development of driver assistance systems. 30 test persons, including 22 men and 8 women, took part. In addition to 16 drivers between 25 and 55 years (m=38.12; sd=5.24), seven participants between 18 and 25 (m=20; sd=1.92) and seven persons over 55 years (m=66.83; sd=6.43) were investigated. The oldest participant was 78 years old at the time of the test. The average distance driven was for participants from 25 to 55 years 16063km/year (sd=6875), for under 25 years 17143km/year (sd=4298) and over 55 years 15250km/year (sd=6364).

4.4 Measuring variables and data processing

The recorded physical driving data is filtered (5Hz low pass) and corrected for offsets. The triggering and the respective vehicle statuses are checked during data processing. 613 measurements with applied additional steering torques were used in the analyses. Minimums and maximums of the steering and vehicle reactions are calculated according to the application of the additional torque. The maximum handwheel rate after the first maximum of the handwheel angle is used as a characteristic value for the strength of the driver reaction (figure 4). As it is not the level, but more the change that is relevant for the driver, for the yaw rate the span was calculated as the difference between minimum and maximum within two seconds after the torque signal was triggered. The calculated characteristic values are combined with the evaluations. The average values are used in the analyses for the repeated faults. For all steering inputs and vehicle reactions a smaller value indicates a better coping of the situation. Due to the experimental design, Split-Plot ANOVAs with repeated measurements are used for the statistical analysis. The amplitude of the additional torque is used in the analysis as within subject factor, the age group as between subject factor. The post-hoc testing of different factor levels is performed using LSD tests.

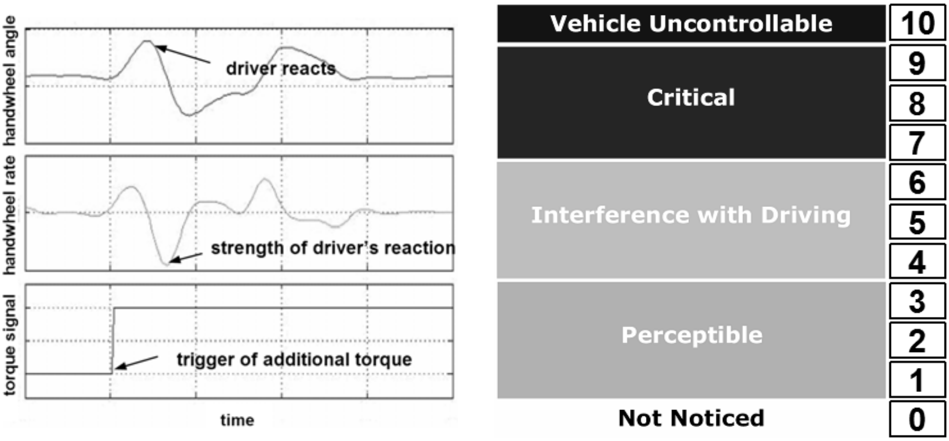

Fig.4. Time pattern of target additional torque, handwheel angle and speed (left). Disturbance rating scale according to [16] (right).

5 Results

The following results show the effects of different amplitudes of the additional steering torques. The direct effects of the torque on the steering as well as the time and strength of the driver reaction are taken into consideration. In terms of the dynamic reaction of the vehicle to the additional torques and the subsequent driver entries, the yaw reaction is analysed and set in relation with the subjective assessments. The analyses compare the different age groups.

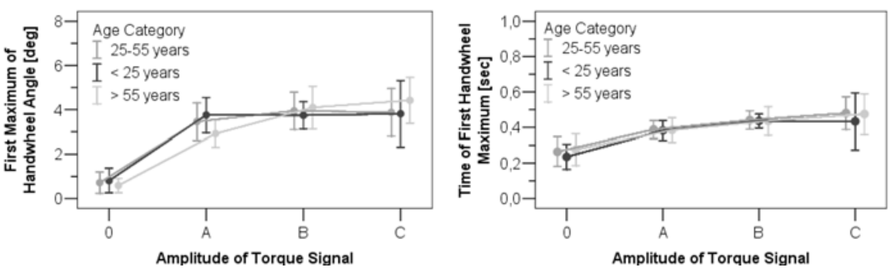

Fig.5. First maximum of the handwheel angle (left) and its time (right) per age level depending on the amplitude of the torque signal.

Figure 5 shows the effects of the additional steering torque on the first maximum of the handwheel angle. For all amplitudes greater than 0, an average movement of the handwheel of 3.77deg results due to the torque application. In the following Split-Plot ANOVAs, only the amplitudes A, B and C are taken into consideration. Incorporating the baseline amplitude 0 is not useful since the effect strengths should be illuminated in the different levels. With regard to the influence of the amplitude of the steering torque, there is a greater handwheel movement at the amplitude B and C compared with A ($p=0.011$; $\eta^2=0.149$; LSD post hoc Tests: $p_{A\text{-}B}=0.002$; $p_{A\text{-}C}=0.018$; $p_{B\text{-}C}=0.657$). This shows that up to a certain amplitude, the effects on the handwheel angle rise. At amplitudes B and C, the signal is compensated by the driver after the same handwheel movement for the signals used here. It cannot be presumed that there are differences between the age groups (p=0.984). Figure 5 (right) shows the reaction time by the time of the first maximum of the handwheel angle after application of an additional moment. This maximum marks the time when the driver is actively intervening to the applied torque. As regards the speed of the reaction, no difference between the age groups can be found here (p=0.714). Younger and older drivers react to the additional torque signals applied here on average equally fast after 431ms. The reaction time of amplitude level A to the two other levels B and C rises significantly here ($p=0.002$; $\eta^2=0.201$; LSD post hoc Tests: $p_{A\text{-}B}=0.003$; $p_{A\text{-}C}=0.001$ $p_{B\text{-}C}=0.334$). As for the higher amplitudes with a limited slope it takes more time until the signal has inclined until the desired amplitude is reached, it can be presumed that the reason for this longer reaction time is due to this longer inclination and not to slower driver response in these cases.

The severity of the driver reaction is described using the maximum handwheel angle rate after the first maximum of the handwheel angle. Figure 6 shows this maximum of the handwheel angle rate on the left-hand side. The observed driver reactions are well below 100°/s on average. These values speak for a quite slow and controlled reaction and support the assumption that the additional steering torque signals presented here were easy to control by the driver. The severity of the reactions is not distinguished between the age groups (p=0.410). At amplitude A, lower values occur compared with B and C ($p=0.001$; $\eta^2=0.214$; LSD post hoc tests: $p_{A\text{-}B}=0.005$; $p_{A\text{-}C}=0.002$; $p_{B\text{-}C}=0.100$). The strength of the yaw reaction shown on the right in figure 6 behaves in a similar way: Here too, there is no difference between the age groups (p=0.496). A greater amplitude leads, however, to greater yaw reactions ($p<0.001$; $\eta^2=0.625$; LSD post hoc tests: $p_{A\text{-}B}=0.004$; $p_{A\text{-}C}<0.001$; $p_{B\text{-}C}<0.001$).

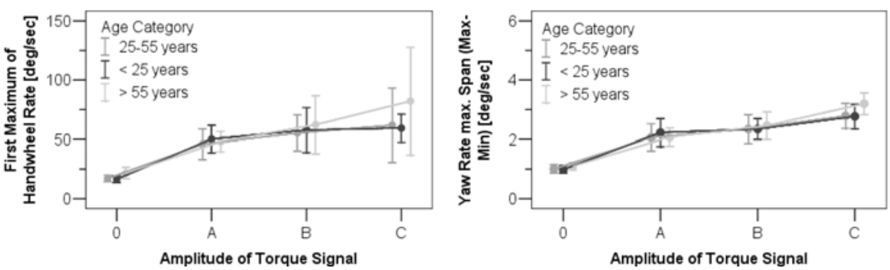

Fig.6 First maximum of the handwheel angle rate after driver intervention (left) and its maximum yaw rate span (right) per age level and amplitude of the torque signal.

The subjective ratings of the disturbance effects in figure 7 on the left shows a significant increase in the ratings with increasing amplitude of the applied additional torque ($p<0.001$; $\eta^2=0.765$; LSD post hoc tests: $p_{A\text{-}B}<0.001$; $p_{A\text{-}C}<0.001$; $p_{B\text{-}C}<0.001$). The assessment of the lane deviation is shown on the right in figure 7. At the greatest amplitude C, the deviation from the centre lane position is rated as greater compared with the lower amplitudes ($p<0.001$; $\eta^2=0.384$; LSD post hoc tests: $p_{A\text{-}B}=0.060$; $p_{A\text{-}C}<0.001$; $p_{B\text{-}C}<0.001$). There are no significant age effects (disturbance rating: p=0.239; lane deviation: p=0.240).

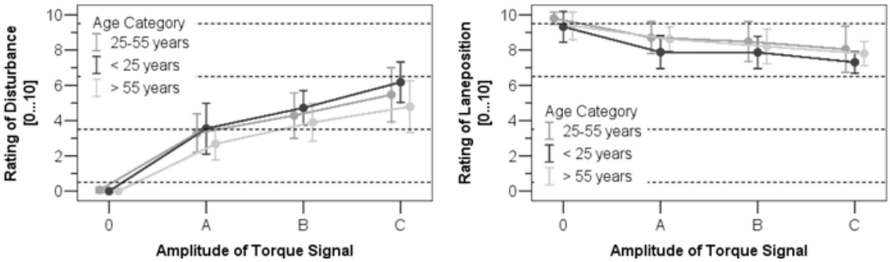

Fig.7. Rating of the effects of the additional torque (left) and the deviation from the lane centre (right) per age level depending on the amplitude of the torque signal.

6 Summary

To summarise, it can be stated that no difference between older and younger drivers can be observed on the level investigated here. However, it should be mentioned that the volunteers who took part in this study tended to be people with an affinity for and who enjoy driving. Drivers with performance limitations, who increasingly face problems on the road, hardly ever volunteer for this kind of driving study. The recruitment of older weaker drivers poses a dilemma that seems impossible to solve for the time being. In the selection for this study, it was important that older participants were taken into consideration.

By investigating younger drivers, we aimed to look into driver experience as a factor. However, the results here do not confirm that little driving experience negatively influences the reaction and perception of additional torque signals. This takes the requirements from RESPONSE into account and includes potentially weaker driver groups in the investigation. It should be expressly stated that the aim was not the identification of a sensitive manoeuvre to differentiate age differences. Moreover the manoeuvre was selected on the basis of ecological validity: It represents a maximum requirement in road traffic with regard to the precision of the lateral guidance. Nevertheless, it can be criticised that these test track scenarios might not cover the full complexity of situations in real traffic.

In the presented study, both older and younger drivers showed the same performance as the middle-aged participants in the set driving task and therefore the results do not indicate that the age is influencing the perception and reaction to steering torque signals. Not least due to the small sample sizes of the subgroups in this experiment, further studies with the same setup are needed for replication.

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