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DOI
10.1016/j.trf.2021.04.019

Publication date
2021

Document Version
Final published version

Published in
Transportation Research Part F: Traffic Psychology and Behaviour

Transportation Research Part F 80 (2021) 399–423

Contents lists available at ScienceDirect

Transportation Research Part F

journal homepage: www.elsevier.com/locate/trf

What makes a good driver on public roads and race tracks? An interview study

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ARTICLE INFO

Article history:
Received 14 August 2020
Received in revised form 26 April 2021
Accepted 26 April 2021

Keywords:
Driver assessment
Racing
Information processing
Situation awareness
Posture

ABSTRACT

Future vehicles may drive automatically in a human-like manner or contain systems that monitor human driving ability. Algorithms of these systems must have knowledge of criteria of good and safe driving behavior with regard to different driving styles. In the current study, interviews were conducted with 30 drivers, including driving instructors, engineers, and race drivers. The participants were asked to describe good driving on public roads and race tracks, and in some questions were supported with video material. The results were interpreted with the help of Endsley's model of situation awareness. The interviews showed that there were clear differences between what was considered good driving on the race track and good driving on the public road, where for the former, the driver must touch the limit of the vehicle, whereas, for the latter, the limit should be avoided. However, in both cases, a good driver was characterized by self-confidence, lack of stress, and not being aggressive. Furthermore, it was mentioned that the driver's posture and viewing behavior are essential components of good driving, which affect the driver's prediction of events and execution of maneuvers. The implications of our findings for the development of automation technology are discussed. In particular, we see potential in driver posture estimation and argue that automated vehicles excel in perception but may have difficulty making predictions.

1. Introduction

More and more automation systems are being developed that take over specific subtasks from the driver. Examples include adaptive cruise control that can approach curves like a human driver does (Zhang, Xiao, Wang, & Li, 2013), automated lane changing that imitates lane changing by a human (Do et al., 2017), and automation that appears to have "mastered the more human-like driving skill of crawling forward at a stop sign to signal its intent" (Niedermeyer, 2019).

The level of automation will increase in the future. This implies new challenges, where the automated car may have to exhibit safe human-like behavior in a variety of road and traffic conditions. Recent driving behavior models can generate human-like behavior in a multitude of conditions (Guo, Kidono, Terashima, & Kojima, 2018; Shin, Kim, Yi, Carvalho, & Borrelli, 2018; Wang, Sun, Li, & Zhang, 2020). For example, a model by Kolekar, De Winter, and Abbink (2020) operationalized Gibson and Crooks's (1938) field of safe travel and can display human-like behavior, including driving with an appro-

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https://doi.org/10.1016/j.trf.2021.04.019
1369-8478/

priate margin from parked cars and cutting curves (i.e., a slight out-in-out line, which increases the effective turn radius and may therefore increase safety).

Automation that behaves in a human-like manner is expected to be better accepted by drivers and other road users as compared to more rigid or non-adaptive forms of automation (Griesche, Nicolay, Assmann, Dotzauer, & Käthner, 2016; Scherer et al., 2015). A problem that researchers are now facing is that, for complex driving tasks, such as driving a series of curves or moving through heavy traffic, it is not clear what are criteria of good human driving behavior. Moreover, what is good driving behavior depends on the target of the driver: A driver can aim to drive comfortably, but can also choose to adopt a sporty driving style.

When extrapolating sporty driving to its extreme, one may consider a race driver who tries to drive as fast as possible on a race track. Several researchers have developed algorithms for automated racecar driving (Betz et al., 2019; Muñoz, Gutierrez, & Sanchis, 2010; Wymann et al., 2000) and for calculating optimal racing lines (Betz et al., 2019; Casanova, 2000; Gundlach & Konigorski, 2019; Talvala, Kritayakirana, & Gerdes, 2011). Until now, automated systems have not been able to drive lap times as fast as human drivers (Belton, 2019; Hermansdorfer, Betz, & Lienkamp, 2020; Knight, 2017). It would be interesting to investigate which information-processing strategies human race drivers use to drive fast and which behaviors make a race driver a good race driver. Such knowledge may prove helpful in developing automated driving systems that can adjust their driving style to the driver's preferences. Furthermore, knowledge about racing driving might prove beneficial when it comes to emergency situations. Like racing driving, emergency situations involve large lateral accelerations while requiring that vehicle control remains stable and that stress of the driver, passengers, and drivers of surrounding vehicles is minimized to the extent possible. We do not insinuate that automated vehicles should break the speed limit or that automated vehicles should accelerate to resolve conflicts (although these options have been proposed, see e.g., Goodall, 2016a, 2016b; Vinkhuyzen & Cefkin, 2016). We also do not suggest that fast driving equals safe driving; in fact the opposite is true (Elvik, 2013; Williams & O'Neill, 1974). However, we do suggest that automated vehicles development may benefit from knowledge about how professionals are able to control their vehicle in a safe manner while driving fast.

Criteria for good human driving behavior may help the development of automated driving systems and be of value for the automated training, monitoring, and assessment of human driving behavior (e.g., Sahayadhas, Sundaraj, & Murugappan, 2012; Schacher & King, 2019). For example, the automated driving systems in the car could calculate normative human behavior and—if the driver is driving manually—monitor the driver and make adjustments or provide feedback where necessary. In this way, cooperation between human and machine arises, where the automation supports the human when needed most (e.g., Cabrall, Janssen, & De Winter, 2018).

Interviews are a powerful method because they enable researchers to find out the thoughts and motivations of drivers, something that is difficult when looking at vehicle performance data only. A prior interview study by Dreger, De Winter, and Happee (2019) examined the information processing strategies of drivers of heavy goods vehicles while merging onto a highway. The interviews revealed, amongst others, that retaining situation awareness (e.g., global traffic analysis, looking in the mirrors) and cooperative strategies with other road users are important determinants of safe driving. In an interview study by Day, Thompson, Poulter, Stride, and Rowe (2018), it was discovered that beginner drivers develop smoother and less attention-demanding vehicle control, greater situation awareness, and better perception of their vehicle's spatial dynamics within the first three months after acquiring a driving license. However, with increasing experience and better vehicle handling skills, they start to drive more aggressively and test the vehicle's limits, especially when driving with same-age peers. In another interview study, it was also mentioned that, regardless of the driver's age, perceived pressure from other drivers contributes to dangerous driving behavior (Fleiter, Lennon, & Watson, 2010).

1.1. Study aims and approach

In summary, for the development of automated vehicles, it is important to determine criteria of good driving. Accordingly, this research aimed to determine these criteria, distinguishing between driving on public roads and driving on race tracks.

In the current study, the choice was made to perform interviews with three groups of drivers: driving instructors (who are likely to be highly skilled and able to identify criteria for good and safe driving behavior), engineers (who may be able to reflect in a more technical manner on criteria of driving behavior), and race drivers (who can be assumed to know how to characterize a fast driver). Video material was used during the interviews to help the participants visualize the driving environment and possible actions. The scenarios addressed involved public roads and race tracks.

The above literature suggests that good and safe driving depends not only on vehicle maneuvering skills. It can therefore be assumed that standard performance criteria, such as criteria describing whether a driver does not swerve on the road (as can be operationalized using the well-known standard deviation of lateral position [SDLP] metric; Verster & Roth, 2011), are not sufficient. Especially for complex driving tasks, the perception of hazards and the decision-making behavior of the driver will have to be considered (Horswill & McKenna, 2004; Vlakveld, 2011).

Since many decades, traffic psychologists and behavioral scientists have been working on models that capture the essential information-processing components of driving, and have identified such essence in terms of 'low-level' control versus 'higher-level' maneuvering and planning (e.g., Donges, 1982; Michon, 1985). Another suitable framework appears to be Endsley's (1995, 2000) well-known model of situation awareness. According to Endsley's model, operators, such as drivers, perceive the environment to understand the situation, anticipate the future, and make decisions that determine driving actions/performance. Based on the fact that Endsley's and Donges's models are influential in manual and automated driving

research (e.g., Damböck, 2013), the present study uses a combination of these models to help categorize the interview responses.

2. Methods

2.1. Participants

Thirty-one participants, consisting of three different expert groups, took part in this study. One participant was excluded due to a bad audio recording. The three expert groups were normal driving instructors, Porsche engineers, and Porsche race drivers from the ADAC GT Masters series and Porsche Mobil 1 Supercup series. Each group consisted of 10 participants. Instructors of driving schools (not affiliated with Porsche) from the Stuttgart area and Porsche racing and chassis engineers were contacted via e-mail and asked if they were willing to participate. The recruitment of the race drivers and the organization of dates and locations for their interviews was managed by the Porsche Motorsports Department. All participants signed a consent form. The research was approved by the Human Subject Research Ethics Committee of the TU Delft and the Porsche works council, as well as the Porsche data protection officer.

2.2. Procedure

Semi-narrative face-to-face interviews were conducted. The first author conducted all interviews in an office environment in which only the participant and the interviewer were present. The interview was recorded with a dictating machine. Twenty-three interviews were conducted in German and seven in English (one engineer and six race drivers). The interview took approximately 60 min per participant.

2.3. Questionnaire

The participants first completed a paper-based questionnaire, which asked for individual characteristics, such as driving experience and experience as a professional driving instructor. More specifically, it asked for age category (Q1), the age when they learned to drive a vehicle (i.e., not necessarily the age they received their driving license; Q2), how frequently they drive on public roads (Q3), years of experience as a driving instructor (Q4), as well as years of experience in racing sports and racing-related practice (Q5, Q6, and Q7).

2.4. Interview

The authors developed a semi-structured interview with seven open-ended questions (Q8–Q14), to be asked and answered orally. It was decided to use open-ended questions, because open-ended offer the opportunity to discover the interviewee's opinion thoroughly and from multiple perspectives. The authors iterated the interview questions three times based on observations made during pilot interviews conducted with two participants.

The interview questions aimed to yield criteria for assessing driver performance on public roads and race tracks. Q8 was a question about good driving behavior in general, used as an opener and introduction to the topic. Q9 asked for the main criteria for being fast on a race track, whereas Q11 targeted safety on public roads.

In the above questions, the participants reported their perspective from their driver's point of view. In Q10 and Q12, the interviewees imagined themselves in the role of an instructor and were asked to point out the greatest opportunities for improvement in driving on race tracks and public roads.

Furthermore, to encourage the interviewees to think of detailed answers, the perspective of the question was changed between that of a driver and that of a co-driver. Accordingly, Q13 placed the participants on the passenger seat. Additionally, not only the driver's role was modified, but also the imagined location: Q14 required the participants to imagine themselves as a pedestrian standing next to the road and assessing the driving by observing the vehicle from the outside. Several follow-up questions for questions Q8–Q14 were prepared for generating deeper insights. These questions discussed the differences between a good and an average driver, traffic scenarios that are suitable for assessing the driver, and how assessment criteria can be recognized from a driver's behaviors, actions, and control inputs. The moment and the frequency of using follow-up question were left to the discretion of the interviewer.

In Q15, participants provided an assessment of driver performance shown in video clips. Besides rating driver performance on a Likert scale, participants were asked to verbally provide their thoughts while watching the video clips, similar to the think-aloud method. Two clips showed driving in a town, two clips showed driving on a curvy rural road, and six clips showed driving on a race track. To generate the clips for the in-town and rural road environments, two Porsche employees recorded their way to the office and back home, driving a Porsche Panamera. The first in-town video clip showed a five-minute drive during morning rush hours in Stuttgart. The second in-town clip and the two rural road clips were recorded in the Harz region (Germany), and each lasted around 20 s. The five-minute video clip included frequent interactions with other road users and infrastructure (e.g., stopping behind a leading/parking vehicle or approaching traffic lights). In the 20-second in-town clip, the driver had to stop behind a vehicle making a right turn. The rural clips depicted sporty curve driving,

the first with one leading vehicle in view, and the second with an overtaking maneuver. The racing video clips were selected from the Most track (Czech Republic) with a Porsche Panamera and the Porsche test track in Weissach (Germany) with a Porsche 911 GT3. The race track videos showed no other drivers. Half of the race-track clips represented a single curve, the other half a combination of curves. The clips included two synchronized camera perspectives: One presenting the driver's view through the windshield and the other presenting the driver's behavior. In addition, a transparent dashboard layer was added, showing the vehicle control inputs of the steering wheel, gas, and brake pedal, as well as position on track, acceleration, gear, speed, and RPM. Examples of the video clips for the three environments are shown in Fig. 1. Table 1 provides an overview of the questions the participants were asked.

2.5. Main categories and subcategories

The main categories that were used for coding the interview responses were based on a combination of Endsley's (1995, 2000) model of situation awareness and the hierarchical driving model of Donges (1982, resembling the subsequent model of Michon, 1985), as illustrated in Fig. 2. It is essential for a driver to perceive relevant elements of the environment. The driver's 'perception ability' represents a main category, corresponding to Endsley's first level of situation awareness. The second category, 'planning ability' includes the 'maneuvering level' of Donges, which determines the desired trajectory and speed, but also encompasses 'gaining a comprehension of the current situation' (second level of situation awareness), 'anticipating future states' (third level of situation awareness), and the 'decision' of the Endsley's model. In the model of Donges, the execution of decisions via the pedals, steering wheel, and the gear lever is called the 'stabilization level', whereas Endsley named it 'performance of action'. The corresponding main category in this work was named 'stabilization ability'. Finally, in Endsley's model, all model components are affected by individual factors, such as the driver's level of experience and stress. In summary, the following main categories were used for assessing driver performance: (1) individual factors, (2) perceptual ability, (3) planning ability, and (4) stabilization ability.

2.6. Analysis of responses

- The interviews were transcribed word by word.
- A draft of categories was inductively developed from the interview material (Mayring, 2000). In this process, the authors used standard text processing steps, such as underlining/highlighting pieces of text, writing notes, searching for keywords in the text, and scrolling to different text passages.
- The draft categories were aligned with theoretical concepts from the literature (e.g., Donges, 1982; Endsley, 2000; Michon, 1985; Rasmussen, 1983). A combination of Endsley's model of situation awareness and Donges's three-level model of the driving task was developed (Fig. 2). The decision for a combined model was based on the draft categories and the observation that a combined model could encompass the entire driving task.
- The transcripts were reread to refine the categories into main categories and subcategories. Furthermore, for each subcategory, a description was created.
- A first coding round of the interviews was performed. Based on this coding, the subcategories were refined, and rarely used ones were merged. Table 2 shows the main categories and their corresponding subcategories. Detailed descriptions of the allocation criteria for the subcategories are provided in Appendix B.
- A second coding round was performed, where the refined coding system was applied to the complete transcribed interviews (Schmidt, 2004). The online tool QCAmap (www.qcamap.org) was used.
- The number of times a subcategory was mentioned per respondent was counted. Multiple mentions (i.e., quotes) of a subcategory by the same respondent equaled a frequency of 1.
- Finally, illustrative quotes of each subcategory were selected for presentation in this paper.

3. Results

3.1. Demographics and experience

Table 3 shows the results of the demographic questions. Of the 30 participants, 28 were male and 2 were female. There were one, eight, nine, eight, and four participants in the range of 18–20, 21–30, 31–40, 41–50, and 51–60 years of age, respectively. The average age when participants learned to drive was 13.1 years. The race drivers (9.2 years) started to drive earlier than the engineers (15.5 years) and the driving instructors (14.6 years). The median of the driving instructor experience was within the range of 11–20 years. Four race drivers indicated that they offer racing instruction sessions. The interviewees rated their racing sports experience as 3.5 on average on a 5-point Likert scale (race drivers: 4.4, engineers: 3.7, driving instructors: 2.9).

A few participants did not provide an answer to Q6 and Q7, because they had difficulty estimating their experience. More specifically, 8 race drivers, 9 engineers, and 10 instructors' answered Q6a. Twenty-three participants (8 race drivers, 7 engineers, and 8 instructors) answered Q6b, whereas two values of the instructor group were missing for Q7b and Q7c as well as one of the race drivers for Q7c.

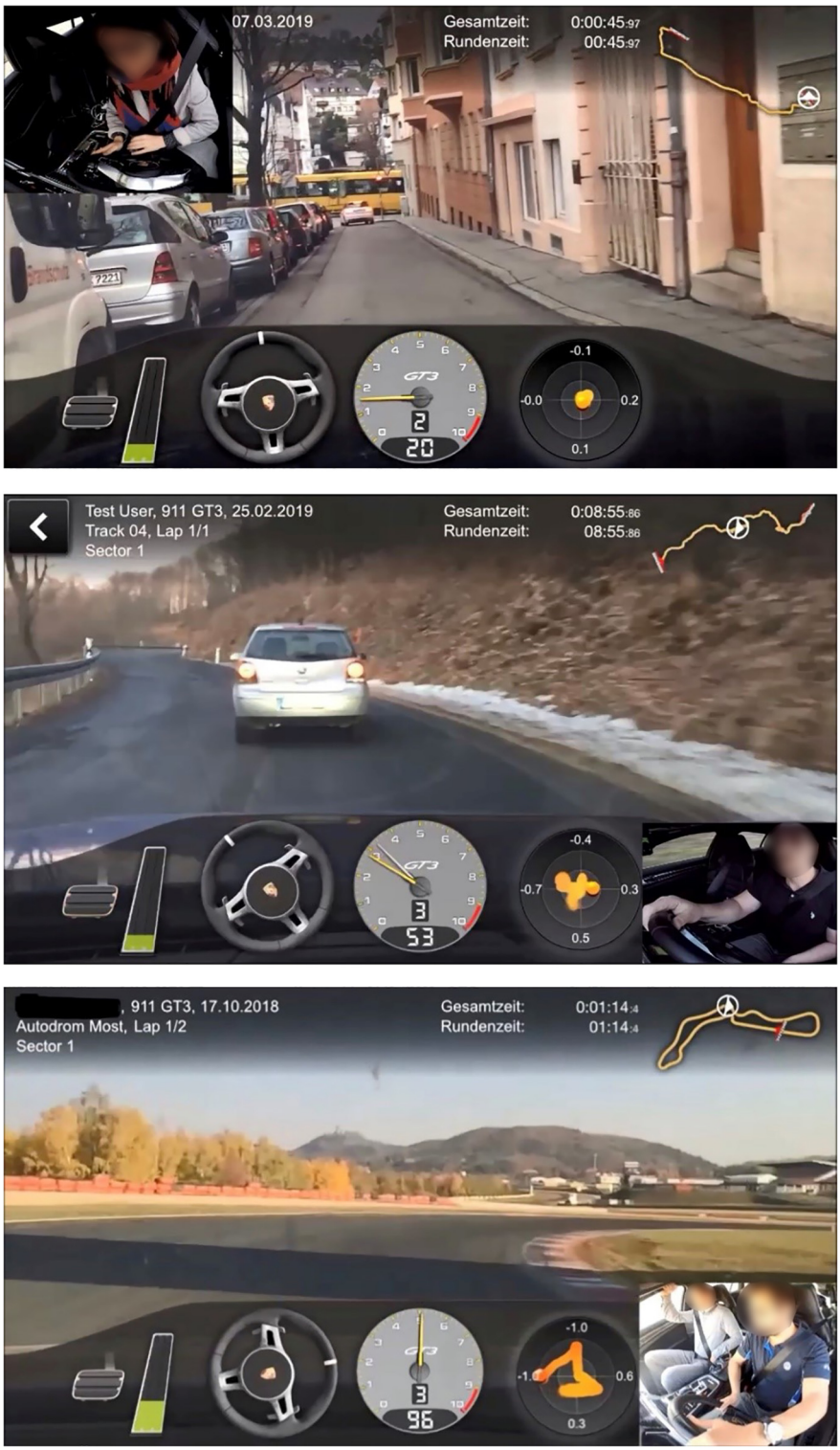

Fig. 1. Examples of in-town, rural road, and race track video clips. For this paper, the faces were blurred.

The results below reflect the participants' responses concerning the characteristics of a good driver and safe driver on public roads, and of a good and fast driver on race tracks. The appendices contain results for the questions that do not relate to these themes (e.g., driving performance ratings, Q15a). After having selected illustrative quotes for each subcategory, the

Table 1
Overview of the questionnaire.

Demographics and Experience	
Q1	Age range
Q2	Age at which the participant learned driving
Q3	Frequency of driving on public roads
Q4	Years (range) of working as a driving instructor
Q5	Experience in racing sports (5-point-Likert scale: None – Very high)
Q6	Participation in racing-related training sessions a) 5-point Likert scale: Never – Very often b) Days per year
Q7	Driving on race tracks or similar courses a) 5-point-Likert scale: Never – Very often b) Days per year c) Percentage of training sessions
Assessment	
Q8	What makes a good driver?
Q9	How do you drive fast on a race track?
Q10	Depending on the driver's level, what has the greatest potential to improve lap times on race tracks.
Q11	How do you drive safely on public roads (in the city and rural roads)?
Q12	Depending on the driver's level, what has the greatest potential to improve safety on public roads?
Q13	a) Imagine you are a passenger on a rural road – What criteria can be used to determine whether the driver is a good or bad driver? b) Imagine you are a passenger on a race track – What criteria can be used to determine whether the driver is a good or bad driver?
Q14	a) Imagine you are standing next to a road – What criteria can be used to determine whether the driver is a good or bad driver? b) Imagine you are standing next to a race track – What criteria can be used to assess whether the driver is a good or bad driver?
Follow-up Questions	**For questions**
What is the difference between a good and an average driver?	Q8
By means of what driving scenarios would you make an evaluation?	Q8–Q14
How can the assessment criteria be seen at the driver's behavior, actions, and control inputs?	Q8–Q14
Video-based Assessment of Driver Performance	
Q15	a) Please rate the performance in the videos (5-point Likert scale: Very bad – Very good) b) Please identify errors/violations, and state the reasons for them 1) In-town scenarios 2) Rural road scenarios 3) Race track scenarios

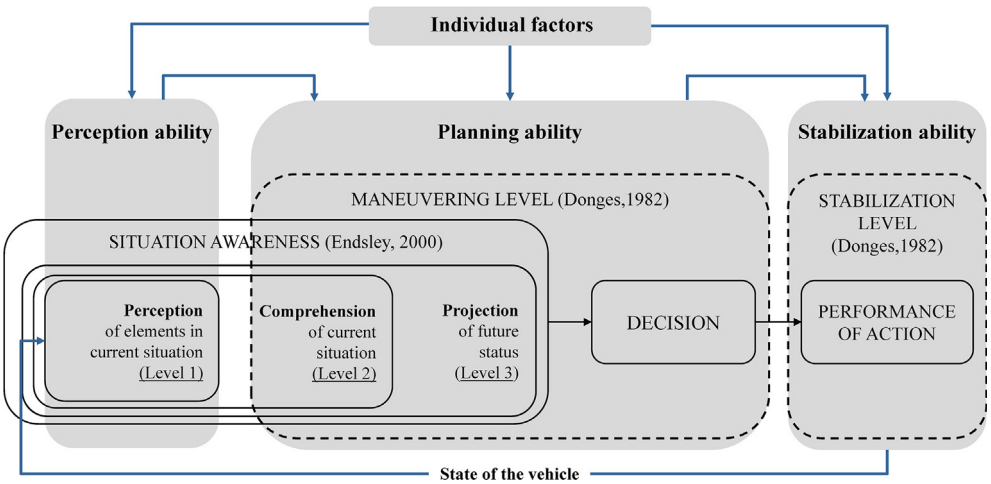

Fig. 2. Information processing model depicting the main driving ability components. This model was based on Endsley's (2000) model of situation awareness and the maneuvering and stabilization levels of Donges's model (1982). The arrows indicate categories that affect each other.

Table 2
Overview of the main categories and their corresponding subcategories.

Individual factors	• Being experienced • Not being overloaded/stressed • Having appropriate goals & motivations • Having a realistic self-assessment • Having a proper driving attitude • Knowing the vehicle's capabilities
Perception ability	• Showing an appropriate body position • Having adequate eye-gaze behavior • Being attentive • Perceiving the vehicle's response
Planning ability	• Appropriately assessing the traffic situation • Showing anticipative driving behavior • Choosing an appropriate line • Following the traffic rules • Avoiding the vehicle's and personal limits
Stabilization ability	• Providing vehement driving inputs • Driving with desirable lateral and longitudinal accelerations • Showing reproducible driving behavior • Maintaining control of the vehicle • Showing smooth driving behavior

Table 3
Results of the demographic questions (N = 10 per group).

Variable	Unit	Race Drivers	Engineers	Driving Instructors	Total
Gender	female; male	0; 10	0; 10	2; 8	2; 28
Age	years (most mentioned range)	21–30	31–40	51–60	31–40
Age of learning to drive	years (mean)	9.2	15.5	14.6	13.1
Instructor experience on public roads	years (most mentioned range)	–	–	21–40	11–20
Racing sports experience	1 to 5 (mean)	4.4	3.7	2.5	3.5

participants' quote content was judged by the authors to be similar for race drivers, engineers, and instructors. Because of this, the authors decided to present the quotes together, without subgroup analysis.

3.2. Public roads: characteristics of a good driver

Questions Q8, Q13a, Q14a, and Q15b aimed to examine what characteristics are typical of a good driver and which performance measures could be used for identifying such drivers. The response to Q15 of one race driver and one driving instructor had to be excluded because of bad audio recordings.

Individual factors: For seventeen interviewees, a good driver is not overloaded or stressed while driving. It was pointed out that stress could be caused by the driving task itself or by prior conditions/activities, such as stress at work or home. Two interviewees explained:

> *"Because the more I drive, the more I train, the more I experience, the more I internalize it. ... And it is no longer a thing that I have to focus on ... the basic things: accelerating, braking, steering, signaling, etc. ... simply become part of me, and I can then concentrate on the outside again, which means to concentrate on the surroundings."*
> *"... stay calm and do not get stressed by other things that happen. ... on the public road, things can happen, and you can be stressed. This can be due to work or stressful situations at home that you bring into the car.?"*

A large number of participants associated body posture and gaze behavior with overload and stressed. Overloaded drivers tend to be cramped, as demonstrated by clinging to the steering wheel, high shoulders, and a backward-tilted head. Head orientation influences gaze behavior, as illustrated by a quote of a driving instructor:

> *"... the head goes back into the neck, and then you can really see that they are only looking to the ground right in front of the bonnet."*

The interviewees mentioned that having a proper driving attitude is an important individual factor. The interviews revealed associations between attitudes and the way drivers treat their vehicle:

> *"... a bad driver treats a car more like an object to show off. So maybe, they want to impress the girls or impress their friends."*
> *"... it is a kind of strange phenomenon, but in the car, people develop a potential for aggression that they would never have outside of the car."*

"... because I only see the car, I do not know whether he [the driver] is well or not, or whether he is old or inexperienced ... That is why it is so stupid when people immediately start to honk or go crazy. Scolding the other person; he is not doing it on purpose, maybe he's got a problem, so you have to be a bit relaxed."

One interviewee made a link between driving attitude and anticipatory driving behavior, while another participant regarded attitude as a reason behind failing to obey the traffic rules.

"Also defensive driving, anticipatory driving. That is what makes a good driver. Not always insisting on your own rights."
"The aggressive driver maintains a much shorter distance, drives faster.... Also, he does not adhere to the rules that much."

Perception: Gaze behavior, as part of perception, is a key factor for appropriately assessing the traffic situation and anticipatory driving behavior. An engineer and a driving instructor stated, respectively:

"The looking direction is even more important on the normal road than on the race track because by looking far and wide, you pay attention to what is coming from the left and right, where you have to go, and whether an obstacle is approaching: Are there people who might come from a street, or a dog, or a child?"
"Learner drivers have blinkers on and only look 8 to 15 meters in front of the vehicle ... if you do not drive with foresight, the rear vehicle that follows you could crash into the rear if you brake too late."

Further, gaze behavior was regarded as related to short-term path planning. One driving instructor explained:

"Because humans are wired like this, they unconsciously always move where they are looking. And if they are looking at the wrong places, then they either drive too slow or move to the wrong places."

Similarly, distracted or inattentive driving was associated with poor planning ability. Two engineers explained:

"... in the end, you always have to stay between two lines. I think that those who are inattentive drive in a more meandering manner in between those lines, whereas somebody who is attentive hardly drives in a meandering manner because he always readjusts a little so that the car drives cleanly as he wants."
"This situation of someone suddenly appearing in front of the vehicle is experienced by many, but the problem is not that someone came out of a blind spot, but rather that the driver was inattentive."

Planning: Traffic rules prevent drivers from reaching the vehicle's limit on public roads. However, a realistic self-assessment and sufficient knowledge about the vehicle's capabilities are relevant factors for avoiding the limit, too.

"I think you can feel more insecure with a slow-moving driver than with someone who is actually speeding ... Also the assessment of what speed he can drive or is at: Is he still in his comfort zone with the speed he is currently driving, or is he actually already exceeding it?"
"... a very good driver ... can assess very well how high the limit of his vehicle is and how high his own limit is."
"On an open road, you should be as far as possible from the performance of the car. You should maximize this gap. You want to drive safely."

A race driver explained:

"... in a road car, you should never be trying to control the car; you should be driving normally and sticking to the speed limit. If it is raining, you reduce your speed, so you do not have to get into a situation where you have to control the car."

Stabilization: The subcategories 'Driving with desirable lateral and longitudinal accelerations' and 'Maintaining control of the vehicle' are closely related, where the former refers to keeping the lateral and longitudinal acceleration within the traction circle, and the latter refers to re-stabilization skills if the traction circle is exceeded.

"... how fast can I drive, accelerate, apply the brakes, can I sometimes exceed my friction limit . . . In most of the cases [that] the speed is too high for the situation, ... the braking dosage is coordinated with the steering angle, which one then initiates, to be able to just save the situation."

Additionally, maintaining control was linked to smooth driving.

"... smooth handling to keep the car stable [is very important]. This is a sign that you master the car. If you are constantly too hectic at the steering wheel, you can. .. strain the car and get into an unstable behavior . . ."

As illustrated in Fig. 2, the mentioned categories (individual factors, perception abilities, and planning abilities) affect driver input and, therefore, vehicle behavior. Regarding public roads, smoothness of driving was often mentioned as an indicator of a good driver:

"I think it is a bit easier to define a good driver on the public road. ... he [the driver] does not have to correct a lot but steers and drives through the bend. No strange cornering and steering five times or anything like that, but he sets a steering angle, drives through the bend, briefly accelerates. Just like that; he drives in a flow."
". . . [the driver] does not brake continuously ... or lets it roll ... brakes, accelerates again, brakes, accelerates again. Simply such an unrhythmic driving. ... I can be very tense about that."

Jerky driving could be caused by an inadequate driving position or motoric/coordination problems:

"... if everything is proceeding normally, all is fine, and it does not matter whether I have stretched elbows or not. But it is often the case when it really matters, and someone has to react, especially if the rear breaks away, then ... you have to work, ... the upper body moves out of the seat, and then the upper body is free ..."
"The feeling with the pedals. Also, how one steps on the pedals. . . . Now, if someone says: 'Slow down a little', there are some people who then go for it and slam the brakes. And there are also some people who have lead feet. They have no feeling at all in their feet."

Fig. 3 presents the distribution of quoted main categories and subcategories regarding a good driver on public roads. It can be seen that good drivers are mainly characterized by posture, gaze behavior, planning, anticipation, and smooth driving behavior.

Some interviewees mentioned that a good driver is able to perform certain driving tasks automatically, that is, with little conscious thinking:

"If someone's movement sequences are not performed reflexively when the car slides sideways, then, of course, the brain is massively stressed to do the right thing, and few resources are free to perceive incidental elements in the situation. Whereas others . . . simply have more resources available to assess the situation better."

3.3. Public roads: characteristics of safe driving

Fig. 4 shows the distribution of the criteria for safe driving on public roads (Q11). Compared to the characteristics of 'good driving', the responses were similar, but their relative frequencies were somewhat different. Regarding individual factors, it was mentioned that safety is affected by workload and stress while driving, as well as driving attitude, whereas knowledge

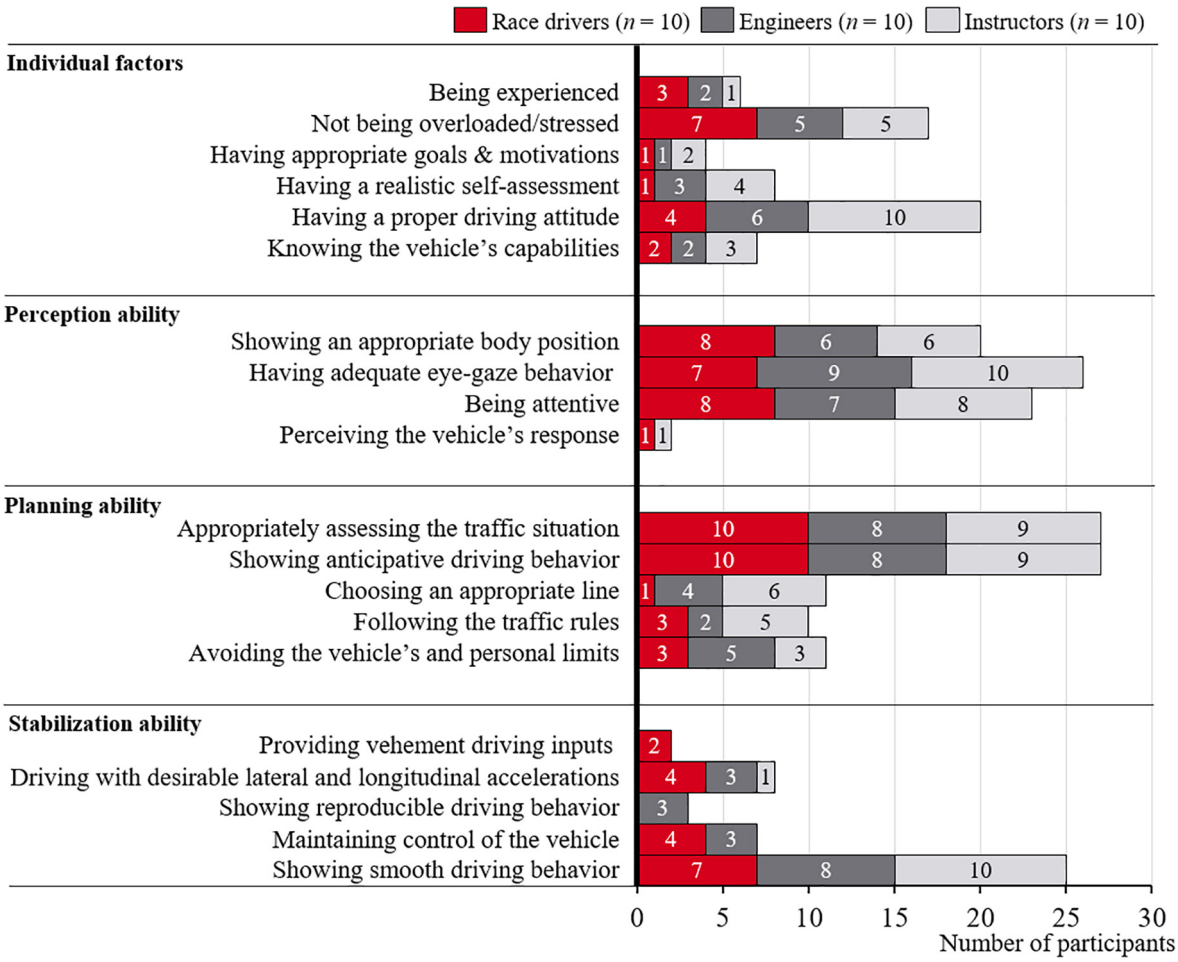

Fig. 3. Mentioned characteristics of a good driver on public roads (corresponding questions: Q8, Q13a, Q14a, and Q15b).

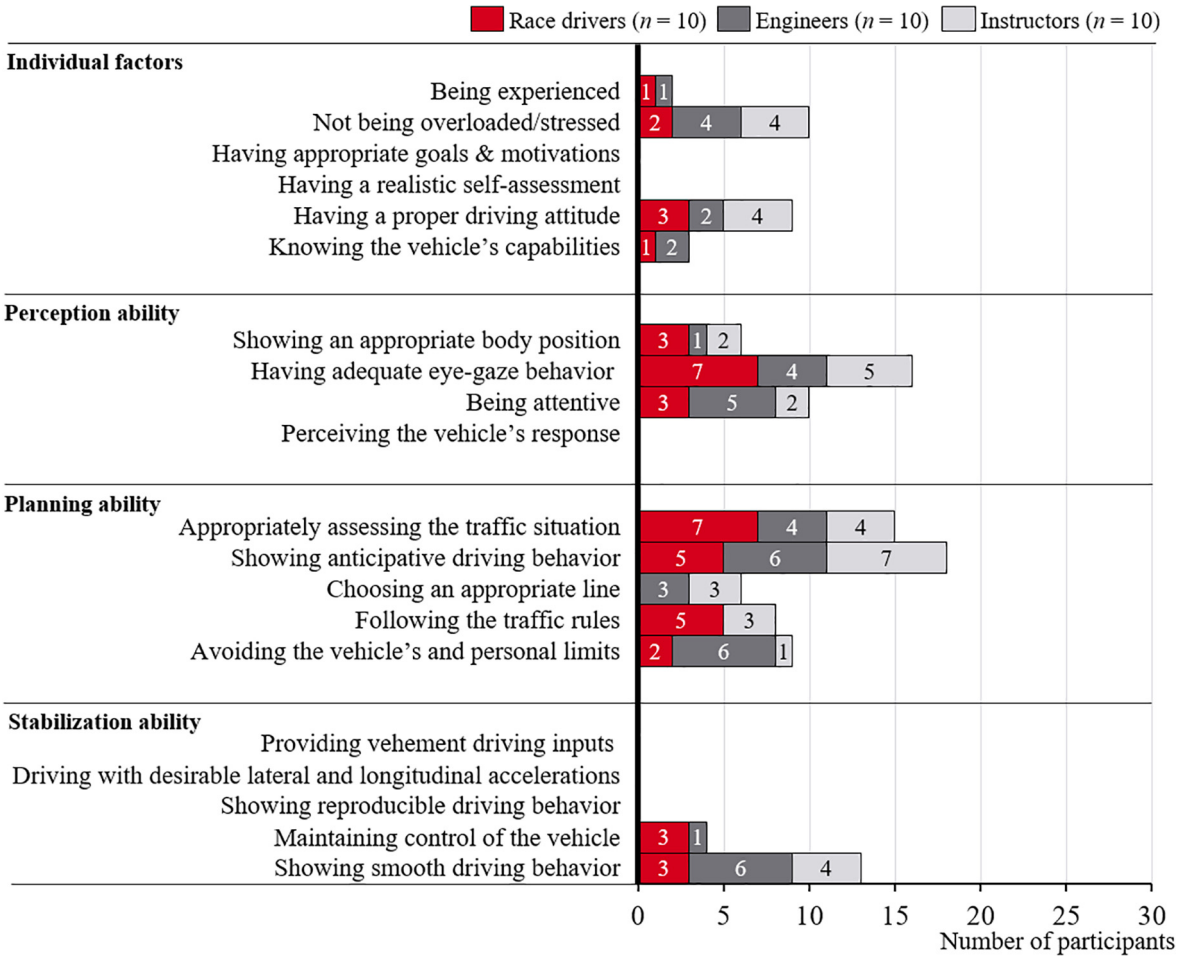

Fig. 4. Mentioned characteristics of safe driving on public roads (corresponding question: Q11).

of the vehicle's capabilities was found to play only a minor role. The motivation to drive and appropriate self-assessment were not referred to at all. Regarding perceptual abilities, gaze behavior and being attentive were often mentioned.

Additionally, safe driving was related to anticipatory abilities, appropriately assessing the traffic situation, avoiding the vehicle's limits, and adhering to the traffic rules:

"... in the city, selective perception is simply crucial. Namely ... recognizing sources of danger. And ... separating the important from the unimportant."
"The accident risk is a million times lower compared to someone who always drives ten or fifteen kilometers too fast."

As can be seen in Fig. 4, the motoric inputs to operate the vehicle are underrepresented compared to the perceptual and planning factors. However, smooth driving was regarded as a determinant of safety.

3.4. Public roads: scenarios to assess driver performance

During the interview, it was asked which scenarios are useful for assessing a driver on public roads. The interviewees generally described scenarios suitable for measuring the assessment criteria that were shown in Fig. 3. As indicated above, individual factors, perception, and planning abilities are frequently reported assessment criteria, so it is not surprising that most scenarios included complex interactions with other road users. Further, six participants mentioned that an assessment of the driver performance on public roads would only be possible in unexpected or unusual traffic situations:

"So I think the distinction [between a good and a bad driver] can only be made ... when there are unforeseen situations, some special situations. Only then you can tell the difference, in my opinion."
"As long as nothing special is going on, everyone is a half-decent driver. On the normal road, you cannot really see whether or not they are a good driver."

Table 4 provides an overview of the reported scenarios. To aid the reader, the scenarios are classified according to their traffic environment: city, rural road, and highway. Appendix C describes the scenarios in the form of quotes from the interviewees.

3.5. Race tracks: characteristics of a good race driver

Q8, Q13b, Q14b, and Q15b were used to characterize a good driver on race tracks. Because of bad audio recordings, Q15b had to be excluded for one race diver and one driving instructor. One finding which immediately stood out was that good driving on the race track was often related to the motoric operation of the vehicle (stabilization ability). Several quotes per category are given below.

Individual factors: Participants often mentioned that a good race driver is experience with the race track itself.

"... I actually start with a track walk first. In this way, you really deal with the entire track intensively. Because when you are walking the track, you often notice details that you do not even see when driving the track."

Participants indicated that stress and workload while driving on the race track lead to a reduced ability to multitask.

"... that the driver is confident or relaxed about what he is doing. And then he can automatically drive fast and also ... has a much wider view. And I think every amateur or someone who is not so experienced ... thinks to himself: 'Okay, I now have to look at the apex, okay, now I have to look at the exit', and simply does not drive in a relaxed manner and see the big picture."

For many interviewees, being aware of the vehicle's capabilities (e.g., vehicle's and tires' limits) was regarded as a factor that affects stabilization ability.

"... no physical knowledge of what is happening, understanding the tires, the car, the vehicle dynamics. For example, if you brake in a very aggressive way, you actually upset the car because you have a lot of longitudinal transfer, so this is a transient state that you want to smoothen as much as possible."

Confidence was reported to be an important determinant of stabilization ability:

"It is also about driving confidence. If the driver has confidence in the car, he will be able to be much more aggressive. If he does not feel confident, he will take away a lot of the margin."
"[The driver in the video] gets scared, releases the gas pedal, and then the car becomes a little bit light. And then he only rolls to the braking point. Then he brakes very timidly ... Yes, so he is not really fast ..."

Perception: Compared to the public road environment, the importance of perceiving the current state of the vehicle is higher. Having a good perceptual ability helps to drive the vehicle on the physical limit, that is, exploiting the maximal lateral and longitudinal acceleration and maintaining the vehicle in a stable condition (or to re-stabilize it).

"The good driver will then unconsciously compensate for this to a certain extent by starting to brake early because he realizes, 'Oh, my deceleration is no longer as good as it was at the beginning.' On the other hand, maybe an inexperienced person, who has this changing vehicle behavior—which can simply be there because of tire warming, air pressure increase, something like that—may have problems noticing it at first and then is totally amazed as suddenly nothing works anymore ... [He] then cannot adjust to this situation: ... 'OK, if I now use the same braking point, I will be somewhere at the exit of the curve because I totally missed the apex because the braking distance became longer.'"
"If ... a driver... goes into the same turn three or four times and pushes the car into oversteer because he was simply too late on the brakes ... it means that the driver does not have this adaptation capability. So he does not learn to implement what he experienced from the turn or lap before, to then improve it. This allows me to classify drivers..."

Table 4
Overview of mentioned scenarios to assess driver performance.

Environment	Scenario	
City	• Braking behavior in front of a traffic light • Braking behavior when arriving at a priority road • Arriving at a crosswalk • Passing a bus stop	• Perception in a residential area • Approaching a road narrowing • Arriving at a roundabout • Looking behavior before making a turn • Gap acceptance
Rural Roads	• Approaching a truck that is turning at an intersection • Encountering a tractor that approaches from a cornfield • Overtaking safely • Perception of wild animals at dusk • Adapting driving behavior to snow or rain	
Highway	• Adapting the driving style to an increase of traffic intensity • Anticipating heavy braking by others	

Similar to path planning on public roads, gaze behavior was regarded to have a strong relationship with the racing line. Two quotes of race drivers describe this in detail:

"Visual guidance is very important in motorsports or when driving on the race track. ... you should always look where you are going. You should aim at the apex ..."
"If I have a corner coming up and I need to brake in 100 meters, I look at the 100 meters mark, and when my eyes are here, and the corner is going right, as it is a right-hander, my eyes will be looking at the left or wherever the sign is and once I hit that mark my eyes move completely straight to the corner, and once I have hit that point, I am looking at where the exit of the corner is and where I would want to put the car on the outside to decide where I want to put my power. If there is a corner coming right after it, it is the same thing, so my eyes are always moving."

Planning: The most common criterion to assess a driver on a race track was by far the chosen racing line. Only one driving instructor did not mention it.

"*The other difficult part is the driving line or, let's say, to understand where the car should be on the track. To be as quick as possible, you should always use the maximum track width. ...the power to weight ratio of the car—cars that are extremely powerful will allow you to take a certain driving line. Cars that are less powerful need to be driven in a different way.*"

On race tracks, the objective is always to reach the limit. Therefore, the limit-avoiding categories are not relevant.

Stabilization: The quotes related to the driver's personal limit and driving the vehicle at its limit. The participants' quotes clarified that jerky driving behavior leads to load changes that make it difficult to keep the vehicle stable at the limit. It was pointed out that vehement driving inputs might be required for reaching the physical limit. In essence, the participants noted that it is not relevant whether the driver provides a maximal or minimal input; rather, the driver needs to provide input in such a way that the vehicle reaches its maximum potential.

"In an ideal car, you would see a very hard hit on the brakes, and then they release it more smoothly, but when they hit the brakes, it is "BAM", like this. A less ideal car is a bit smoother because there is still the possibility that you lock the wheels."
"So I recognize slight reactions on the rear wheel axle, that the axle has a slight tendency to oversteer. That means I am probably in the optimal slip range. Not too much oversteer, but easy work in the car. In this way, I recognize that I am currently operating at the vehicle's limit. ... If I have zero reaction in the car, then in all likelihood, I will have reached the point that I am not yet at the limit, that there is still a bit of potential available."
"I have seen some guys that just hit the brakes and do not stop gearing down until all the way, and they have overdriven the engine, which unsettles the rear of the car, and then they come in, and they complain that the car is oversteered. Because you are forcing the engine to dip to nose so much, when you do that, you are going to oversteer, you know, it is simple things like that."
"... simply ... a certain harmony. So there is no point if you first brake into it, then realize, 'Oh, the curve is not coming yet'. Then you release it again, then maybe you even step on the gas, then you brake again and say, 'Oh, but now I am actually way too fast.' Then you steer in, then you steer wrongly, then you steer again, ... and then you open the steering again. That is inharmonious."
"... he is very smooth; the car is not out of control; it is on the limit. But he is very smooth; he is not having to correct the gas, or really there is not much wrong with it."

Some race drivers mentioned that they sometimes apply an intended load change to turn the vehicle around a corner.

"... we just use load change; when we need the front axle, we activate it by releasing the throttle or braking briefly, and that is just a matter of feeling. ... Many people just lose time because they do not feel or know this."

Fig. 5 shows the distribution of the mentioned factors and criteria of a good driver on race tracks. The interviewees often referred to the driving line and facets of stabilization ability.

3.6. Race tracks: characteristics of fast driving

Once again, one engineer had to be excluded because of a bad audio recording. Further, two driving instructors had no idea what criteria are relevant to fast driving on race tracks, and therefore did not provide a response.

The answers to Q9 regarding what characterizes a good driver on race tracks and what characterizes a fast driver on race tracks were similar. They only differed regarding the number of mentions. In retrospect, this is not surprising. The main criterion of a good driver on a race track is 'being fast', whereas multiple criteria can be used to identify a good driver on a race track, e.g., safety, comfort, in addition to being fast.

"Someone who drives faster looks where he wants to go. And someone who cannot assess where he wants to go, or where he is going, just looks ahead, probably right in front of the bumper."
"The car turns during the braking phase; with the brake pressure, you can also regulate a lot because... without ABS ... you have to regulate all the time... that is the hardest part. If you do something wrong so that it locks too early or you enter the curve too early, you lose time again, or you are still too fast or too slow, and then the whole path of the curve does not fit when you hit the throttle."

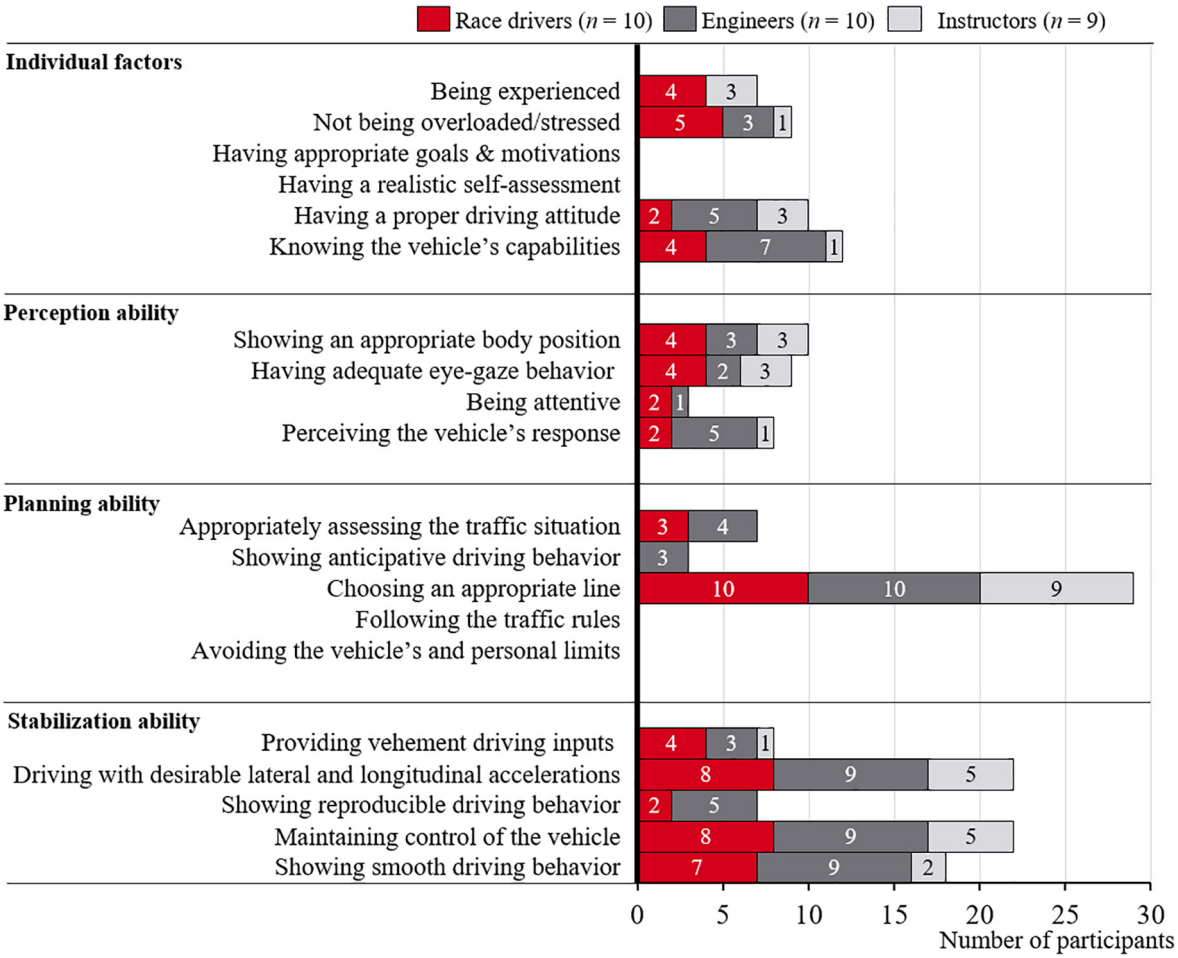

Fig. 5. Mentioned characteristics of a good driver on a race track (corresponding questions: Q8, Q13b, Q14b, and Q15b).

Fig. 6 shows the distribution of the mentioned factors and criteria of a good driver on race tracks.

3.7. Scenarios to assess driver performance on race tracks

In total, 16 interviewees mentioned that they would assess drivers in cornering scenarios on race tracks. However, they provided different emphases within the corner, including (1) the braking actions, (2) the phase between the braking point and the apex, (3) the transition between braking and steering, and (4) the exit of the curve. Seven of them stated that they would assess the ability to choose the racing line via a sequence of curves.

4. Discussion

This interview study aimed to identify characteristics of good drivers on public roads and race tracks. The quotes were grouped according to a model (see Fig. 2) comprising a combination of Endsley's (1995, 2000) model of situation awareness and the driving hierarchy initially proposed by Donges (1982). According to this model, individual factors such as inexperience can be expected to negatively affect perception, which affects planning, decision-making, and in turn, vehicle inputs and driver performance.

The results showed that, on race tracks, the assessment of a driver is based on vehicle-state data, in addition to the driver's workload level and gaze behavior, which are topics also covered by previous studies on race driving (Braghin, Cheli, Melzi, & Sabbioni, 2008; Brown, Stanton, & Revell, 2018; Metz & Williams, 1989; Van Leeuwen, De Groot, Happee,

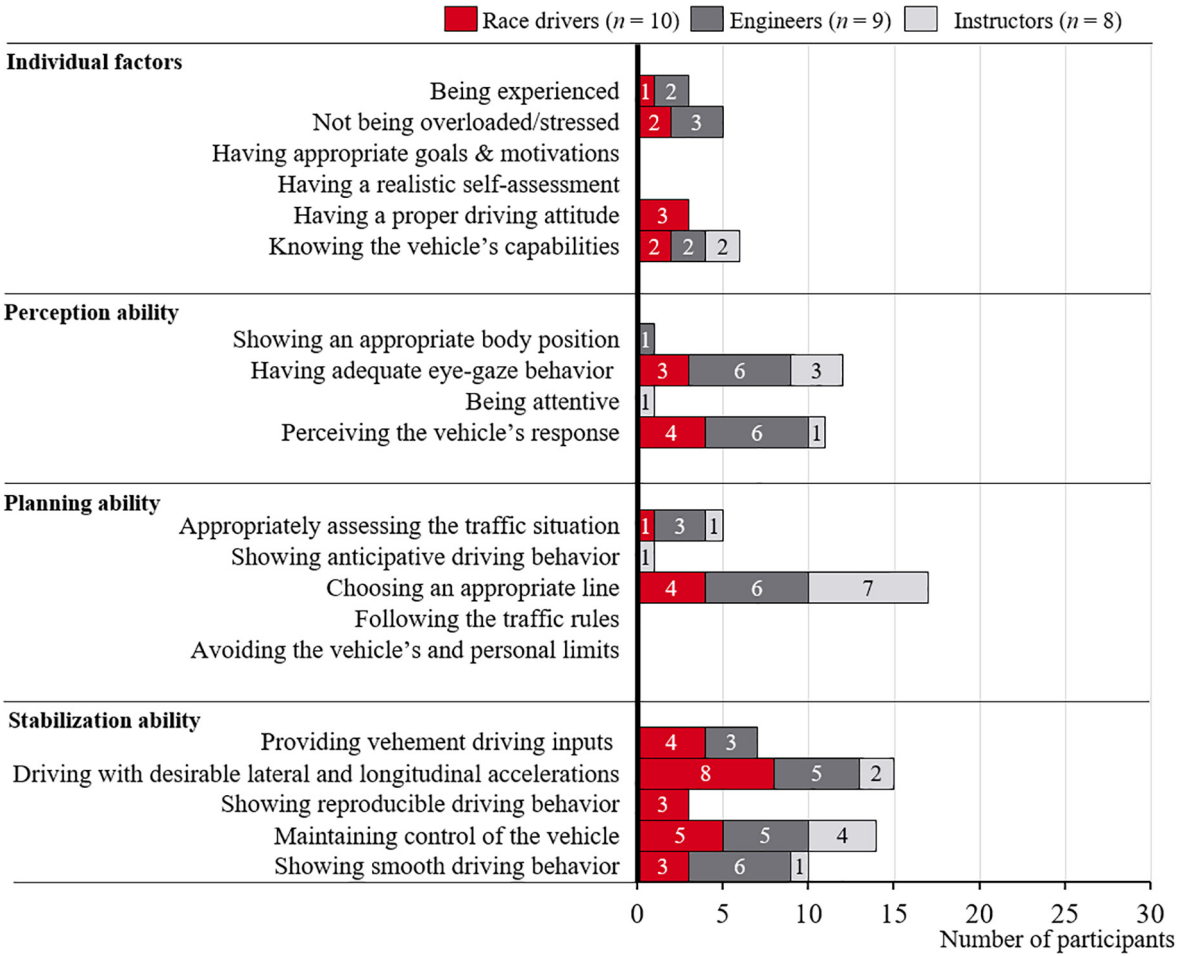

Fig. 6. Mentioned characteristics of fast driving on a race track (corresponding question: Q9).

& De Winter, 2017). On public roads, the focus of the driver assessment was more on the driver's perceptual-cognitive factors. Vehicle control skills were hardly mentioned as a factor on public roads but were regarded as crucial for a race driver. When considering the main objectives of the two environments, the results are sensible: on public roads, the goal is to get safely from place A to B, whereas on race tracks, the driver wants to be as close as possible to the physical limit of the vehicle.

Besides the differences between the assessments for the two environments mentioned above, there were some clear similarities. For both types of environments, it was noted that a good and safe driver is confident and not stressed. He or she is defensive rather than aggressive, calm rather than overloaded, and confident rather than showing off for peers, which is consistent with an interview study by Day et al. (2018), which found that peer pressure is problematic for beginner drivers. Having experience was regularly cited as an enabler of good driving behavior, calmness, and self-confidence. Of course, racecar driving is inherently a stressful task (Reid & Lightfoot, 2019), during which the driver often has to give abrupt inputs, for example by using the threshold braking technique (Sharp, 2009). However, the interviews showed that a good race driver's inputs result from confidence and experience, and not of an aggressive type that can destabilize the car.

Stress can arise from stressors outside the car (e.g., stress at work) that can subsequently be identified in driving behavior, but stress can also be a symptom of insufficient experience or insufficient overview of the traffic situation. Stress or high workload was associated with reduced mental spare capacity for other tasks such as perception, anticipation, and planning, a finding that is consistent with much empirical literature. For example, according to De Waard (1996), an increase in the complexity of a driving task or the driving environment may cause an increase in mental workload, as a result of which the driver has to exert (task-related) effort to maintain performance.

Stress can be recognized, among other things, by a cramped position behind the wheel and related viewing behavior. Many of the interviewees reported the importance of proper viewing behavior. On public roads, viewing behavior is not only about scanning for potential hazards but is directly linked to anticipation of upcoming events and preparedness for future hazards. In turn, good viewing behavior promotes good lane-keeping and the selection of a smooth line through curves, which ensures that the limit of the vehicle is not exceeded and that steering corrections are hardly needed. Likewise, it was noted that braking in a multi-modal manner (i.e., braking in pulses) is indicative of poor driving (see also Boer, Kuge, & Yamamura, 2001). Equivalent to these findings regarding driving on public roads, viewing behavior on the race track was regarded as very important. It was noted that the viewing behavior of race drivers is goal-directed, as can be identified by consistent looking at visual markers that indicate the braking point, looking at the apex of the corner, and so on. These findings mirror earlier research showing that race drivers adopt a viewing pattern towards the edge of the track that is repeatable from lap to lap (Land & Tatler, 2001; Van Leeuwen et al., 2017).

Finally, it is worth mentioning that that good/safe driving behavior is not only characterized by normative viewing behavior and a normative state of the vehicle. The interviews also revealed that adaptation to one's vehicle and to the road conditions is essential. For example, good race drivers are able to recognize when the tires are deteriorating in quality and can adapt their braking inputs accordingly. Similarly, a good race driver can adjust the race line as a function of the vehicle's weight, engine power, and track conditions. Comparable findings were found regarding on-road driving: When the interviewees were asked to propose scenarios that could be used to assess driving behavior, scenarios were given that were in some way unpredictable or unusual. This included approaching a new road type or altered traffic conditions. These findings indicate that it is considered important to assess how drivers respond in situations where they cannot directly rely on previously learned habits.

A limitation of this interview study was the gender imbalance of the participants (2 female and 28 male). On the one hand, this can be regarded as expected and desirable, as professional driving instructors and race drivers are predominantly male (e.g., Waltemeyer, 2018), and so our sample is representative of that population. On the other hand, the results mainly provide insights into the male definition of good and safe driving. At the same time, our observations appear to be generic, and we see no reason why our findings would not generalize to female driving instructors or race drivers.

The present interviews were conducted with the underlying aim of developing recommendations for driver monitoring systems and automated driving systems that mimic human driving abilities. First, we see potential in driver monitoring systems that can measure the posture of drivers, a technology that has been proposed for a long while (e.g., Toma, Rothkrantz, & Antonya, 2012), but is not available in commercial vehicles yet. Driver monitoring system may not only provide insights into individual differences but also into intra-individual differences of driver state such as stress which can change in a matter of seconds (e.g., Gonçalves & Bengler, 2015; Tan et al., 2019). Previous empirical research using a head-tracking system has shown that drivers under stress adopt a more forward-leaning posture (Rendon-Velez et al., 2016), which is consistent with the findings from the interviews. A driver's situational awareness may be identifiable from a driver's looking behavior in relation to the traffic environment, as previously proposed by De Winter, Eisma, Cabrall, Hancock, and Stanton (2019). A second point that came forward in the interviews is that good driving behavior is characterized by being smooth and confident. Automated cars, because of their cameras and radar systems, will probably excel in accurate lane-keeping and noticing objects in the environment. Thus, in some aspects, an automated car can easily meet the criteria for excellent driving behavior. However, something that can be considerably more difficult for automated cars with the current state of the technology is the prediction/anticipation of other road users (Ohn-Bar & Trivedi, 2016) and adaptation to new conditions. These factors were identified as essential determinants of good or safe driving. It may be difficult for developers to create automated vehicles that respond effectively to situations shown in Table 4. A way forward could be to assess how automated cars deal with such situations, and to what extent automated cars should have general intelligence and problem-solving skills.

CRediT authorship contribution statement

Fabian Doubek: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Writing - original draft, Writing - review & editing, Visualization. **Falk Salzmann:** Conceptualization, Methodology, Software, Investigation, Resources, Writing - review & editing. **Joost de Winter:** Conceptualization, Methodology, Validation, Writing - original draft, Writing - review & editing, Supervision.

Data Availability

Supplementary data (transcripts, counts of quotes) are available here: https://doi.org/10.4121/14483220.

Appendix A. German version of the interview

Demographischer Fragebogen

1. Wie alt sind Sie?

0 bis 20	21 bis 30	31 bis 40	41 bis 50	51 bis 60	>60
☐	☐	☐	☐	☐	☐

2. In welchem Alter haben Sie das Autofahren erlernt? _____ Jahren

3. Wie oft fahren Sie auf öffentlichen Straßen?

täglich	mehrmals pro Woche	einmal pro Woche	seltener	nie
☐	☐	☐	☐	☐

4. Seit wie vielen Jahren arbeiten Sie als Fahrlehrer?

0 bis 5	>5 bis 10	>10 bis 20	>20 bis 40	>40
☐	☐	☐	☐	☐

5. Wie schätzen Sie Ihre Rennsporterfahrung ein?

Keine ○ ○ ○ ○ ○ Sehr hoch

6. Wie häufig haben Sie bisher rennsportbezogenes Fahrtraining von einem Fahrlehrer erhalten?

Nie ○ ○ ○ ○ ○ Sehr oft

a) Falls ja, in welcher Regelmäßigkeit? _____ pro Jahr

7. Wie häufig sind Sie bereits auf Rennstrecken oder vergleichbar abgesperrten Strecken gefahren?

Nie ○ ○ ○ ○ ○ Sehr oft

a) Falls ja, in welcher Regelmäßigkeit? _____ pro Jahr

b) Wie oft davon stand das Fahrertraining im Fokus? _____ %

Spezifische Fragen zur Fahrerbeurteilung

8. Was macht einen guten Fahrer aus?

Anschlussfrage:

- Was unterscheidet einen guten von einem durchschnittlichen Fahrer?
- Anhand welcher Fahrsituationen machen Sie die Beurteilung?
- Wie äußern sich die Beurteilungskriterien am Fahrerverhalten, -handlungen, Steuerverhalten (Blick, Beschleunigungs- und Lenkverhalten)?

9. Wie fährt man schnell auf der Rennstrecke?

Anschlussfrage:

- Was unterscheidet einen guten von einem durchschnittlichen Fahrer?
- Anhand welcher Fahrsituationen machen Sie die Beurteilung?
- Wie äußern sich die Beurteilungskriterien am Fahrerverhalten, -handlungen, Steuerverhalten (Blick, Beschleunigungs- und Lenkverhalten)?

10. Was hat das größte Potenzial die Rundenzeit auf Rennstrecken zu verbessern? (in Abhängigkeit des Fahrerniveaus)?

Anschlussfrage:

- Was unterscheidet einen guten von einem durchschnittlichen Fahrer?
- Anhand welcher Fahrsituationen machen Sie die Beurteilung?
- Wie äußern sich die Beurteilungskriterien am Fahrerverhalten, -handlungen, Steuerverhalten (Blick, Beschleunigungs- und Lenkverhalten)?

11. Wie fährt man sicher in der Stadt und auf Landstraßen?

Anschlussfrage:

- Was unterscheidet einen guten von einem durchschnittlichen Fahrer?
- Anhand welcher Fahrsituationen machen Sie die Beurteilung?
- Wie äußern sich die Beurteilungskriterien am Fahrerverhalten, -handlungen, Steuerverhalten (Blick, Beschleunigungs- und Lenkverhalten)?

12. Was hat das größte Potenzial die Sicherheit auf öffentlichen Straßen zu verbessern (in Abhängigkeit des Fahrerniveaus)?

Anschlussfrage:

- Was unterscheidet einen guten von einem durchschnittlichen Fahrer?
- Anhand welcher Fahrsituationen machen Sie die Beurteilung?
- Wie äußern sich die Beurteilungskriterien am Fahrerverhalten, -handlungen, Steuerverhalten (Blick, Beschleunigungs- und Lenkverhalten)?

13. Stellen Sie sich vor sie sind Beifahrer. Anhand welcher Kriterien kann festgemacht werden, ob es sich um einen guten oder schlechten Autofahrer handelt?

a) im öffentlichen Straßenverkehr

b) einer Rennstrecke

Anschlussfrage:

- Was unterscheidet einen guten von einem durchschnittlichen Fahrer?
- Anhand welcher Fahrsituationen machen Sie die Beurteilung?
- Wie äußern sich die Beurteilungskriterien am Fahrerverhalten, -handlungen, Steuerverhalten (Blick, Beschleunigungs- und Lenkverhalten)?

14. Stellen Sie sich vor Sie stehen neben der Straße/Strecke. Anhand welcher Kriterien kann festgemacht werden, ob es sich um einen guten oder schlechten Autofahrer handelt?

a) im öffentlichen Straßenverkehr

b) einer Rennstrecke

Anschlussfrage:

- Was unterscheidet einen guten von einem durchschnittlichen Fahrer?
- Anhand welcher Fahrsituationen machen Sie die Beurteilung?
- Wie äußern sich die Beurteilungskriterien am Fahrerverhalten, -handlungen, Steuerverhalten (Blick, Beschleunigungs- und Lenkverhalten)?

15. Expertenbeurteilung anhand von Videos

a) Bitte bewerten Sie die Fahrleistungen in den Videos

b) Bitte identifizieren Sie Fehler und Verstößen und nenne Sie die Gründe dafür

Innerorts:

Video 1:

Sehr schlecht ○ ○ ○ ○ ○ Sehr gut

Video 2:

Sehr schlecht ○ ○ ○ ○ ○ Sehr gut

Land-/Bundesstraße:

Video 3:

Sehr schlecht ○ ○ ○ ○ ○ Sehr gut

Video 4:

Sehr schlecht ○ ○ ○ ○ ○ Sehr gut

Rennstrecke:

Video 5:

Sehr schlecht ○ ○ ○ ○ ○ Sehr gut

Video 6:

Sehr schlecht ○ ○ ○ ○ ○ Sehr gut

Video 7:

Sehr schlecht ○ ○ ○ ○ ○ Sehr gut

Video 8:

Sehr schlecht ○ ○ ○ ○ ○ Sehr gut

Video 9:

Sehr schlecht ○ ○ ○ ○ ○ Sehr gut

Video 10:

Sehr schlecht ○ ○ ○ ○ ○ Sehr gut

Appendix B. Overview of the categories including descriptions and allocation criteria

Table 5 shows the main and subcategories, including their descriptions and allocation criteria. The first column contains the main categories as described in the Methods section (Fig. 2). The description of the main categories in the second column helps to understand the assignment of the subcategories (third column) to the corresponding main category. The fourth column contains the criteria for each subcategory.

Table 5
Description of the main categories and subcategories.

Main categories	Description	Subcategories	Allocation criteria
Individual factors	Non-situation-specific factors that can influence the ability categories mentioned below	Being experienced	o Frequency and amount of driving (public roads only) o With the traffic situation (public roads only) o With the route (public roads only) o With the track (race track only)
		Not being overloaded/stressed	o Being cognitively overloaded from: ■ The driving task as a whole ■ In a specific driving situation o Being stressed from: ■ Driving tasks ■ Previous activities (public roads only)
		Having appropriate goals and motivations	o Not showing off in front of others o Driving for enjoyment o Keep driving costs as low as possible o Driving with the highest possible comfort o Driving with the minimal of driving time
		Having a realistic self-assessment	o Adequate assessment of one's own capabilities
		Having a proper driving attitude	o Cooperative driving behavior with other road users (public roads only) o Defensive driving behavior (public roads only) o No aggressive driving behavior o Being confident on the track (race track only)
		Knowing the vehicle's capabilities	o Having knowledge about the vehicle's / tire's limits o Understanding the traction circle
Perception ability	Perception of elements of the environment as well as the feedback of the vehicle	Showing an appropriate body position	o Appropriate body position on the seat o Appropriate hands position on steering wheel o Erect head posture o Low shoulder posture o Feed position on the pedals, e.g., heel not on the floor
		Having adequate eye-gaze behavior	o Monitoring the traffic environment (public roads only) o Looking in the direction of driving o Looking far ahead
		Being attentive	o Being focused on the driving tasks and the corresponding driving environment
		Perceiving the vehicle's response	o Perception of the vehicle's dynamics and stability in response to driver inputs and environmental conditions o Adaption to the vehicle's limit (race track only)
Planning ability	Comprehension of the meaning and significance of the situation. Projection of future states and events in dependency of planned actions (driving inputs)	Appropriately assessing the traffic situation	o Appropriately assessing the traffic situation, curves, other road users, driving conditions o Ability to differentiate between relevant and irrelevant information of the traffic environment or vehicle o Not taking risk in inappropriate situations o Ability to make decisions within an appropriate time
		Showing anticipative driving behavior	o Driving proactive and prescient o Expecting mistakes of other road users o Expecting unexpected situations
		Choosing an appropriate line	o Hitting an appropriate braking point and steering point o Not using the whole width of the road while driving slow o Cutting curves if the traffic situation allows (public roads only) o Adapting line within a combination of curves (race track only) o Distance to the apex, and the inner and outer curve side (race track only) o Choosing an appropriate braking point and steering point (race track only) o Using the whole width of the track (race track only)

(*continued on next page*)

Table 5 (*continued*)

Main categories	Description	Subcategories	Allocation criteria
		Following the traffic rules (public roads only)	o Adequate distance to the vehicle in front o Sticking to the speed limit
		Avoiding the vehicle's and personal limits (public roads only)	o Not going over or close to the physical limits of the vehicle o Not going over or close to the limits of one's (driver) own capabilities
Stabilization ability	Active operating the vehicle via the control elements to realize the planned trajectory (target speed and target line)	Providing vehement driving inputs	o Showing vehemence in braking, acceleration, and steering o Braking with maximal pressure in emergency situations (public roads only)
		Driving with desirable lateral and longitudinal accelerations	o Driving with reasonable accelerations and decelerations o Adapting to the vehicle response and the estimated conditions o Adapting longitudinal and lateral accelerations as well as speed to the traffic situation (public roads only) o Utilizing the maximum acceleration potential/ friction coefficient relative to the potential of the vehicle (race track only)
		Showing reproducible driving behavior	o Driving consistently over time o Being reproducible in regards to sequence, timing, and location of driving inputs o Showing reproducible lap and sector times (race track only)
		Maintaining control of the vehicle	o Vehicle instability should be avoided (unless intended) o Being able to correct vehicle instability o Appropriate responsiveness of the driver o Parameters of instabilities are: Preventive system interventions (ABS, ESP,..), wheel lockup, side slip angle jumps, body acceleration of the yaw
		Showing smooth driving behavior	o Harmonious motoric actions/movements of driving inputs o Showing a smooth transition between the driving inputs o Showing a smooth transition of vehicle's load changes o Avoiding jerks

Appendix C. Scenarios to assess driver performance on public roads, including interviewees' quotes

The interview asked for specific scenarios in which driving behavior can be assessed (Table 6). The scenarios were grouped according to their traffic environment (city, rural road, highway). To ensure a common understanding, the table also includes some explanatory quotes of the participants.

Appendix D. Potential to improve safety on public roads and improve lap times on the race track

Q12 asked what has the greatest potential to improve safety on public roads, depending on the driver's skill-level (low vs. high). Most interviewees only provided answers for low-skilled drivers. Two audio recordings had to be excluded, one of a race driver and one of an engineer (Fig. 7).

Q10 asked what has the greatest potential to improve lap times on race tracks, depending on the driver's skill-level (low vs. high). Most interviewees only provided an answer for low-skilled drivers. Three driving instructors had to be excluded because they could not answer the question at all (Fig. 8).

Appendix E. Video ratings of driver performance

Question 15a asked the interviewees to rate the driver's performance on a 5-point Likert scale from "very bad" to "very good". The rating consisted of two in-town clips (videos 1 & 2) and two clips (videos 3 & 4) on rural roads as well as six clips (videos 6–10) on two different race tracks.

Table 6
Interviewees' quotes for scenarios to assess driver performance on public roads.

Traffic environment	Scenario	Quote
City	Braking behavior in front of a traffic light	*"... let's say city traffic, a good driver rolls towards the traffic light... and somehow makes sure that he aligns himself correctly."*
	Braking behavior when arriving at priority road	*"Someone cuts out... suddenly comes from the right or the left, so that you have to brake quickly or something. A good driver ... sees him, but cannot... intuitively apply the brakes immediately, that is, initiate an emergency brake ... These kinds of situations often occur in certain residential areas. ... that is what distinguishes a good driver from a very good driver. A very good driver recognizes this immediately and makes an emergency stop ..."*
	Arriving at a crosswalk	*"... pedestrian crossings, also called zebra crossings: recognize them in time, [take] foot off the throttle, look to the right and left when you are a little further away. And then prepare to brake at about ten meters distance. That means, right foot on the brake pedal. Secure right and left again, and only accelerate again after the zebra crossing."*
	Passing a bus stop	*"... a stationary bus: recognizing [this situation] in a timely manner. A good driver releases the gas pedal and increases the safety distance from the bus, if necessary, in cooperation with oncoming traffic. So, if there is no oncoming traffic, you go into the oncoming traffic a bit to increase the distance; if someone crosses the street, which you do not expect, in front of the bus, for example, you then have adequate reaction time to brake."*
	Perception in a residential area	*"An example ... we drive past a line of parked cars ... with station wagons and everything possible, real visual obstacles ... And on the other side... a family with two smaller children who do not walk by hand... and another grandpa with a walker 50 meters up the road. ... And that is where I think that it is important that I do not only focus on these children who are not walking by hand and on the grandpa but [also] that I do not run over the grandma who is stepping out from between the parked cars because I am concentrating too much on one and then neglecting the other danger somewhere."*
	Approaching a road narrowing	*"If they make a plan beforehand for a bottleneck, for example. So I often have this ... with bottlenecks, when approaching them. And then make sure that if someone approaches you, you stop before it and not try to enter it [the bottleneck] and puzzle around in there. Better stop a hundred meters before it ... and do not maneuver around somewhere when it gets narrow."*
	Arriving at a roundabout	*"Let's assume a roundabout. The typical question from my learner drivers: we are now arriving at the roundabout, and here with a car, like that. And then my learner drivers slam on the brakes at the beginning, and this one here leaves [the roundabout]. And then I say, 'Hey, you could have driven in there'; [and the learner driver says:] 'Yes, but he did not use the indicator'. But I do not even look at whether it is indicating or not because the car's indicator does not really interest me at all. My learner drivers or my older drivers, however, only rely on the indicator. For me, it is actually crucial that I look here at that moment, where are his wheels going, so where is he steering, and where is he looking. Because if he looks around here, then for me, it is 100% sure that he stays in the circle. But he will never, never, leave the circle and look here. Because then he would not be able to steer."*
	Looking behavior before making a turn	*"A good scenario for recognizing whether you have a good view of the surroundings is, ... a controlled lane change or a controlled turn. In other words, am I still driving in a straight line and do I look early whether, for example, I have to brake for a cyclist when turning left or right, or do I only look when I am already steering my vehicle and I have already aligned my vehicle ... When I approach the intersection, I check early on whether something is coming, and then I can still look over the shoulder while driving straight ahead so that it is a controlled look over the shoulder and not an uncontrolled look over the shoulder where I already align the vehicle in the direction of travel or turning direction when I look over the shoulder."*
	Gap acceptance	*"Unfortunately, these days, there is often this 'me me' and the others play more of a secondary role, and that is a shame. ... Jumping into gaps is such a typical story. Because the risk then lies with the others—with him too—but when the others are not considerate, i.e., when someone is not paying attention. ... So this partnership in traffic, which driving instructors try to teach their clientele, is not lived in everyday life."*
Rural Roads	Approaching a truck that is turning at an intersection	*"For example, he is now driving towards an [... intersection ...], he has the right of way, but he sees a truck coming from the left ... The truck might pull a little further; then it will be tight ... So you should release the accelerator or brake..."*
	Encountering a tractor that approaches from a cornfield"	*"... a tractor pulling out of a cornfield, let's say in September when the corn is very high. Someone is not paying attention, and then suddenly there is such a tractor in front of you, and you have to evade. If you then missed it a bit, of course, we come back to looking: because the later I react, the more critical the whole situation becomes. ... This is a classic situation when understeer could appear, I mean in extreme situations or extreme driving conditions ..."*
	Overtaking safely	*"For example, if someone drives behind you and closes up to three centimeters, then swerves, wants to overtake, and the pullout is already with a full load; almost loses the car under load, because he simply could not look ahead."*
	Perception of wild animals at dusk	*"... especially on a rural road early in the morning, there are deer on the road or some animals or something that you just have a little bit of an eye for."*

(*continued on next page*)

Table 6 (*continued*)

Traffic environment	Scenario	Quote
	Adapting driving behavior to snow or rain	*"But if the guy is careful on the snow, then you can understand he is a good driver. ... if he brakes suddenly in the snow, then you can understand he is not an experienced driver. Because if you brake suddenly, the guys on the rear are at risk, so you can understand this kind of situation. So also in rainy conditions, you know, aquaplaning thing. You need to know that you do not need to drive too fast in the rain because it can cause aquaplaning. So you can understand from these situations."*
Highway	Adapting the driving style to an increase of traffic intensity	*"A very good driver who recognizes relatively early on that ... there is suddenly much traffic, that there is a high volume of traffic, and he adjusts his driving style accordingly."*
	Anticipating heavy braking by others	*"... on the highway, he arrives from behind with high speed and there are cars everywhere on the right, someone drives on the left, he cannot turn right, and he approaches with 300 [km/h] and brakes almost in the ABS control range. In such a case, I say, he did not understand that this is not safe, nobody can do that safely, and nobody who has any reasonable foresight and drive a car well does that. He simply cannot assess it."*
		"... in normal traffic, when I am on the highway and have several cars in front of me, I look past the vehicles and see what is developing there. Well, I just see that someone is braking relatively tightly. Then I know exactly what will happen next. The one in front of me will brake even more tightly, and so it builds up, and in the end, someone hits the back somewhere because he just reacts too late. And if you see something like that in advance, you can defuse the situation for yourself and of course for the others too."

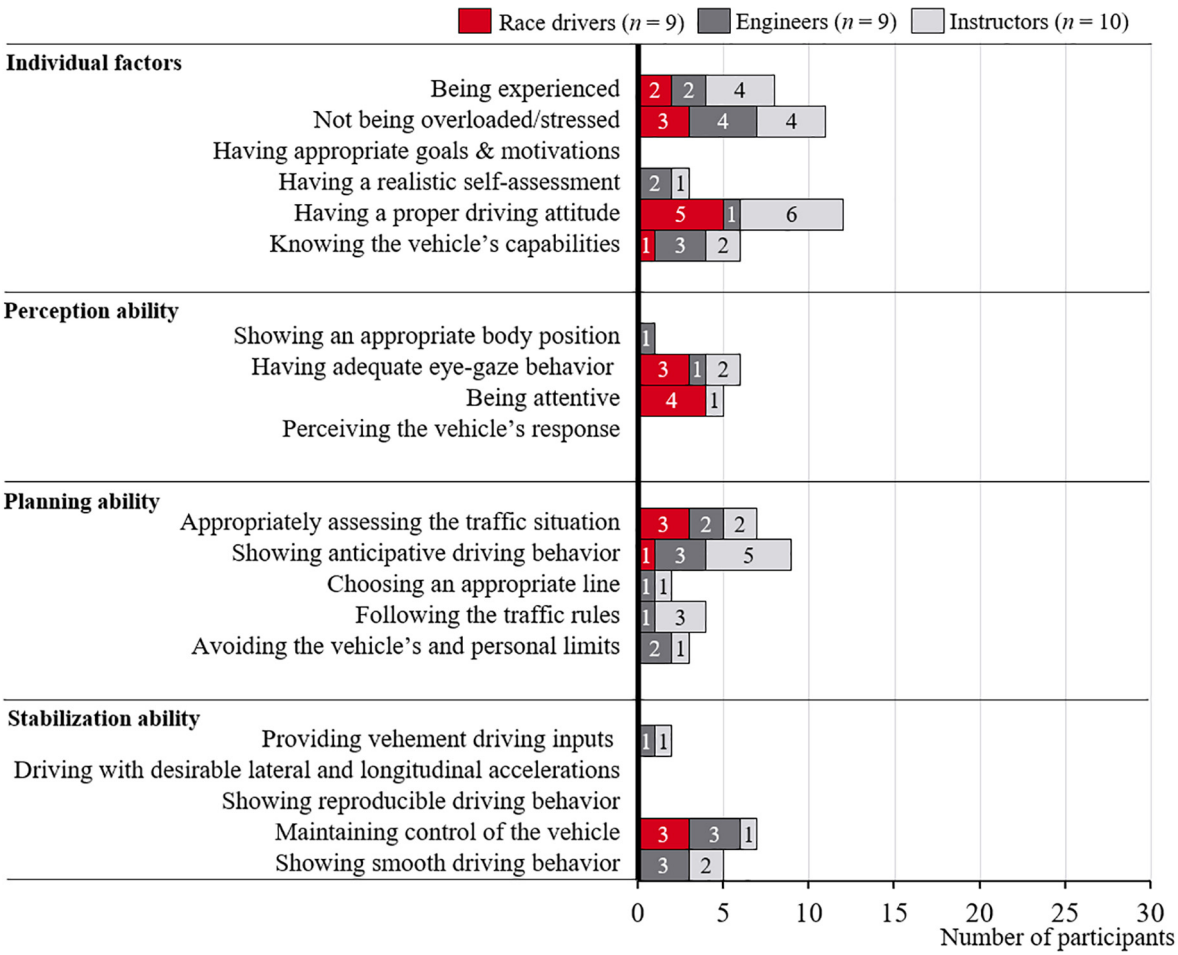

Fig. 7. Mentioned greatest potential to improve safety on public roads for low-level drivers (corresponding question: Q12).

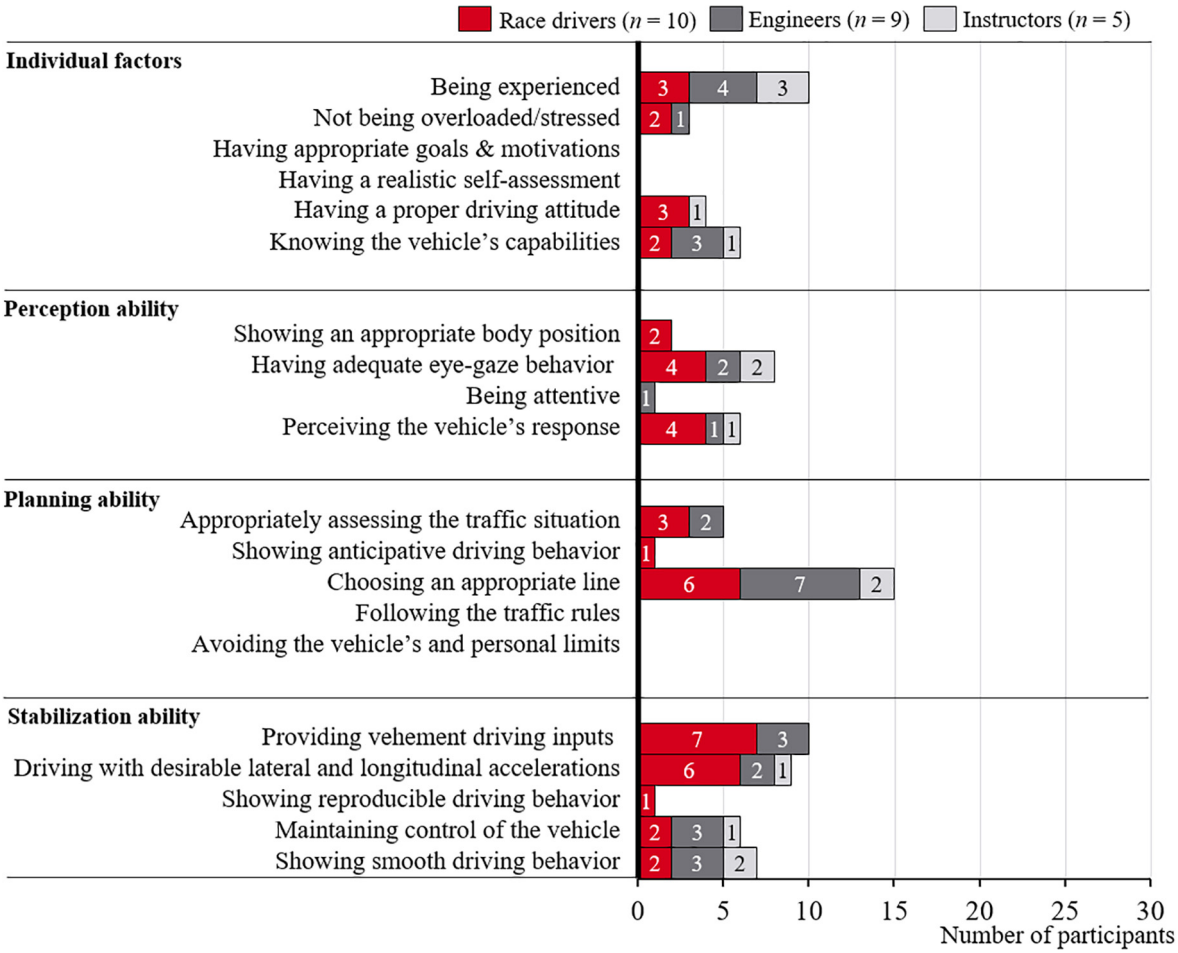

Fig. 8. Mentioned greatest potential to improve the lap time on a race track for low-level drivers (corresponding question: Q10).

Statistics of the video ratings

Table 7 shows all means and standard deviations for three levels of detail. First, averages of all driving environments (city, rural road, and race track) are shown. The second level of detail shows environment-specific ratings of each group. The last level of detail includes means and standard deviations for each video individually.

Table 7
Video ratings: Means and standard deviations for Q15a - Overall assessment of driver performance in the videos (5-point Likert scale: Very bad – Very good). Standard deviations were computed at the level of participants (n = 10 per participant group).

Videos	Race drivers		Engineers		Driving instructors	
All environments	Mean:	2.64	Mean:	2.83	Mean:	2.88
	SD:	0.56	SD:	0.33	SD:	0.47
Each environment separately	In-town mean:	2.50	In-town mean:	2.75	In-town mean:	2.30
	In-town SD:	0.71	In-town SD:	0.59	In-Town SD:	0.54
	Rural road mean:	2.20	Rural road mean:	3.05	Rural road mean:	2.25
	Rural road SD:	0.95	Rural road SD:	0.96	Rural road SD:	0.63
	Race track mean:	2.83	Race track mean:	2.78	Race track mean:	3.28
	Race track SD:	0.75	Race track SD:	0.22	Race track SD:	0.65
Each video separately	Video 1 mean:	3.00	Video 1 mean:	2.80	Video 1 mean:	3.20
	Video 1 SD:	0.67	Video 1 SD:	0.63	Video 1 SD:	0.79
	Video 2 mean:	2.00	Video 2 mean:	2.70	Video 2 mean:	1.40
	Video 2 SD:	1,05	Video 2 SD:	0.82	Video 2 SD:	0.52
	Video 3 mean:	3.00	Video 3 mean:	3.70	Video 3 mean:	3.30
	Video 3 SD:	1.41	Video 3 SD:	0.95	Video 3 SD:	1.25

(*continued on next page*)

Table 7 (*continued*)

Videos	Race drivers		Engineers		Driving instructors	
	Video 4 mean:	1.40	Video 4 mean:	2.40	Video 4 mean:	1.20
	Video 4 SD:	0.70	Video 4 SD:	1.17	Video 4 SD:	0.42
	Video 5 mean:	3,30	Video 5 mean:	3.50	Video 5 mean:	4.00
	Video 5 SD:	0.82	Video 5 SD:	0.85	Video 5 SD:	1.05
	Video 6 mean:	3.70	Video 6 mean:	3.50	Video 6 mean:	3.60
	Video 6 SD:	1.34	Video 6 SD:	0.53	Video 6 SD:	1.26
	Video 7 mean:	2.80	Video 7 mean:	2.50	Video 7 mean:	2.60
	Video 7 SD:	1.23	Video 7 SD:	0.53	Video 7 SD:	1.51
	Video 8 mean:	1.90	Video 8 mean:	1.80	Video 8 mean:	3.40
	Video 8 SD:	1.20	Video 8 SD:	0.42	Video 8 SD:	1.07
	Video 9 mean:	2.60	Video 9 mean:	2.60	Video 9 mean:	2.70
	Video 9 SD:	1.43	Video 9 SD:	0.70	Video 9 SD:	1.25
	Video 10 mean:	2.70	Video 10 mean:	2.80	Video 10 mean:	3.40
	Video 10 SD:	0.95	Video 10 SD:	0.79	Video 10 SD:	0.70

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