Parametrizing an attention-guiding seating concept for conditionally automated driving

The attention-guiding seat is intended to make conditionally automated driving (equivalent to SAE-Level3) even more user-friendly and comfortable. In particular, the developed concept is intended to facilitate a more intuitive and safer take-over of the driving task for the driver. This is provided by a seat that turns the driver slightly inwards while driving automated, thus supporting comfortable use of the infotainment system or communication with passengers. If the driver needs to continue with the driving task, the seat turns the driver back to the steering wheel. Within the EU-funded HADRIAN-project, the kinematic parameters of this concept are being investigated and a prototype of the seat is being developed for testing in a highly dynamic driving simulator at the Institute for Automotive Engineering (ika) at RWTH-Aachen University.

Cover image: (left) Attention-guiding seat; (right) highly dynamic driving simulator

Research on conditionally automated driving (SAE-Level 3)

Since the entry of UN Regulation 157 in January 2021 into force, vehicles with conditional automation (SAE-Level 3) have been eligible for registration on German roads. When the Automated Driving (AD) Mode is switched on, the vehicle executes the driving task and the driver can pursue non-driving related activities (NDRA). Before a system limit is reached, the driver has to take-over the driving task within a few seconds. The Take-Over Request (TOR) in Figure 2 is initiated by the vehicle.

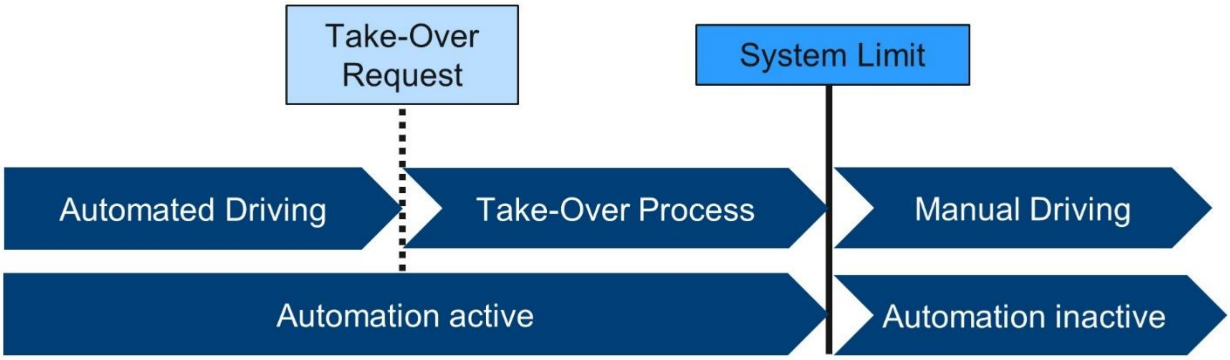

Figure 1: Take-over process for conditionally automated driving (SAE-Level 3)

Today, there is only one vehicle with conditionally automation. In addition to technical challenges, the conception of an intuitive, safe and fast TOR represents a major challenge for car manufacturers. [EUR21] [SAE18], [MER21]

Many NDRA’s, such as watching videos or working, use the sense of sight and the sense of hearing. In his model of multiple resources, Wickens shows a reduced or, in the worst case, even non-existent capacity to receive additional visual and auditory signals when visual and auditory channels are already occupied by other activities. The kinesthetic and vestibular sensory channels are usually not occupied by a secondary task during AD and can comfortably inform the driver to take-over the driving task again. Therefore, using these modalities is expected to improve the TOR, which ultimately also potentially contributes to an increase in the acceptance of AD. Although the TOR process has been intensively investigated worldwide for several years, only a brake jerk has been investigated with regard to kinesthetic and vestibular TOR signals. On the one hand, a brake jerk is a very perceptible signal, but on the other hand, a sudden jerk is also uncomfortable. In addition, a brake jerk is not only noticeable for the driver, but also for other vehicle occupants. [WIC02] [ZHA19], [MEL15] [MEL15]

How the attention-guiding seat works

The attention-guiding seat is a promising option to provide a kinesthetic and vestibular TOR signal. It is based on the hypothesis that the guidance of attention by an externally induced rotation of the seat was already learned in childhood. Kinematically, the rotation is similar to that of an office chair. After the activation of the automation, the seat is slightly rotated towards the center of the vehicle. This new seating position continuously supports the driver's awareness of the current automation mode (Mode Awareness). At the same time, the seating position facing the center of the vehicle facilitates interaction with the infotainment system. When the TOR occurs, the seat turns the driver back to the steering wheel. The resulting kinesthetic and vestibular cue informs the driver by using a low-occupancy modality. At the same time, the orientation of the seat also changes the driver's field of view. The driver's attention should be directed back to the vehicle control elements and therefore back to the driving task.

The attention-guiding seat complements visual and acoustic TOR signals. However, the potential of the attention-guiding seat as a TOR signal has not yet been scientifically investigated. [ECK18]

Kinematic parametrization of the concept

The kinematic parameters have to be defined before the effectiveness of the attention-guiding seat can be examined. As kinematic parameters, the position of the vertical rotation axis and the minimum rotation angle required to achieve reliable Mode Awareness are investigated. The goal is to provide a comfortable rotation in terms of dynamic rotational movement and seating position in automated driving mode. First, the position of the vertical rotation axis and the required angle of rotation are examined. Depending on the position of the rotation axis and the angle by which the seat rotates, the distance between the driver and the steering wheel changes in the rotated seating position.

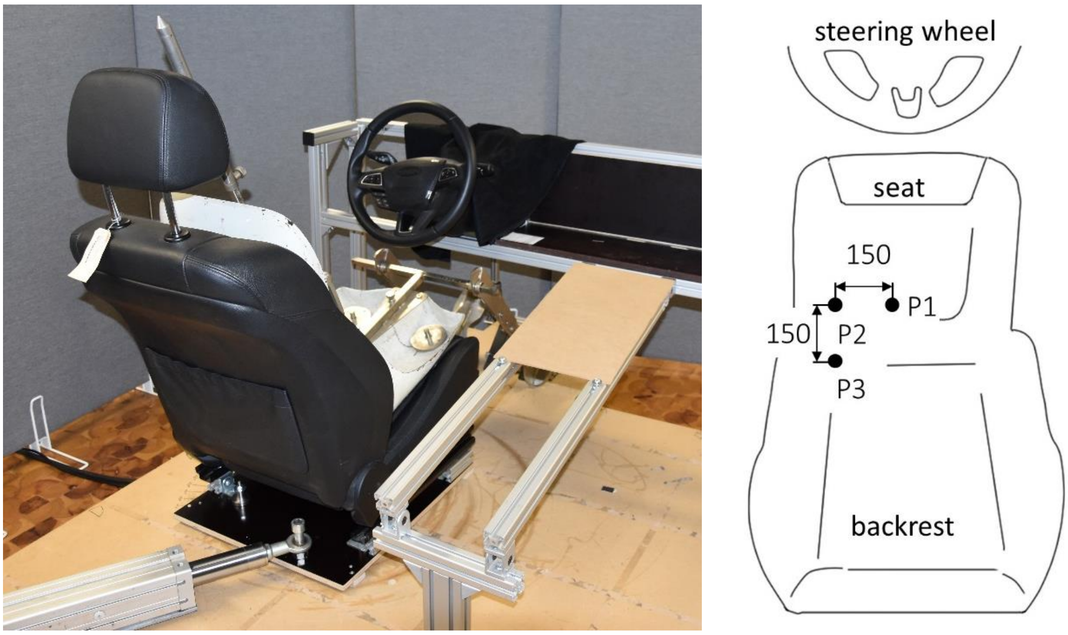

Figure 2: Seating Buck (left); Top view of the position of the vertical rotation axis P1, P2, P3 (right)

In order to investigate kinematic parameters of the attention-guiding seat, the seating buck shown in Figure 2 was built. The seating buck is equipped with a steering wheel, pedals and a center console. The driver's seat is mounted on the black wooden plate, which moves on a base plate by using Teflon-coated stilts. It is possible to choose between three different vertical rotation axes (P1, P2 and P3) by switching a split pin from one position to another. The seat is turned by an electromechanical actuator. Dynamic parameters such as acceleration and speed can be adjusted.

The rotation around the vertical axis in position P1, see Figure 3, conveys a familiar movement, known for example from office chairs. During rotation, the seat's backrest moves towards the door panel, which must be considered when implementing the concept in a vehicle. With a rotation around P1, the right half of the body is moved away from the steering wheel while the left half of the body is moved towards the steering wheel. The seat's maximum rotation is reached before the driver's legs reach the centre console and ultimately offers less space for the driver and potentially restricts comfort in the rotated position.

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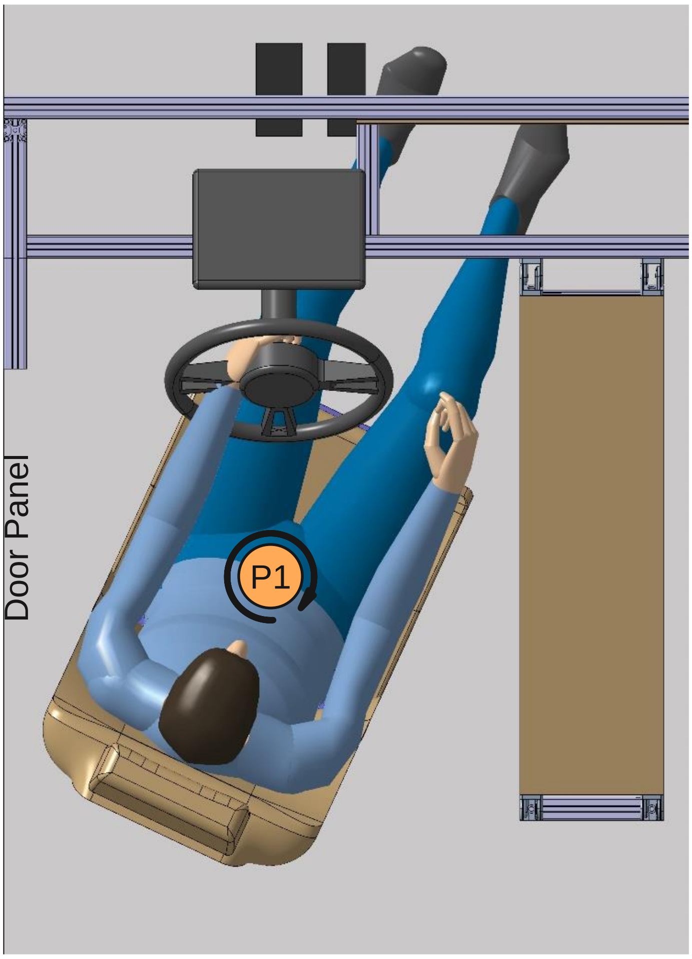

Figure 3: Rotation around the centered rotation axis in P1

The rotation around the vertical axis in position P2, shown in Figure 4, is shifted longitudinally 150 mm towards the left door panel of the vehicle in relation to P1, moving the driver away from the steering wheel during rotation. This type of rotational movement results in a greater distance between driver and steering wheel as well as the pedals. This may have a positive effect on the perception of space. Nonetheless, while rotating around P2, the seat's backrest also moves towards the door panel, and similar to P1, must also be taken in consideration when implementing the concept in a vehicle.

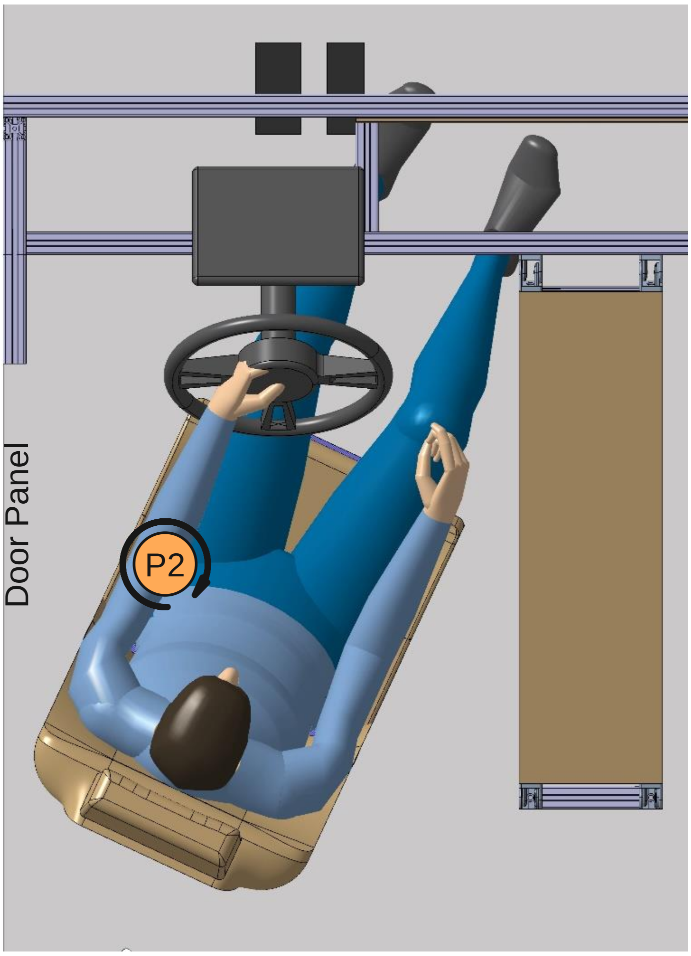

Figure 4: Rotation around the vertical rotation axis in P2

A third possible position for the seat's rotation centre, represented in Figure 5 in position P3, is achieved by shifting the split pin longitudinally 150 mm towards the rear of the vehicle, in relation to the position of P2 presented in Figure 4. This retracts the driver lightly away from the steering wheel yet additionally towards the centre of the vehicle. Compared with the rotation around P1, there is a greater distance between the driver and the steering wheel. In addition, the feet are moved noticeably away from the pedals and further towards the center of the vehicle compared to the rotation around P2, thus providing more legroom. Another advantage of this center of rotation is the smaller space requirement towards the door panel. The choice of a transverse offset for P2 and P3 compared to P1 seems promising in terms of comfort as well as feasibility considering the vehicle package.

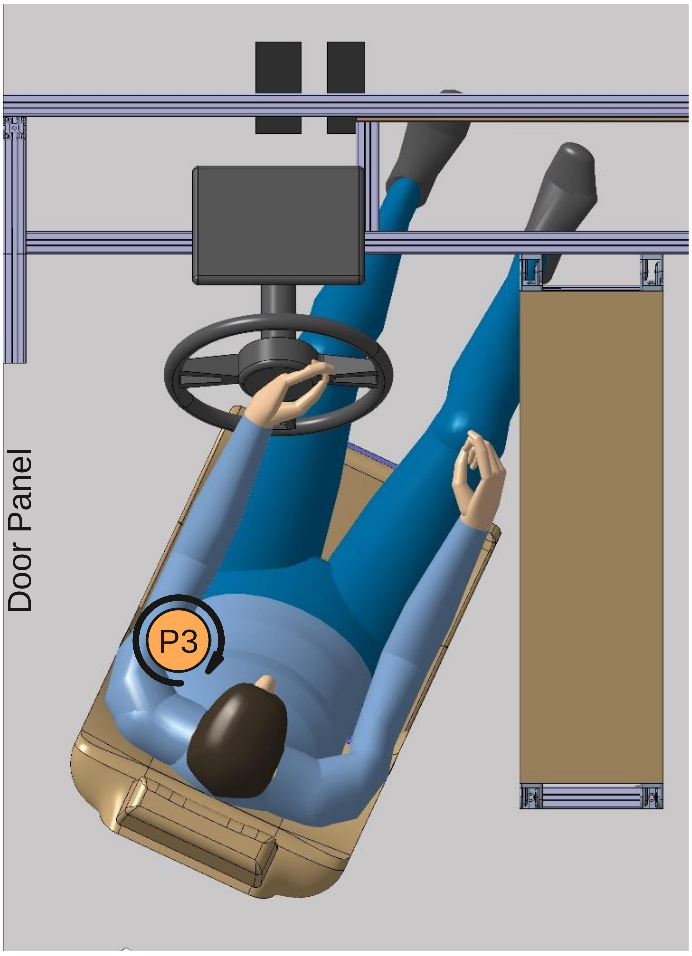

Figure 5: Rotation around the vertical rotation axis in P3

An exploratory expert study was conducted to investigate the kinematic parameters. The following research questions were addressed:

- What is the required minimal turning angle at which the driver can clearly distinguish between the manual and the automated driving position?
- Is the kinesthetic cue provided by the rotation of the driver seat perceived as a take-over cue?
- Which position of the vertical rotation axis (P1, P2 and P3) appears comfortable to the driver?

Thirteen experts tested the different rotation axis positions as well as the different rotation angles of 5°-20° in steps of 5° each. The positioning of the rotation axes was randomized to avoid habituation effects. The information provided by the experts during the experiment was documented in a questionnaire. The evaluation was based on a Likert scale from 1 (poor) to 5 (good). The experts come partly from the engineering and partly from the psychological department and are experienced development in take-over concept development.

Evaluation of the results

A positive rating for mode awareness and perceptibility of the TOR signal was assumed from the threshold value of 4 on the Likert scale. In comparison with P1 and P3, the rotation around the vertical axis in position P2 is rated highest by 92% of the experts. As the evaluation shows, the rotation is clearly perceptible as a takeover signal even at quite small angles of rotation. From a rotation angle of 15°, both the takeover signal and the mode awareness are rated with a mean of 4.5 points for the rotation in P2.

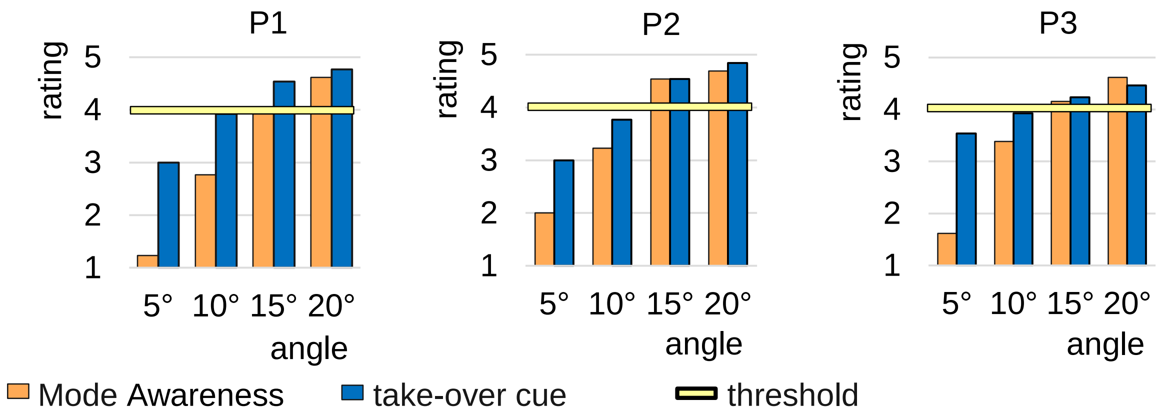

Figure 6: Evaluation of the positions of the rotation axis and rotation angles

In the further comments, four experts stated that the attention-guided seat works very well as a kinesthetic signal. For the perception of the TOR signal, the angular acceleration seems to be more crucial than the amount of the rotation angle. [JOC21]

Conclusion

Conducting and evaluating the expert study provides new insights around the attention-guiding seat and supports answering the research questions. Respondents rated the attention-guiding seat as a useful human machine interface. The kinesthetic and vestibular takeover signal was clearly perceived even at small turning angles. However, reliable mode awareness is only achieved at a larger rotation angle of about 15°. The rotation around P2 or P3 is rated higher than the rotation around P1. Comments suggested that this is related to the additional legroom gained in P2 and P3. The rotation in P2 was rated best, which could be related to the increased distance to the steering wheel and thus more space and roominess for the driver. As a next step in development, the results of this study will be used to build a high fidelity prototype of the attention-guiding seat. With the help of this prototype, the potential of the

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