DOES DRIVING EXPIERIENCE MATTER IN DRIVING SITUATIONS OF VARYING COMPLEXITY? A COMPARISION OF GAZE AND DRIVING BEHAVIOR OF EXPIERIENCED AND INEXPERIENCED DRIVERS

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ABSTRACT: To what extent does driving experience matter? According to Rasmussen's [1] theory on human control and behavior, competences as they are acquired usually pass through three different stages. Once the most advanced level of competence has been reached, reactions become automatic, demanding fewer resources in working memory. Consequently, more experienced drivers possess additional available resources that can be used to improve performance in complex situations [2]. Specifically at high attention demanding road crossings, drivers adapt their gaze and driving behavior [3]. However, both traffic complexity and drivers' experience have been combined in few experimental studies. Our objective was to compare workload and behavior of experienced and inexperienced drivers in low and high complex traffic situations. Results showed that both groups of participants were able to adapt driving behavior and workload to roadways of increasing complexity. Differences were observed with experienced drivers varying their speed to a greater extent than their inexperienced counterparts. An analysis of eye movement behavior did not show main effects of experience, but it revealed significant interactions between experience and road way complexity. Results indicate that drivers of different skill levels apply their knowledge to a different extent. Largely automatic and appropriate speed adaptation needs time to develop whereas adequate visual scanning is likely to occur already at an early level of skill acquisition.

1 THEORY

As maneuvering a vehicle is a highly complex task special skills need to be developed for driving in dynamic and dense traffic. Rasmussen's [1] model of human control and behaviour can be applied to the control of a vehicle. His model is based on the knowledge-based, rulebased, and skill-based framework. With experience, behavior control processes move from a knowledge-based level and a rule-based level towards a skill-based level. Once behavior is automated, situation patterns are processed more flexibly and dynamically. According to the Situation Recognition and Analytical Reasoning (SRAR) model, situation recognition processes for experts are less static than for beginners [4]. Once the situation recognition rocess is more dynamic, the cognitive control and mental workload required for an operation, such as driving a vehicle, continuously decrease and fewer attentional resources are required. Since this results in a larger amount of available resources more attention may be allocated to other relevant objects, such as neighboring traffic. Thus, drivers might handle complex traffic situations more easily. In previous works traffic complexity has often been referred to the amount of new traffic information drivers have to process per time unit [5]. In our manipulation we examined the relevance of objects [6] as a further influencing factor of traffic complexity. The objective of the present study was to compare the driving behavior of differently skilled drivers in traffic situations of increasing complexity.

A small number of previous studies investigated both driving experience and roadway complexity. Patten, Kircher, Ostlund, Nilsson, and Svenson [2] showed that inexperienced drivers had longer reaction times to a peripheral stimulus than experienced drivers. Additionally, in both groups, workload increased when encountering unexpected complex traffic situations. Less experienced drivers rated cognitive workload higher compared to more experienced drivers. This is due to automatic vehicle operation skills or, as in Boy's [4] terms, inexperienced drivers have more simple and static situation recognition patterns. While manipulating roadway complexity by the presence of other traffic members (people and vehicles) at different road crossings, experienced drivers showed a larger variance in speed regulation than inexperienced drivers [7]. Depending on the experience and the complexity of different traffic situations, the gaze behavior of drivers seems to change. Crundall and Underwood [8] reported for experienced drivers a greater variance of fixations on the horizontal axes. According to the type of road, experienced drivers selected appropriate visual strategies. By contrast, novice drivers were not able to apply flexible strategies to changing road demands. Their inflexibility in the application of eye movement strategies relates to the SRAR model [4]. Accordingly, novices usually show a less fuzzy analytical knowledge pattern.

The aim of the present study was to investigate the influence of driving experience and traffic situations of different complexity on workload, driving behavior, and eye movement. According to previous studies measuring human behavior while maneuvering a vehicle, we hypothesized that both driving experience and roadway complexity are important factors. In reference to the results of previous studies, we expected to find differences in workload, gaze behavior, and speed regulation between inexperienced and expert drivers encountering various changes in traffic.

2 METHOD

Forty-five participants (23 inexperienced drivers, 22 expert drivers) took part in the experiment. We defined the level of experience following Durso and Dattel's [9] classification by kilometers driven and years of holding a drivers license. Thus, the inexperienced drivers of the present study with a mean age of 26.3 years had held their driver's license for about 7.8 years and had driven approximately 8,000 km on average. The 22 experts were bus drivers who were employed by local public transportation agencies. Their mean age was 42.3 years and they had held their drivers' licenses for about 30 years. The median of kilometers driven was 300,000 km. None of the participants have ever taken part in a driving simulator study before. We used the STISIM Drive driving simulator. A head-mounted eye-tracking system (SMI) measured eye movement behavior. Workload data were collected by Schießl's [10] workload measurement scale.

The simulation track included six traffic situations of different complexity. The complexity was manipulated by the number of objects (two vs. four vs. six objects). Objects included for example pedestrians and cars that were part of the traffic situation at the same time. In addition, the relevance of these objects for traffic safety varied. Thus, objects in a traffic situation were either relevant (e.g. walking pedestrian on the sidewalk) or less relevant for traffic safety (e.g. walking pedestrian on the sidewalk behind the railing). The criteria defining an object as relevant or less relevant were chosen according to Rösler [6]. Participants drove the simulation track six times. The first three trials (in sum 15 minutes of driving time in the simulator) served as practice trials in which the participants got familiar with the driving simulator and the simulation track. While driving, both eye movement and driving behavior were recorded simultaneously. Afterwards, participants watched their driving records in playback mode. Occasionally, on predetermined track positions, the recording was interrupted and participants evaluated their workload [10].

3 RESULTS

In order to test our hypotheses we calculated multifactorial ANOVAs for repeated measures for all dependent variables. We report the results of the Huynh-Feldt correction when the homogeneity of correlations between the values of all pairs of the conditions is violated. Eye movement data of four inexperienced drivers were excluded from analyses, because their validity was poor due to technical problems during data recording.

3.1 Influence of driving experience

Inexperienced and experienced drivers showed a considerable difference in their speed adaption (see Fig. 1). As expected the standard deviation of speed was higher for expert drivers (M=.75 km/h, SD=.68 km/h) than for inexperienced drivers (M=.49 km/h, SD=.34 km/h). A significant main effect of experience, $F(1, 43)=8.14$, $p=.007$, $\eta^2p=.16$, was observed.

No significant effect of experience was found in the proportion of fixation duration that was used to fixate objects on the horizontal or vertical plane (see Fig. 2 and 3). Concerning the subjective workload, inexperienced drivers (M=5.54, SD=2.67) showed higher values than experts (M=5.28, SD=2.96). However, that difference did not prove to be statistically significant.

3.2 Influence of complexity

By manipulating number and relevance of objects, traffic situations of varying complexity were designed. Traffic complexity proved to have an impact on the participants' workload. For the two variables, number and relevance of objects, significant main effects were found. Workload values that were rated in situations with two dynamic traffic objects were lower (M=4.48; SD=2.34) than the sampled values in situations with four (M=5.40, SD=2.34) or six objects (M=6.40, SD=3.11). The main effect of number of objects was significant and strong, $F(1.81, 77.93)=37.23$, $p<.001$, $\eta^2p=.46$. The different relevance levels of objects also influenced the rated workload. In situations including less relevant objects participants rated workload significantly lower than in situations with relevant elements ($F(1, 43)=39.03$, $p<.001$, $\eta^2p=.48$). In addition, the factors number and relevance of objects interacted. Workload increased more with an increasing number of relevant objects than with an increasing number of less relevant objects, $F(1.90, 81.85)=13.24$, $p<.001$, $\eta^2 p=.24$. The deviation of speed as a dimension of driving performance was also influenced by traffic complexity. Figure 1 shows a main effect of the number of objects that reached statistical significance, $F(1.37, 58.70)=24.19$, $p<.001$, $\eta^2 p=.36$. The deviation of speed varied between situations with relevant and less relevant objects. The lowest values were measured in situations with objects of low relevance, $F(1, 43)=19.69$, $p<.001$, $\eta^2 p=.31$. Furthermore, results of the ANOVA showed a statistically significant two-way interaction between number and relevance of objects, $F(1.69, 72.15)=11.65$, $p<.001$, $\eta^2 p=.21$.

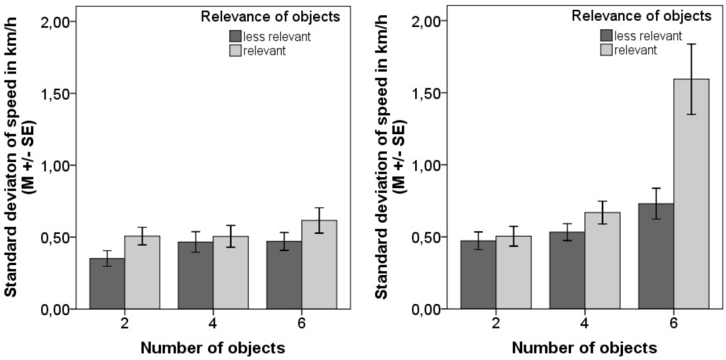

Fig.1. Mean standard deviation of speed (+/- standard error SE) per condition for inexperienced (left) and expert drivers (right) and for the variables number and relevance of objects.

In addition to the driving parameter, eye movement behavior was influenced by complexity. The proportion of fixation duration on dynamic objects on the horizontal plane was higher when situations contained a higher number of objects and/or more relevant objects (see Fig. 2). Regarding fixations on objects in the vertical plane, the proportion of fixation duration decreased (see Fig. 3).

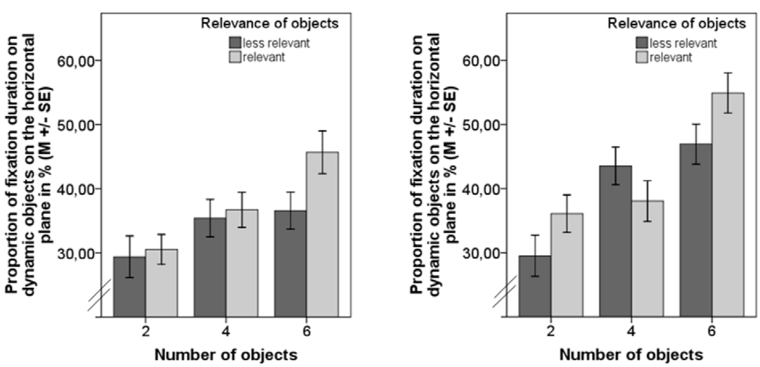

Fig.2. Mean proportion of fixation duration on dynamic objects on the horizontal plane (+/- standard error SE) per condition for inexperienced (left) and expert drivers (right) and for the variables number and relevance of objects.

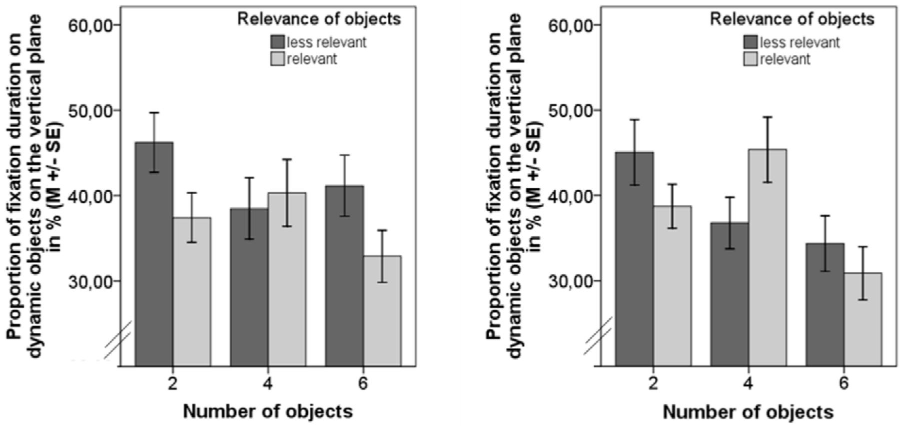

Fig.3. Mean proportion of fixation duration on dynamic objects on the vertical plane (+/- standard error SE) per condition for inexperienced (left) and expert drivers (right) and for the variables number and relevance of objects.

The differences between situations with varying numbers of objects proved to be significant for both parameters. There was a significant main effect of the number of objects for fixations on the horizontal plane, $F(2, 78)=90.76$, $p<.001$, $\eta^2p=.70$, and for fixations on the vertical plane, $F(1.55, 59.04)=10.92$, $p<.001$, $\eta^2p=.22$. Participants looked at dynamic elements on the horizontal plane with a higher percentage of the fixation duration, when the relevance level of the objects was high, $F(1, 39)=9.57$, $p=.004$, $\eta^2p=.20$. For objects on the vertical plane, the main effect was not significant. As for workload and standard deviation of speed, there were significant two-way interactions between number and relevance of objects (horizontal: $F(1.99, 77.63)=12.75$, $p<.001$, $\eta^2p=.25$, vertical: $F(1.53, 58.31)=8.43$, $p=.002$, $\eta^2p=.18$).

3.3 Experience and complexity

The analyses of the standard deviation of speed showed two significant two-way interactions (Figure 1). Expert drivers were influenced more by the increasing number of objects than inexperienced drivers were, $F(1.37, 58.70)=13.36$, $p<.001$, $\eta^2p=.24$. A similar effect was found for the relevance of objects. The difference of standard deviation of speed between situations with relevant or less relevant objects was significantly smaller for inexperienced drivers than for their counterparts, $F(1, 43)=4.99$, $p=.031$, $\eta^2p=.10$. Furthermore, we found a significant three-way interaction between number, relevance, and experience, $F(1.68, 72.15)=9.68$, $p<.001$, $\eta^2p=.18$. Regarding eye movement, results showed only a few significant interactions. While analyzing the proportion of fixation duration that was used to fixate the objects on the horizontal plane a significant two-way interaction of number of objects and experience proved to be statistically significant, $F(2, 78)=5.50$, $p=.006$, $\eta^2p=.12$. Additionally, the three-way interaction between number, relevance, and experience reached statistical significance, $F(1.99, 77.63)=4.16$, $p=.019$, $\eta^2p=.10$. The analysis of the vertical gaze behavior revealed a significant interaction between relevance and experience, $F(1, 38)=4.46$, $p=.041$, $\eta^2p=.10$. For subjective workload no significant interaction between experience and complexity was found.

4 DISCUSSION

According to our assumptions, roadway complexity influences drivers' behavior. In line with increasing complexity the demands on drivers' information processing increase. As expected, drivers reported a higher mental workload when traffic situations became complex. Furthermore, they varied their speed to a greater extent with increasing complexity. Thus, they adapted their driving behavior to compensate for the higher demands. They also varied their gaze behavior and increased the scanning of important horizontal areas in complex situations. In addition, fixation duration decreased on the vertical plane. The driving behaviour observed endorses previous studies [2, 8]. Results indicate that experienced drivers operate their vehicle and scan neighboring traffic depending on the number of objects and the objects' safety relevance. In terms of Rasmussen's framework for any driver, rule-based knowledge is being applied, while experiencing everyday traffic regardless of the drivers' skills acquisition.

However, various complex situations occupy various mental capacities of the working memory. Therefore, mental capacity should not be overloaded. Road design might initially help balance mental capacity and help trigger important relevant knowledge. Through that kind of activation, according to the SRAR model [4] analytical knowledge also triggers situation patterns and therefore appropriate behavior.

Regarding vehicle operation, differences were observed as a function of driving experience and roadway complexity with experienced drivers varying their speed to a greater extent than their inexperienced counterparts. Operating a vehicle in traffic of varying complexity seems to be rather a skill-based, automatic behavior [1]. Situation patterns trigger analytical knowledge and vice versa [4]. For speed variation we were able to show that inexperienced drivers do not yet operate on a skill-based level of skill acquisition. That means they were not yet able to apply knowledge about different traffic situations to their speed adjustment behavior.

Skilled drivers operating on a skill-based level of performance are able to react appropriately due to automatic behavior. However, a comparison of experienced and inexperienced drivers did not reveal differences in general. In most cases, both groups glanced at objects on the horizontal and vertical plane to a similar extent, indicating that similar visual scanning shows similar attention allocation. Usually automatic reactions result in decreasing mental workload [11]. In contrast to our expectations, the results indicate that both skilled and less skilled drivers experience similar mental workload while driving. According to Tränkle and Bailer's [12] arguments that a bus driver's job is very demanding, we assumed therefore that they might be used to experiencing high attention demanding traffic and expected a rather large effect of workload differences when comparing low mileage drivers with bus drivers. We assumed that inexperienced drivers rate workload of the presented traffic situations much higher than bus drivers. Apparently, roadway complexity in this study was not complex enough to reveal any differences. Even though object relevance and number of dynamic elements of situations are suitable factors for the manipulation of traffic complexity, we recommend continuing to increase traffic complexity (e.g. to have oncoming traffic pass when making a left turn) for follow-up studies.

5 CONCLUSION

Well-developed driving and eye movement behavior is necessary in order to react to relevant information or hazards appropriately. As drivers become more experienced they adapt their driving behavior to a greater extent depending on the complexity of the given traffic situation. Thus, experience does matter for applying rule-based knowledge while operating the car. It seems that complexity rather than experience is an influencing factor on drivers scanning behavior as well as on their workload. As a conclusion, more training on vehicle operation skills should improve driving performance in complex traffic situations.

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