ORIGINAL ARTICLE

Effects of training on truck drivers' interaction with cyclists in a right turn

Katja Kircher[1] · Christer Ahlström[1,2] · Jonas Ihlström[1] · Tatu Ljokkoi[3] · John Culshaw[3]

Abstract

With encounters between trucks and cyclists still being a major safety issue and physical as well as technological improvements far from ubiquitous implementation, training truck drivers in anticipatory driving to improve their interaction with cyclists may be a way forward. After a baseline drive in an urban environment, truck drivers inexperienced with urban driving received a dedicated training on anticipatory driving, followed by another drive along the same route several weeks later. The drivers were also interviewed about their opinion about the training. The drivers' behaviour changed from before to after training, resulting in a better speed management in general, and a more intensive monitoring of the cyclists. There were also some improvements with respect to the placement in relation to the cyclist, but this effect was limited mainly because truck drivers performed well already before the training. The observed results correspond well to the opinions and feelings about the training that were reported by the drivers in the interview. Thus, driver training can possibly be one contributor to an increase in safety in urban areas.

Keywords Truck · Driver training · Attention · Glance behaviour · Tactical behaviour

1 Introduction

Approximately, 25% of all cyclist deaths in Europe involve a collision with a truck or bus (Richter and Sachs 2017). Generally, collisions with trucks are more likely to be fatal than collisions with passenger cars (Pokorny et al. 2017). One of the more common collision types is when the truck turns right (left for left-hand traffic) while the cyclist is going straight ahead (Pokorny et al. 2017; Richter and Sachs 2017). Cyclists also perceive near misses in such right-turn scenarios as very scary, because they feel having little control of how the situation unravels (Aldred 2016). As both freight transport and bicycling can be expected to increase in the coming years, it is likely that collisions between cyclists and heavy vehicles will increase (Pokorny et al. 2017), which underlines the need for crash prevention.

Several suggestions on how to physically prevent encounters between trucks and cyclists have been presented (Cumming 2012; Johnson et al. 2010; Loskorn et al. 2013). However, rigorous evaluations of their effect are still lacking (DiGioia et al. 2017), and a large-scale rebuilding of the infrastructure is unrealistic in the short-term perspective. Technical solutions meant to alert drivers to cyclists (Ruf et al. 2019) or to make traffic light cycles more suitable for cyclists (Lu et al. 2018) are being investigated, but it takes a long time to achieve high penetration rates, and effects on actual crash avoidance still need to be shown.

Training in anticipatory driving in relation to vulnerable road users (VRUs) is another approach to reduce the number of dangerous truck–cyclist interactions. Today, with a few exceptions (Pattinson and Thompson 2014), there is a general lack of cyclist-related content in driver education programmes (Bonham and Johnson 2018). In Sweden, interaction strategies with VRUs are not in the curriculum of truck driver education, such that it cannot be assumed that all drivers are aware of the most preferable interaction patterns. An educational intervention can either target the driver's strategies or focus on changing

✉ Katja Kircher
katja.kircher@vti.se

[1] The Swedish National Road and Transport Research Institute (VTI), Linköping, Sweden

[2] Department of Biomedical Engineering, Linköping University, Linköping, Sweden

[3] Volvo Trucks, Gothenburg, Sweden

the tactical behaviour or both (Michon 1985). In this study, a training programme dedicated to anticipatory truck driving contributes to the research needs identified by Pokorny and Pitera (2019b).

The potential to change driver behaviour with training has been shown in other domains. In Australia, five groups of car drivers underwent different interventions, ranging from an online learning to a half-day workshop, with varying emphasis on strategical and tactical advice. Each treatment led to a significantly reduced fuel consumption (Jeffreys et al. 2018). A classroom course and simulator training with Finnish bus drivers, focusing on adopting the tactical "five golden rules of eco-driving", led to a significant drop in fuel consumption, with further improvements after 6 months (Sullman et al. 2015). Also, in-vehicle systems giving real-time feedback on the tactical level were found to be effective in British simulator studies (Birrell and Fowkes 2014; Birrell and Young 2011; Jamson et al. 2015). Results from interventions focusing on behavioural changes on the strategical level were mixed. Stanton et al. (2007) found that training can affect aspects of car drivers' locus of control (Rotter 1966), and Huang and Ford (2012) showed that a change to perceived higher internal control also improved truck drivers' behaviour. For alertness management, however, which mainly involved strategical interventions, the effects of training were inconclusive (Pylkkönen et al. 2018).

In this study, the evaluation of the training programme focuses mainly on potential effects in the scenario where the truck turns right with a cyclist intending to proceed straight ahead in an intersection, including both strategical and tactical levels of the stratified model of driving (Michon 1985). On the strategical level, the truck driver needs to be aware of the possible presence of VRUs. This includes driving at an appropriate speed in locations where VRUs can be present, and having a plan for how to scan for their presence and how to act in relation to them, depending on the situation at hand. The latter also includes communication with the bicyclist. On the tactical level, the truck driver implements the strategies available to him or her. This includes scanning tactics, driving behaviour and timing. This, in turn, has implications for the operational level. For the scenario at hand, Table 1 shows which approach situations can lead to which outcomes, depending on the traffic situation. If the cyclist is initially ahead of the truck (interaction types A–E), the truck driver can choose to remain behind, keeping a direct line of sight to the cyclist, or to overtake, such that the cyclist is only visible via the mirrors. If the truck is stopped or slowed down at the intersection, the cyclist may catch up from behind (situations F, G), such that the cyclist is visible first via the mirrors but may end up later in the truck's blind spots. Depending on how the situation develops, the cyclist has different choices. If the truck stays behind, the cyclist can choose to continue cycling or to stop to let the

truck turn first. If the truck is in front of the cyclist, the cyclist can additionally choose to remain behind the truck.

One study from Norway investigated interactions between cyclists going straight ahead and right-turning trucks in four intersections (Pokorny and Pitera 2019a). In a traffic light-regulated intersection, it was found that the chosen waiting positions of both truck drivers and cyclists varied depending on other traffic already present. When a truck was already present (subset of E, F, G), cyclists were more likely to choose a waiting position in which they were visible to the driver. Similarly, truck drivers were more likely to stop a few metres before reaching the stop line when a cyclist was already present at the intersection (D). In 2–8% of all encounters where both parts were moving (A–C, subset of E, F), the authors identified conflicts, depending on the intersection. These were largely related to a situation where the cyclist approached from behind, overtaking the truck on the right, with the truck driver at the same time initiating the turn. However, due to the study being of observational character, it was not possible to assess whether the truck driver was aware of the cyclist, and the truck drivers' level of experience was unknown.

A semi-controlled field study (Kircher et al. 2017) was conducted to maximise external validity. A confederate cyclist guaranteed the presence of at least one cyclist in the intersections where the truck had to turn right. Focus was solely on the truck driver's behavioural strategies when interacting with the cyclist, and whether the dedicated training led to any behavioural changes. Specifically, the hypotheses investigated in this paper are:

- The drivers will be aware of their global strategies after the training.
- The percentage of time spent speeding and the speed variance over the whole drive will be reduced after the training.
- The average speed for the whole drive will not have changed after the training.
- The number of interactions of types A and D will increase, and types C and E will decrease.
- The percentage of time with the cyclist positioned in front of the truck will increase.
- The drivers will improve their scanning strategies after training. They will notice the cyclist earlier and keep the cyclists in the direct line of sight.
- The necessity for reactive behaviour will decrease, and thus harsh braking will be reduced.

2 Methods

A sample of 15 truck drivers (3 female; mean age 39 ± 14 years; years of truck driving: 3.7 ± 3.8 years) were recruited via a Facebook-advertisement and via direct

Table 1 Schematic overview of different interaction possibilities between truck drivers turning right and cyclists going straight ahead, depending on the approach, including the visibility of the cyclist for the truck driver (green: direct sight through windscreen; yellow: direct sight through side window; red: via mirrors; left bar: cyclist goes first, right bar: truck goes first) and typical traffic situations

Interaction type	Description	Bicyclist's visibility from truck driver perspective	Typical traffic situation
A	Truck approaching cyclist and remaining behind all the time cyclist goes first	Cyclist visible via direct sight at all times	Unregulated intersection or (changing to) green traffic light, no slower traffic ahead
B	Truck catching up with cyclist and going parallel with cyclist cyclist goes first	Cyclist visible either via direct sight forward, or via side window and mirrors; possibly ends up in blind spot	Unregulated intersection or (changing to) green traffic light, no slower traffic ahead
C	Truck passing cyclist, then either braking and waiting or turning into cyclist's path	Cyclist visible via direct sight, then via side window and mirrors, then rear view mirrors, then possibly side again; possibly ends up in blind spot	Unregulated intersection or (changing to) green traffic light, no slower traffic ahead
D	Truck catching up with cyclist, who is already in front, and waiting, truck stops as well in first position; either truck or cyclist goes first	Cyclist visible either via direct sight forward, or via side window and mirrors; possibly ends up in blind spot	Red traffic light, stop, or similar no traffic ahead

Table 1 (continued)

Interaction type				Description	Bicyclist's visibility from truck driver perspective	Typical traffic situation
E				Truck passes cyclist on approach, slows down or stops, cyclist catches up, going parallel and slightly front, either truck or cyclist goes first	Cyclist visible either via direct sight forward or side window and mirrors first, then side and rear mirrors, then side and possibly front again; possibly ends up in blind spot	Red traffic light, stop or similar potentially slower traffic ahead
F				Truck approaching red traffic light, slowing down, cyclist catching up, light turns green, both arrive at intersection together, either truck or cyclist goes first	Cyclist first visible via mirror, then through side window and mirrors; possibly ends up in blind spot	Red traffic light turning green or similar potentially slower traffic ahead
G				Truck stopping at intersection, cyclist approaching from behind and stopping, upon green either truck or cyclist goes first	Cyclist first visible via mirror, upon arrival at intersection also via side window and mirrors; possibly ends up in blind spot	Red traffic light, stop or similar potentially slower traffic ahead

Here, a separate cycle path is depicted, but the pattern also applies to mixed traffic

contact with local fleets. Recruitment criteria were that they had no more than ± 4 dioptres and did not need any other correction for vision (because of limitations set by the eye tracker used in the study), that they had no or little experience with driving a truck in an urban area, and that they were willing and able to participate in the study.

2.1 Design

Using a *within-subject design*, each participant was scheduled to drive the same route twice, once before and once after having received training on anticipatory driving. The first drive took place in September/October 2018, the training was held in March 2019 and the second drive took place in April 2019. Two participants could not be scheduled for the second drive. The study was approved by the Regional Ethics Review Board in Linköping (Dnr 2018/230-31).

2.2 Procedure

The same procedure was used for both driving sessions. Before arrival, the participant received detailed information about the study. On the day of the study the information was repeated, and the participant signed an informed consent form. The participant was equipped with a head-mounted eye tracker (SMI glasses 2.0, SensoMotoric Instruments, Teltow, Germany). The route was driven with an instrumented Volvo FL owned by Volvo Trucks of Volvo AB. This truck, equipped with a cargo box, is typical for urban distribution applications. It was equipped with a data logger (Video VBOX Pro, RaceLogic, Buckingham, UK) that recorded speed, latitude/longitude coordinates, and videos
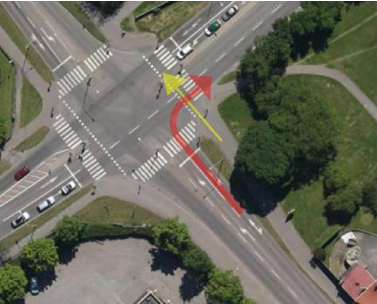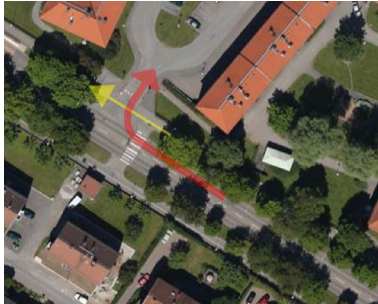
of the view forward, rearward left, rearward right, and of the right side of the truck. The experimenter sat in the passenger seat and provided direction instructions. This was done to prevent a possible confounding with familiarity, as drivers less familiar with the area might have needed more glances to a navigation device than drivers familiar with the area. Before the drive, the participant was instructed to drive normally, as if they were not participating in a study.

The route was approximately 15 km long and went through both the city centre of Linköping, Sweden (right-hand traffic), and near-city living areas. Traffic density varied with time of day, with busy periods during the morning and the late afternoon rush hours and quiet periods during the day. In three intersections (Table 2) where the truck driver had to turn right, a confederate cyclist had the task to cycle straight on, trying to arrive at the intersection at approximately the same time as the truck while acting naturally, such that the truck had to respond to the cyclist and give way. The only task of the confederate was to ensure that traffic was present on the cycle track. The confederate changed jacket and varied the usage of a helmet to prevent being recognised as the same person in all three intersections. After the second drive, the participants were interviewed about the training and whether they had changed their driving behaviour because of the training.

2.3 Training

The drivers participated in an Efficient Driving course that focused on situations encountered in city environments. The main principle of efficient driving is to reduce fuel consumption by becoming more self-aware of the traffic one is

Table 2 The three intersections of interest

Traffic light (TL)	No traffic light 1 (NTL1)	No traffic light 2 (NTL2)
Cycle path, separate traffic lights for motorised traffic and bicycles, partly grass and trees between cycle path and road, dedicated lane for left-turning traffic, speed limit 40 km/h	Cycle path, grass and some trees between road and cycle path, dedicated lane for left-turning traffic, speed limit 40 km/h	Cycle path adjacent to road, one lane, speed limit 40 km/h
Analysed distance: 185 m	Analysed distance: 516 m	Analysed distance: 241 m

The path of the truck is indicated with a red arrow and the path of the cyclist is indicated with a yellow arrow. The analysed distance depended on the distance where the confederate cyclist could be visible

currently in and anticipate what type of traffic one is heading into so that one "flows" better through traffic. A side effect of an efficient driving style is that anticipation and planning to achieve this "flow" make one much more aware of all types of surrounding traffic.

The course began with a theoretical section where the four main factors that influence fuel consumption in urban areas were identified and discussed: *Acceleration* and *Coasting*, which have medium impacts on fuel consumption along with *Speed* and *Braking*, which have higher impacts. A two-part workshop followed the theoretical section where the drivers were given six typical urban driving situations where they first needed to identify the surprises a driver could encounter in each situation, followed by a brainstorming session as to how one could handle each one of the surprises identified. The workshop was followed by a practical exercise where each driver drove, with an instructor present, approximately 45 min in traffic around a route through the city centre of Linköping. This route was different from the official route in the study, but offered similar traffic situations. Instructors helped the drivers to identify and anticipate potential surprises in traffic and gave tips as to how to avoid situations that would inhibit their flow through traffic. The final part of the training consisted of each driver creating their own Personal Action Plan where they identified three areas where they were good at avoiding surprises in traffic and three areas that they could improve in avoiding surprises.

2.4 Analysis

Based on the available video material, 83 right-turn situations were classified into the interaction types depicted in Table 1. One situation was removed beforehand, as the confederate had missed the occasion and no cyclist was present. Two observers classified all situations independent of each other. Initially they agreed in 71% of the cases. The cases without agreement were classified once more by both observers, without checking back to one's previous classification or the other observer's classification. That led to a total agreement rate of 91%. The remaining cases with disagreement were reviewed together. This led to a slight adaptation of the definition of interaction type E, and to agreement in the other cases.

The Observer XT 14.2 (Noldus, Waageningen, The Netherlands) was used for detailed video-based data reduction. For each right turn, the data specified in Table 3 were coded manually.

2.5 Post-driving interviews

Right after the second drive, semi-structured interviews were conducted with the participants. The interviews were based on an interview guide with four main topics: general thoughts and impressions of the training; specific positive and negative aspects of the training; thoughts on whether the training would have influence on their future driving; and thoughts on effects of such training for truck drivers in general. The interviews lasted 5–20 min and were conducted in the truck upon finishing the drive. The interviews were recorded and transcribed. The analysis was content based and focused on the themes of the interview guide. However, a specific interest in the analysis was to identify if and how the drivers spoke of any new-acquired strategies in driving they received from the training.

Table 3 Coding scheme for the interaction of truck driver and cyclist during right turn

Category	Description	Comment or detailed description
Event (TL, NTL1, NTL2)	Start and end of event	Interval for data reduction, starting before the cyclist can be seen for the first time and ending once the turn is completed
Motion of truck	Moving or stopped	
Position of cyclist relative to truck (see Fig. 1)	In front: visible through windscreen	
	Parallel: about the same height as the truck cabin, visible through the side window	
	Behind: behind the cabin, only visible through mirrors or not at all	
Gaze of truck driver (see Fig. 1)	Forward: roughly into direction of travel	Each glance direction was also encoded with the glance target: confederate, other VRU, motorised traffic, signs, traffic light, road markings, check for traffic (also if no traffic actually present), default (forward, without specific gaze target), other, unclear
	Left: to the left of the direction of travel	
	Right: to the right of the direction of travel	
	Down: dashboard, etc.	
	Left mirror: any mirror on the left side	
	Right mirror: any mirror on the right side	
	Other: any other target	
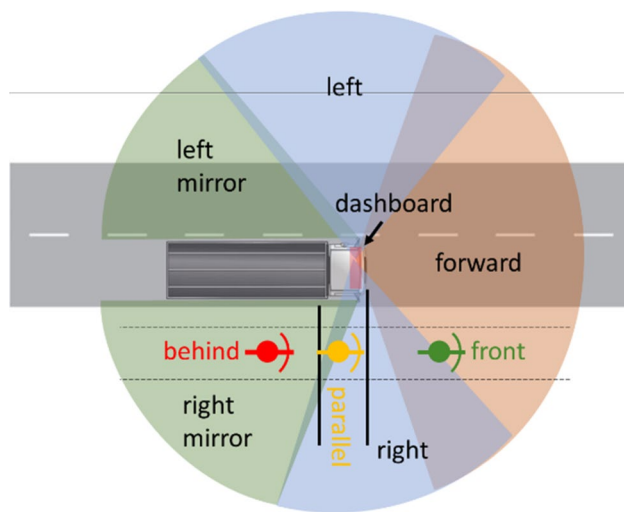
Fig. 1 Scheme for coding the position of the cyclist and gaze direction. The overlapping area between forward, respectively, left and right was coded depending on the driver's head movement. A glance to the overlapping area without head movement belonged to the "forward" category, whereas a glance involving a head movement was coded as "left", respectively, "right". The colours of the cyclist correspond to the line of sight indicated in Table 1

3 Results

In the interviews, four main strategies were brought up by the participants as something they learned or took special notice of from the training. The most brought up strategy was to plan acceleration, deceleration and rolling more carefully. This was motivated as a means of getting a better flow in traffic, decrease fuel consumption and to have a smoother ride. By applying this strategy, safety was also thought to increase, as it implied lower speeds and better situational awareness.

Two of the other strategies mentioned were specially aimed at decreasing risks of hitting cyclists. One was the situation with the truck driver turning right and thereby crossing a cycle path where a cyclist is present. In this situation, the strategy described by participants implied making sure, by adjusting speed accordingly, that the cyclist always remains visible through the windscreen. By applying this strategy, according to the participants, the risk of losing control over the cyclist's whereabouts could be minimized and consequently also the risk of hitting the cyclist. The other cyclist-related strategy was to stop before the stopping line in traffic light-controlled intersections with red light. Thereby, a better view of waiting cyclists could be established, as they would be visible through the windscreen during the waiting time. A last strategy that was mentioned during the interviews was the importance to communicate a lot with other road users, e.g. seeking eye contact and showing intentions.

Table 4 Number of participants with global data from before and after the training who had higher, respectively, lower scores for the three global variables tested

	Mean speed after training	Standard deviation of speed after training	Percentage speeding after training
Higher	1	2	0
Lower	8	7	9

Mean speed, the standard deviation of speed and the percentage of time spent speeding were analysed for the whole trip. Due to technical problems with the data collection for parts of the trip (GPS inaccuracies), these analyses included nine participants in the "after" condition. The global mean speed was reduced from 25.0 ± 2.1 km/h before to 22.5 ± 2.8 km/h after training ($F(1, 13.5) = 5.4$; $p < 0.05$). Similarly, the global standard deviation of speed was reduced from 16.7 ± 0.8 to 15.6 ± 0.9 km/h ($F(1; 15.0) = 10.7$; $p < 0.05$). Finally, the global percentage of time spent speeding was reduced from $7.9 \pm 5.3\%$ before to $2.3 \pm 2.0\%$ after training ($F(1, 19.5) = 13.3$; $p < 0.05$). Table 4 shows the number of participants who showed an increase, respectively, decrease in the analysed variables. Some speeding occurred in all drives, both before and after the training, with the range being 2.3–21.2% before and 0.8–6.1% after.

Based on previous research, the cutoff value for harsh braking was set to 2.5 m/s^2 (Beusen et al. 2009; Larsson and Ericsson 2009). A comparison of the number of occasions with harsh braking showed a significant increase from 8 (1 leading to a stop) before to 76 (42 leading to a stop) after the training, that is from 0.5 to 8.4 times per driver (mixed model analysis of variance; $F(1, 9.8) = 84.0$; $p < 0.05$). The number of drivers who exhibited harsh braking increased from 4 out of 15 before training to 9 out of 13 after training. In all but two cases, the initial speed was below the speed limit.

The intersections were analysed in more detail with focus on the interaction with the confederate cyclist. Mixed model analyses with the factors *event* and *condition* showed that variables related to speed and positioning varied significantly between intersections (Table 5, factor *event*), and that there was a behavioural change from before to after the training. In the TL intersection, the average speed was significantly lower than in the two NTL intersections, and mean speeds were reduced by the training. The bicyclist was positioned in front less frequently than in the NTL intersections, but there is a trend that this effect was weakened after the training, with similar high shares of frontal positioning across intersections, at the cost of the other positions.

Stopping only occurred in the TL intersection. Stop time was analysed for the 13 drivers who participated in both

Table 5 Mean and standard deviation for speed (in km/h) and the percentage of time the cyclist spent in front of, parallel with, or behind the truck per event, including the *F* values of the mixed-model analysis with the factors event and condition

	TL		NTL1		NTL2		Event	Cond	Event * Cond
	Before	After	Before	After	Before	After	$F(2, 78)$	$F(1, 78)$	$F(2, 78)$
Mean speed	12.9 ± 5.1	11.4 ± 5.0	29.1 ± 3.4	24.7 ± 3.5	25.3 ± 3.2	21.5 ± 2.1	109.8**	14.6**	1.1
% Cyclist front	61.6 ± 33.1	87.4 ± 19.6	80.2 ± 15.2	87.2 ± 12.2	91.7 ± 17.4	93.8 ± 16.0	5.6**	6.8*	2.6*
% Cyclist parallel	16.9 ± 16.1	7.7 ± 10.9	18.3 ± 14.1	11.1 ± 10.4	4.2 ± 7.9	3.1 ± 8.3	6.8**	5.2*	0.9
% Cyclist behind	20.3 ± 26.5	4.6 ± 12.0	1.0 ± 4.0	1.8 ± 6.3	3.9 ± 15.0	3.1 ± 11.3	4.4*	2.6	2.7*

*Significant at $p < 0.05$; **Significant at $p < 0.01$

conditions. Before the training, three drivers did not stop at all, while after the training, ten drivers did not stop at all, resulting in a total average stop time of 21.9 s ± 4.3 s (or 27.3 s ± 4.0 s for those who actually stopped) before and 7.6 s ± 4.4 s (or 32.9 s ± 8.8 s for those who stopped) after training. No further inferential analyses were conducted.

The type of intersection also influenced the distribution of interaction types used (Table 6). The low traffic volumes at the intersections without traffic light prevented interaction types D–G from occurring. In NTL2, most drivers chose to stay behind the cyclist both before and after the training (interaction type A). In NTL1, which is a similar intersection as NTL2 except that the cycle track is separated from the road with some greenery, this was less common. At the TL intersection, a greater variety of behavioural strategies was observed. One interaction could not be coded in the before condition, as the cyclist had left the intersection before the truck arrived.

Further investigations of the speed and positioning-related variables were conducted per interaction type. For the NTL intersections, the mean speed per interaction type for the three occurring types (A: 40 cases; B: 12 cases; C: 4 cases) was compared with a univariate analysis of variance, showing no significant difference ($F(2, 53) = 1.9$). Visual inspection of Fig. 2 shows that the percentage of time the cyclist spent behind the truck decreased the most for the interaction types E and G, with F not being present after the training.

The number of glances to and the total dwell time on the cyclist upon approach are linked to information collection and action planning and are used as proxy for how much the driver monitored the cyclist. Depending on the cyclist's position in relation to the truck, the line of sight is either direct through the windscreen or the side window, or indirect via a mirror, which was considered in the analyses. Descriptive results by position are presented in Table 7. An inferential mixed-model analysis with the factors *event* and *condition* was only conducted for the front situation, because the number of observations in the other two positions was too low for reliable results. Generally, the glance frequency to the cyclist was higher in the TL intersection than in the NTL intersections ($F(2, 78) = 5.0$; $p = 0.009$). There was a significant interaction effect with *condition* ($F(2, 78) = 6.4$, $p = 0.003$), however, which showed that an increase of glance frequency after the training only occurred for the NTL2 intersection.

Figure 2 shows the glances towards the confederate cyclist along the approach for each driver over distance. The total mean glance duration was 1.2 ± 0.9 s and did not differ between events ($F(2, 78) = 0.22$) or condition ($F(1, 78) = 0.42$), even though the individual glances vary substantially in duration.

Figure 3 shows that the likelihood to monitor the cyclist increases with decreasing distance to the intersection. In the NTL intersections, the likelihood to monitor the cyclist close to the intersection is higher than in the TL intersection. It appears that in the NTL-intersections, the increased

Table 6 Percentage of occurrences of interaction types as per Table 1 before ($n = 15$) and after ($n = 13$) the dedicated training per event and in total

| Interaction type	TL		NTL1		NTL2		Total		Total
	Before	After	Before	After	Before	After	Before	After	
A	7.1	15.4	46.7	69.2	86.7	84.6	47.7	56.4	51.8
B			46.7	23.1	6.7	7.7	18.2	10.3	14.5
C		7.7	6.7	7.7	6.7	7.7	4.5	7.7	6.0
D	28.6	46.2					9.1	15.4	12.0
E	50.0	23.1					15.9	7.7	12.0
F	7.1						2.3		1.2
G	7.1	7.7					2.3	2.6	2.4
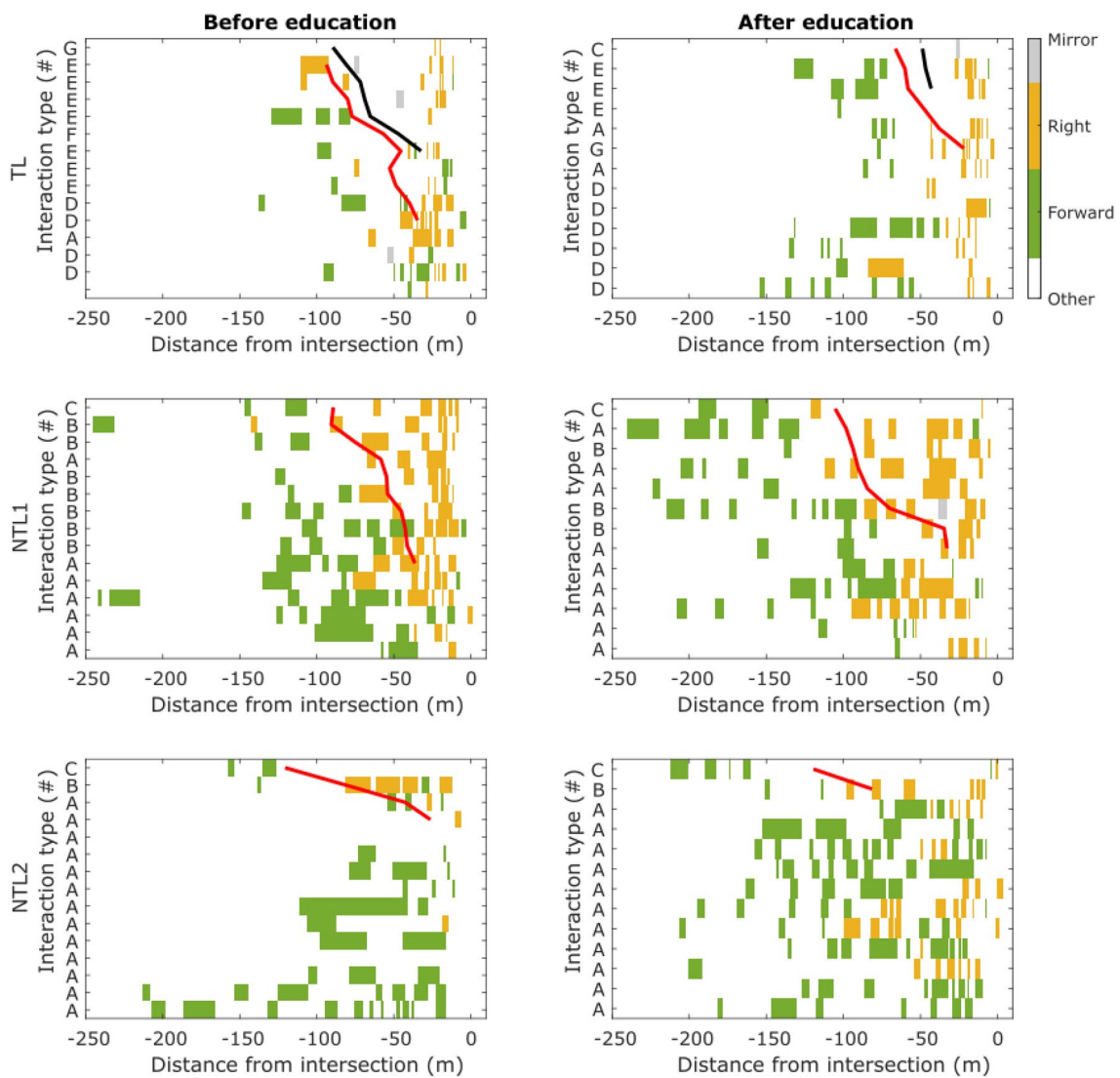
Fig. 2 Individual glance patterns towards the confederate cyclist as a function of the distance to the intersection (with 0 m indicating the end of the event), per event, before and after the training. The red line indicates where the truck and the cyclist went parallel, and the black line indicates where the cyclist got positioned behind the truck. Note that higher speeds generate longer "glance distances" at equal glance durations

Table 7 The number of foveal glances to the cyclist and the total dwell time on the cyclist per intersection and condition depending on cyclist placement, weighted by the percentage of time the cyclist was located in front of, parallel with or behind the truck and by the distance the cyclist was visible (i.e. glances/km)

	TL			NTL1			NTL2		
	Front	Parallel	Behind	Front	Parallel	Behind	Front	Parallel	Behind
n before	*15*	*11*	*7*	*15*	*10*	*1*	*15*	*4*	*1*
n after	*13*	*6*	*3*	*13*	*8*	*1*	*13*	*2*	*1*
# Glances before	34.8±27.7	50.0±52.5	13.7±20.6	23.3±9.4	36.6±9.0	21.6±0	12.9±11.8	29.6±34.2	0
# Glances after	36.9±17.9	49.2±59.2	4.4±7.6	21.2±8.8	31.5±25.0	0	39.9±14.0	48.8±19.4	0
Dwell before	30.0±20.7	59.3±54.1	9.0±13.2	25.9±14.5	46.7±18.3	39.8±0	18.9±15.5	39.6±78.6	0.0
Dwell after	40.8±43.4	33.8±40.9	3.0±5.2	23.0±14.0	46.4±28.5	0	34.6±10.1	36.4±14.8	0.0
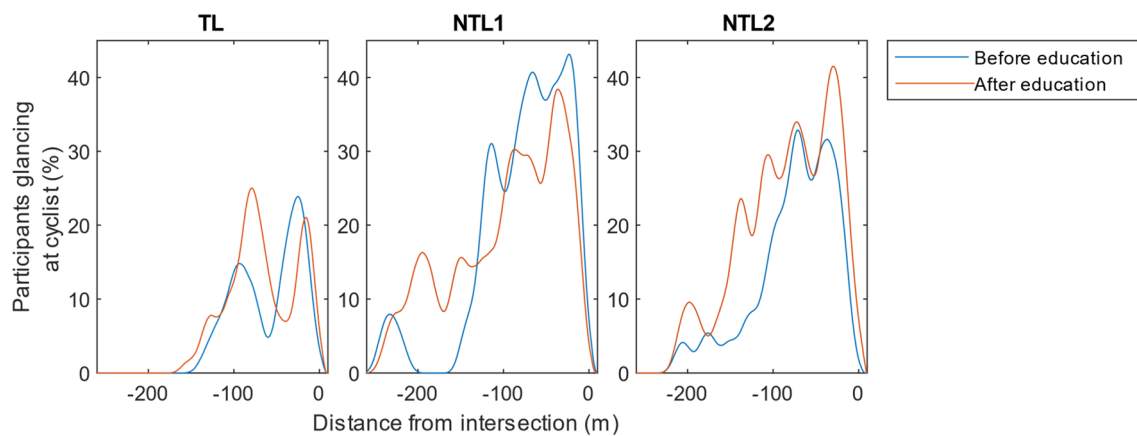
Fig. 3 Percentage of drivers glancing at the confederate cyclist as a function of the distance to the intersection, per intersection

monitoring of the cyclist begins earlier after compared to before the training.

3.1 Participants' perception of the training

All participants thought the arrangement and content of the training were good. The positive aspects they put forward were the combination of theoretical and practical modules, the clear illustration/presentation of certain topics or "facts" in graphs, instances where they worked and discussed in small groups and the noticeable practical truck driving experience that one of the course leaders had. There were individual differences as to what extent the participants thought that they learnt something new, and whether that would alter their driving behaviour in the future or not. Some participants highlighted that they had learned new strategies during the course they thought would be beneficial for their driving. For others, the main content of the course was already known, it had been learned during the years as active professional drivers, but it was still regarded valuable to refresh that knowledge. Some participants stated that they did not learn anything new since they already applied the content of the course in their daily driving.

There were also mixed notions on what the effect of the training would be if given broadly to professional drivers. Basically, these notions were related to the drivers' own experience of the training. Some had the perception that training generally is good, and that there is always content that drivers can implement in their driving. Others agreed to this, though pointed out that to have long-term effects, solely one training occasion would not be enough. According to them, there is a risk that drivers will fall back into old habits if the training is not cemented with follow-up training. Finally, some of the drivers expressed a scepticism towards positive long-term effects of the training. As stated by them, drivers who have been working for years driving a

truck probably have developed and cemented own strategies or have already acquired the same knowledge from years of practical experience. Instead, it was proposed that training of this kind should be integrated in the curriculum of the truck driver education.

4 Discussion

The hypotheses described a scenario in which the training was expected to lead to changes both on the strategical level, including sampling strategies and the planning of position with respect to the cyclist, and on the tactical level, with appropriate observable speed and positioning adaptations. The findings rather appear to point towards a scenario where the sampling procedures are changed less than the tangible response. The two are interlinked, however, as pointed out by Clark (2013). Improved positioning affects the ease with which future information sampling can take place, which, in turn, can help with effortless fine-tuning of the relative positioning.

Looking more specifically at the present data, in the NTL intersections most drivers already employed interaction type A before the training, and in the TL intersection both surrounding traffic and the traffic light had a high impact on the development of the situation. Still, there are indications that the truck drivers changed their behaviour within the possible range in the TL intersection, with fewer stops and a higher percentage of time during which the cyclist was in front of the truck.

Based on the reduction of the overall mean speed and share of speeding, it can be concluded that the drivers also changed their behaviour in other situations along the route that were not part of the analysis. While it is positive that speeding was reduced after training, it is still a concern that speeding also after the training is such a common behaviour

in the presence of VRUs, even when taking part in a study and being aware of being monitored. Considering this, the unpredicted reduction of mean speed in the study may be a positive sign of increased behavioural awareness rather than a reduction in efficiency. The observed and unpredicted increase in harsh braking events is more difficult to explain. Given that almost all instances of harsh braking were initiated when driving below the speed limit, and that they in more than half of the cases led to a complete stop, this would rather indicate a decrease in anticipatory behaviour. A tentative explanation could be that the drivers were still in the process of adjusting to a new, efficient driving technique as taught in the training, which, according to the trainers, can lead to a transient period of over-compensation involving harsh braking. To control for this, an additional measurement at a later point in time would have been necessary.

The increase in monitoring closer to the intersection is likely due to the imminent interaction, and therefore, the exact whereabouts of the cyclist are of higher importance to the driver. The NTL intersections were less complex, with fewer attentional demands than the TL intersections, which may explain the lower likelihood of glances towards the cyclist in the latter. On the other hand, in the TL intersection speeds were lower, including being stopped, which increases the number of glances that can be performed within the same distance. More glances are not necessarily better, as long as each relevant target is sufficiently attended (Kircher and Ahlstrom 2017). In less complex situations like the NTL intersections, it is possible that the drivers monitored the cyclist more than strictly necessary, as he or she often was the only other road user present in the situation. Therefore, the absence of obvious changes in monitoring behaviour due to the training is not necessarily negative. It may well be the case that the drivers' monitoring behaviour was sufficient already before the training, but that the training encouraged a better positioning with the cyclist in front of the truck, which is beneficial since the cyclist can be monitoring via direct sight. In addition, this positioning is positive since it prevents a conflict situation in the first place. As the truck must slow down before the turn, the cyclist will already have passed the intersection before the truck can cross his or her path. Also, it communicates to the cyclist that he or she has been seen, such that the cyclist can continue confidently, making the interaction smooth and efficient.

4.1 Limitations

A design with a comparable control group that did not get any training intervention would have been stronger, as potentially confounding factors such as familiarity with the setup and route as well as learning effects in between test occasions would have been controlled. For financial reasons, this could only have been realised by training fewer participants.

This was not seen as desirable, given the relatively low number of participants to start with. Also, as commented upon by some of the participants themselves, a one-off training is not likely to have a lasting effect. While it is plausible that the participants made an extra effort to behave as expected in the experimental "after"-situation, their speeding behaviour while taking part in a study indicated that they might not be influenced too much by the setting.

A drawback of assessing visual monitoring via eye tracking is the difficulty to measure information intake via peripheral vision. Given the physiological preconditions (Rosenholtz, 2016; Wolfe et al. 2017), it is unlikely that peripheral vision will suffice to detect or monitor a cyclist in the mirror. A position in front of the truck would make peripheral monitoring more feasible and likely. Thus, the monitoring frequencies presented here are more likely an underrepresentation for the frontal position than for the positions parallel with or behind the truck.

As shown by Pokorny and Pitera (2019a), cyclists adapt to the presence of trucks in intersections, for example by placing themselves in a position where the truck driver can see them at a traffic light. However, they also observed numerous situations where the cyclist passed the truck on the inside. In the present study, the confederate on the bicycle operated with the goal to provoke an adaptation manoeuvre from the truck driver, thereby artificially increasing the frequency of this type of manoeuvre, as compared to a completely natural setting. Therefore, the frequency of the interaction types observed here should be viewed as "given that the cyclist does nothing to prevent an encounter". The setup also implies that the cyclist's behaviour cannot be seen as a dependent variable.

That said, even though the confederate should ensure cyclist presence in the intersections, and even though the confederates had practised their riding to ensure comparability, the naturalistic setting introduced so much variation that it was difficult to categorise interaction types in a meaningful manner. The *NTL* intersections were easier to control, as traffic volumes were low, and no traffic light disrupted the flow. However, the cyclist still had to judge the speed of the truck well in advance, to match his or her own speed in such a manner that the encounter would seem natural. The TL intersection was more problematic. If the traffic light was red, other traffic could already be waiting when the truck arrived. This situation was difficult for the confederate cyclist to handle, as the other traffic would typically grant right of way to the VRUs present. If the traffic light for cars was green upon arrival, the traffic light for cyclists travelling into the same direction was not necessarily green, preventing an encounter from occurring. Depending on the traffic light status, the cyclist had to be visible in front already when the truck approached (Types A–E) or would show up only after the truck was already positioned at the intersection

(Types F, G) for a naturalistic interaction. The categorisation of encounters into interaction types was an attempt to reduce the variance while still keeping the essential aspects of the manoeuvre. While the observers arrived at very similar judgements, especially after some practice, there is still variance of qualitative character within the categories, and the driver intention is not accessible for any observation.

4.2 Future work

The training in the current study was focused on efficiency as the main "end product", saving time and fuel with increased traffic safety as a welcome side effect. An evaluation of the same strategies taught as either efficiency or safety centred could give an indication of whether the marketing makes a difference, and in which direction this difference would point.

5 Conclusions

Changes in the drivers' behaviour from before to after training could be observed, such as better speed management, possibly improved strategies when interacting with VRUs, and more intensive monitoring of cyclists. This corresponds to the drivers' reported feeling about the training. It is therefore likely that dedicated training on anticipatory driving can improve truck drivers' interactions with cyclists and lead to a safer traffic environment. However, improvements in the infrastructural design, vehicle design, regulations and technology are still a necessary factor.

References

Aldred R (2016) Cycling near misses: their frequency, impact, and prevention. Transp Res Part A 90:69–83. https://doi.org/10.1016/j.tra.2016.04.016

Beusen B, Broekx S, Denys T, Beckx C, Degraeuwe B, Gijsbers M et al (2009) Using on-board logging devices to study the longer-term impact of an eco-driving course. Transp Res Part D 14(7):514–520

Birrell SA, Fowkes M (2014) Glance behaviours when using an in-vehicle smart driving aid: a real-world, on-road driving study. Transpo Res Part F 22:113–125. https://doi.org/10.1016/j.trf.2013.11.003

Birrell SA, Young MS (2011) The impact of smart driving aids on driving performance and driver distraction. Transp Res Part F 14(6):484–493. https://doi.org/10.1016/j.trf.2011.08.004

Bonham J, Johnson M (2018) Cyclist-related content in novice driver education and training. Accid Anal Prev 111:321–327. https://doi.org/10.1016/j.aap.2017.12.008

Clark A (2013) Whatever next? Predictive brains, situated agents, and the future of cognitive science. Behav Brain Sci 36(3):181–204. https://doi.org/10.1017/S0140525X12000477

Cumming B (2012) Analysing and managing the cyclist-driver interface using "conflict path analysis". In: Paper presented at the ACRS road safety conference, Sydney, Australia.

DiGioia J, Watkins KE, Xu Y, Rodgers M, Guensler R (2017) Safety impacts of bicycle infrastructure: a critical review. J Saf Res 61:105–119. https://doi.org/10.1016/j.jsr.2017.02.015

Huang JL, Ford JK (2012) Driving locus of control and driving behaviors: Inducing change through driver training. Transp Res Part F 15(3):358–368. https://doi.org/10.1016/j.trf.2011.09.002

Jamson SL, Hibberd DL, Jamson AH (2015) Drivers' ability to learn eco-driving skills; effects on fuel efficient and safe driving behaviour. Transp Res Part C 58:657–668. https://doi.org/10.1016/j.trc.2015.02.004

Jeffreys I, Graves G, Roth M (2018) Evaluation of eco-driving training for vehicle fuel use and emission reduction: a case study in Australia. Transp Res Part D 60:85–91. https://doi.org/10.1016/j.trd.2015.12.017

Johnson M, Charlton J, Newstead S, Oxley J (2010) Painting a designated space: cyclist and driver compliance at cycling infrastructure at intersections. J Australas Coll Road Saf 21(3):67–72

Kircher K, Ahlstrom C (2017) Minimum required attention: a human-centered approach to driver inattention. Hum Fact 59(3):471–484. https://doi.org/10.1177/0018720816672756

Kircher K, Eriksson O, Forsman Å, Vadeby A, Ahlstrom C (2017) Design and analysis of semi-controlled studies. Transp Res Part F 46:404–412. https://doi.org/10.1016/j.trf.2016.06.016

Larsson H, Ericsson E (2009) The effects of an acceleration advisory tool in vehicles for reduced fuel consumption and emissions. Transp Res Part D 14(2):141–146. https://doi.org/10.1016/j.trd.2008.11.004

Loskorn J, Mills AF, Brady JF, Duthie JC, Machemehl RB (2013) Effects of bicycle boxes on bicyclist and motorist behavior at intersections in Austin, Texas. J Transp Eng 139(10):1039–1046. https://doi.org/10.1061/(ASCE)TE.1943-5436.0000584

Lu M, Blokpoel R, Joueiai M (2018) Enhancement of safety and comfort of cyclists at intersections. IET Intell Transp Syst 12(6):527–532. Retrieved from https://digital-library.theiet.org/content/journals/10.1049/iet-its.2017.0250

Michon JA (1985) A critical view of driver behavior models. What do we know, what should we do? In: Evans L, Schwing R (eds) Human behavior and traffic safety. Plenum Press, New York

Pattinson W, Thompson RG (2014) Trucks and bikes: sharing the roads. Procedia 125(Supplement C):251–261. https://doi.org/10.1016/j.sbspro.2014.01.1471

Pokorny P, Drescher J, Pitera K, Jonsson T (2017) Accidents between freight vehicles and bicycles, with a focus on urban areas. Transp Res Procedia 25:999–1007. https://doi.org/10.1016/j.trpro.2017.05.474

Pokorny P, Pitera K (2019a) Observations of truck-bicycle encounters: a case study of conflicts and behaviour in Trondheim, Norway. Transp Res Part F 60:700–711. https://doi.org/10.1016/j.trf.2018.11.018

Pokorny P, Pitera K (2019b) Truck-bicycle safety: an overview of methods of study, risk factors and research needs. Eur Transp Res Rev 11(1):29. https://doi.org/10.1186/s12544-019-0371-7

Pylkkönen M, Tolvanen A, Hublin C, Kaartinen J, Karhula K, Puttonen S et al (2018) Effects of alertness management training on sleepiness among long-haul truck drivers: a randomized controlled trial. Accid Anal Prev 121:301–313. https://doi.org/10.1016/j.aap.2018.05.008

Richter T, Sachs J (2017) Turning accidents between cars and trucks and cyclists driving straight ahead. Transp Res Procedia 25(Supplement C):1946–1954. https://doi.org/10.1016/j.trpro.2017.05.219

Rosenholtz R (2016) Capabilities and limitations of peripheral vision. Ann Rev Vis Sci 2(1):437–457. https://doi.org/10.1146/annurev-vision-082114-035733

Rotter JB (1966) Generalized expectancies for internal versus external control of reinforcement. Psychol Monogr Gen Appl 80(1):1–28. https://doi.org/10.1037/h0092976

Ruf M, Neumann C, Lützner J, Eilers C (2019) Digital guardian angels—right-turn assistants for commercial vehicles. ATZ Worldw 121(1):16–21. https://doi.org/10.1007/s38311-018-0189-2

Stanton NA, Walker GH, Young MS, Kazi T, Salmon PM (2007) Changing drivers' minds: the evaluation of an advanced driver coaching system. Ergonomics 50(8):1209–1234

Sullman MJM, Dorn L, Niemi P (2015) Eco-driving training of professional bus drivers—Does it work? Transp Res Part C 58:749–759. https://doi.org/10.1016/j.trc.2015.04.010

Wolfe B, Dobres J, Rosenholtz R, Reimer B (2017) More than the useful field: considering peripheral vision in driving. Appl Ergon 65(Supplement C):316–325. https://doi.org/10.1016/j.apergo.2017.07.009

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.