Driver training in immersive virtual reality (VR) and transfer to the real world: A feasibility study on learning how to drive a truck in VR

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Abstract

Virtual reality (VR) offers important advantages in training complex spatial skills, as required for example in driving, because it enables immersion and experience-based learning, and offers financial, ecological, and safety benefits. In the context of driving, as larger vehicles can be especially challenging to master for beginners, we investigated whether truck driving instruction and practice in a VR-simulator enhances performance, and whether the acquired skills transfer to maneuvering a real vehicle. In an empirical feasibility study, we first measured learners' performance while an experienced instructor trained them on a conventional simulator vs. in VR, following analogous training protocols. The task was to reverse a truck with a trailer, a particularly difficult task that requires extensive practice. After training, participants completed a test on a real vehicle to validate the effectiveness of the training. Participants were asked to report previous experience, attitudes towards the system, motion sickness, and fatigue levels. Four male participants, who had a car driving license but no experience reversing a truck with trailer, completed the training. Results demonstrate that basic maneuvering skills can be trained in VR and transfer to the real vehicle. Even with a low-budget VR solution, participants learned easily, and learning curves were comparable to the simulator condition. Participants reported positive attitudes towards the training in both conditions. Future research could investigate whether using a customized VR environment that takes full advantage of all the benefits of VR, could lead to even greater training gains.

1. Background

Technical innovations will likely change driver training in the near future. Simulator-based systems are already used in specialized driver training such as truck driving, and will likely become even more prevalent in driving instruction due to their multiple benefits. Previous research has suggested several advantages of driving simulators as compared to training on real vehicles. For example, driving simulators can provide safe learning environments and allow for practicing maneuvers that would be risky to train in real environments (Brummerová et al., 2021). This is of special relevance for trucks, as they represent an increased risk because of their greater mass and high road exposure (Hirsch et al, 2017). Simulators can reduce training costs in terms of fuel consumption, vehicle maintenance and repairs, as well as environmental impact (Uhr et al., 2003). They also allow for objective skill assessment, and the highly controllable environments are well-suited for empirical research on learning improvements (Choukou et al., 2014).

Simulator training also offers some didactic advantages. They can be highly efficient, as specific training locations/scenarios can be reached with a few mouse clicks (Uhr et al., 2003). Furthermore, simulated trainings offer selective learning opportunities and can take advantage of five specific effects (Dieterich & Tomaske, 2003, as cited in Uhr et al, 2003): (1) The *aggregation effect:* scenarios that are highly typical, relevant, or hazardous can be trained more often, (2) the *multi-coding effect*: repetition (and reflection) of scenario through playback options can lead to deeper learning, (3) the *isolation effect*: breaking down complex tasks into specific subtasks can alleviate cognitive load and therefore facilitate learning, (4) the *emancipation effect:* autonomous and independent learning is possible (independent of time and space, and the availability of a teacher, etc.), and (5) the *weight-belt effect:* the task presented to the user in the simulator training may be more difficult than in the real system. In sum, these advantages suggest that driving simulators can provide powerful training environments. However, their prevalence in practice remains limited. One possible reason is the still relatively high financial and time costs associated with building most modern simulators. High-performance systems featuring large visual displays, full motion, accurate computer models, and offering a wide range of training options are particularly expensive. Further possible challenges when learning on simulators are the limited realism of the system (e.g., in terms of visual fidelity, resolution, field of view), and the fact that trainees are clearly aware that they are in a safe environment (Brummerová et al., 2021) and might thus behave differently than in the real world. A key question therefore is whether driving skills practiced on a simulator transfer to real-world driving behavior. Systematic reviews on the effectiveness of simulator training concluded that, despite initial positive results, evidence is still inconsistent (Alonso et al, 2023; Krasniuk et al., 2024). Many of the reported studies compared performance to no training, classroom training, or video-based training, and assessed improvements on the driving simulator. Thus, it is largely unclear whether training transfers to real-world on-road driving skills. Moreover, empirical studies have mainly focused on passenger cars and were rarely conducted in the context of large vehicles, such as truck driving (Ribeiro et al., 2021), with few exceptions. For example, in a previous publication that is of direct relevance to the study presented in this paper, Uhr et al. (2003) asked 50 participants to reverse a truck with a trailer, and to change lanes while doing

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so. The experimental study compared training with a driving simulator (FATRAN by Oerlikon Contraves) to training with a real vehicle, allowing for a direct comparison of the effectiveness of training in the two learning environments. Results yielded no significant differences between the two training conditions, neither in terms of success rates nor in the time it took to perform the task, suggesting that simulator training was comparable to real-world training in terms of effectiveness, and that trainees were able to transfer what they had learned on the simulator to the real system. Similarly, Hirsch et al. (2017) found that basic vehicle control skills learned on a semi-trailer truck simulator (VS600M truck simulator) transferred to a real vehicle, and that the time required to learn the skills on the truck simulator was equal or even shorter in some cases. In a study by Morgan et al. (2011), spending 60% of the training time in a simulator (FAAC TT-2000-V7 driving simulator) led to comparable performance on a standard road and range test. Compared to industrial driving simulators, modern head-mounted virtual reality (VR) may present a cost-effective alternative (Çöltekin et al., 2019; Ribeiro et al., 2021), as it continues to advance technologically while becoming increasingly affordable and accessible. However, evidence on the effectiveness of simulated training in VR is still very limited. On the one hand, VR may offer even more benefits than non-VR simulators, providing a realistic feel through sense of presence and immersion, as well as memorable experiences, which may promote more persistent learning outcomes (e.g., Çöltekin et al., 2020; Elmasllari et al., 2025; Lokka & Çöltekin, 2016; Lokka et al., 2018; Proulx & Çöltekin, 2025). On the other hand, communication with the instructor may be restricted, if the instructor is not in the same virtual environment, has insufficient or different visual information, or the trainee cannot see the instructor's gestures. Another common obstacle to the use of immersive VR systems with head-mounted displays is the more frequent occurrence of motion sickness (e.g., Weidner et al., 2017). Based on the literature reviewed above, there is some evidence that simulator training can be useful for truck-driving instruction, at least in combination with traditional training, and that acquired skills can transfer to maneuvering a real vehicle. However, we do not know whether truck-driving training would benefit from simulation in VR. Therefore, in this feasibility study we investigated (a) whether driving instruction and practice in a VR-simulator improves performance within the VR system, and (b) whether the skills acquired in VR transfer to a real vehicle. Specifically, we experimentally compared training outcomes for truck maneuvering in VR with head-mounted display to those in a commercially available simulator with three computer monitors. Reversing with a truck trailer was chosen as the training task, as this is a particularly difficult maneuver for beginners and requires extensive practice, and because it is relevant to everyday tasks such as rearward docking. We assessed performance (task effectiveness and efficiency) throughout the training as well as transfer to the real vehicle after training, and participants' self-reported previous experience, attitudes towards the system, fatigue levels, and motion sickness based on standardized questionnaires.

2. Methods

2.1 Participants

As the main goal of the study was to assess feasibility of the ideas presented above, we recruited a small number of participants and focused on collecting in-depth observations. Four male participants from 18 to 36 years of age took part in the training study (Simulator condition: M = 28 years; VR condition: M = 23 years). Participants all worked at a Swiss institution of higher education, and all had a car driving license (B), three additionally had a motorbike license (-A, A1, or M), and one participant had a tractor license (G). None of the participants had experience with reversing a truck with trailer, but one participant (in the Simulator condition) had some experience in driving a truck with trailer forward, and with driving a car with trailer. None had driven a truck or any other vehicle with a trailer within the last year. Three of the four participants had experience with playing video games, two with video games in VR with a head-mounted display (one in the VR and one in the Simulator condition). These two participants reported to have spent 30 and 8 hours a month, respectively, on VR activities within the last year. All participants had good or corrected eyesight with good acuity. They reported feeling well at the beginning of the experiment, with no known factors that might impede their performance. All participants were fluent in Swiss German and tested in Swiss German; Questionnaires were in standard German, in which they were also fluent. The study was approved by the institution's ethics committee and all participants provided written informed consent.

2.2 Research Protocol & Design

Participants were randomly assigned to one of two conditions. In the *Simulator condition*, participants completed the training in a driving simulator by observing three monitors (Figure 1a). In the *VR condition*, the participants completed the training using the same simulator setup, but wearing a head-mounted display (Figure 1b). Participants were instructed by a qualified instructor with 27 years of experience in truck driving instruction and 14 years of experience in instruction on driving simulators, who was seated behind and slightly to the side of them. Both conditions followed the same training procedure (see Table 1). The training was administered in two sessions with 3 to 5 days in between.

Session 1 started with an instruction and try-out phase. For all participants, brief initial instructions were given by using a small-scale 3D model of a truck with trailer, which participants were allowed to move. Then the instructor demonstrated the maneuver on the simulator, by showing a bird's-eye view of the truck and trailer plus the two rear-view mirrors on one monitor. He reversed the truck about 70 meters and explained what he was doing. Next, the participants were allowed to try for themselves for about two minutes, to get acquainted with the device, before completing a baseline test to measure their initial skill levels. In this test, participants received no further instructions, but were asked to reverse the truck as straight as possible in their respective conditions, with either the monitor or the VR headset showing the front view from the driver's seat plus the rear-view mirrors. After this baseline test, the instructor explained in more detail with the 3D model, and then in the bird's-eye view of the simulator how the trailer can be controlled and how deviations can be corrected. Next, participants completed two 20-minute training blocks, in which they practiced with corrective feedback from the instructor. Participants were encouraged to take at least three short breaks, after each training block and after or before a test if needed. *Session 2* included a short recap of the instructions to refresh participants' memory, and four 20-minute training blocks. Performance was measured at the beginning and end of each session, and after the second training block in the middle of Session 2. Again, breaks could be taken as needed, and three short breaks were suggested between the training blocks and halfway through the session. One to two days after Session 2, all participants completed three test rounds on a real truck, to assess how well the training transferred to the real vehicle.

Table 1: Training procedure. While training blocks were always 20 min., other durations varied slightly from student to student. Tests were terminated after a maximum of 5 minutes.

Session	Duration (minutes)	Program item	Driver	Tool/setup
1	5	Consent & Questionnaire		
	5	Explanation		3D model
	5	Demonstration with Explanation	Instructor	Simulator, top-view, 1 monito + mirrors
	2	Try Out	Trainee	Simulator, top-view, 1 monitor + mirrors
	5	Test (Session 1 Baseline)	Trainee	VR/Simulator, front-view 1 monitor + mirrors
	5	Break		
	6	Instruction		3D model
	5	Demonstration with Instruction	Instructor	Simulator, top-view, 1 monitor + mirrors
	20	Training	Trainee	VR/Simulator, front-view, 1 monitor + mirrors
	5	Break		
	20	Training	Trainee	VR/Simulator, front-view, 1 monitor + mirrors
	5	Break		
	3	Test (Session 1 End)	Trainee	VR/Simulator, front-view, 1 monitor + mirrors
	2	Questionnaire		
2	2	Refresh Instructions		3D model
	5	Test (Session 2 Baseline)	Trainee	VR/Simulator, front-view, 3 monitors
	20	Training	Trainee	VR/Simulator, front-view, 3 monitors
	5	Break		
	20	Training	Trainee	VR/Simulator, front-view, 3 monitors
	3	Test (Session 2 Middle)	Trainee	VR/Simulator, front-view, 3 monitors
	5	Break		
	20	Training	Trainee	VR/Simulator (first 5 min. with different scene: loading ramp)
	5	Break		
	20	Training	Trainee	VR/Simulator (first 10 min. with different scene: narrow track with lines, rain)
	2	Test (Session 2 End)	Trainee	VR/Simulator, front-view, 3 monitors
	2	Questionnaire		
3	15	Test	Trainee	3 test runs on the real truck with trailer

2.3 Instruments & Setup

The device used for the training was a Vogel Simulator (by Vogel-System), with three 27-inch monitors, a steering wheel, a gear stick, and pedals (Figure 1). The Euro Truck Simulator 2 software (SCS Software, 2012) was installed, and a (modded) truck (Scania; 9.8 meters) was chosen with a trailer that was 9 meters long and 2.55 meters wide (Figure 2).

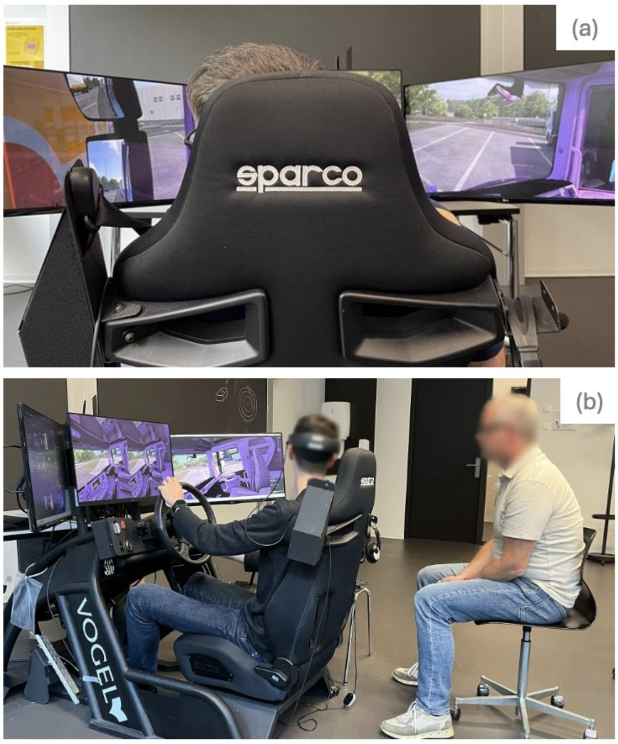

Figure 1. Experimental setup in the Simulator condition (a) and the VR condition (b).

Figure 2. Side view of the truck used in the Euro Truck Simulator 2.

For the training and test track, a straight lane on a parking lot was chosen, with the starting point at the pedestrian walkway (see Figure 3a) and the target end position between two white lines, as depicted in Figure 3c. The track was about 70 meters long. The initial position and orientation of the truck could be reset by returning to a pre-saved game status. This also reset the time and weather conditions in the virtual world. From this position, the target could be reached by reversing the truck and trailer in a straight line, which required constant fine control using visual feedback from the rear-view mirrors. In the Simulator condition, only the middle monitor was used in the first session, showing the front view and the two rear-view mirrors in the upper corners. This had the advantage that the right mirror was slightly bigger, and thus better visible for the student and the instructor. It also made switching between the bird’s-eye view for initial instructions and the front view easier and less disruptive. **In the second session,** the simulator was used with all three monitors (Figure 1), to ease the transition to the conditions on the real truck. In the VR condition, participants sat in the simulator and additionally wore a Meta Quest Pro head-mounted display (Reality Labs, 2022; 1800×1920 per-eye resolution; 106° horizontal field of view; Pancake Lenses; 722 g). **The final assessment and test of**

transfer was conducted on a real truck (IVECO, Stralis, 4x2 with trailer, 2 axles, total length: 17.15 meters, width: 2.55 meters). The test site was gated off from traffic. The test track was 70 meters in length, and two traffic cones were placed 5 meters apart to indicate the target, which could be reached by reversing the truck in a straight line.

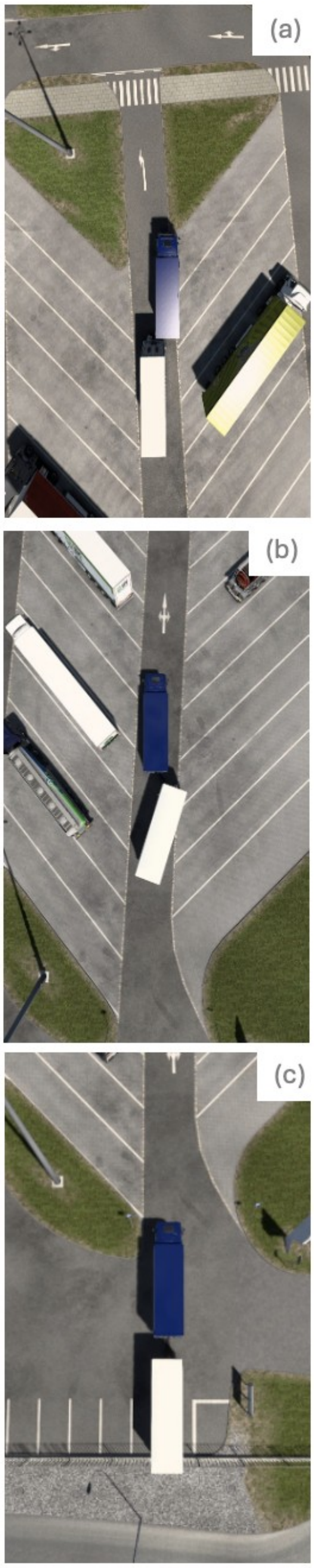

Figure 3. Bird's-eye view of the truck near the beginning (a), middle (b), and end (c) of the track.

2.4 Performance Measures

For the performance tests, participants were instructed to back up the truck as straight as possible, reaching the target position as quickly as they can, while making corrections if needed. To make a correction, the participant changed into the forward gear and moved the truck forward until it was realigned with the target direction. In the simulator, the target was a parking lot, marked by two white lines on the ground, twice the width of the truck. On the real test site, two traffic cones were placed 5 meters apart, which also corresponded to twice the width of the real truck.

Performance was measured in terms of how many corrections were necessary, how much time was needed to complete the task, and the deviation of the trailer's end position from the target position, centered between the traffic cones or parking lot lines. Deviation was measured when the target was reached or when the test was terminated after a maximum of 5 minutes, whichever came first. To measure deviation, the closest point of the left side of the trailer to the left cone or parking line was measured, and the distance to the right-side of the target was measured analogously. From these, the left and right distances of a perfectly centered trailer were subtracted, and the absolute distances were averaged. Thus, a perfect performance was scored with 0.

2.5 Motion Sickness & Fatigue

Participants were asked whether they felt motion sick or nauseous during training and test blocks. We used the Baxter Retching Faces (BARF) Scale (Baxter et al., 2011), which assesses nausea on a 6-point scale, illustrated by line drawings of faces that progress from neutral (coded as 1), via increasingly sick, to vomiting (6). A similar question format was used to ask participants for signs of fatigue or possible drops in concentration, showing line drawings of an alert and focused face (coded as 1) and a tired face (6). Motion sickness and fatigue was rated retrospectively during the breaks for each of the training and test blocks.

2.6 Attitudes & Acceptance

Participants' attitudes towards the system were assessed by standardized questionnaires that were filled out at the end of each session. Participants were asked to what extent they agreed with statements that were assembled from the Technology Acceptance Scale (TAM, Venkatesh & Davis, 2000) and the newer UTAUT (Venkatesh et al., 2003) and UTAUT2 (Schomakers et al., 2022), translated to German and adapted to the content. The statements concerned: *intended use, perceived ease of use, perceived usefulness, output quality* (TAM), *anxiety, attitude towards using technology, performance expectancy* (UTAUT), *hedonic motivation, perceived trust, perceived surveillance* (UTAUT2).

The questionnaires also included some items on learning motivation from the SMR-LS (Skalen zur motivationalen Regulation beim Lernen im Studium; Müller, et al., 2007). Participants answered these questions on a 7-point-scale that ranged from "don't agree at all" (coded as 1) to "very much agree" (7) (in German: Stimme gar nicht zu; Stimme nicht zu; Stimme eher nicht zu neutral; Stimme eher zu; Stimme zu; Stimme sehr zu).

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3. Results

3.1 Performance Measures

Corrections: Figure 4a shows the average number of corrections made across the two training sessions (S1 and S2) and on the real truck, in the VR and Simulator conditions. The corrections decreased drastically throughout the first training session. At the start of the second session a few days later, most participants again needed more corrections, on average about two times more, but then quickly recovered and were able to perform the task with 1 or zero corrections by the end of the second session. When transitioning to the real truck all participants made more corrections, particularly in the Simulator condition. However, by the second test round, the two conditions were comparable and only one correction was needed on average. In the third test round, three participants succeeded in reversing the truck without correction, while one participant in the Simulator condition made one correction (Figure 4b). Similar improvements and learning trajectories were observed in the two experimental conditions (see almost congruent lines in Figure 4a).

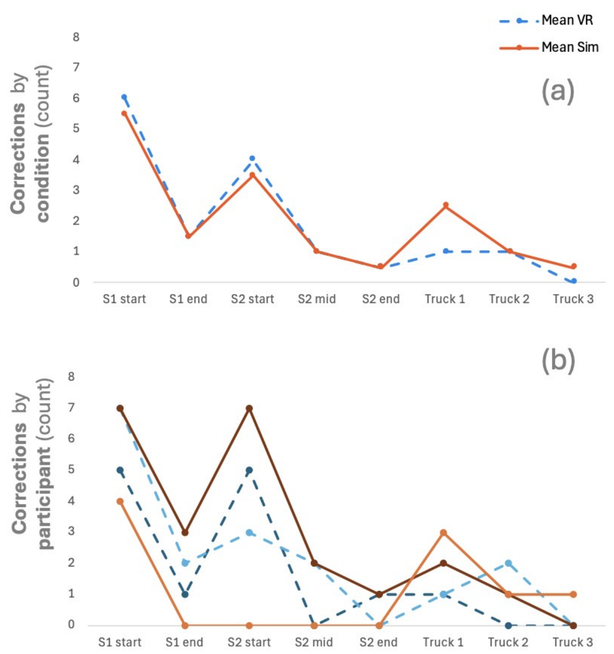

Figure 4. Number of corrections by condition (a) and participants (b). Solid lines depict the Simulator condition, dashed lines the VR condition.

Time to complete: The truck traveled at a rather constant speed after tipping the gas pedal slightly; without corrections, the time needed to cover the distance at this minimal speed was about 2 minutes. The time participants needed to complete the task (Figure 5a) was heavily influenced by the number of corrections. At the start of Session 1, none of the participants succeeded in reaching the target within 5 minutes; at the beginning of Session 2, two participants (one per condition) timed out. Therefore, these data points are omitted in the Figures. Across the second training session, completion times stayed roughly the same or decreased slightly. Participants needed more time to reach the target on the first trial with the real truck. However, by the third test round, average completion time (M = 2 minutes, 8 seconds) was comparable to the shortest time on the simulator (M = 2 minutes, 10 seconds). Again, the two conditions exhibited similar trajectories with similar improvements across the sessions. In the last test on the real truck, the VR group (M = 1 minute, 52 seconds) was on average slightly faster than the Simulator group (M = 2 minutes, 25 seconds), and this also held true for every single participant (Figure 5b).

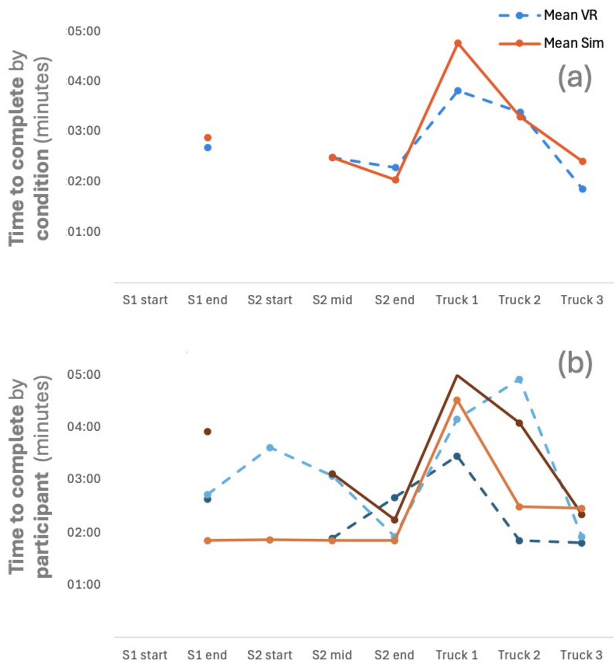

Figure 5. Time to complete by condition (a) and participants (b). Solid lines depict the Simulator condition, dashed lines the VR condition. (Omitted datapoints: timeout after 5 minutes.)

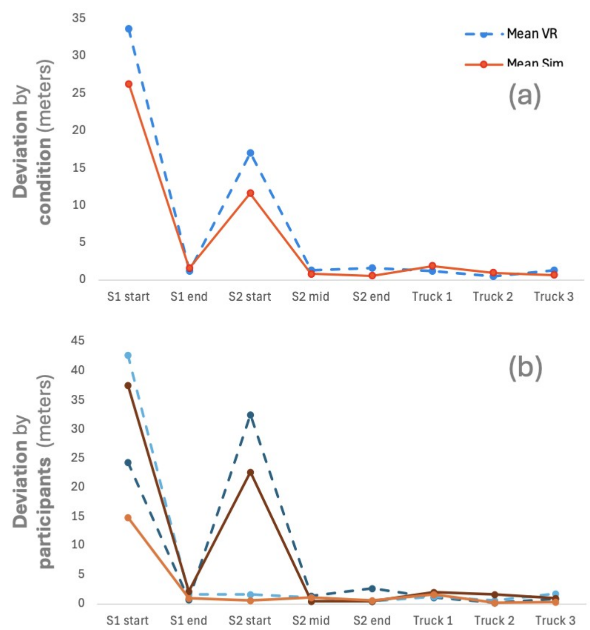

Figure 6. Deviation from target in meters by participant (a) and by condition (b). Solid lines depict the Simulator condition, dashed lines the VR condition.

Deviation: Participants’ aim, in terms of average absolute deviation from ideal target position, centered between the traffic cones or lines demarking the parking space, increased drastically in Session 1. The two conditions again showed rather parallel patterns of improvement across the sessions (Figure 6a). Two participants (in each condition; see Figure 6b) started into Session 2 with a performance loss as compared to where they left off at the end of Session 1, but they quickly regained their precision by the middle of Session 2. Notably, precision did not decrease by much when transitioning to the real truck. In the first test round on the real truck, the VR group missed the ideal position by 1.2 meters, while the Simulator group deviated by 1.88 meters (M = 1.54 meters). On the second and third test round, the two groups performed comparably, with the VR group 0.89 meters and the Simulator group 0.83 meters off target, respectively, which was even slightly less than the last test on the simulator (M = 1.09 meters).

3.2 Motion Sickness & Fatigue

Only one participant in the VR condition (who had previous experience with gaming but not with head-mounted displays) reported slight discomfort (rating of 2 out of 6) on the BARF scale. This occurred in Session 1 after the second training block, and in Session 2 after the first test and last training block. The ratings returned to normal (1) after a short break. All participants reported minimal fatigue (1 out of 6) throughout the two training sessions.

Table 2: Mean, standard deviation (*SD*) and range of all participants' responses to the questionnaire after the last training session (lowest agreement: 1, highest agreement: 7). Where low values are *positive*, an asterisk is added.

Question (translated to English)	mean	*SD*	range
I would recommend this driving training to my friends.	6.5	0.58	6-7
I would do this type of driving training again in the future.	6.5	1.00	5-7
I found it easy to learn in this driving training.	6	0.82	5-7
The device/vehicle behaved the way I wanted it to.	6.5	0.58	6-7
It was easy to steer the device/vehicle.	5.75	1.50	4-7
I find this kind of driving training to be useful.	6.75	0.50	6-7
I have learned a lot in this driving training.	6.75	0.50	6-7
I felt safe during this driving training.	7	0.00	7-7
*I often hesitated during the driving training for fear of damaging something.	1.25*	0.50	1-2
This kind of driving training would make me feel more confident driving a real truck.	6.75	0.50	6-7
*I think I have learned less in this driving training than on a real truck.	4.25*	2.75	1-7
*The use of simulators in driving training is a bad idea.	1*	0.00	1-1
Simulators make driving training more interesting.	6	1.41	4-7
Learning with simulators is fun.	6.25	0.96	5-7
This type of driving training is really fun.	6.5	0.58	6-7
I enjoy this type of driving training.	6.25	0.96	5-7
I find this type of driving training very entertaining.	6.25	0.96	5-7
I am confident that this driving training improves my skills.	6.75	0.50	6-7
*I am concerned that in this type of driving training more information is collected about me than I would like.	2*	1.41	1-4

3.3 Attitudes & Acceptance

The mean and range of responses to the questions concerning participants' acceptance and evaluation of the simulation training after the last training session are shown in Table 2. A rating of 1 means that they not at all agreed with the statement, whereas a value of 7 means that they very much agreed with the statement. While most items were formulated positively, such that high values indicate positive attitudes towards the training, items with asterisks were formulated negatively, so that low values indicated positive attitudes. The ratings showed that participants generally had very positive attitudes towards the training. The average agreement in the Simulator condition (M = 6.16) was slightly lower than in the VR condition (M = 6.47). The largest range of responses was obtained regarding the question of whether participants thought they had learned less in this training than on a real truck.

4. Discussion

In this empirical feasibility study, we investigated whether maneuvering a truck with a trailer can be trained in VR, and whether the learned skills transfer to a real vehicle. We compared performance in a VR condition, with head-mounted display, to a simulator condition with monitors. Performance was measured continuously across the training, as well as in a final test on a real truck. Participants' previous experience, attitudes towards the system, motion sickness, and fatigue levels were assessed through standardized questionnaires.

4.1 Performance

At the start of the experiment, none of the participants succeeded in reaching the target in the allotted 5 minutes. Participants' performance increased greatly across the first and the second training sessions in terms of time needed to complete the task, corrections, and precision in reaching the target position. Not surprisingly, transitioning to the real truck required some readjustment, and participants needed more time and more corrections to reach the target, as compared to the last test on the simulator. In contrast, precision did not suffer as much when transitioning to the real truck, suggesting that participants were more careful when reversing the real vehicle for the first time, but almost as accurate as at the end of the simulator training. On the second and third trial on the real truck, they even outperformed the last test on the simulator.

The two experimental groups showed similar improvement across the sessions. The slightly higher completion time of the Simulator group on the last test trial on the real truck was at least partly due to a single correction by one participant in this condition. Yet, this participant also showed the highest precision on this trial and overall. On the second and third trial with the real truck, the two groups performed comparably, suggesting that the VR training resulted in similar performance gains as the Simulator training. Their final performance was remarkable considering that at that point, they only had 2.5 hours of practice (training plus test time) in reversing a truck with trailer.

4.2 Motion Sickness & Fatigue

Participants reported minimal fatigue and only one participant reported slight discomfort in the VR training, which dissipated quickly after a short break. Participants with experience in VR reported no signs of nausea or motion sickness. Motion sickness was likely not experienced by most participants as the truck typically moved at a rather constant and low speed when reversing. The one participant who reported slight discomfort commented that he was mostly getting dizzy when moving forward to realign the truck, or when moving to the starting point at a faster speed. With breaks after 20-minute training sessions, nausea should not pose a big problem for training these kinds of slow maneuvers in VR.

4.3 Attitudes & Acceptance

Participants had very positive attitudes towards the training, and there were no substantial differences between the two conditions. However, they were most ambivalent about the question as to whether they think they have learned less in the simulation training than on a real truck. This shows that, at the end of the training, some participants were skeptical about whether their skills would transfer to the real truck, even though their performance on the subsequent real-world test was unanimously excellent.

4.4 Limitations & Outlook

While the observations we obtained in this feasibility study informs us further regarding the potential of VR as a driver training tool, and allows us to build stronger hypotheses, a clear limitation for the generalizability of the present findings lies in the small and exclusively male sample. This, in combination with the generally high performance in the final transfer test, precluded any statistical comparisons of participants' performance between the two conditions. In subsequent studies, a quantitative comparison with appropriate statistical power, a third comparison group trained on a real truck, and ideally a delayed test to assess retention over time should be included to confirm the robustness observations in this study. Nevertheless, the steep and parallel learning curves of the participants, and their consistent ease of transitioning from the simulated and virtual to the real truck, suggest that the training in both simulator and VR was effective and transferrable. These results can provide the basis for future research to fully assess the potential of VR training and inform the design of such systems.

For the instructor, the VR condition proved somewhat challenging, as it was more difficult to observe from the outside and give corrective feedback. While he could observe part of the participant's visual field on the monitor, especially the right rear-view mirror was hard to see, as it was rather small. In addition, participants' head movements made it difficult to observe some details, especially when they were focusing on the wrong mirror. Some of these problems were solved by giving the first instructions with the 3D model and using the bird's-eye view of the simulator, before the participants put on the headset. A larger observation monitor for the instructor would likely improve his visibility of the rear-view mirror. Providing the instructor with a second headset in a multi-player setup would enhance his visual access to the training environment even more and decouple it from the participant's perspective.

While the potential for motion sickness must be considered, this challenge can likely be addressed through thoughtful design, such as including frequent breaks, practicing at low speeds, or resetting the game status rather than driving the truck to its initial position.

5. Conclusions

This study suggests that a VR driving training is feasible even for complex vehicles such as a truck, and participants can be trained in basic maneuvering skills that transfer to the real vehicle. Even with a low-budget VR solution, participants learned easily, and participants in both conditions reported positive attitudes towards the VR training. A customizable VR environment that takes full advantage of all the benefits of VR could be expected to lead to even greater training gains. Developing effective, affordable and widely accessible driver training systems has the potential to enhance overall traffic safety for the public.

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