Potential Individual Differences Regarding Automation Effects in Automated Driving

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ABSTRACT

Currently, the legal, technical and psychological regulatory framework of automated driving is being discussed by car manufacturers and researchers to guarantee its safe and smooth introduction into the traffic system. This discussion is accompanied by plenty of studies that seek to study the human side of the interaction with automation and to expose potential problems and hazards. Past research from other domains has shown that the studies' subjects differ considerably, for example in their abilities (e.g. ability to monitor) or in their attitudes (e.g. trust in automation). In this work we discuss potential individual differences – classified into dispositions, stable traits, operator state, attitudes and demographics – that could influence the human performance in interactions with automation. Where they exist, valid methods of measurement are referenced. The review closes with a deduction of potential risk groups that were inferred based on the reviewed literature.

Categories and Subject Descriptors

H.1.2 [**Information Systems**]: User/Machine Systems – *Human factors.*

General Terms

Performance, Experimentation, Human Factors.

Keywords

Individual differences, automation, human performance.

1. INTRODUCTION

Technological progress in advanced driving assistance systems (ADAS; [15]) nowadays provides the ability to let the longitudinal control (e.g. Adaptive Cruise Control; ACC) as well as the lateral control (e.g. Lane Keeping Assistant) be carried out by these systems [20]. Currently, advances in sensory technology and data processing make it possible to remove the driver completely from the driving task in such a way that, contrary to manual driving, a vehicle automation system fully operates the vehicle. In case of partial automation, the driver still has to monitor the automation throughout all the time. In case of highly automated driving, the driver only has to pay attention and take back control if it is requested by the automation (a so-called take over request; TOR), caused for example by a system failure [17]. The goals of introducing automation are to reduce the driver's workload [72], and to increase traffic safety [36, 56] and comfort [73]. Automation has already been an energetically discussed topic in other domains like aviation [47, 84], and multiple authors have highlighted the potential risks that accompany the benefits [3]. In order to minimize these risks, many researchers are currently conducting studies to analyze human performance in handling a vehicle automation system, and to expose potentially dangerous situations [16, 21]. If a study is to produce valid representative results, a representative sample must be used. Conclusions from current studies on vehicle automation are therefore limited, firstly, because they in many cases use a specific group participants (e.g. employees, test drivers, students) and secondly, because they concentrate on means and the average population. It is crucial to also consider the distribution boundaries in order to guarantee safe use for the whole population. For example, instead of the mean reaction time, Sohn and Stepleman [71] recommend using 85th or 99th percentile data in order to give a suggestion for a safe headway distance. This paper lists individual differences that could potentially influence human performance in interactions with vehicle automation and therefore should be considered in the process of choosing participants, inferring results and discussing limitations.

2. POTENTIAL INDIVIDUAL DIFFERENCES

The following section is structured according to dispositional factors, stable personality traits and behavior patterns, current operator state, attitudes and demographic factors. Thereby, we take into consideration the current situation and condition of a participant (states, attitudes) as well as stable factors that are distinctive for the participant and do not change or vary much. There are further relevant influence factors, e.g. the participant's instruction to an experiment, that do not directly trace back to individual differences and therefore are not being discussed in this paper, but still remain important.

2.1 Dispositional Factors

A disposition refers to a person's innate natural abilities that are seen as more or less unaffected by learning. One of the most crucial dispositions in traffic safety is the *individual reaction time* to events. Even if the driving task is carried out by a vehicle automation system, reaction times still remain important: If the automation reaches a system limit or fails, the driver is required to quickly take back control as a response to a take over request (TOR; e.g. an earcon) by the vehicle. Manual driving requires the driver's attention constantly on the road, but automated driving makes it possible for the driver to engage himself in other activities like reading the newspaper or playing a video game and

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this opportunity is used increasingly with increasing level of automation [6]. Hence, if a TOR is signaled, the driver's attention is probably focused on a non-driving activity, and because of that an individual's ability to detect the TOR signal outside of his attentional focus (i.e. spotlight of attention) and then to react adequately and quick is crucial for a fast takeover. The combination of those two abilities is called *peripheral detection*. Its operationalization, the *peripheral detection task* [23], could be used to assess how fast an individual can naturally react to a TOR signal independent of the experimental setup.

When the driver reacts to the TOR signal, he then quickly has to refocus on the traffic situation, scan the vehicle's environment and comprehend what is going on – i.e. gain situation awareness [11]. This process is determined by the individual's *perceptual speed* [34] and the *speed of information processing* [13]. In addition, there is evidence of differences in the *ability to switch between tasks* [44] which could be an important determinant of takeover quality too. Tests for these constructs [13, 34, 83] could be used to remove bias in the data.

In the case of partial automation, the driver still has to keep the automation under surveillance and takes the passive role of a system monitor. Individual differences in a person's ability to monitor and sustain attention to rare and randomly appearing stimuli, also known as *vigilance*, have been the focus of research for a long time [35]. A decrement in signal detection can be found from a 30-min watch, a time frame that is also relevant for automated highway drives. Variability in monitoring ability becomes apparent in the sensitivity to target stimuli, in the reaction times to them, in the number of false alarms and in the decrement of these indicators over time. Monitoring is perceived as stressful and hard work [81] because one has to use attentional resources to remain focused despite a low stimulus rate: The task is monotonous and not demanding, effort has to be spent to stay alert and on-task, also known as state-related effort [9]. Therefore, if a driver uses partial automation for a longer period of time, his attentional resources could more or less slowly diminish, and eventually his reaction times could increase and sensitivity could decrease. Temple and colleagues [75] introduced a 12-minute *short vigilance test* (SVT) that can induce the vigilance decrement within a very short time. Test performance could be a relevant predictor of a person's ability to stay attentive in partially automated driving.

2.2 Traits

Stable personality traits determine behavior patterns and explain individual differences in responses to a certain situation, condition or task characteristic as a moderator variable. As already mentioned, in the case of partial automation , the driver takes on a passive monitor role confronted with low event frequency and almost no novel stimulation, which leads to states of monotony and boredom [74]. Mindlessness theory [58] proposes that in such states, the mind starts to wander and thoughts and inner monologues occur that are unrelated to the task [18, 24]. The occupation with thoughts leads to more variability in response times [64] and to longer response times to events [86]. The subject is lost in thought and takes longer to detect critical situations, to respond to events and to regain situation awareness. Individuals differ in their ability to concentrate, to sustain their attention and to stay on task [65]. For example, people with a high *propensity to daydream* [2] perform worse in vigilance tasks. Scores of the correspondent questionnaire developed by Singer and Antrobus [66] could therefore be a promising covariate for studies with monotonous conditions. Mrazek and colleagues [45] recently published and validated a trait-level questionnaire on mind wandering, the *Mind-Wandering Questionnaire* (MWQ). 5 items measure the extent to which a person is prone to the interruption of task focus by task-unrelated thought (TUT; [70]), which is seen to be responsible for attentional lapses in response times during driving [86]. Broadbent and Colleagues [4] have developed a related questionnaire, the *Cognitive Failures Questionnaire* (CFQ), a self-report inventory that focuses instead on lapses of attention and slips of action [14]. Since monitoring the system requires a person to stay attentive for considerable uninterrupted periods of time, this could be a promising branch for research.

Research on vigilance tasks also shows that these tasks are perceived as mentally straining and distressing [81]. Therefore it is important to have a look at how individuals deal with the imposed workload and stress. The Coping Inventories for Task Stress (CITS; [38]) distinguishes between three coping strategies: *task-focused coping, emotion-focused coping* and *avoidance.* Task-focus coping represents the strategy of creating a plan to solve the task in the best way and finding a way of coping within the task. Emotion-focused coping tries to reduce the task-induced stress via positive emotions and positive thinking. Avoidance represents the strategy of negating the importance of the task and distracting oneself from the task. Research has shown [65] that individuals who rely on task-focus coping perform better in vigilance tasks, and individuals with avoidance coping perform worse. This relationship could also transfer to automated driving.

Monitoring tasks are generally seen as boring [62], and boredom leads to less engagement with the task and increased engagement with other activities or mind wandering [24]. Farmer and Sundberg [12] pointed out that there are individual differences in how fast individuals become bored. They introduce the *Boredom Proneness Scale*, a questionnaire that measures how much stimulation is enough to keep a person from becoming bored. In their model of fatigue, May and Baldwin [41] remark that the causes of negative effects of fatigue can be categorized in *active task-related fatigue*, *passive task-related fatigue* and *sleep-related fatigue*. They state that monotonous driving, underload conditions and automated driving promote passive task-related fatigue. Matthews and colleagues [40] published the *Driver Stress Inventory* (DSI), a questionnaire that measures – in addition to aggression, dislike of driving, hazard monitoring, and thrill-seeking – a subject's proneness to fatigue. The items include ratings about changes in boredom, attention and vision that appear due to a long drive. If a study includes a long or very monotonous drive and possibly even a high level of automation, it could be useful to use this questionnaire as a covariate. Less automation-specific, but still potentially relevant is the personality trait of preserving task motivation and energetic arousal even during boring tasks, which can be controlled by use of the *Dundee Stress State Questionnaire* (DSSQ, [39]). This questionnaire contains a factor called *task engagement* that quantifies a person's ability to stay motivated, energetically aroused and concentrated, which is positively correlated to vigilance performance [65].

Currently, to our knowledge, there is no naturalistic driving study published about how much individuals can really free themselves from monitoring the automation even in a highly automated drive. It is possible that the driver, especially in the beginning, still monitors the automation the whole drive because of a lack of trust or experience. Therefore, these results could be important not only for partial automation but also for high automation.

2.3 Driver State

Studies on automated driving often use reaction times to the TOR and visual attention as dependent variables in their experimental design (e.g. [20]). Goel and colleagues [19] have shown that many factors relevant to driving performance, such as reaction times and attention, are affected by *sleep deprivation* and resulting *sleepiness*, which can also be seen in real accident data [7]. Evidence like the post-lunch dip in performance caused by *circadian rhythm* [57] suggests that sleepiness may also play a role in studies that do not especially focus on it. The *Karolinska Sleepiness Scale* [1] is a one-item questionnaire that validly measures current sleepiness and is sensitive to deterioration in driving performance due to sleepiness [52]. A related state questionnaire is the *Epworth Sleepiness Scale* [29] which is a measure of general propensity toward *daytime sleepiness*. The passive role in an automated drive and the seated body position represent a situation that could induce daytime sleepiness. Indeed, people with a high propensity show more micro-sleeps in a driving simulator [43], and the questionnaire scores are positively correlated to reported nodding off in real traffic [78].

2.4 Attitudes

One of the best-known problems in interacting with automation is *complacency*, a strategy of allocating attention away from an automated task to another concurrent task [50]. In situations of high workload and concurrent tasks, the operator relies on the automation, shifts his attention away, and failures in these functions are then not detected. The tendency to complacency is influenced by automation reliability [48], but also by the operator himself, for example his expertise with the system [67], propensity to attentional lapses [53] and individual complacency potential [69]. An individual's vulnerability can be assessed by the Complacency-Potential Rating Scale [68]. In addition to that, individual *trust in automation* provides a potential for complacency, but complacency is not a direct consequence of it. Trust in automation represents the personal attitude of how much one relies on the automation and of how much one thinks that the automation is beneficial [33]. This attitude determines the operator's reliance on automation and his attentional strategy, e.g. how much he gets involved in non-driving activities. Merritt and Ilgen [42] reported that besides actual objective automated machine characteristics (e.g. reliability), the perception of an automated machine has a significant impact on the trust in an automated machine. Furthermore, the subjective perception is in turn influenced by the operator's personality and propensity to trust. The negative effect of automation failures on trust in automation were also dependent on the subjects' general propensity to trust, another indicator of the importance of personality in human-automation interaction. In another study, Parasuraman and colleagues [48] show that constant reliability of an automation leads to lower failure detection rates, and this lowered rate is probably caused by over-reliance, i.e. too much trust in automation. Detection of hazardous situations can also suffer if the driver over-trusts the automation, i.e. if he relies on the automation beyond the automation's abilities and does not maintain an appropriate situation awareness to respond adequately and in time. For example, Damböck [8] found that with an increasing level of automation, visual attention is increasingly relocated away from the driving scene to a secondary task. Beyond that, performance measures also exist: overreliance leads to later braking with ACC, [54] and trust calibrated to the system's abilities leads to better takeover reactions in automated driving [25]. To sum up, trust in automation and complacency determine attention allocation and thereby the maintenance of situation awareness, which is crucial for being ready to take over vehicle control and to detect system failures.

2.5 Demographics and Other Factors

The impairments that come with increasing *age* have been noted in various articles and are relevant for traffic safety: the perception of hazards is slowed down [27], reaction times to hazards are longer [82], the information processing speed is slower [79], the visual search is altered [37], older drivers make more mistakes in estimating the speed of other vehicles [63], they take longer to switch tasks [32], and they have problems in novel situations and with fast decisions [22]. In addition, their monitoring ability is lowered: They detect fewer signals and produce more false alarms in a vigilance test [10], and their vigilance decrement is greater [49]. Furthermore, their interaction with automation is different because they perceive automation reliability differently and therefore differ in how much they trust in automation [61]. It is therefore very likely that the ability to monitor an automated vehicle and the ability to take over and respond appropriately within seconds is impaired for older people. Petermann-Stock and colleagues [51] found no significant difference in the reaction time to a TOR signal between younger (25–35 years) and older (50–70 years) drivers although the difference was up to 1s in the high workload condition. The degree of the impairments caused by aging is highly variable [28] and accordingly the standard deviation in the study's sample was very high for the older driver group, which could be the reason for the non-significant results. Also, no immediate reaction by the participants was necessary, because the take over situation was rather uncritical. It is possible that the drivers took their time to comfortably take over and this could have ruled out any differences in reaction times. Thus it is not certain whether situations that can be solved by young drivers can also be solved by older drivers.

Although it is common practice to collect information about the subject's driving experience – e.g. to exclude novice drivers from the sample – little attention is paid to *expertise with ADAS and automation*. As already mentioned, expertise with a system promotes the tendency toward complacent behavior [67]; it also influences risk perception [26, 55] and influences trust in a system [60]. For this reason, not only driving experience, but also experience with ADAS and automation should be collected by means of a questionnaire.

A disease that is relevant to monitoring automation is *attention deficit hyperactivity disorder* (ADHD) since patients with that disorder are greatly vulnerable to distraction, tend to wander with their thoughts and have trouble remaining calmly in a single position. Accordingly, they perform worse in vigilance tasks [85]. The inattentiveness may be caused by deficits in central executive processing [31], particularly deficits in working memory that have already been associated with impairment in vigilance performance [5]. Symptoms of ADHD can still be prevalent in personality traits in adulthood without reaching a pathological level [46]. This can be seen in studies that found a relationship between personality traits like extraversion or impulsivity and impairment in vigilance performance [30, 59, 76]. In addition, monotonous, long-distance driving leads to a greater decrease in vigilance and increase in fatigue for individuals who score high on extraversion and sensation-seeking [77, 80]. Neuropsychological tests that are sensitive for ADHD, for example for *subtests for working memory* [83], could therefore exhibit predictive validity.

Table 1. Overview of the mentioned potential individual differences.

Category	Relevant Constructs
Dispositional Factors	Individual reaction time; peripheral detection; perceptual speed; speed of information processing; ability to switch between tasks; vigilance performance.
Traits	Propensity to daydream/mind wandering/attentional lapses; coping strategy; boredom proneness; task engagement.
Driver State	Prior night sleep/sleep deprivation; current sleepiness; circadian rhythm; daytime sleepiness.
Attitudes	Complacency-potential, trust in automation.
Demographics and Other Factors	Age; expertise with ADAS and automation; ADHD; working memory capacity.

3. CONCLUSION

In this article, we reviewed literature on potential individual differences in interaction with vehicle automation. It became evident that the participant's age, because of its multiple and well-studied accompanied impairments, is a major influence factor: slower reaction times and slower information processing lead to a deteriorated ability to respond to critical traffic situations and TORs. Another relevant group is formed by individuals who get bored easily, need a lot of stimulation to stay on task and tend to solve this boredom or monotony with mind wandering and distractive thoughts or activities. Beyond that, individual strategies of attention allocation, and the degree of trust in automation determine how drivers interact with the automation. Future studies could, first of all, empirically estimate effect sizes of the mentioned constructs in the interaction with automation. In addition, it is necessary to examine the relationships between the mentioned factors and quantitatively compare their effects on operating a vehicle automation. Besides that, this article is exclusively focused on individual differences. There are other factors outside of this focus, e.g. the effects of instruction or of training that are also relevant for the interaction with automation and should for sure also be considered for discussion and further empirical research. Ultimately, more naturalistic driving studies have to be conducted in order to determine the actual interrelationship of automated driving on participant's subjective state.

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