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Driver Instruction for Automated Vehicles: Assessing the Role of Specific Elements on Learner Motivation and Mental Model Development

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ABSTRACT

Along with the increasing degree of automation of the driving task, calls for user education on automated driving have emerged. Although earlier studies confirmed that such education can have positive effects, there has been no examination of the role of specific elements in such educational concepts. Research in educational psychology has shown that motivation to learn is crucial for learning success. Thus, in the present study we examined the role of specific instructional elements on learner motivation for automated vehicles. In an online study ($N = 193$) we assessed the role of the instructional elements feedback and choice in task completion, and a combination of both elements after instruction and at a two-weeks follow-up. Results indicate that, compared to a control group without these elements, feedback enhances motivation to learn, could support mental model development and exert a positive influence on trust in the automated vehicle.

Keywords: Automated driving, Driver education, Trust, Mental model

INTRODUCTION

Currently, drivers face a transition phase, in which the driving task is increasingly automated. According to the Society of Automotive Engineer's taxonomy (SAE, 2018), Level 2 (L2) or partially automated driving functions are available in on the market, which take over lateral and longitudinal guidance. However, the driver always has to supervise the system and the environment. In contrast, Level 3 (L3) functions allow drivers to allocate their attention to non-driving related tasks (NDRT) and issue a take-over request (TOR) when the driver is required to drive manually again. L3 functions are not available on the market yet, however, future vehicles might feature both, L2 and L3 functions (Winner and Merkel, 2017), which leads to a fundamental change in the interaction between driver and vehicle, and thus to new challenges for drivers (Kyriakidis et al., 2019). In that context, drivers' mental models are crucial to ensure adequate trust and acceptance (Beggiato and Krems, 2013). A mental model is defined as knowledge structure in long-term memory that includes the user's understanding of the automated driving system's scope, its functionality, and the reasons for system behavior (Carroll and Olson, 1987; Durso and Gronlund, 1999). To support mental model formation, user education is considered a key element (Casner and Hutchins, 2019). Indeed, recent research provides first evidence that user education beyond the user manual enhances, e.g., mental model formation (Krampell et al., 2020).

To design an effective educational concept it is crucial to consider learner motivation (Noble et al., 2020). More specifically, intrinsic motivation (Ryan and Deci, 2000) to learn fosters cognitive processing of the learning material (Cordova and Lepper, 1996) and transfer of learning (Blume et al., 2010). Thus, by enhancing motivation to learn, mental model formation in the context of automated driving could be promoted (Feinauer et al., under review). Following this line of reasoning, we aimed to assess how specific elements can foster learning motivation, as well as mental model formation and development. In addition, we evaluated the effect on trust in and acceptance of the automated vehicle. To that end, we developed an instructional concept that provided information on a L2/L3 automated vehicle and implemented it in an online study. Information was either enriched with feedback elements, opportunities for choice, a combination of both, or none of these, resulting into four experimental groups. To assess long-term effects of these elements on mental model development, trust, and acceptance, we included a follow-up measurement of these variables two weeks after the manipulation.

METHOD

Instructional Design

The content of the instruction was structured into four sections: Human-machine interface, the driver's responsibilities, functionality, and purpose of the function. The information was provided on two pages of text and figures.

To promote intrinsic motivation, according to basic psychological needs theory (Ryan and Deci, 2017), three needs should be fulfilled: Competence, autonomy, and social relatedness. In the present study we focused on the two needs of competence and autonomy. To fulfil the need of competence, *feedback* has been shown to be an effective measure (Ryan and Deci, 2017). Thus, yes/no questions at the end of each section were included. After a correct answer a green check mark and 'well done, this answer is correct' was displayed (Figure 1a). To enhance feelings of autonomy, conveying *choice* is a potential measure to provide an autonomy-supportive context (Joussemet et al., 2004). In the present study, participants were free to choose the order in which they read the four sections (Figure 1b). However, all sections had to be read to continue the study. Additionally, in the combination group, both elements (feedback and choice) were included. As a control condition, a fourth group did not receive any of these elements.

Online Study

Sample. $N = 220$ participants completed both parts of the survey. Twenty-seven participants had to be excluded due to a short processing time (below

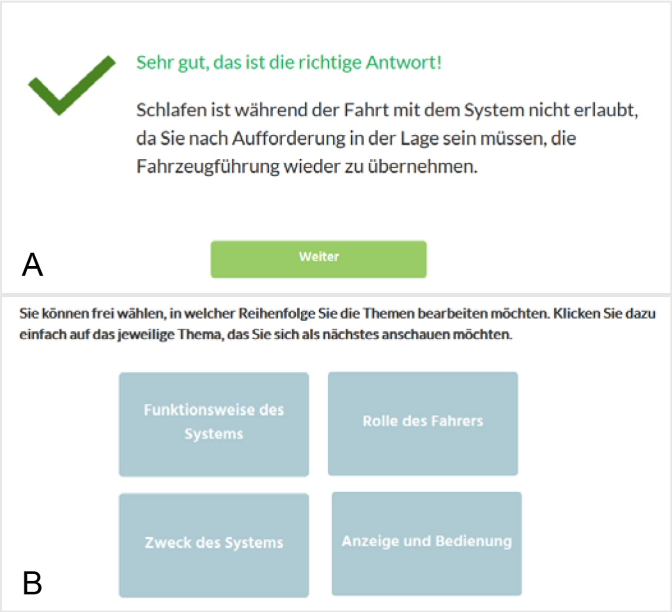

Figure 1: A: Feedback to a correctly answered question. B: Sections provided which could be read in a freely chosen order.

median time divided by two) or to a long processing time (part one: above 80 minutes, part two: above 40 minutes) for either part of the study. The remaining $N = 193$ participants (44% female) were included in the data analysis. Mean processing times were 31 minutes ($SD = 14$ min) in part one, and 10 minutes ($SD = 6$ min) for part 2. Participants were recruited via a German online survey service. The sample's mean age was 46.3 years ($SD = 13.4$, $min = 20$, $max = 75$). Cell sizes were $n = 43$ for the combination group, $n = 47$ for the competence group, $n = 46$ for the autonomy group and $n = 57$ for the control group. The four groups' mean age ranged between 44.6 and 47.5 years and the proportion of female participants between 33% and 58%.

Dependent Variables. To measure *intrinsic motivation* to learn the provided information, the subscale 'Interest' of the Intrinsic Motivation Inventory (Ryan et al., 1983) was applied as it has previously been used as self-report measure of intrinsic motivation (Deci et al., 1994). The subscale consists of seven statements, to which participants rated their agreement on a five-point Likert scale.

Participants' *mental models* were assessed with a self-developed questionnaire which included knowledge of the L2/L3 vehicle covered in the instruction. It consisted of 36 statements, to which participants stated their agreement on a 5-point Likert scale. Higher values indicate a better performance on the questionnaire. In addition, we aimed to measure the transfer of knowledge to situations that could be encountered when using the vehicle described in the instruction. Twelve situations (e.g., that required a take-over or referred to system functionality) were designed in a CarMaker (IPG Automotive, 2019) and displayed as pictures from the driver's

Figure 2: Example of an item to measure knowledge transfer to situations.

perspective (Figure 2). Fifteen items were developed in which participants had to anticipate the vehicle's behavior and choose the correct reaction within a single-choice scheme.

Trust was assessed with the Automation Trust Scale (Jian et al., 2000) in a German translation. *Acceptance* was measured with the acceptance scale by Van der Laan et al. (1997), which consists of the two dimensions usefulness and satisfaction. Nine pairs of adjectives are rated on a 5-point semantic differential.

Study Design and Procedure. The study employed a two-factorial mixed design with the four-level between factor instruction type and the within factor time of measurement. After giving consent, participants filled out questionnaires on trust in and acceptance of the automated vehicle as baseline measure of these constructs. Then, they were randomly assigned to one of the experimental groups and received the instruction, followed by the measurement of intrinsic motivation. Afterwards, the questionnaires on acceptance, trust and mental model were filled out. After two weeks, participants received an invitation for the follow-up, in which again mental model, trust, and acceptance were assessed.

Statistical Procedure and Data Analysis. Data was analyzed and visualized in R (R Core Team, 2020) and SPSS (IBM, 2011). To examine the effect of the factor instruction type, we employed an analysis of variance (ANOVA), which always involved the between factor instruction type, and, depending on the dependent variable, a two- (mental model) or three-level (trust, acceptance) within factor for the time of measurement. If the assumption of sphericity (as indicated by Mauchly's Test) was violated, Greenhouse-Geisser corrected degrees of freedom were used. Due to unequal cell sizes, the ANOVA was based on Type 3 Sum of Squares (Bortz and Schuster, 2010). In case of a significant effect for instruction type, post-hoc Dunnett tests were computed, in which each group was compared with the control group. An alpha level of $\alpha = 0.05$ was applied unless stated otherwise.

RESULTS

Intrinsic Motivation

A one-factorial ANOVA with the between factor instruction type indicated that the experimental groups differed in their motivation to learn the provided information, $F(3,189) = 3.20$, $p = .025$, $\eta_p^2 = 0.05$. Post-hoc Dunnett comparisons yielded a significant difference between the control ($M = 3.50$, $SD = 0.80$) and combination group ($M = 3.85$, $SD = 0.73$), $p = .047$, and control and competence group ($M = 3.78$, $SD = 0.86$), $p = .032$. The comparison of the autonomy ($M = 3.44$, $SD = 0.93$) with the control group was not statistically significant, $p = .80$. Generally, motivation to learn the provided content tended to be high across all groups.

Mental Model

Figure 3 shows the results of the mental model questionnaire. Also concerning this dependent variable, ratings on the questionnaire generally tended to be high. The ANOVA yielded significant main effects for instruction type, $F(3,189) = 3.90$, $p = .01$, $\eta_p^2 = 0.06$, and time of measurement, $F(1,189) = 16.10$, $p < .001$, $\eta_p^2 = 0.08$, indicating a decrease in knowledge (Figure 3). The interaction effect was not statistically significant, $F(3,189) = 2.47$, $p = .06$, $\eta_p^2 = 0.04$. Post-hoc comparisons of the control group with the other groups revealed a significant difference to the competence group, $p = .03$, but not to the combination, $p = .73$, or autonomy group, $p = .99$.

Concerning knowledge transfer, participants in the competence group achieved the highest number of correct answers after the instruction ($M = 8.2$, $SD = 2.6$), followed by the combination ($M = 7.7$, $SD = 2.6$), control ($M = 7.4$, $SD = 3.1$), and autonomy groups ($M = 6.9$, $SD = 2.7$). At follow up, similar means were found: On average 8.3 correct answers of the competence group ($SD = 2.9$), the combination group achieved 7.5 correct answers on average ($SD = 2.9$), the control group 7.2 correct answers ($SD = 2.7$) and the autonomy group a mean of 6.9 ($SD = 2.4$) correct answers. Inferential statistics did neither yield a significant main effect for instruction type, $F(3,189) = 2.39$, $p = .07$, $\eta_p^2 = 0.04$, nor time of measurement, $F(1,189) < 1$, nor the interaction of both factors, $F(1,189) < 1$.

Trust and Acceptance

The results of the trust questionnaire are presented in Figure 4. No significant differences between the experimental groups were found, $F(3,189) < 1$. The ANOVA yielded significant effects for the factor time of measurement, $F(1.81,342.75) = 42.26$, $p < .001$, $\eta_p^2 = 0.18$, and the interaction effect, $F(5.44,342.75) = 3.06$, $p = .008$, $\eta_p^2 = 0.05$. As shown in Figure 4, this effect may be caused by an increase in trust ratings of the competence group in comparison to the control group at follow-up.

Concerning acceptance, a multivariate analysis of variance (Wilk's Lambda) of the two scales usefulness and satisfaction revealed no effects of instruction type, $\Lambda = 0.98$, $F(6,376) < 1$, or an interaction effect, $\Lambda = 0.94$,

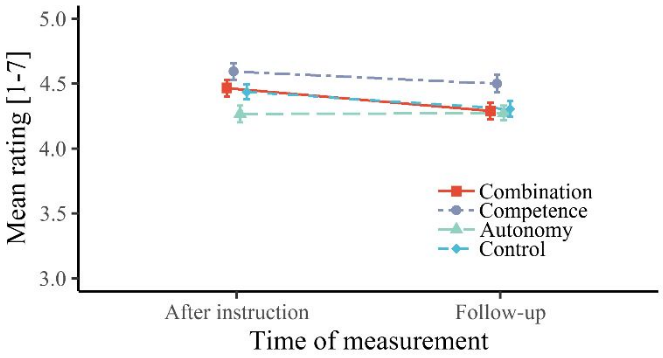

Figure 3: Means (± 1 SE) of the mental model questionnaire at the two times of measurement.

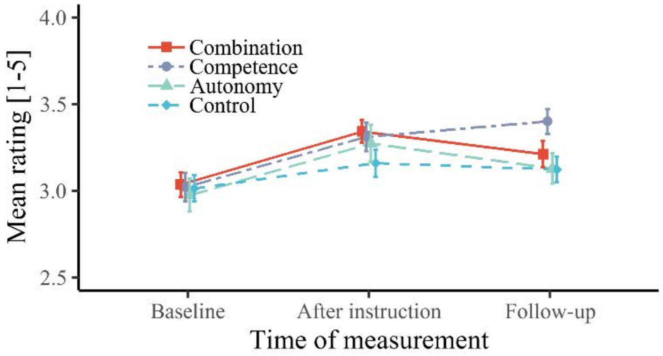

Figure 4: Means (± 1 SE) of the trust questionnaire at the three times of measurement.

$F(12,492) < 1$; however, it yielded a significant effect for time of measurement, $\Lambda = 0.94$, $F(4,186) = 2.87$, $p = .025$, $\eta_p^2 = 0.06$. Following univariate ANOVAs ($\alpha = .025$) indicated that for the scale useful, ratings increased over the course of the experiment, $F(1.90,358.19) = 5.19$, $p = .007$, $\eta_p^2 = 0.03$: Means especially increased from baseline ($M = 0.24$, $SD = 0.67$) to after the instruction ($M = 0.32$, $SD = 0.69$) and also slightly to follow-up ($M = 0.35$, $SD = 0.64$).

DISCUSSION

Based on basic psychological needs theory, the present study examined the effect of specific elements (feedback and choice in task completion) on intrinsic learning motivation and learning outcomes in the context of user education for automated driving.

Results of the intrinsic motivation questionnaire revealed that, indeed, feedback elements promoted learning motivation compared to the control group; a result that is in line with previous literature (Ryan and Deci, 2017). This was also the case when combined with choice in task completion. However, merely having a choice did not enhance motivation to learn. A potential reason could be that the manipulation was not efficient in inducing feelings of autonomy because participants had to complete all chapters to proceed with the survey and receive full compensation.

Further, we predicted an enhanced mental model formation for the experimental groups compared to the control group. Results show that, again, the competence group performed better than the control group, indicating that feedback elements supported mental model formation. Looking at Figure 2, this effect may be caused especially by a better performance on the questionnaire at the follow-up point of measurement, indicating that this group forgot less information on the automated vehicle. Contrary to our expectation, choice, and a combination of choice and feedback, did not lead to better performances compared to the control group on the mental model questionnaire. As outlined above, a reason might be the manipulation of choice. Additionally, task autonomy may also be a double-edged sword: its effects can be moderated by different state or trait dependent determinants, e.g., by the need for autonomy (Langfred and Moye, 2004). Depending on the participants' characteristics, it can thus potentially affect learning performance in a negative way. Concerning the transfer of knowledge to specific situations, no differences between groups were found, though on a descriptive level again the competence group performed best. However, it should be noted that this kind of knowledge was measured with pictures and predefined answer categories, which might have compromised external validity.

Concerning trust, the significant interaction effect indicates that at follow-up, higher trust in the automated vehicle was developed for the competence group compared to the other groups. In the literature, mental model quality has been associated with trust (Beggiato and Krems, 2013), so feedback could have led to a better mental model and thus also affected trust into the automated vehicle in a positive way. However, contrary to our expectation, this effect was not found for acceptance. Nevertheless, results indicate that acceptance increases along with a more comprehensive knowledge, which is again in line with the study by Beggiato and Krems (2013).

A major limitation of the study is that it was executed online, which can constrain external validity and reduce experimental control. Furthermore, the control group in this study received the same information as the other groups. It can be assumed, however, that drivers do not necessarily have considerable knowledge on the automated vehicle before they interact with it for the first time. Thus, future studies also could include a less informed control group. Additionally, the role of motivation in driver education for automated vehicles could be further assessed with studies on the presentation of the educational material, e.g., on a tablet or in written form.

Overall, the present study contributes to the growing body of research on driver education for automated vehicles and suggests that feedback elements seem to have the possibility to enhance mental model formation and trust in the automated vehicle. Because such elements are comparatively easy to implement, they could be included into different means of instruction.

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