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Vertical field of view restriction in driver training: A simulator-based evaluation

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A B S T R A C T

The young driver problem requires remedial measures against speeding and overconfidence. Previous research has shown that increasing the task difficulty during training can enhance subsequent retention performance and prevent overconfidence. In this driving simulator study, we evaluated the training effectiveness of vertical field of view restriction during a self-paced lane-keeping task. Sixty-two young, inexperienced drivers were divided into three groups: a near view (NV) group (upper part of the screen was blanked), a far view (FV) group (lower part of the screen was blanked), and a control group driving with full sight. All groups drove three training sessions lasting 8 min each on a curved rural road, followed by two retention sessions with full sight. The first retention session took place on the same rural road and the second session on a highway. Compared to the control group, the NV group drove with lower mean speed and had more road departures during training. Furthermore, NV drivers reported significantly lower confidence during the training sessions and the second retention session. NV drivers directed their eye gaze more closely to the vehicle during training and both retention sessions. FV drivers approached corners with lower speed compared to the control group during training and had a higher number of rapid steering wheel turns during training and both retention sessions. In conclusion, removing visual information resulted in lower reported self-confidence (NV) and altered steering behavior (FV) in retention sessions compared to driving with full sight. Furthermore, NV training caused drivers to direct their gaze closely to the vehicle during retention, which may be negative for road safety. Possible effects of simulator-based driver training on eye-scanning and safety are discussed.

1. Introduction

Worldwide, 1.2 million fatalities occur in traffic every year, and millions more individuals are injured (World Health Organization, 2009). Young drivers are vastly overrepresented, a public health concern also known as the young driver problem (Drummond, 1989; Organization for Economic Co-operation, 2006; Williams, 2006).

It is possible to classify the causes of the young driver problem using a three-level behavioral taxonomy developed by Michon (1985; see also Lee, 2007). At the strategic level, young drivers are overconfident in their own abilities and have an elevated acceptance to take risks and commit traffic violations (Brown & Groeger, 1988; Horswill, Waylen, & Tofield, 2004; Matthews & Moran, 1986). Loss of control due to speeding is a particularly frequent cause of accidents among young

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drivers (Laapotti & Keskinen, 1998; McGwin & Brown, 1999). At the tactical level, young drivers demonstrate inadequate hazard perception and inadequate 'calibration' of task demands with respect to their own abilities. The lowest level is the operational level, at which young drivers tend to have imperfectly learned skills for longitudinal and lateral vehicle control. Furthermore, young drivers tend to experience a high mental workload, particularly in environments that are new to them. There is growing consensus that driver training that focuses solely on the operational level (i.e., what the driver is able to do) is ineffective in reducing accident risk and that the higher levels (i.e., what the driver is willing to do) have to be targeted as well (Goode, Salmon, & Lenné, 2013; Hatakka, Keskinen, Gregersen, Glad, & Hernetkoski, 2002; Mayhew & Simpson, 2002).

For many decades, researchers have studied the effectiveness of training and enforcement methods, but the young driver problem has proven to be robust to interventions (Beanland, Goode, Salmon, & Lenné, 2013; Elvik, 2010). Based on a meta-analysis, Elvik and Vaa (2004) concluded that formal driver training is not an effective road-safety measure. Their analysis included 16 studies that compared formal driver training provided by driving schools with informal driver training, that is, self-training or training provided by family or friends. An analysis of the methodologically best studies (i.e., experiments that distributed participants randomly between formal and informal driver training) showed that formal driver training resulted in a 0% difference in the number of crashes per driver and 11% more accidents per kilometer driven compared to informal training. Elvik and Vaa (2004) also showed that the more lessons one had taken, the more the crash rate increased. Possible reasons for the lack of effectiveness may be that basic driver training increases self-confidence (Mayhew & Simpson, 2002) and normalizes risk taking behavior.

Driving simulators are recognized as tools that may be effective for driver training and driver assessment, although much research still needs to be done in these areas (Beanland et al., 2013; Goode et al., 2013; Medeiros, Weinreb, Boer, & Rosen, 2012; Pollatsek, Vlakveld, Kappé, Pradhan, & Fisher, 2011). An advantage of using simulators for training relative to on-the-road training is the controllability of road infrastructure, weather, and traffic, as well as the fact that dangerous situations can be practiced without risk of collision. Such conditions open up possibilities for new types of driver training, such as learning from errors (Ivancic & Hesketh, 2000; Underwood, Crundall, & Chapman, 2011; Vlakveld, 2011) and exposing drivers to abstracted environments that depart from physical reality (Rizzo, Severson, Cremer, & Price, 2003).

Research in motor learning shows that by making the training task difficult—for example, by depriving the trainee from knowledge-of-results feedback—long-term retention and generalizability of skills can improve (Schmidt & Bjork, 1992). A driving-simulator study by Ivancic and Hesketh (2000) as well as a driving simulator study by De Groot, Centino Ricote, and De Winter (2012) showed that by eliciting errors during training, performance in transfer-driving tests improved. Driving with reduced visibility, such as driving at night or driving in fog, reduces drivers' confidence and increases the perceived risk level (Saffarian, Happee, & De Winter, 2012; Stasson & Fishbein, 1990). Gregersen and Nyberg (2003) observed reduced accident rates in the first years of licensure for novice drivers who had completed a driver training course under dark driving conditions. Reduced visibility may cause drivers to become more vigilant, allowing them to react more accurately to hazardous events (Van der Hulst, Rothengatter, & Meijman, 1998). Additionally, emotional arousal promotes memory consolidation (Kleinsmith & Kaplan, 1963; McGaugh, 2000) and may therefore benefit driver training (Vlakveld, 2011).

Many studies have demonstrated the importance of visual information during driving (e.g., Mourant & Rockwell, 1972; Riemersma, 1979; Sivak, 1996; Wallis, Chatziastros, Tresilian, & Tomasevic, 2007). A number of studies have used visual occlusion (i.e., a technique whereby the driving scene is temporary occluded, typically by means of shutter glasses) to determine visual demand while driving (Backs, Lenneman, Wetzel, & Green, 2003; Senders, Kristofferson, Levison, Dietrich, & Ward, 1967; Van der Horst, 2004). Occlusion techniques have also been used to determine the effect of visual information on drivers' speed choice and curve driving performance (Cavallo, Bran-Dei, Laya, & Neboit, 1988; Godthelp, 1986; Hildreth, Beusmans, Boer, & Royden, 2000; Kondo & Ajimine, 1968; McLean & Hoffmann, 1973; Tsimhoni & Green, 1999).

Land and Horwood (1998) found that for low speeds (<12.5 m/s), a narrow horizontal visual aperture ranging from 7 to 8 deg below the horizon is sufficient for lateral vehicle control, as it yielded lane-keeping performance that is equivalent to the performance achieved with the whole scene visible. For higher speeds, Land and Horwood (1995) showed that with two narrow visible horizontal apertures displayed concurrently—one near the vehicle and one far from the vehicle—drivers achieved similar lane-keeping accuracy to that attained when driving with full sight. More recent studies (Chatziastros, Wallis, & Bülthoff, 1999; Cloete & Wallis, 2011; Neumann & Deml, 2011) with larger sample sizes and more sophisticated simulator technology have tried to replicate the experiments by Land and Horwood (1995). Using two narrow apertures placed 8.3 and 12.8 m in front of the vehicle, Neumann and Deml (2011) showed that steering precision was equivalent to that achieved under a condition with full sight, confirming the findings of Land and Horwood (1995). Cloete and Wallis (2011) did not find evidence of equivalent lane-keeping performance between driving with two narrow apertures and driving with full sight. The authors observed that lane-keeping accuracy was always substantially poorer when two narrow apertures were available compared to that under a control condition with full sight. These results suggest that drivers use more visual information (such as tangent points) than can be perceived through only two narrow apertures and/or that the position of relevant visual features changes dynamically depending on road curvature and speed (Cloete & Wallis, 2011).

Eye-tracking studies (e.g., Gordon, 1966; Lappi, Lehtonen, Pekkanen, & Itkonen, 2013; Wilkie & Wann, 2003) have shown that drivers direct their visual attention to the near and far parts of the visual environment during straight-path driving and curve negotiation. Most researchers agree that the distant region is used by drivers to anticipate oncoming vehicles, obstacles, and road curvature (Lehtonen, Lappi, & Summala, 2012), whereas the near region of the road is used to estimate lateral position in the lane. This concept of preview vs. lateral position estimation is consistent with several models of driver steering behavior (Donges, 1978; Salvucci & Gray, 2004). These models distinguish between anticipatory open-loop control (steering actions based on curvature ahead) and compensatory closed-loop control (minimization of heading and lateral deviation errors with respect to the lane center); see Steen, Damveld, Happee, van Paassen, and Mulder (2011) for a review. Recently, Frissen and Mars (2014) used visual degradation of the near vs. far regions to investigate the robustness of these two visual processes. When the far visual region was blanked, lane-keeping accuracy was considerably worse and steering velocity considerably higher than with full vision, a finding that is consistent with the idea that lack of preview places increasing demands on compensatory control. Removing the visibility of the near region also resulted in deteriorated lane-keeping accuracy, but steering wheel velocity was virtually unaffected. Frissen and Mars (2014) concluded that these "observations add to Land and Horwood's (1995) findings that an impairment of near vision allows smooth steering but yields large lateral position error" (p. 12).

In the present study, we evaluated a simulator-based training method that targeted young drivers' risk awareness and speed choice by removing near or far visual road information using field of view (FOV) restriction. In the near view (NV) condition, the far part of the screen was blanked such that the driver could only see up to 5 deg below the horizon, corresponding to a distance of 8.5 m in front of the vehicle. Accordingly, the driver could correct lateral position errors but was unable to preview the curves farther ahead. Because of the lack of preview information, the driver would have to be continuously wary of upcoming curves that require braking. It was expected that the NV drivers would adopt a low speed to maintain acceptable task demands (cf. Fuller, 2005) and that the NV drivers would report lower levels of confidence and higher levels of risk compared to a control group driving with normal sight. We also evaluated a far view (FV) condition, achieved by blanking the bottom part of the screen up to 4 deg below the horizon, corresponding to 12.5 m ahead of the vehicle. This blanking was expected to make compensatory control difficult because the visual information about momentary lateral position error would be virtually absent. Training in the FV condition forces drivers to direct their gaze farther from the vehicle than they would when driving with full sight and may result in comparatively smooth steering wheel movements (cf., Frissen & Mars, 2014).

To summarize, in this study, three training groups were compared: NV and FV groups and a control (C) group driving with full sight. It was hypothesized that the NV group would drive with low speed and would report high risk and low confidence. Furthermore, it was hypothesized that the FV group would use smoother steering control compared to the C group. Finally, it was expected that these behaviors would be retained after training in retention sessions with full visibility.

2. Method

2.1. Participants

Sixty-two participants were recruited from the student community. Eligibility criteria were as follows: being in possession of driver's license, having limited driving experience (defined as having less than 3 years and less than 15,000 km of driving experience), and having normal or corrected-to-normal eyesight. Prior to the experiment, all participants completed an intake questionnaire with the following variables: (1) Number of half-years in possession of driver's license (*1 to 6*); (2) Total amount of driven kilometers (*0–15,000, in steps of 3000 km*); (3) Experience with race/simulator games (*never/sometimes/occasionally/often*); (4) Wearing glasses or lenses during the experiment (*glasses/lenses/neither*); (5) Experience in driving simulators (*never/sometimes/occasionally/often*); and (6) Experience with mopeds (*never/sometimes/occasionally/often*). The mean age of the participants was 19.9 years ($SD = 1.2$). Of the 62 participants, 14 were female. Participants had their driver's license for 1.4 years on average ($SD = 0.8$) and reported an average total mileage of 4065 km ($SD = 3{,}207$). Three participants reported more than occasional experience (two occasional, one often) with race/simulator games, six participants reported that they had sometimes driven in a simulator before, and one participant reported having driven in a simulator frequently. Thirty-two participants had no moped experience, and 19 participants had some-to-occasional experience with driving mopeds. Five participants wore their glasses, and 13 participants wore contact lenses. Using the results of the six questionnaire variables, participants were assigned to one of the three groups using the minimization method of Taves (1974). Twenty-one participants were included in the NV and FV groups and 20 in the control group. Participants received a compensation of ten euro and provided written informed consent. The research was approved by the Human Research Ethics Committee of the Delft University of Technology.

2.2. Apparatus

The simulator used for this study was a Green Dino driving simulator (classic model), which is also used for initial driver training in The Netherlands. This fixed-base simulator provided surround sound and a field of view spanning approximately 180 deg horizontally and 45 deg vertically. The vehicle dynamics represented those of a middle-class passenger vehicle. The seat, pedals, and steering wheel originated from a real car. Gear changing was automated; participants were only required to steer, accelerate, and brake. Steering force feedback was passive based on a spring system. Steering sensitivity was calibrated with respect to on-road vehicles (Katzourakis, De Winter, De Groot, & Happee, 2012). The virtual world was projected using three LCD projectors (front projector NEC VT676, brightness 2100 ANSI lumens, contrast ratio 400:1, resolution 1024 × 768 pixels; side projectors NEC VT470, brightness 2000 ANSI lumens, contrast ratio 400:1, resolution 800 × 600 pixels), and the dashboard, interior, and mirrors were integrated into the projected image. Head motion and gaze direction were measured with a SmartEye eye tracker (SmartEye, 2012, software version 5.6), which consisted of three Sony XC HR50 cameras (12-mm focal length, iris range: F1.4-closed) and two infrared illuminators. Two cameras were mounted above the steering wheel and below the virtual scenery, and the third camera was mounted behind the steering wheel, above the steering wheel center. The simulator model was updated at 100 Hz, and the visual update rate was 75 Hz. The screen frame rate was estimated to be a minimum of 30 Hz and was sufficiently high to guarantee a smooth visual projection. The driving simulator and eye tracker data were sampled and stored synchronously at 60 Hz.

2.3. Independent variable

The independent variable was the visual restriction. One group drove through the environment with full sight (control group). The second group (FV) drove the training sessions with the lower part of the screen blanked. No information was projected below a horizontal line 4 deg below the horizon, meaning that the driver could only see information that was farther than 12.5 m in front of the vehicle. The third group (NV) drove the training sessions with the upper part of the screen blanked. No information was projected above a horizontal line 5 deg below the horizon, and consequently, the driver could only see up to 8.5 m ahead. These thresholds were based on pilot testing with drivers that did not participate in the experiment, to ensure that it was possible to drive the vehicle in a reasonable manner. The 4-deg threshold in the FV condition gave participants sufficient sight to steer through the corners. Our chosen thresholds of 4 and 5 deg are in approximate agreement with the thresholds reported by Land and Horwood (1995) and Cloete and Wallis (2011), who both evaluated the effect of horizontal apertures ranging between 1 deg (extremely far) and 9 deg (extremely near) below the horizon. Our FOV restriction was independent of vehicle speed and blanked the visual scenery; the mirrors and car instruments remained always visible. For an illustration of the three conditions, see Fig. 1.

2.4. Procedure

First, participants completed the intake questionnaire and received a paper handout explaining the experimental procedure. After being seated in the simulator, the eye tracker was calibrated. Each participant drove three training sessions lasting 8 min each and two retention sessions lasting 8 and 6 min. Each session was followed by a break of no more than 5 min. During all breaks, the participants completed the NASA Task Load Index (TLX) questionnaire for measuring workload (Hart & Staveland, 1988) and a confidence questionnaire (De Groot, De Winter, López-García, Mulder, & Wieringa, 2011). After the three training sessions, participants completed the 8 min retention session, followed by the second retention session of 6 min in a different simulated driving environment. During the two retention sessions, the visual FOV restriction was disabled and participants drove with full sight. Table 1 provides an overview of the experimental sessions and the three groups.

Fig. 1. Photos of the driving simulator; Top = control condition (C); Bottom left = near view (NV), all sight above 5 deg below the horizon was blanked; Bottom right = far view (FV), all sight under 4 deg below the horizon was blanked.

Table 1
Experimental conditions during the training and retention sessions for the control, far view, and near view groups.

	Rural environment (8 min sessions)				Highway environment (6 min session)
	Training 1	Training 2	Training 3	Retention 1	Retention 2
Control (C)	No restriction	No restriction	No restriction	No restriction	No restriction
Far view (FV)	Far visibility	Far visibility	Far visibility	No restriction	No restriction
Near view (NV)	Near visibility	Near visibility	Near visibility	No restriction	No restriction

2.5. Driving task

The three training sessions and the first retention session took place on a two-lane rural course 7.5 km length, with a 5-m lane width (De Groot et al., 2012). The course consisted of 25 curves: 22 90-deg corners, two smooth chicanes, and a 180-deg corner with a road-center radius of 40 m. Of the 22 90-deg corners, 14 corners (eight right corners and six left corners) had a road-center radius of 20 m or less. The course also included a tunnel and two hills with an elevation of 4 m. There was no other traffic, and no traffic signs were present in the virtual scenery, other than signs showing a 20-kph advised corner speed. The second retention session took place on a two-lane highway (3.6 m lane width) consisting of several slight bends and a 270-deg left curve with a 300-m radius. No other traffic and no traffic signs were present in the second retention session. All sessions commenced with the vehicle in the center of the right lane with zero speed, and participants started the session by turning the ignition key.

A paper handout explained that the experiment consisted of three training sessions followed by two testing sessions. It was further stated that the task was to keep the vehicle as accurately as possible in the center of the right lane, not to change lanes, drive safely, and follow Dutch traffic rules (Dutch traffic rules prescribe a speed limit of 80 kph on rural roads). Before starting the first training session, the driving task instructions were repeated in the simulator, with the following on-screen instructions (translated from Dutch): "Use only your right foot to operate the throttle and brake pedal; gear changes are automatic", "In case of a road departure, restart the car and continue driving", "Drive as accurately as possible in the center of the right line", and "Drive safely and according to Dutch traffic rules". Prior to the first training session, the NV and FV groups received the following additional instruction: "During the training sessions, part of your sight will be blanked. Before the first retention session, the NV and FV groups received the following instruction in the simulator: "In the following session, full sight will again be available".

2.6. Dependent measures

The following dependent measures were determined for each participant and each session. All measures (except for mean corner entry speed and standard deviation lane position) were calculated over the complete driven course including corners. The first 20 s of each session were regarded as lead-in and discarded from the analyses. The steering wheel angle was filtered using a 3-Hz low-pass filter before analysis.

2.6.1. Driving performance

2.6.1.1. Mean speed (m/s). The mean speed of the vehicle is a measure of driving style. Speed has been previously associated with crash involvement (Aarts & Van Schagen, 2006; Cooper, 1997; Elvik, Christensen, & Amundsen, 2004).

Mean corner entry speed (m/s). The corner entry speed was established at positions between 20 m before and 20 m after corner onset. A large reduction in speed before the corner may indicate that the driver anticipated the corner and was able to slow down before the start of the corner (cf., Comte & Jamson, 2000; Lee & Lishman, 1977). The measure was averaged across the first 12 sharp 90-deg corners (seven right-hand and five left-hand corners with a radius of 15 or 20 m).

2.6.1.2. Number of road departures. The number of times the vehicle crossed the lane boundaries with all edges of the vehicle represents the number of road departures. Road departures are usually the consequence of inadequate lane-keeping performance or high speed resulting in loss of control. After a road departure, the vehicle was reset in the center of the lane, and the participant was able to restart the vehicle using the ignition key. All data 10 s before and 20 s after a road departure were removed from the analysis of the other dependent measures.

2.6.1.3. Mean lane position (MLP) (m). The mean lateral position of the vehicle center represents the systematic deviation from the lane center (right = positive). Corner segments were excluded from this measure because smooth curve negotiation (e.g., corner cutting) could bias the MLP.

2.6.1.4. Standard deviation of lane position (SDLP) (m). The standard deviation of the lane position is a measure of lane-keeping precision, where a lower SDLP indicates less swerving on the road (e.g., Dijksterhuis, Brookhuis, & De Waard, 2011). SDLP was calculated by taking the standard deviation of the lateral position of the vehicle center and is thus insensitive to the mean lane position. Corner segments were excluded from this measure because smooth curve negotiation (e.g., corner cutting) results in lateral deviations biasing the SDLP.

2.6.2. Vehicle control

2.6.2.1. Steering reversal rate (SRR) (#/min). The SRR was defined as the number of clockwise to counterclockwise changes in steering wheel direction per minute. Only clockwise to counterclockwise reversals were counted if the counterclockwise steering velocity exceeded 3 deg/s (De Groot et al., 2011; He & McCarley, 2011; Theeuwes, Alferdinck, & Perel, 2002). Steering wheel reversal rate is a measure of control activity and correlates with other measures of control frequency (McLean & Hoffmann, 1975).

2.6.2.2. Rapid steering wheel turns (RSWT) (#/min). This measure was calculated as the number of instances per minute during which the steering wheel velocity exceeded 15 deg/s. RSWT may be indicative of driving in critical situations because drivers typically turn the steering wheel rapidly to avoid road departures (Johansson et al., 2004).

2.6.3. Gaze direction

2.6.3.1. Mean gaze pitch angle (deg). The mean vertical angle is the angle between the gaze vector and the horizon. A higher value indicates a larger angle down from the horizon. Data regarding gaze (including fixations and saccades) directed between the horizon and the dashboard were included, whereas data regarding gaze directed at the rear-view mirror and the dashboard dials were excluded. Eye fixations were determined via a dispersion-based method (Shic, Scassellati, & Chawarska, 2008) using a sliding window of 100 ms, a dispersion threshold of 2 deg, and a fixation duration threshold of at least 150 ms (Hornof & Halverson, 2002; Salvucci & Goldberg, 2000).

2.6.4. Subjective measures

2.6.4.1. NASA TLX (%). The NASA TLX is a subjective assessment of workload in the form a questionnaire (Hart & Staveland, 1988). The assessment is widely used in driving-behavior research (Hart, 2006) and includes the following six aspects of workload: mental demand, physical demand, temporal demand, performance, effort, and frustration. Scores were marked on a 21-tick horizontal bar with anchors on the left side (*very low*) and the right sides (*very high*). For the performance item, the anchors (*perfect*) and (*failure*) on the left and right side were used. A total score was calculated by averaging the six items and expressing the results on a scale from 0% (lowest rating on all items) to 100% (highest rating on all items).

2.6.4.2. Confidence questionnaire (%). The participant's confidence was assessed using our confidence questionnaire, which contained the following three statements (translated from Dutch): (1) "I had a feeling of risk during driving", (2) "I think I drove safer compared to the average participant of this experiment", and (3) "I feel confident in my abilities to respond adequately". These items were inspired from previous questionnaires assessing drivers' confidence (De Craen, 2010; De Groot et al., 2011; Ivancic & Hesketh, 2000; Wells, Tong, Genderton, Grayson, & Jones, 2008) and adapted to the present simulator-based lane-keeping task. Reactions to the statements could be given by marking a cross on a 21-tick horizontal bar identical to the bars used in the NASA TLX, with anchors on the left (*strongly disagree*) and right (*strongly agree*) sides. A total score was calculated by reversing the results from statement 1, averaging the three items, and expressing the results on a scale from 0% (lowest rating on all items) to 100% (highest rating on all items).

2.7. Statistical analyses

Loss of eye tracker data occurred due to the system's inability to track relevant facial features, pupils, or corneal reflections. Loss of tracking can be caused by eye blinks, large head movements, or physical obstruction of the tracker cameras (e.g., by glasses). All eye tracker data captured 0.25 s before and after sequences of lost data were removed from the dataset. If more than 70% of eye tracker data were removed in a session, all eye tracker data were discarded for that particular session.

The results were statistically compared between the NV and C groups and between the FV and C groups, for each session, using an independent two-sample t test. Results between two sessions were compared using paired t tests. A result was declared statistically significant if $p < 0.05$ (or $p < 0.01$ in figures in which multiple tests were performed). Because the number of departures and the number of rapid steering wheel turns (RSWTs) had a skewed distribution (see also De Groot et al., 2012), these data were fractionally ranked (Conover & Iman, 1981) over all sessions and participants prior to conducting the statistical analyses.

3. Results

Two participants were excluded from the analysis. One participant from the NV group did not comply with the instructed driving task because he seemed to drive as fast as possible. The second participant (FV) was removed due to misinterpretation of the driving task and receiving additional instructions after the first driving session. Both excluded participants were removed from the Taves group assignment procedure as well and were replaced by two other participants. No participants ended the experiment due to simulator discomfort. Eye tracking data for 28 sessions were removed from the analysis; see Table 2 for further details about missing eye tracker data.

Table 2
Number of excluded eye tracker sessions and mean percentages of missing eye-tracker data across the included sessions (standards deviation across subjects in parentheses). *p* Values are shown for comparison between control (C) vs. far view (FV) and control vs. near view (NV).

		Excluded sessions			Percentage of missing data			*p* Value	
		Control	Far view	Near view	Control	Far view	Near view	C vs. FV	C vs. NV
Training	T1	1	1	2	25 (14)	26 (15)	36 (18)	0.958	0.086
	T2	2	2	1	27 (14)	24 (15)	33 (23)	0.608	0.353
	T3	2	2	2	32 (15)	28 (9)	31 (23)	0.416	0.972
Retention 1		3	2	3	32 (15)	29 (13)	34 (18)	0.631	0.729
Retention 2		2	1	2	28 (16)	30 (19)	22 (18)	0.763	0.236

3.1. Dependent measures

Table 3 presents the means and standard deviations of the dependent measures and includes the *p* values of comparisons between sessions and between groups.

3.1.1. Driving performance

3.1.1.1. Mean speed. NV drivers drove significantly slower than the C drivers in all training sessions and reduced their mean speed from Training 1 to Training 3. The three groups drove with similar mean speeds in both retention sessions. Both FV and NV drivers increased their mean speed after training.

3.1.1.2. Mean corner entry speed. NV drivers drove significantly faster into the corners than drivers in the C group. FV drivers significantly reduced their corner entry speed during training and drove significantly more slowly into the corners than drivers in the C group during the last training session.

3.1.1.3. Number of road departures. NV drivers showed significantly more road departures than drives in the C group and a significant reduction in road departures between Training 3 and Retention 1. There was no significant difference in road departures between the FV and C groups in any of the training and retention sessions. During the highway retention drive, no road departures occurred for any of the three groups.

3.1.1.4. Lane-keeping performance (SDLP). Significant differences were found in the training sessions between drivers in the C and FV groups and between drivers in the C and NV groups, with those in the C group exhibiting the best lane-keeping performance of the three groups. Both the NV and FV groups improved significantly from training to the first retention.

3.1.1.5. Mean lane position (MLP). The NV group drove closer to the right of the lane compared to the C group (significant in the first and second training sessions). The NV group drove significantly closer to the center of the lane in the third training session than in the first training session. No significant differences were found between the NV and C groups in the first and second retention sessions. No differences were found between the FV and C groups with respect to the MLP measure.

3.1.2. Vehicle control

3.1.2.1. Steering reversal rate (SRR). The FV group showed a significantly *lower* steering reversal rate than the C group during training but a significantly *higher* steering reversal rate during the first retention session. Both the FV and C groups showed a reduction in steering activity from Training 1 to Training 3, whereas the steering activity of the NV group remained at approximately the same level across the three training sessions.

3.1.2.2. Rapid steering wheel turns (RSWTs). The FV group showed significantly more RSWTs compared to the C group in all five sessions. The number of RSWTs decreased among all groups from Training 1 to Training 3.

Fig. 2 (left) shows the steering wheel angular position for the NV and FV groups during all three training sessions for a typical right-hand corner. The NV group steered into the corner later and more abruptly compared to the C group. The FV group can be observed to have steered earlier into the corner and turned less after the initial steering movement compared to the C group, resulting in a wider vehicle path, as shown in Fig. 2 (right).

Fig. 3 (left) shows the probability density function of the steering wheel speed for the three groups cornering in the training sessions. The NV group showed significantly fewer lower-speed (<135 deg/s) steering wheel movements and significantly more high-speed (>270 deg/s) wheel movements compared to the C group. The higher steering wheel speeds of the NV group represent abrupt steering movements when entering corners and the corrective steering movements performed to prevent road departures (cf. Fig. 2 left). The FV group showed significantly more steering movements at speeds between 26 and 38 deg/s compared to the C groupin the corner segments. On the straight road segments (right figure), the NV group showed significantly more movements at lower speeds (10–18 deg/s) and fewer at higher speeds (>35 deg/s) compared to the C group. This finding suggests that the NV group was more inclined to make small corrective steering movements on the straight road segments than the C group.

Table 3
Results for the three training sessions and the two retention sessions. For each group the table shows mean values (standard deviations in parentheses) and *p* values for group comparisons between far view (FV) and control (C) and for near view (NV) and C. *P* values for session comparisons are indicated for the first vs. last training session and the last training session vs. first retention session.

	Training			Retention		*p* Value	
	T1	T2	T3	R1	R2	Training T1 vs. T3	Retention T3 vs. R1
Mean speed (m/s)							
FV	16.4 (1.5)	16.3 (1.5)	16.2 (1.8)	16.9 (2.1)	32.3 (2.4)	0.929	0.018
NV	15.1 (1.9)	14.0 (2.0)	13.7 (1.6)	16.6 (2.2)	30.9 (3.7)	**0.002**	**<0.001**
C	17.1 (1.7)	17.1 (1.7)	17.2 (1.8)	17.3 (1.8)	31.7 (2.2)	0.166	0.798
p Value FV vs. C	0.147	0.115	0.098	0.606	0.449	–	–
p Value NV vs. C	**<0.001**	**<0.001**	**<0.001**	0.382	0.413	–	–
Mean corner entry speed (m/s)							
FV	12.4 (1.5)	11.6 (1.3)	11.2 (1.3)	11.8 (1.4)	–	**0.007**	0.125
NV	13.8 (1.9)	13.6 (1.6)	13.3 (1.4)	12.2 (1.6)	–	0.122	0.064
C	12.4 (1.7)	12.3 (1.3)	12.3 (1.2)	12.1 (1.5)	–	0.932	0.454
p Value FV vs. C	0.930	0.135	**0.016**	0.755	–	–	–
p Value NV vs. C	**0.015**	**0.006**	**0.021**	0.762	–	–	–
Road departures (#)							
FV	1.6 (2.4)	1.7 (2.7)	1.5 (2.6)	0.8 (1.3)	0.0 (0.0)	0.796	0.256
NV	13.9 (8.4)	9.2 (9.7)	6.4 (5.9)	0.7 (1.6)	0.0 (0.0)	0.087	**0.017**
C	1.8 (3.2)	0.5 (1.2)	0.4 (1.3)	0.3 (1.0)	0.0 (0.0)	0.159	0.079
p Value FV vs. C	0.811	0.105	0.103	0.364	–	–	–
p Value NV vs. C	**<0.001**	**<0.001**	**<0.001**	0.722	–	–	–
MLP straights (m)							
FV	−0.06 (0.27)	−0.09 (0.27)	−0.07 (0.17)	−0.12 (0.15)	0.18 (0.17)	0.876	0.441
NV	0.13 (0.23)	0.09 (0.27)	0.02 (0.26)	−0.16 (0.28)	0.20 (0.18)	**0.004**	**<0.001**
C	−0.06 (0.23)	−0.12 (0.25)	−0.12 (0.26)	−0.16 (0.22)	0.22 (0.23)	0.115	0.514
p Value FV vs. C	0.924	0.678	0.465	0.546	0.579	–	–
p Value NV vs. C	**0.015**	**0.011**	0.079	0.980	0.774	–	–
SDLP straights (m)							
FV	0.72 (0.21)	0.58 (0.14)	0.48 (0.13)	0.38 (0.11)	0.42 (0.08)	**<0.001**	**0.003**
NV	0.53 (0.16)	0.48 (0.13)	0.49 (0.16)	0.37 (0.13)	0.40 (0.11)	0.914	**0.002**
C	0.37 (0.12)	0.38 (0.14)	0.35 (0.12)	0.34 (0.11)	0.39 (0.11)	0.342	0.926
p Value FV vs. C	**<0.001**	**<0.001**	**0.002**	0.285	0.280	–	–
p Value NV vs. C	**0.003**	**0.046**	**0.004**	0.573	0.665	–	–
Steering reversal rate (#/min)							
FV	39.6 (3.8)	36.2 (3.8)	34.9 (4.6)	42.3 (3.4)	55.4 (4.5)	**<0.001**	**<0.001**
NV	42.0 (6.9)	39.5 (6.8)	39.6 (9.6)	41.8 (3.5)	55.0 (5.0)	0.137	0.177
C	43.0 (3.7)	40.3 (3.8)	39.3 (3.6)	39.7 (3.8)	53.9 (5.4)	**<0.001**	0.842
p Value FV vs. C	**0.008**	**0.002**	**0.003**	**0.044**	0.343	–	–
p Value NV vs. C	0.604	0.632	0.885	0.111	0.522	–	–
Rapid steer wheel turns (#/min)							
FV	36.5 (10.6)	29.5 (7.2)	27.5 (6.9)	26.3 (6.6)	3.42 (2.2)	**<0.001**	0.065
NV	35.3 (12.6)	27.6 (11.5)	28.6 (16.5)	25.5 (8.9)	2.85 (2.9)	**0.024**	0.541
C	30.6 (9.1)	22.0 (6.1)	22.1 (6.4)	22.6 (7.1)	3.19 (6.1)	**<0.001**	0.319
p Value FV vs. C	**0.042**	**0.001**	**0.005**	**0.037**	**0.047**	–	–
p Value NV vs. C	0.127	0.070	0.141	0.180	0.615	–	–
Mean gaze pitch angle (deg)							
FV	3.50 (1.2)	3.54 (1.3)	3.42 (1.4)	4.44 (1.8)	3.59 (2.1)	0.515	**0.001**
NV	7.89 (1.9)	7.47 (1.4)	7.72 (1.6)	4.70 (1.5)	4.05 (1.7)	0.714	**<0.001**
C	4.19 (1.2)	4.39 (1.4)	4.08 (1.5)	3.68 (1.2)	2.87 (1.0)	0.169	0.163
p Value FV vs. C	0.079	0.065	0.164	0.137	0.188	–	–
p Value NV vs. C	**<0.001**	**<0.001**	**<0.001**	**0.039**	**0.016**	–	–

Note: The sample sizes for the FV, NV, and C groups were 21, 21, and 20, respectively. For the eye-tracking data, the number of excluded sessions are reported in Table 2. *p*-values < .05 are in boldface.

3.1.3. Gaze direction

The effect of the FOV restriction during training on the participants' vertical gaze distribution is shown in Fig. 4. Participants from the FV and NV groups directed their gaze above and below the FOV restriction border, respectively. The FV group directed their gaze between the FOV restriction border and the horizon, whereas the NV group directed their gaze close to the FOV restriction border, presumably in an attempt to maximize their preview distance. The NV group gazed significantly closer to the vehicle in both retention sessions compared to the C group. Fig. 5 illustrates fixations for three representative participants from each group in the second retention session. The figure illustrates that the selected NV participant fixated more closely to the vehicle than the other two participants.

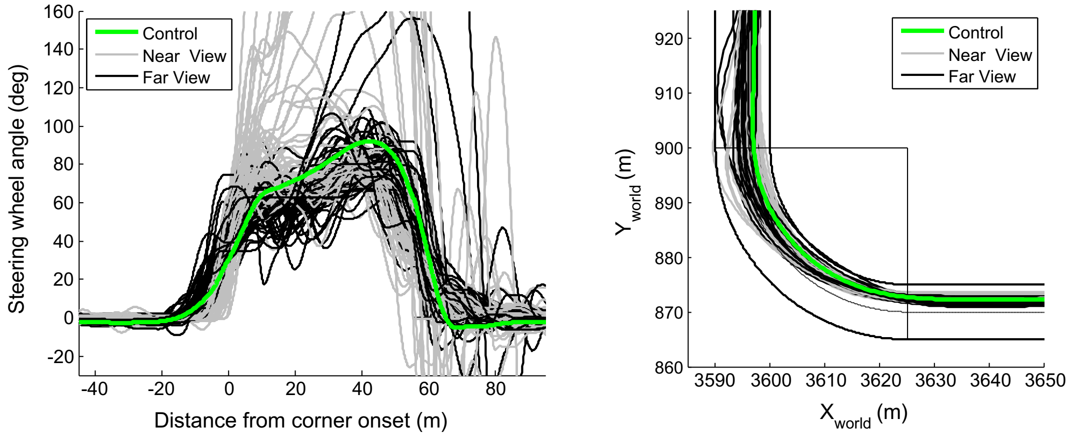

Fig. 2. Left: Individual steering wheel angle for the near view ($n = 52$) and far view ($n = 60$) groups during a typical 30-m road-center radius right-hand corner for all three training sessions. The green line indicates the mean steering wheel angle of the control group ($n = 59$), averaged across Training 1 to 3. Right: Individual paths of the center of the car of the near view ($n = 52$) and far view ($n = 60$) groups during a typical 30-m road-center radius right-hand corner for all three training sessions. The green line indicates the mean path of the control group ($n = 59$), averaged across Training 1 to 3. Road departures were removed from the figure for clarity. The participants approached the corner from the right of the figure. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

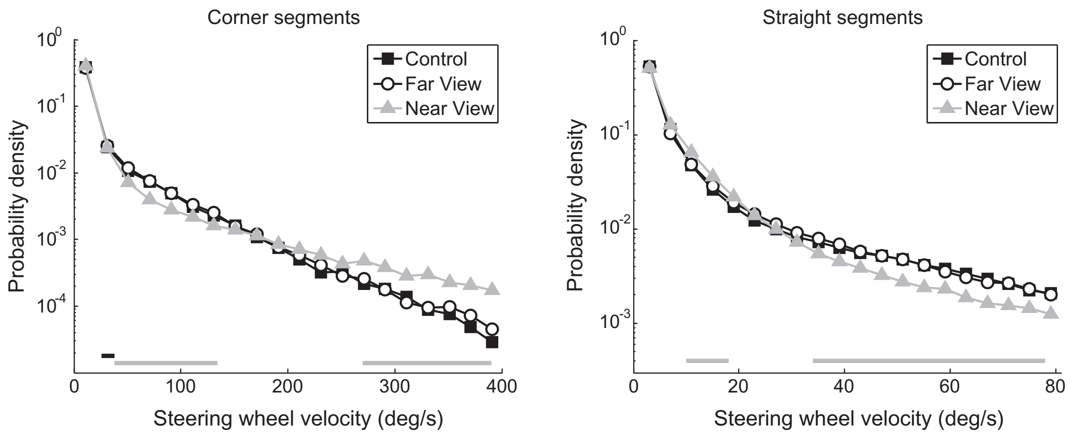

Fig. 3. Probability density function of steering wheel speed during corners (left) and straight road segments (right) for Training 1 to 3 combined. The distribution was determined by aggregating the steering wheel speeds of all participants into 4 deg/s bins. Significant differences ($p < 0.01$) between far view and control are indicated by black horizontal lines. Significant differences ($p < 0.01$) between near view and control are indicated by gray horizontal lines.

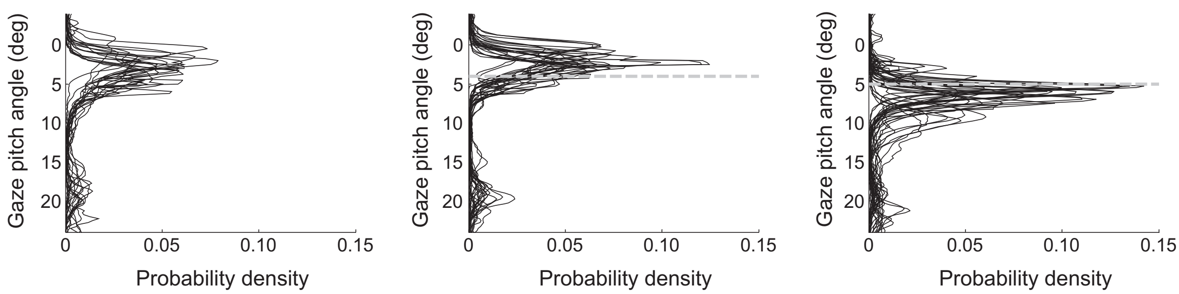

Fig. 4. Vertical gaze pitch distributions for all groups in the third training session. Control (left, $N = 18$), far view (center, $N = 19$), and near view (right, $N = 19$). The distribution is derived over 0.25 deg bins. The gray dashed horizontal lines represent the restriction borders. Each black line represents one subject. Note that the speedometer is located at 18 deg.

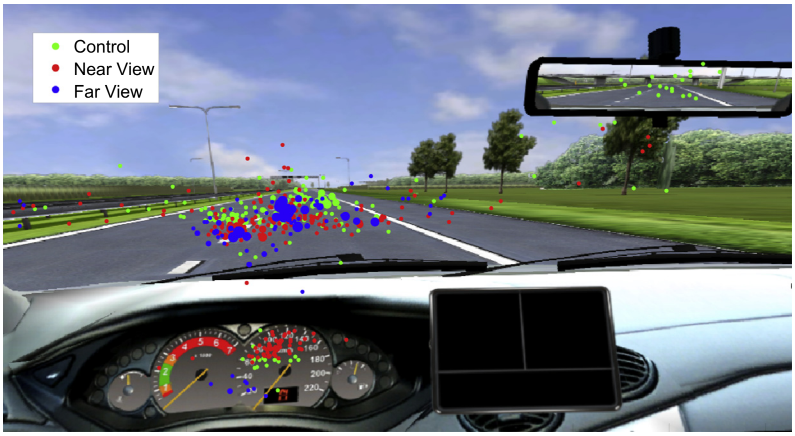

Fig. 5. Fixation distribution during the second retention session for one participant from the control group, one participant from the near view group, and one participant from the far view group. Their mean gaze pitch angles were 2.9, 3.9, and 3.5 deg, respectively. Fixation duration is indicated by the circle radius (the radius in the legend corresponds to approximately 3.5 s). Fixations during cornering were omitted from the figure.

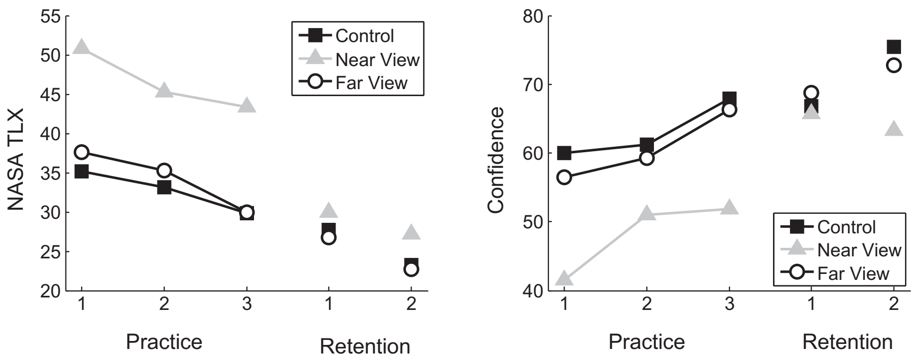

Fig. 6. Self-reported workload (NASA TLX; left) and self-reported confidence (right) for the training and retention sessions (mean across subjects).

3.1.4. Subjective measures

3.1.4.1. NASA TLX. Fig. 6 (left) shows the means for all TLX items as a function of session and group. A significantly higher workload was reported by the NV group for each of the three training sessions ($t(39) = 4.04$, $p < 0.001$, $t(39) = 3.02$, $p = 0.005$, and $t(39) = 4.60$, $p < 0.001$ for session 1, 2, and 3, respectively). Additional analysis showed that these effects were most pronounced for the physical demand, effort, and frustration scales. Both the NV and FV group reported significantly reduced workload from Training 1 to Training 3 ($t(20) = 3.51$, $p = 0.002$ and $t(20) = 3.10$, $p = 0.006$ for NV and FV, respectively). The workload for the NV group significantly decreased ($t(20) = 7.24$, $p < 0.001$) from Training 3 to the first retention session. No differences between groups were observed in the retention sessions with respect to the workload measure.

3.1.4.2. Confidence questionnaire. Fig. 6 (right) shows lower confidence levels for the NV group than for the C group during all training sessions ($t(39) = 4.18$, $p < 0.001$, $t(39) = 2.82$, $p = 0.008$, and $t(39) = 3.80$, $p < 0.001$ for Training sessions 1, 2, and 3, respectively). Significantly higher levels of self-reported risk ($t(39) = 2.25$, $p = 0.028$) and lower levels of safety ($t(39) = 2.09$, $p = 0.049$) and confidence ($t(39) = 2.52$, $p = 0.016$) were reported in the second retention session by the NV group compared to the levels reported by the C group. There were no significant differences between the C and FV groups with respect to the total confidence score. All three groups showed an increase in confidence from Training 1 to 3 ($t(20) = 3.23$, $p = 0.004$, $t(20) = 2.99$, $p = 0.008$, and $t(19) = 2.60$, $p = 0.017$ for FV, NV, and C, respectively).

3.2. Corner entry analysis

Fig. 7 shows the mean corner entry speed for the 90-deg corners in the case of no road departures (left figure) and road departures (right figure). The corner starts at 0 m and −20 and −10 m indicate 20 and 10 m before the start of the corner, respectively. The NV group drove more slowly 20 m before the corners compared to the FV and C groups when no road departures occurred and drove faster 20 m before the corners when road departures did occur. In both cases, the NV group

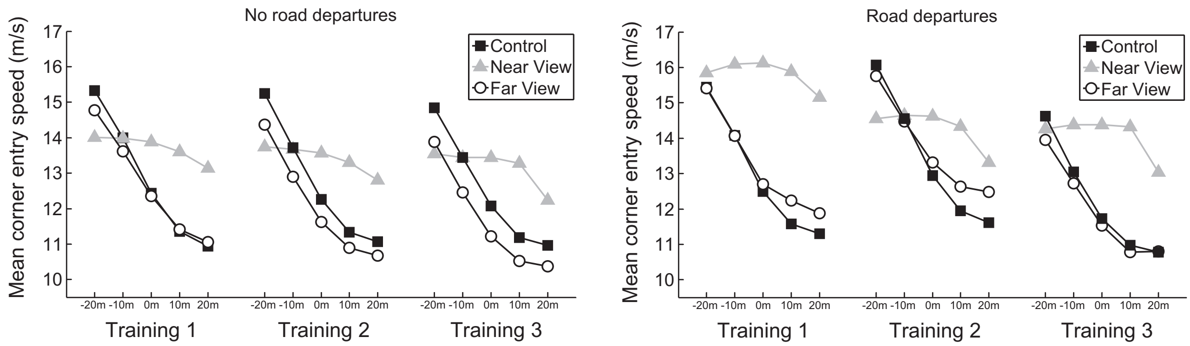

Fig. 7. Mean corner entry speed from 20 m before corner onset (−20) to 20 m after corner onset (+20), for corners without (left) and with road departures (right).

took the corners at higher speeds than the FV and C groups did. The speed pattern through the curve was roughly similar between the FV and C groups. However, the FV group approached the corners significantly more slowly than the C group in Training 3 (see also Table 2). During Retention 1, there were no significant differences in corner entry speeds between the three groups.

4. Discussion

This study investigated a simulator-based training method targeting speed choice and risk awareness. We hypothesized that by removing visual information during training, participants would drive with lower speed and report lower levels of confidence than a control group driving with full sight in both the training and retention sessions.

Consistent with our hypotheses, the NV group drove with significantly lower speed and had more road departures and poorer lane-keeping performance than the C group. Most of these training effects did not transfer to post-training retention sessions, with the driving performance of the NV and C groups being statistically indistinguishable in this phase. The confidence was retained, however: NV reported the lowest confidence during training, and this low confidence was still detected in the second retention session in a highway environment.

The mean speeds of the FV and C groups were similar during both training and retention sessions. However, during training, the FV group approached and negotiated the corners at a lower speed and started steering into the corners earlier than the C group. Training with far view required the participants to control the vehicle with information from far ahead. However, compensatory control was more difficult for the FV group and consequently resulted in impaired lane-keeping precision compared to the C group during training. This difficulty in exerting compensatory control may have caused drivers in the FV group to be more cautious when approaching and negotiating corners.

Generally, the FV and NV groups' training did not result in improved driving performance or driving behavior in the retention sessions compared to training with full sight. This result demonstrates the ineffectiveness of the visual FOV restriction training method compared to the self-training of the C group drivers. The restriction of visual information possibly causes trainees to over-rely on one region of the visual field, resulting in sub-optimal performance in the retention sessions. Previous research has demonstrated the ineffectiveness of basic driver training compared to self-training or informal training (Beanland et al., 2013; Lund, Williams, & Zador, 1986; Vernick et al., 1999). Driver training may promote overconfidence in one's own skills (Lee, 2007; Mayhew & Simpson, 2002), which suggests that reducing self-confidence can be beneficial in reducing crash risk for newly trained drivers. Training with near visibility reduced the overall confidence level and increased workload during training. One cause of the reduced confidence of the NV group may be the large number of road departures. The NV group, unable to anticipate oncoming corners, approached corners faster and braked later, resulting in more road departures than the other two groups. Ivancic and Hesketh (2000) previously showed that making errors during training is an effective learning strategy for reducing confidence during simulator-based training. Second, the inability to see information far ahead may be a cause of the observed low confidence and increased perception of risk, similar to driving in fog (Saffarian et al., 2012; Stanton & Pinto, 2000).

The visual behavior of the NV group transferred to the retention sessions. In both retention sessions, NV drivers directed their gaze more closely to the vehicle compared to drivers in the C group. It is known that inexperienced drivers fixate more closely to the vehicle (Falkmer & Gregersen, 2005; Mourant & Rockwell, 1972) and have poorer anticipation of future events compared to experienced drivers. This study showed that removing visual information during training can have post-training effects on visual behavior with respect to a control group, a finding that must be applied cautiously. Training drivers to reallocate their visual attention during a lane-keeping task may reduce their attention to other vital visual tasks. Driving consists of many combined visual tasks, and looking close ahead reduces attention to information further ahead, potentially reducing the time to anticipate future events; this behavior may cause drivers to fail to respond to hazards farther down the road (e.g., corners, traffic).

During training, FV drivers controlled the vehicle with a lower steering reversal rate compared to C drivers and showed more (jerky) rapid steering movements. The latter finding may have been caused by the lack of immediate lateral position information: FV trainees made rapid corrections when the lateral error was perceived as too large but had no visual incentive to correct minor errors. The higher number of rapid steering wheel turns was retained in both retention sessions, which is in line with our earlier research showing that steering behavior is more easily retained than observable metrics of driving performance such as lane-keeping accuracy or mean speed (De Groot et al., 2011; Van Leeuwen, De Groot, Happee, & De Winter, 2011). Previous research in motor learning concurs that subjects tend to repeat previously learned error-correcting behavior (Schmidt, 1991).

The NV group had steering reversal rates comparable to those of the C group during the training sessions, but showed more high-speed steering movements during cornering and greater active steering control on the straight road segments compared to the C group. These findings are consistent with those of Frissen and Mars (2014), who found higher steering activity when driving with blanked far sight compared to driving with full sight during a forced-paced condition in which speed was constant. In our self-paced experiment, NV drivers' mean speed was found to be significantly correlated with the steering reversal rate ($r = .56$, $p < 0.001$, $n = 63$). In other words, the speed of the drivers was an important factor in explaining the drivers' steering activity. In the training sessions, the NV drivers adopted lower speeds than those observed for the C drivers, most likely as a compensatory strategy to maintain acceptable performance while driving with the impoverished visual scene. However, the lane-keeping performance and number of road departures of the NV group were still substantially worse than those of the control group driving with full sight. Furthermore, the NV group reported higher levels of risk and workload compared to the C and FV groups during training. Presumably, the NV group insufficiently regulated their speed and consequently their time to react to oncoming curvature. These findings are not in agreement with the task difficulty homeostasis and risk homeostasis theories (Fuller, 2005; Wilde, 1982), which predict that perceived task difficulty and perceived risk, respectively, are used as normalizing mechanisms while driving. In other words, although drivers compensated for the reduced visual information by slowing down, they did not compensate sufficiently to maintain their nominal lane-keeping accuracy.

To summarize, there are clear differences between the steering behavior of the NV and the FV groups. These differences appear to be consistent with two-level models of steering, which state that far visual information is used for smooth steering control and near visual information is used for lateral error correction (e.g., Salvucci & Gray, 2004). NV drivers showed active steering behavior (Fig. 3 right) with similar SRR and RSWTs as C drivers but were unable to keep the vehicle as precisely in the center of the lane as C drivers. The sharp corners were particularly problematic for the NV group. The lack of preview prevented the trainees from anticipating upcoming corners, resulting in high corner entry speeds, abrupt and high-speed steering corrections (Fig. 3 left), and many road departures. Drivers in the NV group drove with a lower mean speed than drivers in the C group and thereby moderated their own steering demands. Similarly to the NV group, the FV group also showed deficient lane-keeping precision. However, in contrast to the NV group (which showed active steering behavior), the FV group had a relatively low steering reversal rate. The low reversal rate can be explained by the fact that the FV drivers had no visual incentive to correct minor lane center errors. Furthermore, the FV group entered the corners more carefully and steered earlier into these corners compared to the C group, consistent with a preview strategy.

This study consisted of three sessions with 24 min of practice per participant, whereas driving skill and driving style are usually developed over years of driving experience (Mayhew, Simpson, & Pak, 2003; Pradhan et al., 2005). Transfer of training was assessed in a new simulated environment but in the same simulator, in the same virtual vehicle, and with the same driving task instruction to keep the vehicle centered in the right lane. Groeger and Banks (2007) argued that for driver training to be effective, skills learned during driver training will have to transfer positively under new and more demanding traffic circumstances. Groeger and Banks further argued that transfer needs to occur along several dimensions (knowledge domain, physical context, temporal context, functional context, modality, and state/task/situation demand). For future work, it is recommended to investigate longer training periods, long-term retention, and far transfer effects of FOV restriction on a driving task. Driving simulators are known to be able to provide metrics that are predictive of real-world driving (e.g., Lee, Cameron, & Lee, 2003). However, several relevant perceptual cues (e.g., sustained g forces, tactile road rumble, photorealism) and environmental aspects (e.g., other cars) were not provided in our driving simulator experiment. More research regarding the transfer of learning from simulated tasks to real vehicle tasks is therefore recommended. Another limitation is that our study was conducted with participants recruited from a technical university. Engineering students tend to have above-average intelligence (Wai, Lubinski, & Benbow, 2009), and intelligence is known to be predictive of driving safety (Whitley et al., 2010). Furthermore, engineering students tend to be specifically interested in (simulator) technology. Hence, the present results may not be readily generalized to the entire population of young drivers.

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