# The consequences of an increase in heavy goods vehicles for passenger car drivers' mental workload and behaviour

de Waard, Dick ; Kruizinga, A; Brookhuis, Karel

*Published in:*
Accident Analysis and Prevention

*DOI:*
10.1016/j.aap.2007.09.029



*Publication date:*
2008

# The consequences of an increase in heavy goods vehicles for passenger car drivers' mental workload and behaviour: a simulator study.

## 1. Introduction

Martens et al. (2007) expect a 70% increase in Heavy Goods Vehicles (HGVs) in the Netherlands in the year 2020 compared with 2000. In the same period they foresee a 30% increase in the number of private cars. The consequences of the increase, and the imbalance in increase between private cars and HGVs, are manifold. Congestion will undoubtedly increase: HGVs occupy more physical space, and the slow lane of motorways may be filled predominantly with columns of HGVs.

Driving in heavy traffic will increase mental workload. Brookhuis et al. (1991) found that on a busy ring road, the driver's mental effort was increased compared with driving on a quiet motorway. De Waard (1991) found effects on driver's heart rate that coincided with an increase in traffic flow, and in a four year field trial in New York Zeitlin (1995) has shown the effect of high density traffic on mental workload while driving a vehicle. Increased traffic density has been shown to increase workload and the probability that errors will lead to accidents. As long as drivers can self-pace the driving task they can compensate for additional load, e.g. by driving more slowly (e.g. Brouwer & Ponds, 1994, Brown et al., 1969). However, filtering into traffic is a complex task that is only partly self-paced. Drivers have to decide whether to maintain speed, to accelerate, or to slow down. They also have to decide when to change lane. These tasks impose high time pressure and may lead to overload (e.g. Lundqvist, Gerdle, & Rönnberg, 2000).

If traffic flow approaches road capacity, speed will be reduced, ultimately leading to congestion. To alleviate congestion, ramp metering programmes have been in use with positive effects on flow and merging conditions (e.g. Wu et al., 2007). However, a large increase in HGVs will lead to a different situation in the acceleration lane; filtering into a column of HGVs may lead to different behaviour from that of joining a mixed stream of traffic. Hill and Boyle (2007) report that merging into heavy traffic on a freeway is one of eighteen stressful roadway events. They also found that the primary cause of stress

associated with HGVs stems from reduced visibility as a result of the large vehicles. Hill and Boyle (2007) mention that large volumes of HGVs in particular may be of concern for driver stress, as these obstruct vision and reduce the driver's ability to change lane. There are more indications that HGVs are related to stress and safety critical driving manoeuvres. Stuster (1999) in the USA reviewed collision reports, and interviewed truck drivers and experts on unsafe driving behaviour in the vicinity of HGVs. According to the experts interviewed in that study, the most critical behaviour is driving with insufficient attention, e.g. using a cell phone or driving while fatigued. Criticality here is defined as a combined score based on danger and frequency of the behaviour. The second most critical driving behaviour is merging improperly into traffic, causing an HGV to manoeuvre or brake quickly (Stuster, 1999).
A column of HGVs in the slow lane will also stimulate drivers to stay in the faster lane. Dangerous lane change manoeuvres may then occur, both during filtering into traffic, and during a lane change from the faster to the slower lane, in particular directly before leaving the motorway. An additional negative effect of a column of HGVs on the slow lane might be that the driver's view of traffic signs on the road shoulder is blocked. Adverse weather conditions may further increase driver workload, as decreased vision affects the ability to estimate safety margins (Cavallo et al., 1997).

Driving behaviour during filtering-in and leaving the motorway can be assessed by looking at driving performance parameters, at the driver's physiology, by observing overt behaviour, and by self-reports (e.g. De Waard, 2002). Measures of driving performance reflect speed and accuracy of the manoeuvre. In practice these variables are the average and variation of driving speed, lane keeping, and distance keeping. For distance keeping, advanced measures that reflect safety margins are recommended, such as time-headway and time-to-collision (Van der Horst, 1990). These measures take driving speed and behaviour of other vehicles into account. Physiological measures are useful to assess momentary increases in mental workload without having to disrupt performance as, for instance is required by requesting ratings. Heart rate and heart rate variability, in particular the 0.10 Hz component of variability, are instructive measures here (Backs & Seljos, 1994, Fairclough et al., 2005, Mulder, 1992, Mulder et al., 2005). Self-reports can be applied after trials, e.g. to assess mental workload on scales such as the NASA TLX (Hart & Staveland, 1988), and to obtain ratings of experienced safety or risk.

To study the effects of an increase in HGVs on passenger driver behaviour a simulator study was performed. The following hypotheses were evaluated;

1. An increase in HGVs will make merging into traffic more difficult and will require more mental effort
2. Driving behaviour during merging in conditions of increased numbers of HGVs will be less safe as indicated by headway safety margins
3. Reduced visibility will negatively affect the estimation of safety margins and will lead to shorter time-headways while merging
4. Changing from the fast lane to the slow lane before leaving the motorway will be more effortful if the slow lane is filled with HGVs
5. An increase in HGVs will block the driver's view of (exit) signs, leading to missed exits.

## 2. Method

### *2.1 Simulator*

The driving simulator consisted of a vehicle mock-up with a functional steering wheel, indicators, and pedals. The simulator was surrounded by three frontal 32-inch diagonal LCD screens, and one additional screen on the left-hand side behind the participant, to enable the "look over the left shoulder" when merging. Not surprisingly, without the latter screen it has been found that drivers focus only on vehicles in front when joining the traffic on the motorway (Sarvi et al., 2004). Each screen provided a 70° view, leading to a total 280° view. The driving simulation software was developed by ST Software©, and is capable of simulating fully interactive traffic.

For the experiment a section of Dutch motorway was prepared, consisting of two 3.6 metre wide lanes and a hard shoulder of 3 metres. One acceleration lane and three exits provided entrance to and exit from the motorway. The acceleration lane and exits were each 300 metres in length. The distance between the entrance and the first exit, and between the consecutive exits, was 2 kilometres. Signage was according to Dutch motorway regulations, at respectively 1200 metres, 600 metres, 300 metres and 0 metres in advance of the exit. On the 1200, 600 and 0 metre signs, names of the exit destinations were displayed. On the 300 metre sign a long-distance destination of the motorway was displayed (for examples see De Waard et al., 2005).

### *2.2 Participants*

Participants holding valid drivers licences were invited via publication boards and word of mouth. Both experienced (i.e. holding at least 5 years their licence and driving more than 5 000 km/year), and inexperienced drivers (holding a licence ± 2 years) were invited.

A total of 42 drivers participated in the experiment. 32 were experienced drivers, 10 inexperienced. The total group consisted of 25 males and 17 females. 19 of the males were experienced drivers. The average age of the experienced drivers was 30.5 years (range 23-52 years). They had held their licences on average 10.4 years and had an average annual mileage of 16 000 km (SD 13 000). The inexperienced participants were on average 22.5 years old (range 19-28), held their licence on average 2.2 years, and had an average annual mileage of 2 500 km (SD 2 900). The experienced participants drove on average 4.3 hours per week on the motorway, while the inexperienced drivers spent on average 1.1 hours each week on the motorway.

*2.3 Design, conditions, instructions*

The following conditions were part of the study:

a. Traffic, three levels
   - Passenger cars: Only private cars, relative high traffic volume of a total of 3600 vehicles/hour (1800 per lane), average speed 110 km/h (Standard Deviation, SD 9 km/h), average time-headway 2 seconds on the right hand (merge) lane, 3 seconds in the left hand (fast) lane.
   - Mix: The 2006 common mix of HGVs and private cars, about 200-250 HGVs /hour all on the right hand (slow) lane, about 1500 private cars / hour.
   - HGV Column: A column of HGVs on the slower lane, on average 950 HGVs/hour, all on the slow lane. Average speed 80 km/h, SD 4 km/h, average time-headway 2 seconds. Apart from HGVs there were also private cars, mainly in the left hand lane.

b. Visibility, two levels
   - Clear: Bright weather
   - Fog: Visibility 150 metres

c. Repetition
   - All conditions were repeated twice

This accounted for a total of 3 x 2 x 2 = 12 trials per participant. A within-subjects design was used, conditions being counterbalanced in order over the participants to control for order-effects.

Participants received the instruction to drive to a specific city that was listed on the exit signs. On an exit sign two cities were mentioned, there were 3 exits per motorway and two "worlds" (variations of signs), i.e. a total of 12 different cities. The names of the cities were invented, to ensure that all drivers had to read the signs closely. All trial runs started on the acceleration lane where drivers could accelerate and join the traffic. There was always an HGV or a private car driving on the main carriageway at the moment the acceleration lane was adjacent to the main road. The speed of the vehicle on the main road was at first identical to that of the simulator car, to ensure that they would end up next to each other. From that moment the link between the two speeds was broken and the participant could either speed up and merge in front of the vehicle, or slow down and merge behind it. Participants were instructed to drive in the left hand (fast) lane as soon as traffic allowed. In this way it could be studied whether exits would be missed more frequently in the condition of high HGV intensity due to blocking the view of the signs.

The simulator car was equipped with an automatic gear. A trial would consist of the following manoeuvres: start the engine and accelerate on the acceleration lane, decide to join the traffic on the main road, merge, change lane to the left hand lane, drive until the exit is spotted, change to the right hand lane, exit traffic, stop, and fill in questionnaires (see 2.6). A practice session preceded the experiment.

The two manoeuvres selected from each trial, joining the traffic and leaving the motorway, are shown in more detail in Figure 1.

= = =

Insert Figure 1 here

= = =

*2.4 Performance measures*

During the trials driving speed, time-headway, and lane position were sampled at 10 Hz and stored to disk. During manoeuvre a) (Figure 1), the average and SD of driving speed and lateral position were determined. Directly after merging (manoeuvre b), minimum time-headway and time-to-collision (TTC) to the lead vehicle were determined in a timeframe of 5 seconds to assess how safety-critical the manoeuvre had been. After that, participants drove in the left hand lane until they spotted the instructed exit. From that point they were allowed to change to the slow lane to comfortably exit the motorway. The moment of merging into the right hand lane (manoeuvre d) was stored as distance to the start of the exit ramp. Directly after that lane change, the minimum time-headway and TTC to lead cars were determined, again in a time frame of 5 seconds (manoeuvre d).

*2.5 ECG*

The participant's Electro Cardio Gram (ECG) was registered using three small Ag/AgCl electrodes that were attached to the chest. The R-peak in the ECG signal was detected with 1 ms accuracy, time-stamped, and stored to disk. Inter-beat-interval times were analysed, and the power spectrum of heart rate variation in the 0.10 Hz band were calculated by the programme CARSPAN (Mulder et al., 1995). Heart rate variability, in particular variability in the 0.10 Hz band is suppressed during mental effort (e.g. Mulder et al. 2005). Heart rate was compared between conditions and with three-minute rest measurements that were completed both before and after the experiment. Power spectral data of the 0.10 Hz component were Ln-transformed to reduce inter-individual differences in range (Van Roon, 1998).

*2.6 Questionnaires*

After each trial a subjective rating on the unidimensional Rating Scale Mental Effort (RSME, Zijlstra, 1993) was requested, separately for joining and for exiting traffic.

Ratings of experienced risk on 5-point Likert scales were asked for, again separately for joining the traffic and for merging out of traffic. Participants were asked to indicate “how risky joining [leaving] the motorway had been”. This type of questionnaire has been used before by Heino (1996). Also, over each trial a rating of annoyance was assessed on a continuous scale.

*2.7 Observed behaviour*

During each trial the location where the participant merged was recorded; where on the acceleration lane the participant changed lane, and whether the participant merged in front or after the HGV (manoeuvre b). Whether the participant took the correct exit was also noted (manoeuvres d and e).

*2.8 Analyses*

The data were analysed using the General Linear Model Repeated Measures test of SPSS. Repeated Measures MANOVAs were run on speed variables (average and SD of speed), lateral control variables (average and SD of the lateral position), and headway variables (time-headway and TTC, see also Figure 1). ANOVAs were run on the continuous rating scale scores.

A NewRisk rating was calculated by taking the *Mix condition* as a reference (i.e. equal to zero):

$$\text{NewRisk}_{\text{HGV}} = ((\text{Risk-rating}_{\text{Mix trial 1}} - \text{Risk-rating}_{\text{HGVs trial 1}}) + (\text{Risk-rating}_{\text{Mix trial 2}} - \text{Risk-rating}_{\text{HGVs trial 2}}) / 2$$

and

$$\text{NewRisk}_{\text{passenger cars}} = ((\text{Risk-rating}_{\text{Mix trial 1}} - \text{Risk-rating}_{\text{passenger cars trial 1}}) + (\text{Risk-rating}_{\text{Mix trial 2}} - \text{Risk-}_{\text{rating passenger cars trial 2}}) / 2.$$

The NewRisk parameters are normally-distributed allowing for analysis of variance.

Variables were evaluated on main effects of Experience (between subjects) and Traffic, Visibility, and Repetition (within subjects). For Traffic, two contrasts were used, the effect of the *increase in HGV* was evaluated by contrasting the '*Mix*' with the '*HGV Column*' condition, the effect of *HGV presence* was evaluated by contrasting the '*Passenger car*' condition with the two other Traffic conditions.

For all analyses SPSS for Windows version 14.0.2 was used.

## 3. Results

*3.1 Driving parameters on the acceleration lane: manoeuvre a.*

In the left hand part of Figure 2 the average speed on the acceleration lane is shown (manoeuvre a in Figure 1). All Traffic conditions differed significantly (see Table 2 for the results of the statistical tests). Average speed was highest in the condition with only private cars on the motorway. There were also effects of Visibility (on average speed was 6.5 km/h lower in conditions of fog) and Repetition (during the second trials speed was on average 8.1 km/h higher).

Variation in speed, SD speed, was also larger in conditions with HGVs (on average 5 km/h, compared with 3.1 km/h in the condition with only private cars). Experienced drivers displayed more variation in speed than inexperienced drivers.

= = = =

Insert Figure 2 about here

= = = =

Lateral position in the acceleration lane while driving next to HGVs or private cars differed between these conditions as well; average position was 0.45 metres to the left of the centre in the *Passenger car condition*, and 0.72 metres to the left in the two HGV conditions. This means that on average drivers kept almost 0.30 metres more distance from HGVs than from private cars. SDLP (Standard Deviation of the Lateral Position) on the acceleration lane did not differ between conditions, the average being 0.196 metres.

= = = =

Table 1 about here

= = = =

*3.2 Driving parameters after joining the traffic:, manoeuvre b.*

Directly after joining the traffic, manoeuvre b in Figure 1, driving speed differed significantly between conditions (Figure 2 right hand part, and Table 2), similar to driving speed in the acceleration lane.

Differences in SD speed between conditions were both significant and large. In particular in the *HGV Column condition* SD Speed was high, on average 7.8 km/h, compared with 4.8 km/h in the *Mix*, and 3.4 km/h in the passenger car only condition. No main effect for Visibility was found. As merging behind an HGV will restrict speed choice, post-hoc speed data in the *Mix* and *HGV Column* condition were analysed by location of lane change manoeuvre: in front of the HGV, or behind the HGV (see 3.5). These data are presented in Figure 3. In the *Mixed Traffic* condition SD speed does not differ between drivers who join in front or behind the HGV. However, in the *HGV Column condition* SD speed is almost twice as large if drivers change lane in front of the HGV.

= = = =

Insert Figure 3 about here

= = = =

After the lane change from the acceleration lane to the main road, minimum Time-headway (THW) and minimum Time-To-Collision (TTC) were determined. The smallest minimum THW, on average only 0.66 seconds (s), was found in the *HGV Column condition*. In the *Mix condition* the average was 0.88 s, in the *Passenger car condition* 1.02 s. There was also an effect of experience, the inexperienced drivers keeping on average 0.2 s more distance. In Figure 4 THW data are again post-hoc split up depending on the location of the merge manoeuvre, in front or behind the HGV. Differences in minimum THW between the *Mix* and *HGV Column condition* are small for drivers who merged behind the HGV. However, smaller minimum THWs were measured in the *HGV Column condition* compared with the *Mix condition* for drivers who merged in front of the HGV. The smallest minimum THWs were measured for drivers merging behind the HGV.

= = = =

Insert Figure 4 about here

= = = =

Average time-headway (TTC) shows a similar picture to THW. The lowest values were measured in the *HGV Column condition*. There was a main effect of Traffic on TTC, a decrease from 8.9 s (only private cars) to 4.7 s (HGV Column). The value of 4.7 s is still above what Minderhout and Hoogendoorn (2001) labelled as uncomfortable (3 s), or dangerous (1.5 s).

= = = =

Insert Table 2 about here

= = = =

*3.3 Driving parameters before exiting: manoeuvre d.*

The distance before the exit where drivers changed from the left hand to the right hand lane (manoeuvre d. in Figure 1) did not differ between conditions. It was on average 619 metres before the start of the exit, i.e. at the location of the second exit sign.
After the lane change minimum THW and TTC were determined. There was no effect of condition on TTC (average 13.9 s). Average minimum THW was lowest, 0.81 seconds, in the *Passenger car condition*, 1.31 s in the *Mixed Traffic condition*, and 1.17 s. in the *HGV Column condition*. Differences are statistically significant between the HGV conditions and the condition with only passenger cars (see Table 3).

= = = = =

Table 3 about here

= = = = =

*3.4 Self-reports*

Leaving the motorway was rated on the Rating Scale Mental Effort (RSME) to be less effortful than entering (see Figure 5, Table 4).
When joining the traffic, the *HGV Column condition* was rated as most effortful. The *Passenger car condition* was least effortful. The second time conditions were completed these were rated to be less effortful than the first time.

= = = =

Insert Figure 5 about here

= = = =

The risk ratings were recalculated in such a way that values were compared with the present situation, the *Mix condition*. This condition was set to be equal to zero (see 2.8). Eight new parameters were calculated; two traffic conditions (passenger cars and HGV Column), by two manoeuvres (entering and leaving the motorway), by two visibility conditions. The new parameters were normally distributed (skewness of all parameters between –0.12 and +0.44), and had a range of –4 to +4. A positive score indicated increased perceived risk compared with the present situation (*Mix condition*). A negative score denoted decreased subjective risk.
Main effects were found for Traffic ($F(1,39)=25.69$, $p < 0.001$, $\eta_p^2=0.397$), and the interaction Traffic x Manoeuvre ($F(1,39)=24.1$, $p<0.001$, $\eta_p^2=0.382$). Average recalculated risk ratings for entering the motorway were –0.32 (private cars) and +0.59 (HGV Column), and for leaving the motorway +0.17 (private cars) and +0.22 (HGV Column).

The extent to which a condition had been experienced as annoying was assessed on a continuous scale running from 0 (not annoying at all) to 50 (very annoying). Average score for the *Passenger car condition* was 12.2, for the *Mix condition* 10.6, and for the *HGV Column condition* 15.2. Only the latter condition differed significantly from the other two ($F(1,39)=22.9$, $p < 0.001$, $\eta_p^2=0.364$).

= = = =

Table 4 about here

= = = =

*3.5 Observed behaviour*

The location where participants changed lane from the acceleration lane to the main road, and the position of the lane change in relation to the HGV that drove up with them, was observed and noted (manoeuvre b). In the *Passenger car condition* most participants changed lane at the beginning (15%), or middle (56%) of the acceleration lane. In the HGV conditions the majority, 56%, changed lane at the end of the acceleration lane. Only 7% filtered into traffic at the beginning, and 37% changed lane in the middle of the acceleration lane.

However, although the location of lane change on the physical lane did not differ between the *Mix* and *HGV Column conditions*, the location of lane change in relation to the HGV on the right hand lane did. In the *Mix condition*, in 72% of the trials drivers merged in front of the HGV. In the *HGV Column condition* this happened in 50% of the trials. To see if there would be an evolution in this relative location of lane change, the trials containing HGVs have been displayed in successive order in Figure 6. Only after the first two trials is there a shift towards merging in front of the HGV that stabilises subsequently.

= = = =

Insert Figure 6 about here

= = = =

The number of times exits were missed is shown in Table 5. It is clear that in the *HGV Column condition* more exits were missed. Also in conditions of fog the exit was missed almost twice as often as in clear weather. The effect of order was small. In the first trial the exit was missed five times. After that on average one or two participants missed an exit on each consecutive trial.

= = = =

Insert Table 5 about here

= = = =

*3.6 Physiology*

The profile technique (Mulder, 1992) provides an output in the form of a moving average of heart rate, and of the 0.10 Hz component, with 10 seconds resolution. For the ECG, joining the traffic is represented by four points, in sequence: driving on the acceleration lane, the start where the acceleration lane is parallel to the motorway, the end of the acceleration lane, and the moment after joining the traffic. Exiting traffic is depicted by five points, centred around the left to right lane change. ECG data of 32 of the participants were used as these were complete, artefact-free, or could be corrected.
Figure 7 shows the average heart rate. No significant differences between conditions were found. However, the increase in heart rate during joining the traffic while driving on the acceleration lane differs significantly from the points before and after that (speeding up and after the merge, points j2 and j3 in Figure 7, quadratic trend on the four points $F(1,31)=74.4$, $p < 0.001$, $\eta_p^2=0.706$). A similar significant effect was found during the lane change before exiting; there is a peak in heart rate while changing from the left hand to the right hand lane (analysis performed on the points e2-e5, quadratic trend $F(1,31)= 44.2$, $p < 0.001$, $\eta_p^2=0.588$).
In Figure 8 the 0.10 Hz component of HRV is shown, normalised by a Ln-transformation (Van Roon, 1998). A decrease in power corresponds with an increase in controlled information processing and mental effort. Again the moment of joining the traffic is visible, as a dip in variability (quadratic trend: $F(1,31)= 48.2$, $p < 0.001$, $\eta_p^2=0.609$). During merging, a difference between conditions was found. The *HGV Column condition* differs significantly from the *Mix condition* ($F(1,31)= 6.59$, $p = 0.027$, $\eta_p^2=0.148$). However, the effect is in the opposite direction to that expected, more variability (less effort) being evident in the *HGV Column condition*.

Changing lane before exiting also decreased HRV variability in the 0.10 Hz band (quadratic trend on points e2-e5: $F(1,31)= 11.0$, $p = 0.002$, $\eta_p^2=0.262$).

Finally, the increase in heart rate and the decrease in the 0.10 component of HRV during driving (whole conditions) compared with the resting measurements (two times three minutes) were both significant (HR: $F(1,31)=12.63$, $p = 0.001$, $\eta_p^2=0.289$; HRV: $F(1,31) = 15.0$, $p = 0.001$, $\eta_p^2=0.326$).

= = = =

Insert Figure 7 about here

= = = =

= = = =

Insert Figure 8 about here

= = = =

## 4. Discussion

In a driving simulator, the effects of an increase in the number of HGVs on the motorway on drivers' behaviour and mental workload during filtering into traffic, and leaving the motorway, were studied. Five hypotheses were formulated.

*1. An increase in HGVs will make merging into traffic more difficult and will require more mental effort.*

Support for this hypothesis was found: the presence of an HGV while joining the traffic slowed drivers down, but also increased speed variation. After joining the traffic, speed variation was greater in conditions with HGVs, and time-headway was shorter compared with the condition with only passenger cars. An important difference in behaviour was found for the merge manoeuvres behind as opposed to in front of the HGV, as drivers could either speed up and join in front of the HGV, or slow down and merge behind the HGV. The latter manoeuvre was more frequent if there was an HGV column on the main road. When drivers speeded up and changed lane in front of the HGV that was followed by the largest speed variations after the merge manoeuvre.

In the ECG a clear peak was found for the moment the driver had to take the merge manoeuvre decision. The peak was visible both in heart rate and in heart rate variability (HRV), indicative of increased mental effort. There were no differences found between the three traffic conditions, with the exception of an effect on HRV in the *HGV Column condition*. That effect however, was in an unexpected direction; more variability (less effort) in the *HGV Column condition*. A possible explanation for this might be that drivers were heavily loaded, felt they could not compensate any more, and resigned themselves to the situation. Although this is a tentative conclusion, it is a type of motivational or strategy change that would account for the effect found in variability, and this has been found in other areas of research (e.g. Wright et al., 1986, Eubanks et al., 2002). A change in motivation/strategy would also account for the dissociation of physiology and self-reports. The self-reports indicated an increase in effort (and risk) in the HGV conditions. The reason why the *HGV Column condition* was rated as most effortful may be that in self-reports the task demands of the situation were also considered.

*2. Driving behaviour during merging in conditions of increased numbers of HGVs will be less safe as indicated by headway safety margins*

Support for this hypothesis was found: after joining the traffic, drivers' time-headway was shorter in conditions with HGVs, compared with the condition with only passenger cars.

The shortest minimal time-headway values were measured for drivers joining the traffic behind the HGV. Nevertheless, even though short time-headways reflect low safety margins, large speed variations and adaptations could be more dangerous than slowing down and smoothly merging behind an HGV at short distance.

*3. Reduced visibility will negatively affect the estimation of safety margins and will lead to shorter headways while merging*

No effects of visibility on headway were found. However, drivers' average speed on the acceleration lane and directly after filtering into traffic was lower in conditions of fog. Accordingly, drivers did adapt their behaviour and increase time margins, the type of behavioural adaptation that is frequently found (Summala, 1996). If all traffic, i.e. also the HGVs, on the motorway slow down then this should not lead to problems. In the simulator the speed of the HGVs was coupled to the simulator car, so traffic on the main road also drove slower. In general it can be expected that all traffic will slow down in adverse weather conditions (e.g. Khattak et al., 1998).

Another effect of fog was that relatively more frequently exits were missed as a direct effect of reduced visibility.

*4. Changing from the fast lane to the slow lane before leaving the motorway will be more effortful if the slow lane is full with HGVs*

Only subjective ratings of effort indicate that this is the case. Although in the physiological response the lane change manoeuvre was also noticeable, no differences

between traffic conditions were found. There was also no difference between conditions in the location where drivers changed from the fast to the slow lane.
According to the self-reports, filtering into traffic is judged to be a more effortful task than leaving the motorway.

*5. An increase in HGVs will block the driver's view on (exit) signs, leading to missed exits.*
With an HGV Column drivers did not change lane earlier than in the *Passenger car condition*s, however, they did miss the exit signs and thereupon the exit more frequently in that condition. This seems to confirm the idea by Hill and Boyle (2007) that HGVs are mainly seen as large objects that restrict vision.

## 5. Conclusions

Joining the traffic with an increased proportion of HGVs requires more mental effort, is considered riskier, leads to larger speed variation, and to shorter time safety margins. Before merging, drivers adapt their speed to the traffic on the main road. After joining the traffic, minimum time to collision decreases from 9 s (*Passenger cars only condition*) to 5 s (*HGV Column condition*), rapidly moving in the direction of values that are described as uncomfortable (i.e. 3 s, see Minderhout & Hoogendoorn, 2001). With a column of HGVs on the main road, drivers complete the merge manoeuvre just as frequently in front as behind the HGV. However, in the present *Mixed condition*, 72% merged in front of the HGV. Variation in speed is largest for those who merge in front of the HGV. Merging in front of the HGV means that directly after joining, speed has to be decreased due to another HGV ahead. Joining behind the HGV is a smoother manoeuvre, but the smallest minimum time-headways are found for these manoeuvres. Effects on physiology are limited, although in the condition with only HGVs, heart rate variability may reflect resignation to the situation.

Exiting traffic, or more specifically, the lane change manoeuvre from the fast to the slow lane before entering the deceleration lane, is judged to be more effortful in conditions with only HGVs, but it was only in the self-reports that negative effects were found, not in vehicle parameters or physiology. However, in conditions of an HGV column in the slow lane, the exit signs and exits were most frequently missed. Drivers could compensate for the obstruction of their view of the exit signs by the HGVs by changing to the right hand lane earlier, but they did not do that. The dangerous 'last minute lane change' that was feared beforehand, was not found either.

In conditions of reduced visibility drivers drove more slowly and reported increased mental effort, but only when joining the traffic, not when exiting. Effects of driving experience were limited. Experienced drivers displayed more speed variation in the acceleration lane, and minimum time-headway after joining the traffic was smaller. This means that inexperienced drivers maintained safer margins.

If the amount of HGVs continues to increase as predicted (Martens et al., 2007), drivers are likely to miss more exits, leading to unnecessary kilometres driven. Additional signs above the road or in the central reserve may prevent this. Route navigation devices may also help to reduce this problem. However, the main problem probably lies in driving and joining the traffic, which will be a more demanding task with increases in HGVs. The increased task demands imposed upon drivers are likely to increase errors and thus accidents (e.g. Brookhuis et al., 2003). A further complicating factor will be that we live in an ageing society. The proportion of elderly drivers will increase (e.g. Waller, 1991). Elderly drivers have problems with taking decisions under time pressure, and with dual task performance (Brouwer & Ponds, 1994, Brouwer et al., 2002). Joining motorway traffic is a clear example of a task where difficulties can be expected; drivers have to accelerate to be able to merge smoothly, while time to take a decision is restricted, as the task is not completely self-paced. The elderly driver's typical response is to slow down to create time for decision taking (e.g. Brundell-Freij & Ericsson, 2005), while that is actually behaviour that will make merging more difficult.

Perhaps relief can come from new Advanced Driver Assistance Systems (ADAS). These may protect the driver from overload, or may assist in performing the merge manoeuvre safely. A Blind Spot Detector (Ward & Hirst, 1996) may be such a device. Future studies could incorporate a condition with elderly drivers and ADAS, to assess the extent of the problem and to assess potential beneficial effects, as the problems that we will face in 2020 with respect to the 70% increase in HGV will at least lead to uncomfortable, and potentially to unsafe, situations.

**Acknowledgment**

This study was commissioned by the Dutch Ministry of Transport (Transportation Research Centre AVV). We would like to thank Onno Tool and Michel Lambers of the Ministry for their contributions to the study. We also thank Peter van Wolffelaar, Wim van Winsum, and Jeroen Meijer of StSoftware for creating simulated HGVs and making the driving simulator operational. Furthermore, we would like to gratefully acknowledge the help of Jeremy Hinton in the final stage of preparation of this manuscript, and to thank the two anonymous reviewers for their helpful comments.

## 6. References


Backs, R.W., & Seljos, K.A., 1994. Metabolic and cardiorespiratory measures of mental effort: the effects of level of difficulty in a working memory task. *International Journal of Psychophysiology, 16*, 57-68.

Brookhuis, K.A., De Vries, G., & De Waard, D., 1991. The effects of mobile telephoning on driving performance. *Accident Analysis & Prevention, 23*, 309-316.

Brookhuis, K.A., de Waard, D., & Fairclough, S.H., 2003. Criteria for driver impairment. *Ergonomics, 46*, 433-445.

Brouwer, W.H. & Ponds, R.W.H.M., 1994. Driving competence in older persons. *Disability and Rehabilitation, 16*, 149-161.

Brouwer, W.H., Withaar, F.K., Tant, M.L.M., & Van Zomeren, A.H., 2002. Attention and driving in traumatic brain injury: a question of coping with time pressure. *Journal of Head Trauma Rehabilitation*, *17*, 1-15.

Brown, I.D., Thickner, A.H., & Simmonds, D.C.V., 1969. Interference between concurrent tasks of driving and telephoning. *Journal of Applied Psychology, 53*, 419-424.

Brundell-Freij, K. & Ericsson, E., 2005. Influence of street characteristics, driver category and car performance on urban driving patterns. *Transportation Research Part D*, *10,* 213-229.

Cavallo, V., Mestre, D., & Berthelon, C., 1997. Time-to-collision judgements: visual and spatio-temporal factors. In J.A. Rothengatter and E.J. Carbonell Vayà (Eds.), Traffic and transport psychology: theory and applications. Pergamon, Oxford, pp 97-111.

De Waard, D., 1991. Driving behaviour on a high-accident-rate motorway in the Netherlands. In C. Weikert, K.A. Brookhuis, and S. Ovinius (Eds). *Man in complex systems*, Proceedings of the Europe Chapter of the Human Factors Society Annual Meeting 1991. Work Science Bulletin 7. Work Science Division, Department of Psychology, Lund University, Lund, Sweden, pp 113-123

De Waard, D., 2002. Mental Workload. In: R. Fuller and J.A. Santos (Eds.) *Human Factors for Highway Engineers.* Pergamon, Oxford, UK, pp. 161-175.

De Waard, D., Brookhuis, K.A., & Mesken, J., 2005. Evaluation of legibility of not properly reflecting signs. *International Journal of Industrial Ergonomics, 35*, 645-651.

Eubanks, L., Wright, R.A., & Williams, B.J., 2002. Reward influence on the heart: cardiovascular response as a function of incentive value at five levels of task demand. *Motivation and Emotion, 26*, 139-152.

Fairclough, S.H., Venables, L., & Tattersall, A., 2005. The influence of task demand and learning on the psychophysiological response. *International Journal of Psychophysiology, 56*, 171-184.

Hart, S.G. & Staveland, L.E., 1988. Development of NASA-TLX (Task Load Index): results of empirical and theoretical research. In: P.A. Hancock & N. Meshkati (Eds.), *Human Mental Workload*. North-Holland, Amsterdam, The Netherlands, pp 139-183.

Heino, A., 1996. *Risk taking in car driving; perceptions, individual differences and effects of safety incentives*. PhD thesis. University of Groningen, Groningen, The Netherlands.

Hill, J.D. & Boyle, L.N., 2007. Driver stress as influenced by driving maneuvers and roadway conditions. *Transportation Research Part F, 10*, 177-186.

Khattak, A.J., Kantor, P., & Council, F.M. (1998). Role of adverse weather in key crash types on limited-access: roadway implications for advanced weather systems. *Transportation Research Record,1621*, 10-19.

Lundqvist, A., Gerdle, B., & Rönnberg, J., 2000. Neuropsychological aspects of driving after a stroke –in the simulator and on the road. *Applied Cognitive Psychology, 14*, 135-150.

Martens, G., Scheper, W., Hoogendoorn, S, & Tool O., 2007. Onze wegen slibben dicht met vrachtwagens [Our roads are silted up with HGVs]. *Verkeerskunde*, 2007 (1), 22-27.

Minderhout, M.M., & Hoogendoorn, S.P., 2001. *Extended Time-to-Collision Safety Measures for ADAS Safety Assessment.* Proceedings on the 5th International Conference on Technology, Policy, and Innovation. Delft. retrieved January 29, 2007 from http://www.delft2001.tudelft.nl/paper%20files/paper1145.doc

Mulder, L.J.M., 1992. Measurement and analysis methods of heart rate and respiration for use in applied environments. *Biological Psychology, 34*, 205-236.

Mulder, L.J.M., Van Roon, A.M., & Schweizer, D.A., 1995. CARSPAN Cardiovascular Data Analysis Environment. Groningen, The Netherlands: IEC Progamma.

Mulder, L.J.M., De Waard, D., & Brookhuis, K.A., 2005. Estimating Mental Effort Using Heart rate and Heart Rate Variability. In: N. Stanton, A. Hedge, K.A. Brookhuis, E. Salas, and H. Hendrick (Eds.) *Handbook of Human Factors and Ergonomics Methods*. CRC Press, Boca Raton, pp.20-1 – 20-8.

Sarvi, M., Kuwahara, M., & Ceder, A., 2004. Freeway ramp merging phenomena in congested traffic using simulation combined with a driving simulator. *Computer-Aided Civil and Infrastructure Engineering, 19*, 351-363.

Stuster, J., 1999. *The unsafe driving acts of motorists in the vicinity of large trucks.* Santa Barbara, CA: Anacapa Sciences. Retrieved January 15, 2007, from http://www.fmcsa.dot.gov/documents/udarepo.pdf

Summala, H., 1996. Accident risk and driver behaviour. *Safety Science, 22*, 103-117.

Van der Horst, A.R.A., 1990. *A time-based analyses of road user behaviour in normal and critical encounters.* PhD Thesis, Delft University of Technology, Delft, The Netherlands.

Van Roon, A.M., 1998. *Short-term cardiovascular effects of mental tasks. Physiology, experiments and computer simulation*. PhD thesis, University of Groningen. Groningen, The Netherlands.

Waller, P.F., 1991. The older driver. *Human Factors, 33*, 499-505.

Ward, N.J. & Hirst, S.J., 1996. Design considerations for a Blind Spot Detector. *International Journal of Vehicle Design, 17*, 198-207.

Wright, R.A., Contrada, R.J., & Patrane, M.J., 1986. Task difficulty, cardiovascular response, and the magnitude of goal valence. *Journal of Personality and Social Psychology, 51,* 837-843.

Wu, J., McDonald, M., & Chatterjee, K., 2007. A detailed evaluation of ramp metering impacts on driver behaviour. *Transportation Research Part F, 10*, 61-75.

Zeitlin, L.R., 1995. Estimates of driver mental workload: a long-term field trial of two subsidiary tasks. *Human Factors, 37*, 611-621.

Zijlstra, F.R.H., 1993. *Efficiency in work behavior. A design approach for modern tools*. PhD thesis, Delft University of Technology, Delft University Press, Delft, The Netherlands.

**Figure Captions**

Figure 1. The manoeuvres selected for analysis. In the images only the "*HGV Column condition*" is depicted, with HGVs (large rectangle), private cars, and the simulator car (black filled rectangle). Manoeuvres a, b, and c are performed during filtering into traffic, manoeuvres d and e before and during the exit. SD = Standard Deviation, THW = Time-headway, TTC = Time-to-Colission.

Figure 2. Average speed (and Standard Error, SE, as error bars) in the three traffic and two visibility conditions. Left hand of figure: speed in the acceleration lane (manoeuvre a in Figure 1). Right hand of figure: speed directly after the merge manoeuvre (manoeuvre b). Passenger cars = Only private cars on the motorway, Mix = 2006 mix of HGV (Heavy Goods Vehicles) and private cars, an HGV next to simulator car when on the acceleration lane, HGV Column = a column of HGVs on the motorway, an HGV next to the simulator car when on the acceleration lane. Clear = clear weather, Fog = visibility about 150 metres.

Figure 3. Standard Deviation (SD) of the driving speed on the right hand lane of the motorway directly after the merge manoeuvre in the two conditions with HGVs, split up by merge manoeuvre relative to HGV on main road. Mix = a mix of HGV and private cars, HGV Column = a column of HGVs on the motorway.

Figure 4. Average minimum THW on the right hand lane of the motorway directly after the merge manoeuvre in the two conditions with HGVs, split up by merge manoeuvre relative to HGV on main road. Mix = a mix of HGV and private cars, HGV Column = a column of HGVs on the motorway.

Figure 5. Average score on the Rating Scale Mental Effort for joining the traffic and exiting from traffic. The scale has a range from 0 to 150. A rating of 12 coincides with the investment of "hardly any effort", 28 = "a little effort", 38 = "some effort", 58 = "rather much effort", 112 = "extreme effort". Passenger cars = Only private cars on the motorway, Mix = a mix of HGV and private cars, HGV Column = a column of HGVs on the motorway.

Figure 6. Location of merge manoeuvre relative to HGV on main road in order of trials (only trials with HGV, Passenger car condition excluded).

Figure 7. Average heart rate in beats/minute (bpm) during the before and after rest period (each 3 minutes), and during *joining* the traffic (j1-j4, j for joining) and *exiting* from traffic (e1-e5, e for exiting). Points j1-j4 and e1-e5 are each based on 30 seconds of ECG data, the step size between separate points is 10 seconds. At points j2 and j3 participants drove in the acceleration lane next to the motorway and performed the join manoeuvre. The exit manoeuvre was centred around e3, the lane change from left hand to right hand lane preceding the real exit. Passenger cars = Only private cars on the motorway, Mix = a mix of HGV and private cars, HGV Column = a column of HGVs on the motorway.

Figure 8. Average heart rate variability in the 0.10 Hz band during before and after rest (each 3 minutes), and during joining the traffic (j1-j4) and exiting from traffic (e1-e5). At points j2 and j3 participants drove in the acceleration lane next to the motorway and performed the join manoeuvre. The exit manoeuvre was centred around e3, the lane change from left hand to right hand lane preceding the real exit. Passenger cars = Only private cars on the motorway, Mix = a mix of HGV and private cars, HGV Column = a column of HGVs on the motorway.

Tables

Table 1. Results of the statistic tests on lateral control and speed during filtering into traffic, manoeuvre a in Figure 1. E = effect of Experience, T = effect of Traffic, Pr = effect of HGV Present, T-In = effect of HGV Increase, Sig. = significance level, $\eta^2 = \eta^2_{partial}$

**Joining the traffic**

**a. driving on the acceleration lane**

Significant effects ($\alpha < 0.05$) are displayed **bold**

**Speed Control**

| | Multivariate | | | Univariate | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Mean Speed | | | SD Speed | | |
| *Effect* | Hotelling's T | Sig. | $\eta^2$ | F(1,40) | Sig. | $\eta^2$ | F(1,40) | Sig. | $\eta^2$ |
| Experience (E) | **0.188** | 0.035 | 0.158 | <1 | ns | 0.003 | **7.20** | 0.011 | 0.153 |
| Traffic (T): | **0.854** | <0.001 | 0.461 | | | | | | |
| HGV presence (T-Pr) | | | | **20.62** | <0.001 | 0.340 | **7.92** | 0.008 | 0.165 |
| HGV increase (T-In) | | | | **6.99** | 0.012 | 0.149 | <1 | ns | 0.000 |
| Visibility | **0.319** | 0.005 | 0.242 | **12.10** | 0.001 | 0.232 | <1 | ns | 0.000 |
| Repetition | **0.798** | <0.001 | 0.444 | **31.74** | <0.001 | 0.442 | <1 | ns | 0.018 |
| E x T | 0.104 | ns | 0.094 | | | | | | |
| E x T-Pr | | | | <1 | ns | 0.001 | 1.33 | ns | 0.032 |
| E x T-In | | | | 1.36 | ns | 0.033 | <1 | ns | 0.004 |

**Lateral Position Control**

| | Multivariate | | | Univariate | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Mean Lateral position | | | SD Lateral Position | | |
| *Effect* | Hotelling's T | Sig. | $\eta^2$ | F(1,40) | Sig. | $\eta^2$ | F(1,40) | Sig. | $\eta^2$ |
| Experience (E) | 0.132 | 0.089 | 0.117 | 3.75 | 0.060 | 0.086 | 1.44 | ns | 0.035 |
| Traffic (T): | **0.369** | 0.018 | 0.269 | | | | | | |
| HGV presence (T-Pr) | | | | **10.34** | 0.003 | 0.205 | <1 | ns | 0.000 |
| HGV increase (T-In) | | | | <1 | ns | 0.001 | <1 | ns | 0.005 |
| Visibility | 0.096 | ns | 0.087 | 1.44 | ns | 0.035 | 1.2 | ns | 0.029 |
| Repetition | 0.036 | ns | 0.035 | 1.38 | ns | 0.033 | <1 | ns | 0.003 |
| E x T | 0.084 | ns | 0.078 | | | | | | |
| E x T-Pr | | | | 1.25 | ns | 0.030 | <1 | ns | 0.013 |
| E x T-In | | | | <1 | ns | 0.001 | <1 | ns | 0.000 |

Table 2. Results of the statistic tests on speed and-headway control after filtering into traffic, manoeuvre b in Figure 1. Sig. = significance level, $\eta^2 = \eta^2_{partial}$

Joining the traffic

**b. completing the merge**

Significant effects (α < 0.05) are displayed **bold**

**Speed Control**

| | Multivariate | | | Univariate: Mean Speed | | | Univariate: SD Speed | | |
|---|---|---|---|---|---|---|---|---|---|
| *Effect* | Hotelling's T | Sig. | $\eta^2$ | F(1,40) | Sig. | $\eta^2$ | F(1,40) | Sig. | $\eta^2$ |
| Experience (E) | 0.019 | ns | 0.018 | <1 | ns | 0.018 | <1 | ns | 0.000 |
| Traffic (T): | **2.220** | <0.001 | 0.690 | | | | | | |
| HGV presence (T-Pr) | | | | **48.24** | <0.001 | 0.547 | **43.63** | <0.001 | 0.522 |
| HGV increase (T-In) | | | | **25.73** | <0.001 | 0.391 | **14.84** | <0.001 | 0.271 |
| Visibility | **0.178** | 0.041 | 0.151 | 1.74 | ns | 0.042 | 2.67 | ns | 0.063 |
| Repetition | 0.108 | ns | 0.095 | 2.92 | ns | 0.068 | <1 | ns | 0.000 |
| E x T | 0.150 | ns | 0.131 | | | | | | |
| E x T-Pr | | | | <1 | ns | 0.000 | 2.36 | ns | 0.056 |
| E x T-In | | | | 1.54 | ns | 0.037 | <1 | ns | 0.001 |

**Headway Control**

| | Multivariate | | | Univariate: Time-headway | | | Univariate: Time to Collision | | |
|---|---|---|---|---|---|---|---|---|---|
| *Effect* | Hotelling's T | Sig. | $\eta^2$ | F(1,40) | Sig. | $\eta^2$ | F(1,40) | Sig. | $\eta^2$ |
| Experience (E) | 0.109 | ns | 0.098 | **4.24** | 0.046 | 0.096 | <1 | ns | 0.000 |
| Traffic (T): | **1.297** | <0.001 | 0.565 | | | | | | |
| HGV presence (T-Pr) | | | | **7.13** | 0.011 | 0.151 | **20.84** | <0.001 | 0.343 |
| HGV increase (T-In) | | | | **8.99** | 0.005 | 0.184 | **17.60** | <0.001 | 0.306 |
| Visibility | 0.068 | ns | 0.063 | 1.46 | ns | 0.035 | <1 | ns | 0.018 |
| Repetition | 0.074 | ns | 0.069 | 1.29 | ns | 0.031 | 1.49 | ns | 0.036 |
| E x T | 0.113 | ns | 0.101 | | | | | | |
| E x T-Pr | | | | <1 | ns | 0.002 | <1 | ns | 0.002 |
| E x T-In | | | | 3.12 | ns | 0.072 | <1 | ns | 0.012 |

Table 3. Results of the statistic tests on headway control during the lane change preceding the exit manoeuvre, manoeuvre d in Figure 1. Sig. = significance level, $\eta^2 = \eta^2_{partial}$

Leaving the motorway

**d. changing from the fast to the slow lane**

Significant effects (α < 0.05) are displayed **bold**

**Headway Control**

| | Multivariate | | | Univariate: Time-headway | | | Univariate: Time to Collision | | |
|---|---|---|---|---|---|---|---|---|---|
| *Effect* | Hotelling's T | Sig. | $\eta^2$ | F(1,40) | Sig. | $\eta^2$ | F(1,40) | Sig. | $\eta^2$ |
| Experience (E) | 0.066 | ns | 0.062 | 2.19 | ns | 0.052 | <1 | ns | 0.010 |
| Traffic (T): | **0.686** | 0.001 | 0.407 | | | | | | |
| HGV presence (T-Pr) | | | | **24.52** | <0.001 | 0.380 | <1 | ns | 0.015 |
| HGV increase (T-In) | | | | 3.88 | 0.056 | 0.088 | <1 | ns | 0.011 |
| Visibility | 0.014 | ns | 0.014 | <1 | ns | 0.000 | <1 | ns | 0.013 |
| Repetition | 0.000 | ns | 0.000 | <1 | ns | 0.000 | <1 | ns | 0.000 |
| E x T | 0.076 | ns | 0.071 | | | | | | |
| E x T-Pr | | | | <1 | ns | 0.004 | <1 | ns | 0.012 |
| E x T-In | | | | 2.46 | ns | 0.058 | <1 | ns | 0.012 |

Table 4 Results of the statistical tests on the Rating Scale Mental effort during filtering into traffic, and leaving the motorway. Sig. = significance level, $\eta^2 = \eta^2_{partial}$

Self-reports

Significant effects ($\alpha < 0.05$) are displayed **bold**

**Rating Scale Mental Effort**

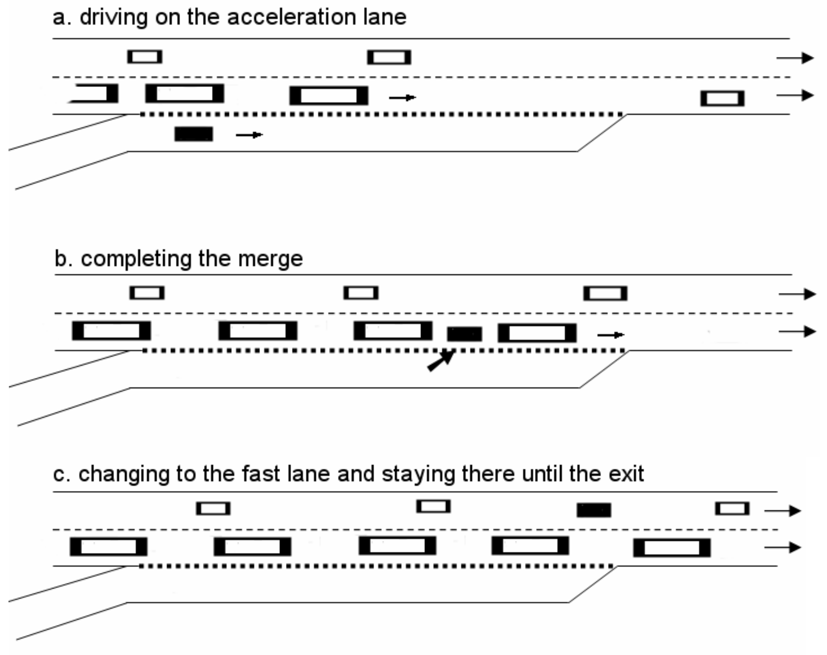
| | Univariate | | |
|---|---|---|---|
| | Time-headway | | |
| *Effect* | F(1,39) | Sig. | $\eta^2$ |
| Experience ( E) | <1 | ns | 0.001 |
| Manoeuvre (M) | **50.08** | <0.001 | 0.562 |
| HGV presence (T-Pr) | **17.45** | <0.001 | 0.309 |
| HGV increase (T-In) | **20.09** | <0.001 | 0.340 |
| Visibility | 2.43 | ns | 0.059 |
| Repetition | **5.98** | 0.019 | 0.133 |
| E x T-Pr | <1 | ns | 0.006 |
| E x T-In | **5.62** | 0.023 | 0.126 |

Table 5. Percentage of times exits were missed

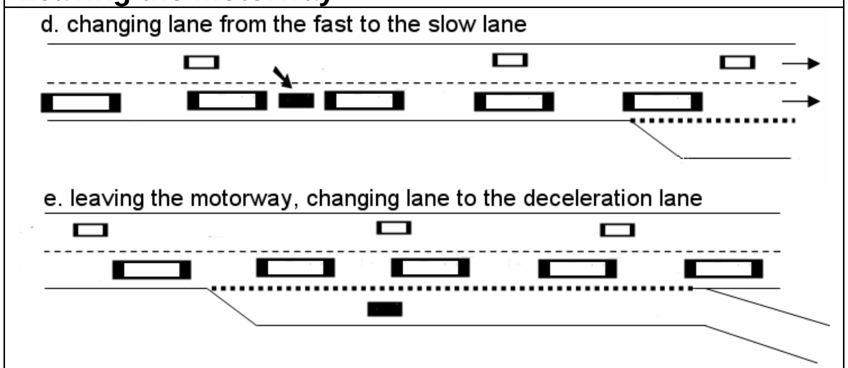
| *Condition* | Clear | Fog | Total |
|---|---|---|---|
| Passenger cars | 1.2 | 2.4 | 1.8 |
| Mix | 1.2 | 2.4 | 1.8 |
| HGV Column | 6.0 | 8.3 | 7.1 |
| Total | 2.8 | 4.4 | 3.6 |

Figure 1

## Joining the traffic




## Leaving the motorway




| Measure \ manoeuvre: | a. | b. | c. | d. | e. |
|---|---|---|---|---|---|
| Average speed | + | + | | | |
| SD Speed | + | + | | | |
| Average Lateral position | + | | | | |
| SD Lateral position | + | | | | |
| Minimum THW | | + | | + | |
| Minimum TTC | | + | | + | |
| Location Lane Change | | + | | + | |

**Figure 2**
Click here to download high resolution image

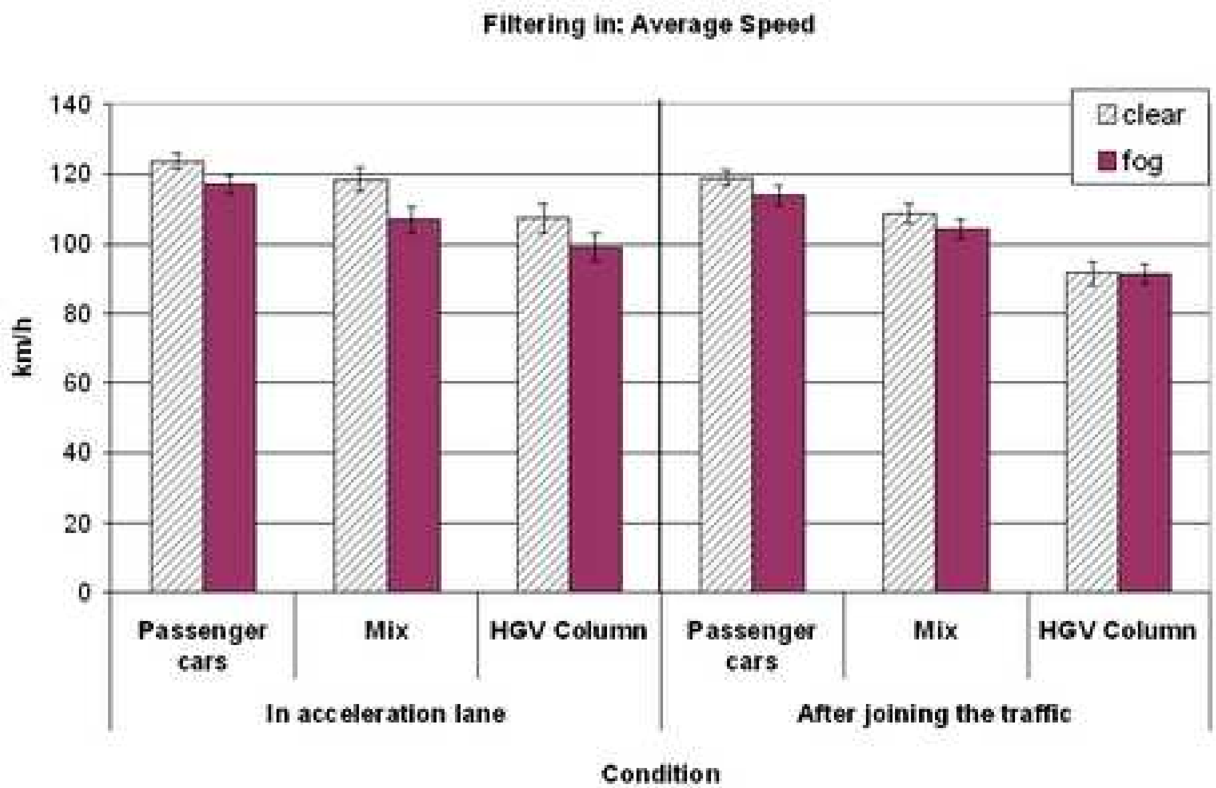


Figure 3
Click here to download high resolution image

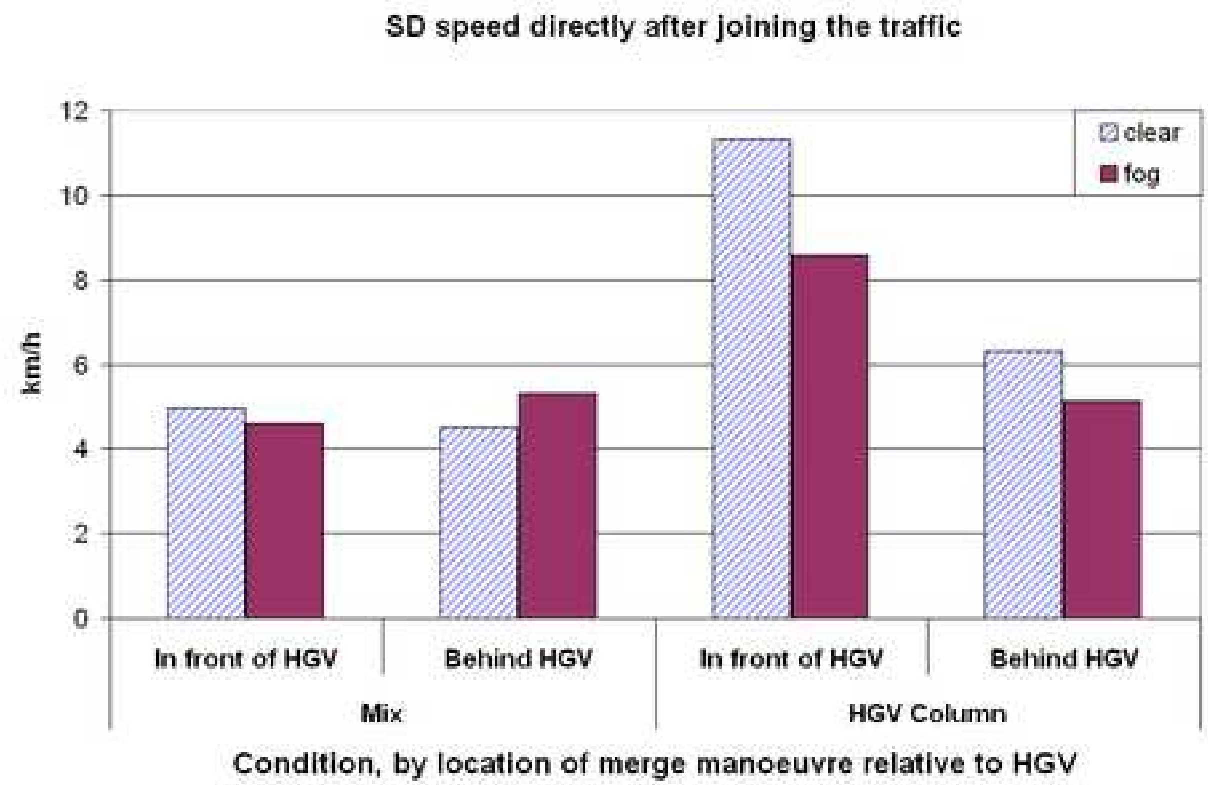


Figure 4

Click here to download high resolution image

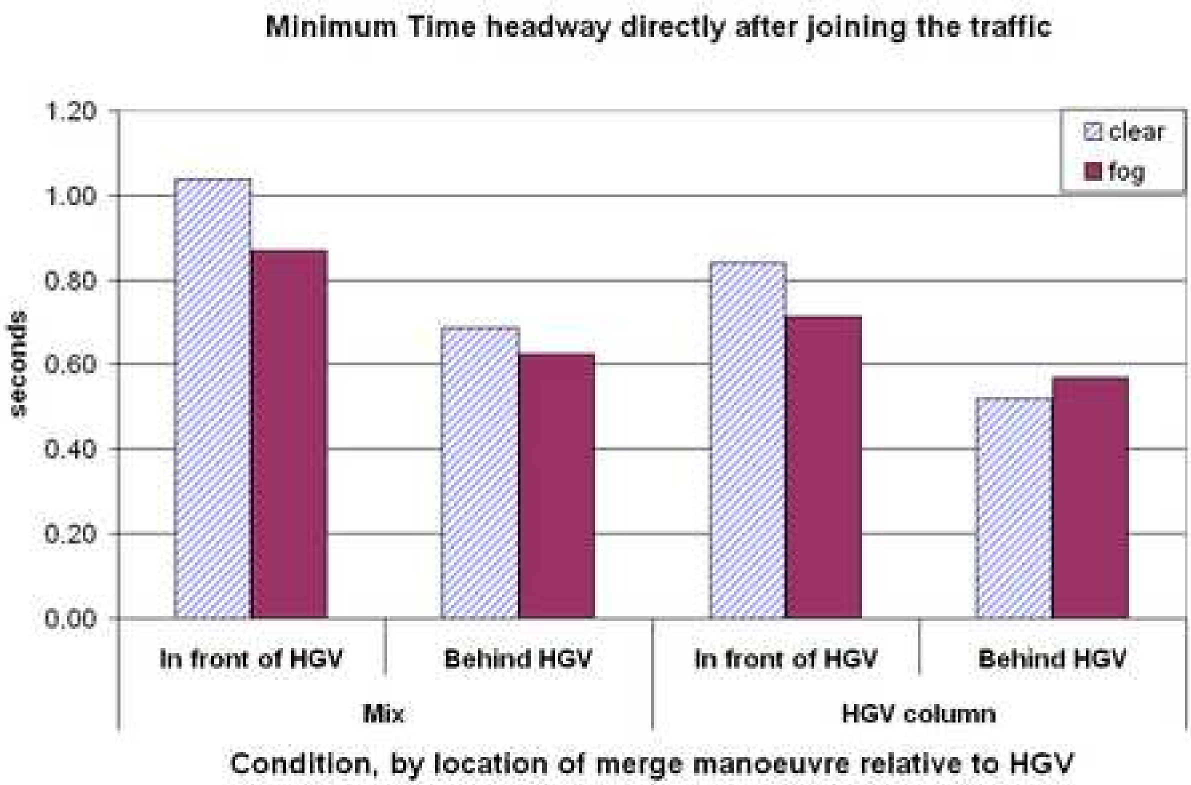


Figure 5
Click here to download high resolution image

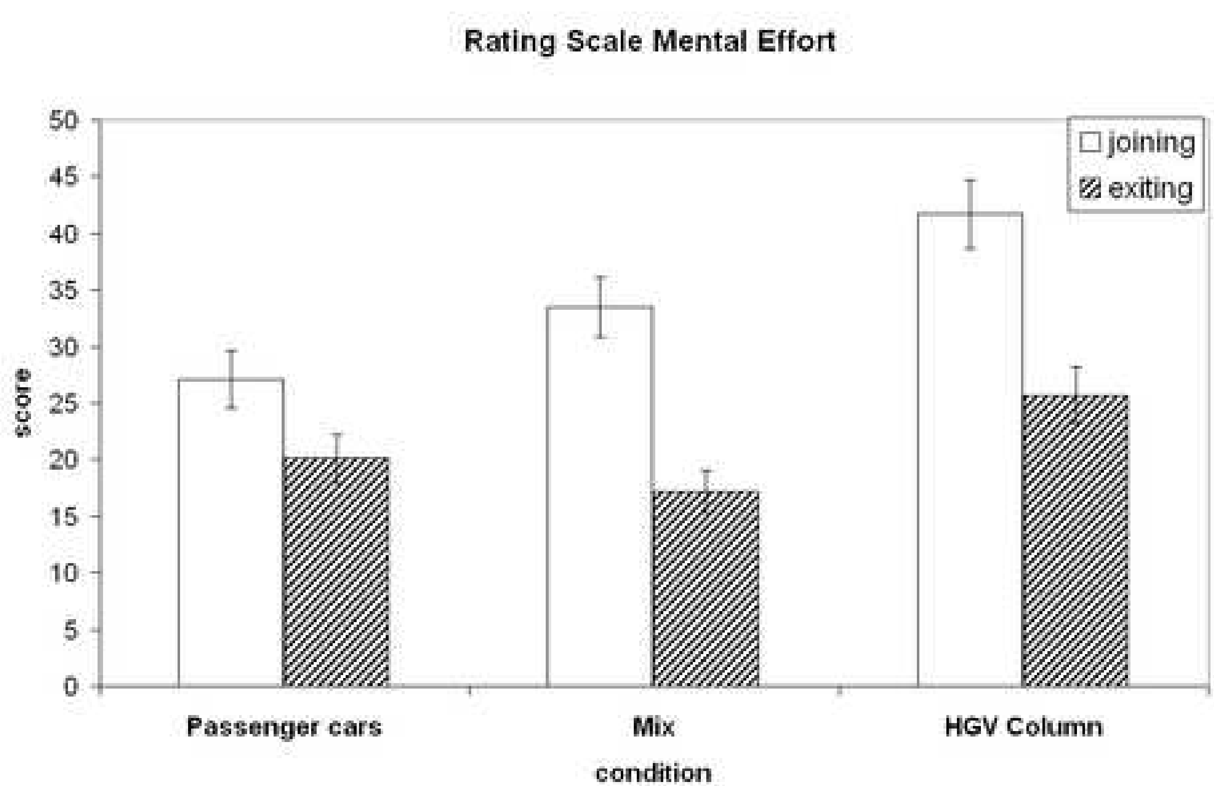


Figure 6
Click here to download high resolution image

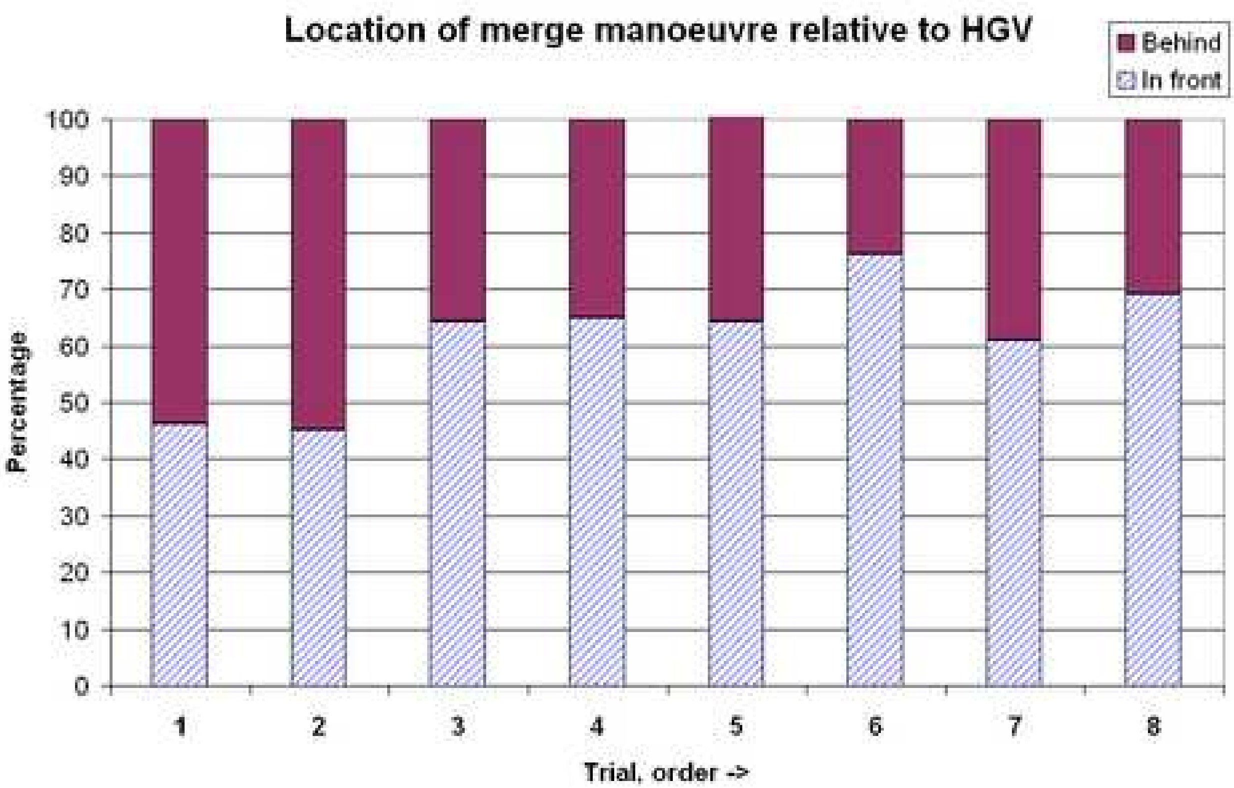


Figure 7
Click here to download high resolution image

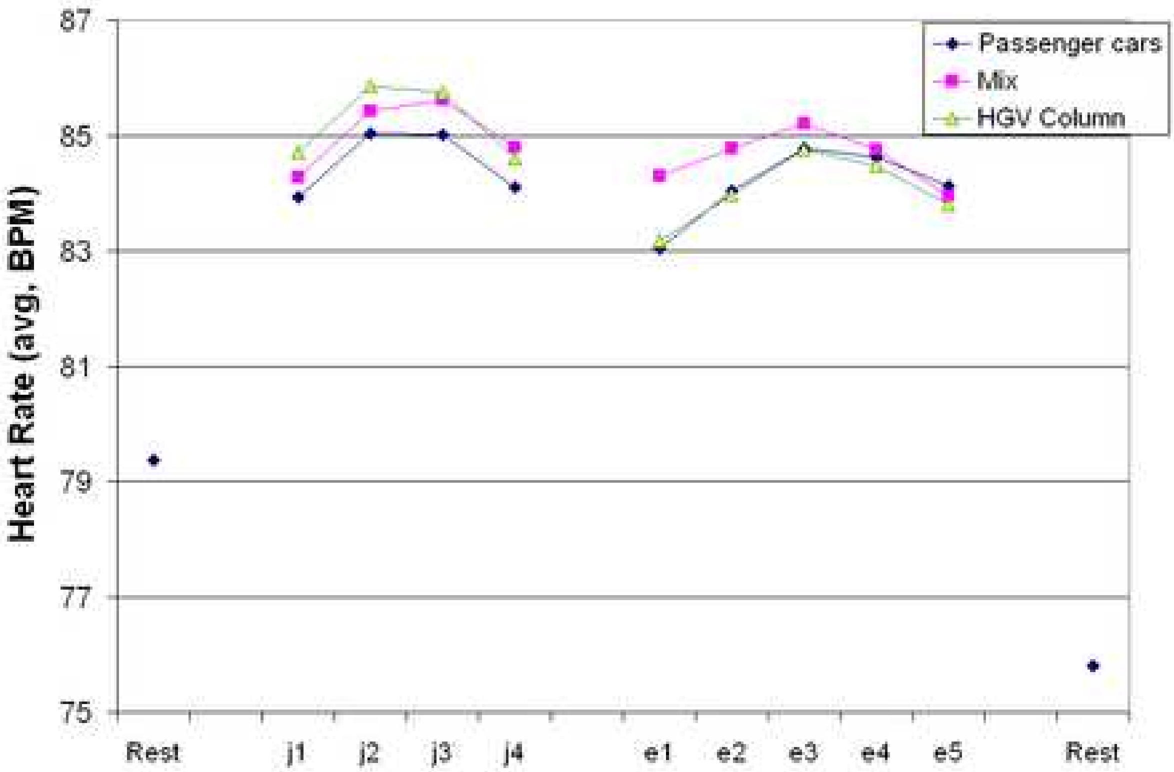


Figure 8

Click here to download high resolution image