Can driver education be improved by computer based training of cognitive skills?

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Abstract

Deficits in cognitive skills, such as hazard perception, appear to have a tremendous influence on accident involvement of younger drivers. However, conventional forms of driver training have largely failed to build skills that extend beyond the provision of a descriptive knowledge of how to drive. Computer based training (CBT) has the potential to provide new ways to deal with this problem. In this study, a CBT module was developed to complement existing driver training programs by addressing critical cognitive skills. The CBT made use of video sequences of potentially hazardous driving situations, including multiple-choice questions with adaptive feedback, to increase levels of elaboration and understanding. To test effects, a sample of learner drivers completed either CBT, paper based training with similar content, or no training at all. A simulator experiment confirmed that CBT participants exhibited earlier glances towards critical cues and relevant areas in the visual field than participants of the other two groups. It is concluded that CBT can potentially assist instruction of cognitive skills necessary for save driving.

1. Introduction

Crash statistics show an extremely higher risk for the involvement of novice drivers in traffic accidents, than for experienced drivers. According to the Organisation for Economic Co-operation and Development (OECD), "Traffic crashes are the single greatest killer of persons aged 15–24 in OECD countries, accounting for 35% of all deaths, or approximately 25,000 people annually in recent years" (OECD, 2006, p. 27). Twenty-seven percent of all traffic fatalities occur in the young-driver group, although they represent only 10% of the population. In Germany, every fifth road fatality or injury occurs in the 18- to 24-year-old age group, although this group accounts for only one-twelfth of the overall population (Statistisches Bundesamt, 2008). Clearly, young drivers are at an increased risk on the road and, simultaneously, pose a major hazard for other road users.

A model proposed by Gregersen and Bjurulf (1996) attempts to explain young drivers' accident involvement. Social and individual circumstances, as well as the learning process, are identified as causal factors that influence accident involvement in various ways. Social influence and individual preconditions mainly refer to age-related characteristics of novice drivers. Subjective norms differ fundamentally in the young-driver age group, and heavily influence how and why decisions are made that ultimately make young drivers more accident prone than their older counterparts. At the same time, lack of driving experience, and thus, underdeveloped skills necessary for safe driving, compound this problem. A vast body of experimental research shows that novice drivers have deficits especially in driving-relevant cognitive skills. Whelan and colleagues (2004) found differences in hazard perception and situation awareness between novice and experienced drivers, in line with similar research on the effects of experience on hazard perception (e.g. Crick and McKenna, 1992; Mills et al., 1998; however see Sagberg and Bjornskau, 2006). This finding is reflected in the introduction of hazard perception tests in licensing processes of several countries. Another issue is calibration, which is the balancing of task demands and driver capabilities (Kuiken and Twisk, 2001). Novice drivers have problems correctly assessing task demands, and this is reflected in their failure to perceive and evaluate risky driving situations appropriately (Finn and Bragg, 1986). At the same time, novice drivers exhibit a substantial disparity between self-assessment of driving skills and their actual capabilities, which leads to fatal errors when adjusting task demands (e.g. adjust speed, overtake a vehicle, etc.) to available resources. Although an overestimation of abilities is rather common for all age groups of drivers (e.g. Groeger and Grande, 1996; Svenson, 1981), novice drivers seem especially prone to this kind of misjudgement. Matthews and Moran (1986) report that young male drivers tend to rate their skills as similar to those of older drivers, a result that was later confirmed for young drivers in general (Groeger and Brown, 1989). Given the difference in driving experience between these two groups, younger drivers are clearly at a higher risk of mismatching driving task demands to their actual skills.

Traditional driver education does not appear equipped to deal with these issues. Indeed, as Mayhew and Simpson (1996) demonstrate in their review, scientific proof is lacking to support the claim that institutionalised driver education is more beneficial in terms of safety compared to private instruction. Accordingly, Mayhew (2007) argues that driver education should exploit available opportunities that will help drivers achieve safety objectives. One such opportunity is computer based training (CBT). The rise of multimedia applications has provided novel ways of delivering content to learners. One of the most important aspects is the possibility of including dynamic visual content, for example, real-life video footage or computerised animation in such applications. In this way, learner drivers have the opportunity to experience potentially critical situations without actually endangering themselves or others. The realism of such animated depictions, compared to static textbook images, is a true benefit of CBTs. The adaptability of CBTs to the needs of trainees, both generally (e.g. in setting different levels of difficulty depending on pretest results) and specifically (e.g. repeating incorrectly answered questions, giving feedback depending on answer), constitutes another major advantage over textbook- or lecture-based learning. Yet, as Niegemann and colleagues (2004) note, many multimedia applications fail to meet expectations. That is, the unique characteristics of new media alone do not suffice, in the absence of an appropriate instructional strategy. Also, the use of CBTs places a higher demand on both learners and teachers. Important concepts in this regard are media literacy and self-regulated learning competence (Schnotz et al., 2000). Simply incorporating new media features in a training program does not guarantee effectiveness. Theoretically sound design of an application, including appropriate instructional strategies, is absolutely essential.

On an international level, few CBTs exploit the opportunities provided by multimedia to teach driving-relevant skills. Applications such as Driver ZED (Blank and McCord, 1998), DriveSmart (Regan et al., 1999) or CDDrives (Cockerton and Isler, 2003; Isler and Cockerton, 2003) employ real-life video footage and require users to answer multiple-choice questions, to react to hazards by pressing buttons, or to mark hazardous areas in the the context of virtual scenery. Evaluation of these applications (Fisher et al., 2002; Regan et al., 2000) shows that there are indeed measurable effects. However, it should be noted that such applications were developed and tested in countries (United States, Australia and New Zealand) where driver education differs fundamentally from most institutionalised European driver education schemes. In Germany, for example, a learner driver is required to attend a minimum of 14 driving theory lessons (90 min each) before being allowed to take the theoretical test (FahrschAusbO, 1998). The content of these lessons is federally regulated, and therefore, highly standardised. In the United States, rules vary from state to state, for example, certain states only require theoretical driver training for learners under 18 years of age (e.g. California Department of Motor Vehicles, 2012), and others require no training at all (Massachusetts

Department of Transportation, 2012), before being permitted to take a theory test. In New Zealand (New Zealand Transport Agency, 2012) and Australia (e.g. Western Australia Department of Transport, 2012; Roads and Maritime Services New South Wales, 2012), the theory test is the first mandatory step for all potential learner drivers, and no prior attendance at a driver theory class is required. It can be assumed that theoretical knowledge about road rules and behaviour is, on average, higher in countries with an institutionalised driver education scheme, and is more homogeneous compared to countries lacking standardised theoretical instruction. Additionally, driving environments in the aforementioned countries differ significantly from those in a European context. Therefore, it might prove difficult to directly translate study effects. Additionally, although these evaluations provide evidence for the general effectiveness of the tools measured, they do not reveal the actual potential of multimedia applications, as comparisons to non-multimedia types of training are lacking. If it could be established that CBT are not only effective, but also superior to other forms of training, CBT could be considered a useful addition to driver education. When reviewing models of skill acquisition (e.g. Anderson, 1982), it becomes clear that for aspects of driving that require automation (e.g. glance behaviour), a higher level of physical fidelity in the training is necessary than for the acquisition of purely explicit knowledge (e.g. understanding traffic signs) to optimally prepare the learner (Haworth et al., 2005). In that sense, especially for such skills, a textbook-like instruction should produce results that are not much different from a control group with no training at all, whereas an appropriate CBT should have advantages. If such results can be found, it would make an even stronger case for CBT. Given the limitations of the available studies, we wish to respond to the need for the development and testing of new cognitive training applications.

2. Computer based training

Central to the development of a new cognitive training application was the integration of multimedia elements. To prove that such an application can contribute to driver education, we decided on anticipatory behaviour, and more specifically hazard perception and glance behaviour as relevant skills to address, rather than trying to design a complete educational package. In particular, we focused on the proceduralisation of knowledge already acquired during theoretical lessons, notably, developing a link between lessons and actual driving. In response to the need for individual application of acquired knowledge and skills in contexts close to reality, we employed a problem-based approach when constructing the multimedia training application. It was highly important to include potentially harmful traffic situations in which the driver should act (or stop acting) in a certain way to prevent an accident (i.e. the problem needing to be solved). The display of such scenarios should exploit the most obvious advantage of multimedia applications – moving pictures. Rather than simply showing a still image of a ball lying on a street as an indicator for children, who might run

across (which is an item out of the German theoretical examination), the criticality of the situation should develop out of its dynamic depiction. In addition, we wanted to employ some form of adaptive feedback (e.g. related to a respective mistake), to extend beyond the character of simple "drill and practice" types of learning (Bodendorf, 1993). This should help stimulate greater elaboration and information processing in the learner driver.

The resulting application consisted of three parts: (1) a pretest on theoretical knowledge, (2) an instructional phase, and (3) actual training. The pretest comprised 23 items selected from the set of questions used in the official theoretical examination in Germany. The main objective of this pretest was the activation of previous knowledge in the participant. However, data were recorded as control variables as well. In the instructional phase, the relevance of training and its contents were communicated. Essential knowledge for the successful completion of training concerning the operation of the application, as well as important previous knowledge related to issues that the training tried to address, were given.

Training used short clips of traffic scenes, embedded in a Flash environment, to present information. Instead of real-life video footage we generated artificial animations, whereby many aspects were comparable to those in a driving simulation, but with much higher visual quality (see Figure 1 for an example). This strategy allowed us to have absolute control of any variable that we might want to manipulate in the video. Participants watched 50–70 s video sequences from the point of view of a driver, and were instructed to observe the evolving situations as if they were driving. This experience was supported by a "navigation system," which informed learners about the designated route (e.g. "turn left").

Figure 1: Example CBT screenshot.

Sequences were developed to reflect various aspects of the driving task, and can be broadly classified in two categories (1) hazard indicators in vertically distant positions (e.g. something ahead in the driver's lane) and (2) hazard indicators in horizontal positions (e.g. something on an intersecting road). For situations in which critical information was placed in a vertically distant position (e.g. information far ahead), displayed driving scenarios included car-following situations, passing/overtaking or being overtaken. When critical information was located horizontally (e.g. information left and right), driving scenarios again were car-following situations, but also included passing straight through intersections, or turning left or right. These two categories are rather artificial; a hazard indicator is usually only indicative of a critical situation when occurring in relation to other information. However, the categories reflect a crucial handicap of novice drivers, that is, focusing on areas directly in front of the vehicle, and neglecting distant vertical and horizontal areas (e.g. Mourant and Rockwell, 1972).

Another important aspect of the tool was the repetition of driving situations and potential risks. So, although a complete situation was not displayed twice, situation elements were repeatedly experienced. Training was composed of two different sessions, both containing 13 video sequences. Each video sequence contained two or three relevant situations, whereby sequences were paused at various positions and questions presented. Most questions were presented in multiple-choice format (see Figure 2), and some required participants to mark certain relevant areas in the paused video. Participants received feedback as to whether answers were correct or not, followed by either continuation of the sequence or repetition of the previous segment (in the case of an incorrect answer). Questions in the first session varied – they dealt with observation of the traffic environment as well as understanding and prediction of presented situations. In the second session, the format was more standardised. Once a sequence was stopped, the first question was always: "Is there a need for action?" If yes, then this was followed by a multiple-choice question asking what this action would be, followed by a third question as to why this action would be necessary. At the end of each session, the CBT gave general feedback on the participants' performance, highlighting issues that should be addressed in further training.

Figure 2: Example screenshot for multiple-choice item. The item reads: "Which of the following statement(s) is/are true?" (a) the lead vehicle might brake; (b) I cannot safely pass; (c) pedestrians might cross the street; (d) the bus is about to leave the stop.

In a first small experiment (Petzoldt et al., 2011a), we tried to assess whether our implementation of the CBT indeed addresses the deficits of novice drivers identified previously. Assuming that the scenes we used met requirements, novice drivers should be unfamiliar with the situations depicted. In comparison, experienced drivers should already have knowledge (and respective skills) to deal with the presented situations. Thanks to the question-based format of the application, this difference in familiarity or experience with situations should be reflected in different rates of correct and false answers to these questions. Experienced drivers should, on average, answer more questions correctly than novice drivers. Our experiment showed that a group of experienced drivers answered more questions correctly than a group of novice drivers, confirming our assumption that the situations we created for the CBT address the deficits of inexperienced drivers.

3. Method

3.1. Design

To assess whether the developed CBT has positive effects on a novice driver's abilities, and whether these are different than effects that training in a classical format might produce, we employed a simple one-factorial between-subjects design. Participants completed (a) the aforementioned CBT of cognitive driving skills or (b) a paper based training of cognitive driving skills, or they (c) served as a control group without any learning intervention. The central dependent variable for the assessment of possible learning effects was participants' glance behaviour in a subsequent driving simulator test.

3.2. Participants

The selection of our sample was subject to strict criteria. Prospective participants had to be learner drivers (car) with no other driving licenses (e.g. motorcycle) previously obtained. Although they needed to have sufficient theoretical knowledge (i.e. a minimum of 10 theory lessons completed), they could not have acquired substantial practical driving experience (a maximum of five practical lessons completed). We recruited 58 participants from local driving schools. However, since this paper focuses on glance behaviour recorded with an eye-tracker, the usable dataset for this analysis included 36 participants (19 female/17 male) with a mean age of 17.4 years (SD = 1.6). There were no relevant differences between the three experimental groups (11 participants in control group, 13 participants in paper based intervention group, and 12 participants in CBT group) with regard to age, gender distribution, colour vision or spatial abilities. All subjects received monetary compensation for participation (i.e. 20–30 €, depending on treatment group).

3.3. Apparatus/Material

3.3.1. Computer based training

For the CBT intervention, we used the training that we developed as described above. Although the two different training sessions were originally intended to be completed during two different appointments, we opted for one single training day, including both sessions for economic reasons. There was a 20 min break between the two sessions. One session was completed in about 40 min, with only limited variance, since the video sequences (which could not be paused or terminated early) contributed to the largest share of this duration.

3.3.2. Paper based intervention

The paper based intervention was designed to resemble the CBT as closely as possible, except for the way the respective information was presented. A pretest on theoretical knowledge was again included to activate previous knowledge. The same general instructions and information were given to facilitate the learning process. As in the CBT, actual training depicted the same 26 traffic sequences, again in two sessions, separated by a 20 min break. However, only static images were used, so there was no dynamic presentation of content. For each relevant situation, one image was presented together with a multiple-choice question (or the task of identifying relevant areas), identical to the ones in the CBT. This was followed by another image, in which the further development of the situation was displayed, together with feedback about the correctness of the answer, and further explanation about the situation, both unrelated to the quality of the learner's answer (see Figure 3 for an example). Thus, the feedback given was not adaptive. One section of the

paper based intervention was usually completed within 25 min, with some variance, as there was no restriction on time spent on each image.

Figure 3: Example sheet of the paper based intervention (same item as Figure 2). This is the second of two sheets for each situation. Whereas the first one introduces the situation and the multiple choice questions, the second one presents a view of how the situation progressed, gives feedback regarding the answers that would have been correct, and provides general information and guidance regarding the depicted situation.

3.3.3. Simulator scenarios

We constructed simulator scenarios to reflect different aspects of the learning process. Some scenarios resembled situations included in the training as closely as possible, to allow for the assessment of the near transfer of acquired knowledge. In other situations, a general link between a hazard indicator and a critical area in the training environment was shared, whereas specific elements of the respective situations differed. For such situations, greater effort to apply acquired knowledge was expected, allowing for the assessment of far transfer. All situations were constructed to assess the anticipation and perception of potential hazards, and the respective responses to such situations, as this was the goal of the CBT (and the paper based training). The focus of these situations was mainly on the early anticipation of potentially dangerous situations. When interpreted correctly, critical situations could often be solved by slowing down sufficiently or changing lanes early enough to avoid possible conflicts. The intent was not to create situations in which mostly unexpected events required immediate and extreme reactions (e.g. emergency braking), but rather scenarios that are easily navigated by an experienced driver with sufficient anticipatory skills, but might cause inexperienced drivers some difficulties.

We designed three different test tracks, in which the critical scenarios were included. One track was an urban road, with single traffic lanes in each direction and a 50 km/h speed limit. The second track, also an urban setting with a 50 km/h speed limit, had two lanes in each direction. Track three was set

on a motorway, with three lanes in each direction and a speed limit of 110 km/h. Each of the tracks comprised six scenarios originally relevant for the analysis. However, track three was not included in the analysis, as it became clear during testing that the fragile dynamics of the developed scenarios were unable to cope with the high variance in the participants' behaviour, such that the intended hazardous situations often did not materialise as planned (see Table 1 for an overview of scenarios on the two urban tracks, Figure 4 for an example). Each scenario was presented once for each participant, resulting in 18 scenarios per participant overall (12 of which were analysed).

Table 1: Overview of test scenarios implemented in the two urban simulator tracks.

Situation	Short description	Transfer	Lanes (per direction)	Unspecific hazard indicator	Relevant area
1.1.	Delivery truck stopped on driver's lane, oncoming traffic	Near	1	Delivery truck	Opposite lane (to overtake)
1.2.	Cross traffic on intersection with equal right of way	Near	1	Intersection / intersection sign	Crossing road to the right
1.3.	Turning left into minor road, pedestrian about to cross that road	Near	1	Pedestrian to the left	Pedestrian to the left *
2.1.	Road works on driver's lane, approaching traffic on adjacent lane	Near	2	Road works	Adjacent lane via mirror or shoulder check (to overtake)
2.2.	Congestion on gas station (into driver's lane), lead vehicle brakes	Near	2	Congestion on gas station	Lead vehicle or adjacent lane via mirror or shoulder check (to overtake)
2.3.	Bus at bus stop on driver's lane	Near	2	Bus at bus stop	Adjacent lane via mirror or shoulder check (to overtake)
1.4.	Traffic light turns to yellow, lead vehicle brakes	Far	1	Traffic lights	Lead vehicle
1.5.	Bus stopped on opposite lane, pedestrian quickly approaching from the right	Far	1	Bus at bus stop	Sidewalk with approaching pedestrian
1.6.	Bus leaving bus stop on driver's lane, oncoming traffic	Far	1	Bus leaving bus stop	Opposite lane (to overtake)
2.4.	Bus leaving bus bay, entering driver's lane, lead vehicle brakes	Far	2	Bus leaving bus bay	Lead vehicle or adjacent lane via mirror or shoulder check (to overtake)
2.5.	Byclist from cycle path about to change to driver's lane	Far	2	Road works on cycle path	Cyclist to the right
2.6.	Turning right into minor road, cyclist about to cross that road	Far	2	Cyclist to the right	Cyclist to the right *

* In these situations, an unspecific hazard indicator assumed higher relevance/criticality once the participant had been informed that he would have to turn, crossing the path of the respective road user that constituted the hazard indicator. Here, the critical glance sequence was defined as two fixations towards that object/area separated by only one single fixation elsewhere. In all other cases, the critical glance sequence was defined as a glance towards the unspecific hazard indicator, directly followed by a glance towards the relevant area.

Figure 4: Example screenshot of simulator test situation. Here, situation 2.3: gas station to the right, cars waiting in line, lead vehicle about to turn into gas station, need to brake and stop for lead vehicle, subject could either safely overtake or brake.

3.3.4. Equipment

Test scenarios were implemented in a STISIM simulation environment. The hardware setup included a static full size vehicle (BMW 350i) with force feedback steering and automatic transmission. Three projectors produced an image with 135° horizontal visual field of view. To acquire data on glance behaviour, a head-mounted eye-tracking (SMI IView X HED) system was used.

3.4. Procedure

All three groups were required to attend a learning session. Two groups of learners filled in questionnaires, completed the pretest on theoretical knowledge, and completed the two training sections, with a 20 min break between the two. The control group only completed the questionnaires. The duration of this learning session varied. The control group needed only 20 min to complete the questionnaires, while it took the CBT group approx. 120 min. The duration of the paper based training was, on average, slightly shorter than the CBT. Two days later, participants were tested in the driving simulator. First, they completed a battery of tests (e.g. Ishihara test, paper folding test). Then, they received instructions regarding control of the simulation vehicle, followed by a short practice drive. The eye-tracking system was introduced and calibrated. After calibration, participants completed the three order-balanced test tracks. The typical duration of the simulator test was from 90 to 120 min.

3.5. Data analysis

As glance behaviour played a central role in our assessment of possible learning effects, its coding and scoring were crucial elements in this process. Pollatsek et al. (2006) defined the key glance behaviour as characterised by "the participant making at least one fixation on an appropriate region of the environment within a certain temporal window" (p. 458). We considered a glance sequence from an unspecific hazard indicator directly to an area where experienced drivers would be looking if they understood the meaning of the unspecific hazard indicator, as evidence for understanding the potentially hazardous situation (e.g. a glance at the gas station, which should lead to the understanding that vehicles in front might turn right, which should be followed by a glance to the lead vehicle; see Table 1 for an overview). For situations in which the hazard indicator itself became the area to observe to avoid a potentially hazardous situation (see Table 1), the critical sequence was defined as two fixations towards that area separated by only one single fixation elsewhere (e.g. glance sequence: "cyclist to the right", "road ahead", "cyclist to the right" as indicative of the driver's understanding of the cyclist's relevance). The selection of hazard indicators and relevant areas to be attended to was largely based on situations and respective explanations that were presented in the CBT (e.g. the gas station sequence, after which it was explained that when noticing a gas station, one should be aware that vehicles in front might be slowing down to turn into that gas station, with changing lanes as a behavioural option if indeed the lead vehicle decelerates). The time between the occurrence of the hazard indicator and the first completion of the glance sequence was measured, assuming that a learning effect would be reflected by an earlier completion of the sequence (Müsseler et al., 2009). All participants completed the critical glance sequence.

As we assumed that all scenarios assess the same skill (hazard anticipation), all measurements can be considered as items of the same scale. There should be a considerable correlation between the values of a single item (i.e. performance in one of the scenarios) and the overall scale. The relevant correlations were computed, and, after the removal of scenarios that did not correlate substantially with the overall score, Cronbach's alpha was calculated as a measure of the internal consistency of the remaining scenarios. To compare the different experimental groups, one-factorial between subjects ANOVAs were calculated (α - level .05), followed by pairwise comparisons of the groups (LSD-corrected, α - level .05). Effect sizes were calculated for both ANOVAs (η^2) and post-hoc tests (d).

4. Results

In a first step, we performed a reliability analysis on the 12 urban track scenarios. Three of the scenarios produced correlations below $r = .2$ and were excluded from the analysis, resulting in a final dataset of nine measurements with a Cronbach's alpha for standardised items of $\alpha = .72$.

To better visualise results, we considered the control group as a form of baseline in terms of reaction time, and plotted the performance of the other groups as differences from this baseline (see Figure 5). Absolute values for the different scenarios varied between 3.8 s and 16.6 s. The group that completed the CBT showed the required glance sequence earlier than the other two, with the paper based intervention group performing even worse than the control group. An ANOVA showed a significant effect for the group factor, $F(2, 33) = 6.82$, $p = .003$, $\eta^2 = .29$. Pairwise comparisons (LSD-corrected) revealed significant differences between the CBT group and the other two groups (paper based intervention: $p = .001$, $d = 1.37$; control group: $p = .032$, $d = .90$). There was no significant difference between the paper based intervention and the control group ($p = .204$, $d = .61$), but nevertheless a medium effect size (see Cohen, 1988).
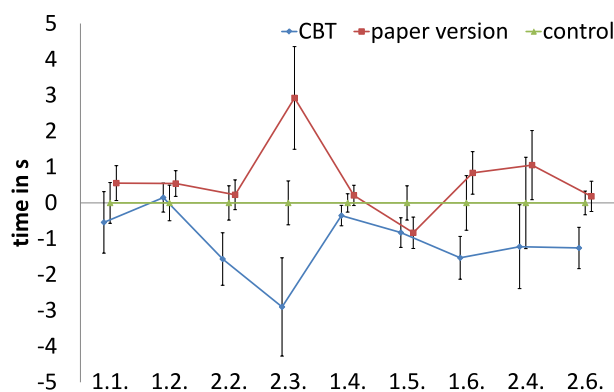

Figure 5: Difference in time until completion of relevant glance sequence compared to control group, separate for each situation (error bars indicate standard error).

A separate analysis of near (scenarios 1.1., 1.2., 2.2. & 2.3.) and far transfer (scenarios 1.4., 1.5., 1.6., 2.4. & 2.6.) situations produced similar patterns. For near transfer, the ANOVA showed a significant effect, $F(2, 33) = 5.57$, $p = .008$, $\eta^2 = .25$. Pairwise comparisons (LSD-corrected) showed a significant difference between CBT and the paper based intervention ($p = .002$, $d = 1.16$). There was no significant difference between the control group and the other two groups, however again with medium effect sizes (CBT: $p = .097$, $d = .71$, paper based intervention: $p = .138$, $d = .79$). For far transfer, the ANOVA showed a significant effect as well, $F(2, 33) = 3.55$, $p = .040$, $\eta^2 = .18$. Pairwise comparisons (LSD-corrected) again showed a significant difference between CBT and the paper based

intervention (*p* = .015, *d* = 1.10). There was no significant difference between the control group and the other two groups (CBT: *p* = .064, *d* = .79, paper based intervention: *p* = .588, *d* = .21).

In addition to the analysis of the completion of a critical glance sequence as performance indicator, we also analysed glances to the different elements of the traffic situation that constituted the critical sequence. Figure 6 shows the time that passes from the occurrence of the hazard indicator to the first glance to the hazard indicator, or, more precisely, the change in that measure caused by the different interventions in comparison to the control group (similar to Figure 5). Absolute values for the different scenarios varied from 3.3 s to 11.4 s. Overall, the pattern appears similar to the one for the glance sequence: members of the CBT group fixated the hazard indicator earlier, and participants with paper based intervention, later than the control group. An ANOVA showed a significant effect for the group factor, *F*(2, 33) = 3.79, *p* = .033, *η²* = .19. Pairwise comparisons (LSD-corrected) showed a significant difference between CBT and the paper based intervention (*p* = .010, *d* = 1.14). There was no significant difference between the control group and the other two (CBT: *p* = .107, *d* = .72, paper based intervention: *p* = .332, *d* = .42).
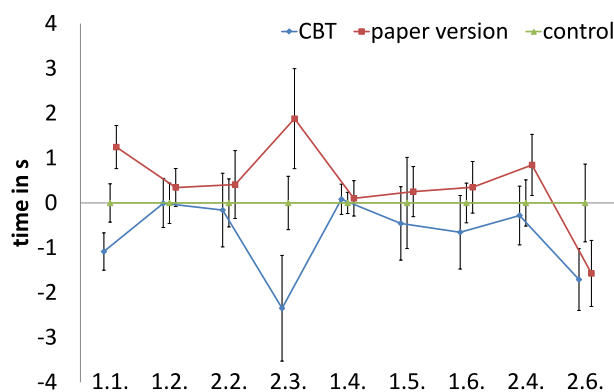

Figure 6: Difference in time until first glance to hazard indicator compared to control group, separate for each situation (error bars indicate standard error).

Finally, we analysed the time it took from the first glance at the hazard indicator to the first completion of the glance sequence (again visualised as the change in that measure caused by the different interventions in comparison to the control group; see Figure 7). Absolute values for the different scenarios varied from 0.5 s to 5.2 s. Again, the pattern appears to be somewhat similar to the ones for the glance sequence and the hazard indicator, however less coherent. For most situations, members of the CBT group were faster than the control group to complete the glance sequence once they had fixated the hazard indicator for the first time, participants with paper based intervention were slower. However, an ANOVA showed no significant effect for the group factor, *F*(2, 33) = 1.29, *p* = .289, *η²* = .07. Consequently, pairwise comparisons (LSD-corrected) showed no

significant differences between groups, however a medium effect size for the difference between CBT and the paper based intervention (p = .122, d = 0.66). When comparing the control group to the other two groups, we found only small effects (CBT: p = .329, d = .43, paper based intervention: p = .592, d = .23).
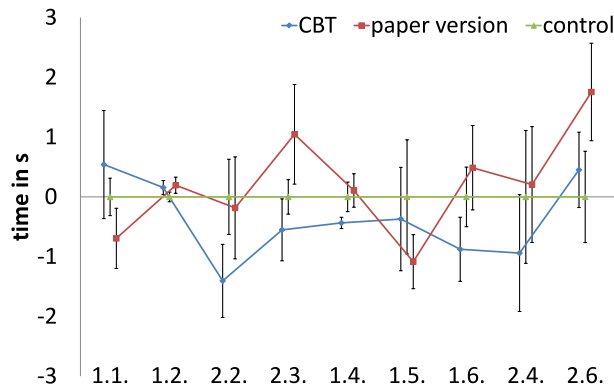

Figure 7: Difference in time from first glance to hazard indicator until completion of relevant glance sequence compared to control group, separate for each situation (error bars indicate standard error).

The fact that the CBT group appears to perform worse than the paper based intervention group for situations 1.1 and 1.5 seems counterintuitive. A look at the raw data showed that in both situations, the variance was much higher for the CBT group. This was the result of two (or three) participants being much slower than the rest, resulting in an overall slightly distorted image of the CBT group's performance. Even so, pairwise comparisons of the two groups for the two situations did not show significant differences.

5. Discussion and conclusions

To determine whether CBT could complement existing driver training, and whether there is an advantage of CBT over paper based training, we developed an experimental CBT and tested its effects in a driving simulator study.

The results of our simulator study confirmed that the constructed CBT had a positive effect on participants' glance behaviour. The analysis showed that participants who practiced with the CBT were faster in fixating the hazard indicator, and faster in completing a critical glance sequence than a control group, as well as a group that received a paper based training with similar content. This positive effect occurred in near as well as far transfer situations. These results strengthen our claim that the developed CBT is effective, and that its added value is higher than paper based training with similar content.

This assessment of the CBT's effects, however, is rather general. Did the CBT simply improve scanning behaviour, or indeed facilitate the understanding of traffic situations? Our results do not

provide an answer to this question. As CBT participants fixated earlier on the hazard indicator, it can be assumed that the CBT had a positive effect on scanning behaviour. When looking at the time it took from the first fixation to the hazard indicator to the first completion of the critical glance sequence (which can be interpreted as the time it took from acquiring crucial information to understanding the possible consequences and taking action), it appears that there are no significant differences between the groups. However, effects sizes indicate that there are small to medium effects, again in the same direction as the general trend (i.e. CBT group best, paper based group worst). At this stage, it is probably fair to conclude that the training affected both scanning behaviour and understanding of traffic situations, with a higher impact on scanning.

Surprisingly, for participants that completed the paper based training, there was a tendency to perform even worse than the control group. Puzzling at first, but we believe that Anderson's (1982) classical model of skill acquisition provides ground for a plausible explanation. The way the CBT is designed, it should not only provide explicit knowledge, but also support the proceduralisation of skills. That is, skills acquired in the repeated observation of traffic situations just as they would occur in real traffic that require, and therefore train, scanning behaviour. In contrast, the static depictions of traffic situations in the paper based version do not allow for such a proceduralisation. Knowledge is mainly acquired on a declarative level. Following the model, action based on declarative knowledge rather than procedures is characterised by a number of slow and error-prone sub-steps. In comparison to participants in the control group, who acted "out of instinct", participants that received the paper based training deliberately tried to apply the declarative knowledge they acquired, which slowed them down in the beginning. However, this would, according to the model, sooner or later lead to a proceduralisation (and finally automation) of skills, which would ultimately allow them to perform on a higher level than the control group.

Despite the overall promising results, questions remain. While there appears to be a clear pattern in the results across the majority of scenarios, the exact values seem to differ quite substantially, which is as of now unexplained. Unfortunately, it is unclear whether any differences between the scenarios are an effect of the training, of the scenarios, or both. It is quite possible that the relevant skills for some of the scenarios can be taught easier than for others. However, it is just as possible that the CBT we developed is just more appropriate for some scenarios than for others. So, differences in performance in the test scenarios cannot easily be attributed to the training or the scenario. In addition, the fact that a rather small sample with was tested in a rather variable environment (the driving simulation) leads to a lot of variance, which makes a scenario-wise analysis impossible. In that sense, the results of this study can only serve as a broad indicator that a CBT can have positive effects on glance behaviour, without too specific interpretations of CBT items or driving scenarios.

Furthermore, while the CBT developed in this study made use of dynamic content and adaptive feedback, it is unclear to what extent each of these aspects contributed to results. Thus, independent manipulation of each aspect could shed further light on mechanisms behind the positive effects found. Informal comments of participants indicate that the elaborate adaptive feedback was perceived as rather annoying, and was sometimes ignored. It also has to be acknowledged that the differences between CBT and paper based training extend beyond simple manipulation of dynamics and adaptability. Other factors, which are directly linked to these two central aspects, vary accordingly. One example is the total duration of training. While the average durations did not differ greatly, there was a rather high variance of duration within the paper based training group, as this form of training is self-paced to a much higher extent than CBT. In terms of ecological validity, this appropriately reflects a real-life situation. However, from a researcher's point of view, parallelisation of the two interventions may uncover the precise mechanisms behind the effects.

Finally, although results show that CBT might have positive effects compared to a control group and another form of training, it is unclear how much closer CBT brings the learner to becoming an experienced driver. Further investigation of experienced drivers' performance in the same test scenarios will allow us to relate the performance of each of the three groups to the ultimate goal of training – driving like an expert.

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