The impact of a dedicated lane for connected and automated vehicles on the behaviour of drivers of manual vehicles

Razmi Rad, Solmaz; Farah, Haneen; Taale, Henk; van Arem, Bart; Hoogendoorn, Serge P.

DOI
10.1016/j.trf.2021.08.010

Publication date
2021

Document Version
Final published version

Published in
Transportation Research Part F: Traffic Psychology and Behaviour

Citation (APA)
Razmi Rad, S., Farah, H., Taale, H., van Arem, B., & Hoogendoorn, S. P. (2021). The impact of a dedicated lane for connected and automated vehicles on the behaviour of drivers of manual vehicles. *Transportation Research Part F: Traffic Psychology and Behaviour*, *82*, 141-153. https://doi.org/10.1016/j.trf.2021.08.010

Transportation Research Part F: Psychology and Behaviour 82 (2021) 141–153

Contents lists available at ScienceDirect

Transportation Research Part F: Psychology and Behaviour

journal homepage: www.elsevier.com/locate/trf

The impact of a dedicated lane for connected and automated vehicles on the behaviour of drivers of manual vehicles

Solmaz Razmi Rad [a,*], Haneen Farah [a], Henk Taale [a,b], Bart van Arem [a], Serge P. Hoogendoorn [a]

[a] *Department of Transport and Planning, Delft University of Technology, Delft, The Netherlands*
[b] *Rijkswaterstaat Water, Traffic and Environment, Rijswijk, The Netherlands*

A R T I C L E I N F O

Keywords:
Connected and automated vehicles
Dedicated lanes
Behavioural adaptation
Car-following
Gap acceptance in lane changing

A B S T R A C T

Connected and automated vehicles (CAVs) are expected to enhance traffic efficiency by driving at shorter time headways, and traffic safety by shorter reaction times. However, one of the main concerns regarding their deployment is the mixed traffic situation, in which CAVs and manually driven vehicles (MVs) share the same road.

This study investigates the behavioural adaptation of MV drivers in car-following and lane changing behaviour when they drive next to a dedicated lane (DL) for CAVs and compares that to a mixed traffic situation. The expectation is that in a mixed traffic situation, the behavioural adaptation of MV drivers is negligible due to lower exposure time and scarce platoons, while concentrating the CAVs on one dedicated lane may cause significant behavioural adaptation of MV drivers due to a higher exposure time and conspicuity of CAV platoons.

Fifty-one participants were asked to drive an MV on a 3-lane motorway in three different traffic scenarios, in a fixed-base driving simulator: (1) Base, only MVs were present in traffic, (2) Mixed, platoons of 2–3 CAVs driving on any lane and mixed with MVs, (3) DL, platoons of 2–3 CAVs driving only on a DL. The DL was recognizable by road signs and a buffer demarcation which separated the DL from the other lanes. A moderate penetration rate of 43% was assumed for CAVs.

During the drives, the car following headways and the accepted merging gaps by participants were collected and used for comparisons of driving behaviour in different scenarios.

Based on the results, we conclude that there is no significant difference in the driving behaviour between Base and Mixed scenarios at tested penetration rate, confirming our research expectation. However, in DL scenario, MV drivers drove closer to their leaders specially when driving on the middle lane next to the platoons and accepted shorter gaps (up to 12.7% shorter at on-ramps) in lane changing manoeuvres. Dedicating a lane to CAVs increases the density of CAV platoons on one lane and consequently their conspicuity becomes higher. As a result, MV drivers are influenced by CAV platoons on a DL and imitate their behaviour.

The literature suggests that dedicating a lane to CAVs improves the traffic efficiency by providing more possibilities for platooning. This study shows that implementing such a solution will affect the driving behaviour of human drivers. This should be taken into consideration when evaluating the impacts of dedicated lanes on traffic efficiency and traffic safety.

* Corresponding author.
E-mail address: s.razmirad@tudelft.nl (S. Razmi Rad).

https://doi.org/10.1016/j.trf.2021.08.010
Received 17 May 2021; Received in revised form 28 June 2021; Accepted 10 August 2021
Available online 27 August 2021

1. Introduction

Connected and automated vehicles (CAVs) are expected to enhance the traffic efficiency by driving with shorter time headways and the traffic safety by shorter reaction times (Fagnant & Kockelman, 2015). However, one of the main concerns regarding their deployment is the mixed traffic situation, in which CAVs and manually driven vehicles (MVs) share the same road. A key research gap in this respect is whether MV drivers would interact differently with CAVs compared to their interaction with other MVs (Razmi Rad, Farah, Taale, van Arem, & Hoogendoorn, 2020).

A field study by Rahmati et al. (2019) suggests that there is a statistically significant difference between human drivers' behaviour when following an automated vehicle compared to an MV. Participants were asked to perform two drives in platoons of three vehicles. The participants always drove the last vehicle in the platoon, following an automated vehicle (scenario A) or an MV (scenario B). The lead vehicle was an automated vehicle following a series of speed profiles extracted from the Next Generation Simulation dataset, NGSIM (US Department of Transportation – FHWA, 2007). Based on the results, MV drivers felt more comfortable following an automated vehicle and drove closer to their leader if they followed an automated vehicle, compared to following an MV.

Driving simulator experiments have studied the interaction between MVs and CAVs in a mixed traffic situation (Gouy et al., 2013; Gouy et al., 2014; Schoenmakers, Yang, & Farah, 2021). Gouy et al. (2013) tested the car-following behaviour of MV drivers in the presence of CAV platoons in a driving simulator experiment to investigate if there is any behavioural adaptation in the car-following behaviour of MV drivers. In this study, participants drove an MV and followed a lead vehicle in the vicinity of CAV platoons keeping long (1 s) or short (0.3 s) time headways (THWs). They found that MV drivers drove very close to, but not under their minimum preferred THW in the scenario with CAV platoons specially when CAVs kept short THW.

In a later study, Gouy et al. (2014) studied the behavioural adaptation of MV drivers in car-following, this time with higher exposure time to CAV platoons and higher conspicuity of the platoons by using trucks instead of personal vehicles. Platoons of trucks kept long (1.4 s) or short (0.3 s) THWs. According to the results, MV drivers imitated the truck platoons' behaviour by keeping significantly shorter THWs and also spent more time keeping a THW below a safety threshold of 1 s. The results suggest that there can be negative behavioural adaptation when humans drive next to CAVs, especially when the exposure time and conspicuity of platoons are increased. However, the authors reported that this behavioural adaptation is not long lasting since there were no carryover effect from platoon condition with THW of 0.3 s to the other one (1.4 s).

Dedicating a lane to CAVs is suggested in the literature to overcome the difficulties with the mixed traffic situation (Kockelman et al., 2016; Shladover, 2005; Lumiaho & Malin, 2016; McDonald & Rodier, 2015; Milakis et al., 2015). However, the implications of implementing such a lane is still understudied (Razmi Rad et al., 2020). Schoenmakers et al. (2021) hypothesized that drivers will adapt their driving behaviour when driving in proximity to a platoon of CAVs on a dedicated lane by reducing their THW and that this effect would be different for different types of separations. They conducted a driving simulator study to test this hypothesis. Participants were assigned to a car-following task in four different scenarios: a) Baseline with no CAVs, b) CAVs drove on continuous access dedicated lane, (c) CAVs drove on a limited access dedicated lane with buffer, and (d) CAVs drove on a limited access dedicated lane with barrier. The results show that compared to the baseline scenario with no CAVs, MV drivers drove with a significantly lower THW from the lead vehicle when driving on the lane adjacent to the continuous access dedicated lane and limited access dedicated lane with buffer. However, MV drivers' THWs were only marginally different in the scenario with limited access dedicated lane with barrier compared to the baseline. In fact, the barrier partially blocked the view of MV drivers towards the CAV platoons and consequently (partially) prevented the behavioural adaptation. Although barrier separated DL was shown to be the safest scenario considering the car following THW, implementing such barriers would be expensive and counterproductive for the flexibility of the road system. Moreover, more crashes happen near the beginning of highway sections with barrier compared to the sections without barrier (Tsao, Hall, & Hongola, 1995).

Dedicating an existing highway lane to CAVs implies restricting MVs from using one lane of the motorway which could significantly increase their travel time if the actual share of CAVs in traffic or penetration rate (PR) of CAVs is lower than the lane saturation level (Ivanchev et al., 2017; Van Arem, Van Driel, Visser, 2006). So, exploiting the beneficial implications of a DL would only be possible when we reach to moderate PRs around 30–50% (Ivanchev et al., 2017; Van Arem, Van Driel, Visser, 2006; Vander Laan & Sadabadi, 2017; Xiao, Wang, & Van Arem, 2020; Madadi, Van Nes, Snelder, & Van Arem, 2021). This raises the question as to how would be the behavioural adaptation of MV drivers at moderate PRs of CAVs just before we can implement a DL.

Moreover, the extent of the behavioural adaptation might be different for different drivers. Driver characteristics and driving styles may influence driving behaviour. Studies in the literature suggest that drivers with different self-reported driving styles show different behaviour when driving. Taubman-Ben-Ari et al. compared the scores of four broad driving styles measured by the Multidimensional Driving Style Inventory (MDSI) with the naturalistic driving recorded by an in-vehicle data recorder. They found that risky behaviours measured by the in-vehicle data recorder positively correlate with high MDSI scores on the risky and hostile driving styles and negatively correlate with high MDSI scores on the anxious and careful driving styles (Taubman - Ben-Ari, Eherenfreund - Hager, & Prato, 2016). In another driving simulator study, Farah et al. found a correlation between the MDSI score for the hostile driving style and overtaking accepted gaps and driving speeds (Farah, Bekhor, Polus, & Toledo, 2009).

Furthermore, age and gender of drivers play important roles in driving behaviours (Rajalin, Hassel, & Summala, 1997; Farah, 2011; Bener & Crundall, 2008). According to the literature, young, male drivers are more likely to follow a lead vehicle more closely (Rajalin et al., 1997), overtake while accepting shorter gaps (Farah, 2011), and perform risky manoeuvres (Bener & Crundall, 2008). Schoenmakers et al. also studied the relationships between car-following and sociodemographic variables reported in a questionnaire by participants. According to the results, the average THW and its standard deviation were distinctly lower in males than females

(Schoenmakers et al., 2021). Given these results it is relevant to investigate the behaviour of different groups of drivers (age, gender, and driving style) when driving next to CAVs.

Previous research has suggested that MV drivers drive closer to their leaders when driving next to CAV platoons keeping short THWs (Gouy et al., 2013; Gouy et al., 2014; Schoenmakers et al., 2021). It is suggested by these studies that the behavioural adaptation is more significant when the exposure time and conspicuity of the platoons (i.e., larger vehicles such as trucks) increase. However, these studies assumed very large platoons, representative of high PR in situations that there is no limitation for platoon size which is a quite unlikely scenario. Moreover, most of these studies focused on the longitudinal driving behaviour and did not consider behavioural adaptation in lateral manoeuvres. Further research is therefore needed to firstly examine this behavioural adaptation in both the longitudinal and lateral dynamics; Secondly, to investigate if the behavioural adaptation happens at moderate PRs before implementing DLs; and thirdly, to investigate the relationship between this behavioural adaptation and driving style and characteristics of MV drivers.

Therefore, the main objective of this study is to investigate the behavioural adaptation of MV drivers in car-following and lane changing when driving adjacent to the DL and compare that to the behavioural adaptation when driving in a mixed traffic flow at a moderate PR. It should be noted that, in this paper, CAVs refer to connected and automated vehicles which are able to drive in platoons keeping short THWs (0.3 s), which corresponds to SAE levels 4 and 5 (SAE, 2018).

The main expectations are:

i. In a mixed traffic situation and at moderate PRs (43% in this study) of CAVs the behavioural adaptation of MV drivers is negligible due to lower exposure time and scarce platoons (Expectation 1).
ii. MV drivers adapt shorter time headways (Expectation 2a) and merging gaps (Expectation 2b) in car-following and lane changing respectively when driving next to CAV platoons concentrated on one lane.
iii. This behavioural adaptation is different for drivers with different demographics and driving styles (Expectation 3).

To test the aforementioned expectations and given the difficulty in doing on-road experiments with CAVs, a driving simulator experiment was developed using a medium fidelity driving simulator.

The rest of the paper is structured as follows. In Section 2 the method, the experimental setup and scenario details are described following the data collection and processing and analysis approach. The results are provided in Section 3, followed by the discussion in Section 4. Finally, Section 5 provides the main conclusions and formulates recommendations for further research.

2. Methodology

The following sub-sections explain the recruitment of participants for the driving simulator experiment, the apparatus set-up, the driving simulator scenarios, the questionnaires used, the experiment procedure, the data collection and processing, and finally the analysis approach.

2.1. Participants

A total of 51 participants (22 females, 29 males) took part in the experiment. They were recruited via a panel provider company based in the Netherlands and an advertisement on the TU Delft campus (Delft, The Netherlands). All participants held a valid driver's license and had experience driving on the Dutch freeways. Their age and gender distribution is illustrated in Fig. 1.

2.2. Apparatus

The study was conducted in a fixed-based driving simulator comprised of a dashboard mock-up with three 4 K high resolution screens, providing approximately a 180-degree vision, Fanatec steering wheel, pedals and a blinker control (Fig. 2).

2.3. Design of the driving environment

The simulated road environment consisted of a typical three-lane Dutch motorway. A double crash barrier separated the two

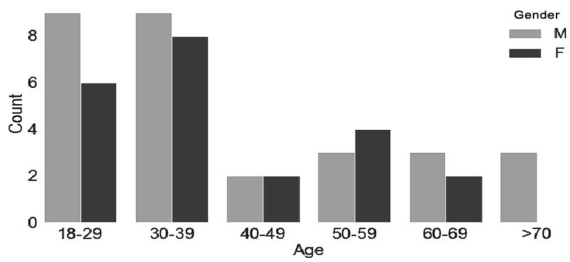

Fig. 1. Age and Gender distribution of participants.

Fig. 2. The fixed-based driving simulator.

carriageways and a single crash barrier was present on both sides of the motorway. The speed limit was set to 100 KPH according to the Dutch regulations regarding daytime speed limits. The route included three stretches of motorway which were connected to each other with on- and off-ramps via large curves. The traffic flows were equal per lane in all scenarios. Three scenarios were designed as follows:

Base: all vehicles were manual in this scenario, keeping THWs in the range of 2 to 4 s. Vehicles on the right lane were slower than others to motivate the participant to change lanes towards faster lanes given that one of the objectives of this study was to measure accepted gaps when changing lanes. The signage and demarcations of the driving environment was designed according to what drivers experience on a typical Dutch motorway (see Fig. 3(a)).

Mixed: this scenario contained both MVs and CAVs in a mixed driving situation. The PR of CAVs was set to 43% and they could drive on any lane of the motorway in platoons of 2 to 3 vehicles. The intra-platoon and inter-platoon THWs were set to 0.3 s and 2 s, respectively. The signage and demarcation of the motorway did not differ with that of the Base scenario (Fig. 3(a)).

Dedicated lane: The left most lane of the motorway was dedicated to CAVs and therefore, CAVs were not allowed to drive on the other lanes. Intra-platoon and inter-platoon THWs were set to 0.3 s and 2 s, respectively, similar to the Mixed scenario. Also the platoon size (2 to 3 vehicles) and the PR were similar as in the Mixed scenario (43%). To inform the participants about the dedicated lane, a buffer demarcation separating the DL and the other lanes was applied. Road signs were also added as illustrated in Fig. 3(b) to further clarify the purpose of this lane. Participants also read about the DL concept in the instruction before performing the drives.

2.4. Road sign for the DL

The road sign contained a "no entry" symbol with an exception (uitgezonderd in Dutch) for CAVs. The platooning pictogram was selected based on results of a survey on symbol comprehension. A total of 455 respondents filled in the survey which consisted of different pictograms. They were asked to write down the meaning of the symbols and take an "educated guess" if they were not sure of the meaning. According to the survey results presented in word clouds, Fig. 4(c) was the most likely pictogram which was comprehended as CAV platoon. Moreover, in a multiple choice question, respondents were asked to choose a pictogram which could best illustrate CAVs. Pictogram (a) to (d) were selected by 21%, 11%, 44%, and 24% respectively. So, based on these results Fig. 4(c) was chosen as the CAV pictogram for the DL sign, as can be also seen in Fig. 3(b).

2.5. Experimental design and procedure

The experiment consisted of a questionnaire and three consecutive drives in the driving simulator. Before performing the drives,

Fig. 3. Driving environment, (a) Base and Mixed scenario, (b) Dedicated lane scenario.

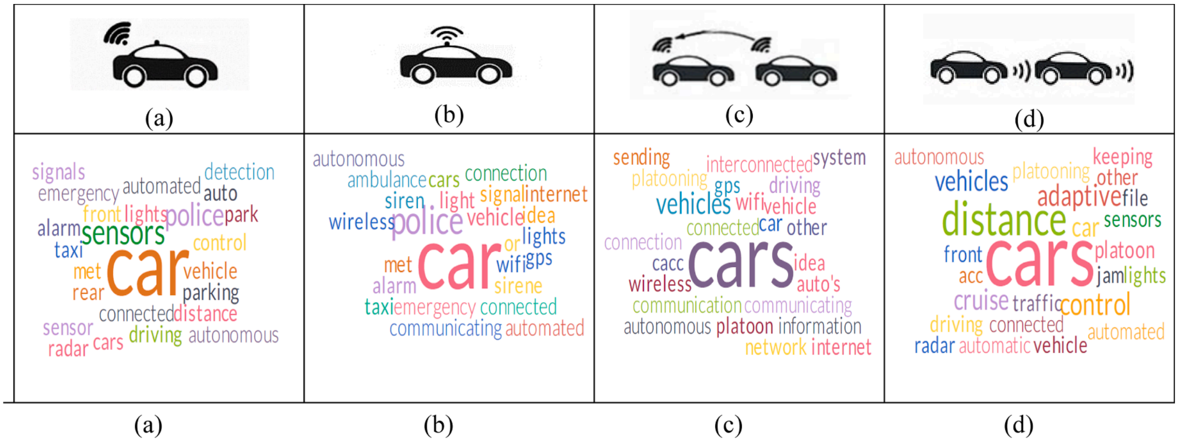

Fig. 4. Pictograms for the DL sign.

participants were presented with a leaflet explaining their task and the procedure of the experiment as well as the concept of dedicated lanes. The leaflet also mentioned that they should drive as much as possible as they would normally do in real life. They were also advised to stop the experiment if they felt any discomfort (i.e., simulation sickness). Next, participants signed a consent form to allow the usage of their data for the research. The experiment was approved by the Human Research Ethics Committee of the Delft University of Technology.

The participants were asked to start the engine, exit a parking lot, enter the motorway and follow the road signs towards their destination, as was given to them at the beginning of the experiment. The route was exactly the same for all scenarios. However, the surrounding environment, the destination, and the road signs were different to minimize the bias effect of familiarity and drivers' expectation. Before starting each scenario, a sticker mentioning the destination was attached to the dashboard in case the participant needed to recall it.

The base scenario (i.e., all vehicles are manual) was always performed first, while the Mixed and DL scenarios were randomized. The participants could not differentiate between the Base and Mixed scenario as the CAVs were not distinguishable. They were only told that in one of the scenarios all vehicles are manual and in another one there will be CAVs driving on any lane. But, before the DL scenario, participants were informed explicitly that CAV platoons will be present and will only drive on the fast lane which is separated via lane marking. They were also told that they cannot drive on that specific lane.

2.6. Questionnaires

The Participants were also asked to fill in a set of questionnaires. The first questionnaire was administered to the participants to obtain information about the participants' demographics and driving styles. The multidimensional driving style inventory questionnaire (MDSI) by Taubman-Ben-Ari, Mikulincer, & Gillath (2004) was used for this purpose. MDSI questionnaire contains statements that should be rated on a 6-point scale ("not at all" to "very much"). The questionnaire assesses four broad domains of driving style and reveals eight main factors: dissociative driving, anxious driving, risky driving, angry driving, high-velocity driving, distress-reduction driving, patient driving, and careful driving. The participants were asked to complete the MDSI questionnaire beforehand at home and to subscribe for a timeslot to participate in the driving simulator part of this study. In total 182 people filled in the questionnaire out of which, 51 participated in the driving simulator experiment as well.

The second questionnaire was administered after the completion of the driving simulator experiment and measured if participants experienced any discomfort such as nausea, oculomotor discomfort, and disorientation, throughout the experiment while driving using the Simulation Sickness Questionnaire by Kennedy, Lane, Berbaum, & Lilienthal (1993). Participants reported on a 4-point Likert scale from 0 (no) to 3 (severe) about how much they felt affected by each symptom.

Finally, the last questionnaire examined participants' presence during the drives. For this purpose the 19 core items of the Presence Questionnaire was used (Witmer, Jerome, & Singer, 2005). It includes four factors, namely involvement, visual fidelity, adaptation/immersion, and interface quality which influence user presence during the drives with the driving simulator. The items were rated on a 7-point scale.

2.7. Data collection and processing

The driving simulator records vehicles' trajectories and time stamps every 0.02 s (50 frames per second) during the drives. The following variables were collected for the ego vehicle and other agents: speed [m/s], position (x, y, z), headings (direction of movement), and driving lane.

The following driving behaviour characteristics were calculated from the vehicle trajectory raw data:

- **Time headway (THW) in car-following** was calculated as the distance between ego and lead vehicle plus the length of the lead vehicle (headway) [m] divided by the speed of the ego vehicle [m/s] (see Fig. 5(a)). The car-following event was considered five seconds after the moment when the participant changed lane and ended five seconds before the next lane change. This is to exclude those moments just before a lane change when the driver may get closer to the lead vehicle as a preparation for the lane change, or just after a lane change until the driver adjusts the gap to the car-following situation. In addition, to differentiate the car-following and free flow driving, car-following was defined as when the ego vehicle is following a lead vehicle with THW equal or less than 3 s (Pasanen & Salmivaara, 1993; Highway Capacity Manual, 2010).
- **Time gap in lane changing** was calculated as the sum of the headway [m] divided by the speed of the ego vehicle and distance between ego and lag vehicle (lag gap) [m] divided by the speed of the lag vehicle [m/s]. A lane change gap is calculated the moment when the centre of the ego vehicle passes the lane marking (see Fig. 5(b)). Four types of lane changes were defined (Fig. 6):
- **On-ramp**: when the ego vehicle accepts a gap to enter the slow lane from the on-ramp (acceleration lane). In total there were 4 on-ramps in every scenario. The first one was excluded from the analysis since it happened at the beginning of the scenario without being next to any traffic.
- **Off-ramp**: when the ego vehicle accepts a gap in order to change lane from the middle lane to the slow lane to enter the off-ramp (deceleration lane) to exit a section of the highway. This type of lane change happened when the deceleration lane is available and the participant has already seen the road sign showing the destination. In total there were 3 off-ramps in every scenario. However, those participants who kept driving on the slow lane did not have to accept any gap when changing lane to the deceleration lane. As a result, only 45 out of 51 participants have off-ramp gap measurements.
- **Keep right**: when the ego vehicle changes lane to the slow lane after he/she has completed an overtake.
- **Overtake**: when the ego vehicle changes lane to the fast lane for an overtake.

It should be noted that, a limitation of 75 m for the longitudinal distance for lane change gaps were considered for inclusion in the analysis. This is suggested by Yang et al. to determine that the ego vehicle has interaction with the lead vehicle (Yang, Wang, & Quddus, 2019). We considered this limitation for both lead and lag gaps. This way total merging gaps will be limited to maximum150m or around 6 s.

2.8. Analysis approach

A two-step analysis approach was implemented to test the research expectations. First, a principal component analysis was conducted on the answers to the MDSI questionnaire. The purpose was to determine the latent behavioural components relevant to the driving styles. Secondly, Linear Mixed Effects Models (LMM) were estimated to investigate the importance of several predictors (i.e. scenario, demographics, and driving style) on car following and lane changing behaviour of drivers. The analysis of the questionnaires and LMMs were performed using the Statistical Package for the Social Sciences (SPSS) version 25.0 and Python package statsmodels respectively (Seabold & Perktold, 2010).

3. Results

This section presents the results of the collected data in the experiment. The results of the questionnaire data is presented in Section 3.1. The descriptive statistics of the driving behaviour is presented in Section 3.2, followed by the results of the Linear Mixed Effects Models considering the three scenarios presented in Section 3.3.

3.1. Questionnaires

Multidimensional driving style inventory questionnaire (MDSI): A Principal Component Analysis (PCA) was conducted on the questions of MDSI questionnaire to combine variables which have a common background into a new variable (component). The PCA was performed with orthogonal rotation (varimax) and based on eigenvalues greater than 1. Since the number of participants who completed both the questionnaire and the simulator drives was considered low (51 participants) for PCA analysis, we conducted the PCA on the answers from all 182 respondents of the questionnaire. After checking communalities between indicators, four components were obtained, which cumulatively accounted for 47.94% of the total variance. Items with a communality lower than 0.4 were excluded from the exploratory factor analysis. The Kaiser-Meyer-Olkin measure of sampling adequacy was satisfactory (0.87) and Bartlett's test of sphericity was significant ($p < 0.0001$) which means that the data was suitable for the proposed statistical procedure of PCA (Williams, Onsman, & Brown, 2010). In conclusion, 35 out of the 44 questions were part of the final 4-component solution. The

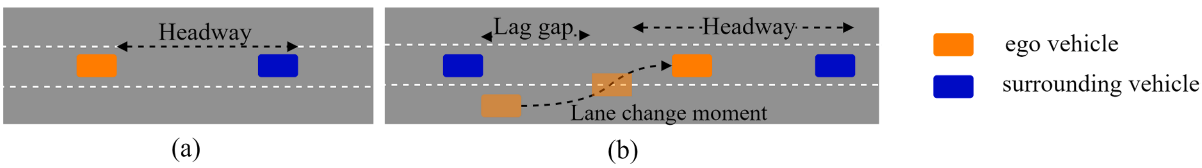

Fig. 5. (a) Car-following and (b) lane changing parameters.

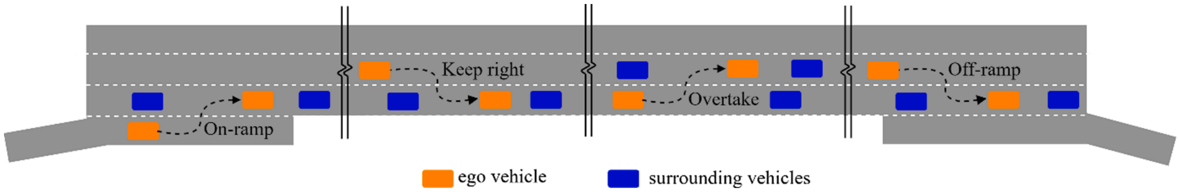

Fig. 6. Illustration of different lane change types.

components are in line with the factors defined by Taubman-Ben-Ari et al. (2004). The latent variable Component 1 can best be described as "Risky" drivers, Component 2 reflects the driving style "Angry & high-velocity", Component 3 refers to "Dissociative & anxious" driving style, and finally, Component 4 refers to "Patient & careful" drivers. Fig. 7 illustrates the distributions of each driving style for the 51 participants who completed the questionnaire and the experiment. As it can be seen in Fig. 7, participants who completed the experiment mostly reported their driving styles as not "Risky" and not "Angry & high-velocity". However, their "Dissociative & anxious" driving style ranged from not "Dissociative & anxious" to very "Dissociative & anxious". Also, there were both not "Patient & careful" and very "Patient & careful" drivers.

Simulation Sickness Questionnaire (SSQ): The mean score and the standard deviation of the simulation sickness questionnaire were also calculated. The score of SSQ reflects the symptomatology of participants' experience in the virtual environment. Higher scores mean higher symptoms. The maximum total score of the SSQ is 236 (Kennedy et al., 2003). The total score of all participants in this study was fairly low with a mean and standard deviation of 29.55 and 22.67, respectively which means the simulator study did not lead to serious simulation sickness.

Presence Questionnaire (PQ): Besides that, the score of the Presence Questionnaire was obtained. Summing the 19 responses of the core questions, the range of scores could be between 19 and 133. The total score of the PQ with a mean of 83.1 and a standard deviation of 12.44 indicated that participants experienced a higher-than-average amount of presence during the drive in the driving simulator.

3.2. *Driving behaviour descriptive statistics*

Prior to conducting the analysis, the number of observations for each manoeuvre was derived for comparisons between scenarios. Based on the size of THW, longitudinal manoeuvres were divided into three different groups: a) free flow when the THW is larger than 3 s and the speed of the ego vehicle is not restricted by any other vehicle, b) car-following when the THW is equal or smaller than 3 s, and c) critical car-following when the THW is equal or smaller than 1.5 s. The THW $\leq$ 1.5 s was chosen as the critical THW because in practice, the average THW during the capacity conditions of a Dutch freeways is approximately equal to 1.5 s, which represents a capacity of 2.400 veh/hr/lane (Grontmij, 2015). As can be seen in Table 1, the number of observations for critical THW of the ego driver in DL scenario is considerably higher compared to Base and Mixed scenarios. The merge gaps are not equal across different scenarios, because: a) they are filtered by the 75 m criterion (Yang et al., 2019), and b) some participants did not perform some of the merge manoeuvres. For example, they might have been driving on the slow lane and did not have to accept any off-ramp gaps, or they did not overtake or keep right as much as other drivers.

Boxplots of car following THWs were generated to see if there are any visible differences between scenarios and for each lane separately (Fig. 8 (a, b, c)). The THWs on the fast lane were not shown since participants rarely entered that specific lane in Base and Mixed scenarios and were not allowed to drive on this lane in DL scenario. As it can be seen in the figure, car-following THWs of the ego vehicle are visibly smaller in DL scenario compared to the Mixed or Base scenarios, especially on the middle lane which is next to the dedicated lane where CAV platoons drive.

Three more boxplots were generated to examine the critical car following THWs, i.e., THW $\leq$ 1.5 s of ego drivers (Fig. 8 (d, e, f)). The critical THWs in DL scenario and on the middle lane are obviously smaller compared to Base and Mixed scenarios (Fig. 8 (f)). It shows that drivers are more likely to follow a car very closely when driving next to the DL where they were exposed to CAV platoons.

As far as the lane change gaps are concerned, the boxplots in Fig. 9 shows that participants were more likely to accept smaller merging gaps in DL scenario.

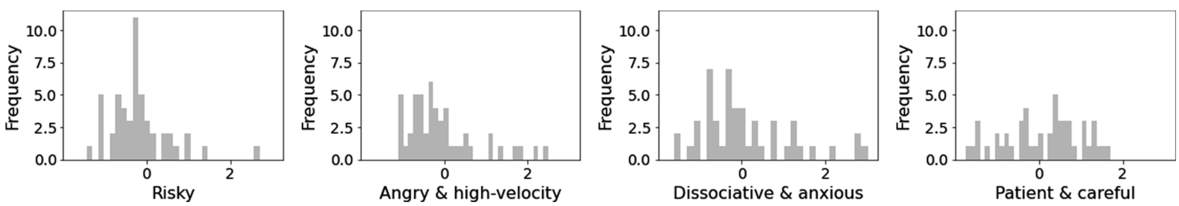

Fig. 7. Driving styles distributions.

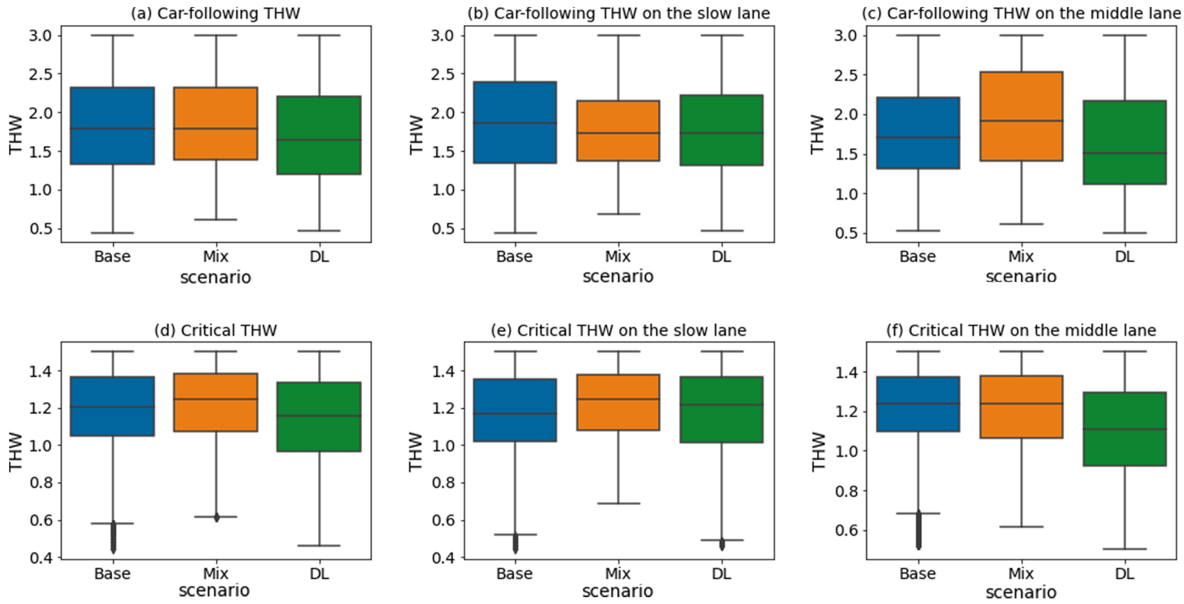

Fig. 8. Boxplots of car-following THWs.

Table 1
Number of observations for each manoeuvre per scenario.

Car-following THWs	Number of observations			Merge gaps	Number of observations		
	Base	Mixed	DL		Base	Mixed	DL
Free flow THW	99,081	134,069	65,114	**On-ramp**	111	80	109
Car-following THW	245,747	195,453	307,666	**Off-ramp**	62	57	62
THW ≤ 1.5 s	88,350	64,025	133,167	**Keep right**	70	76	48
				Overtake	102	19	83

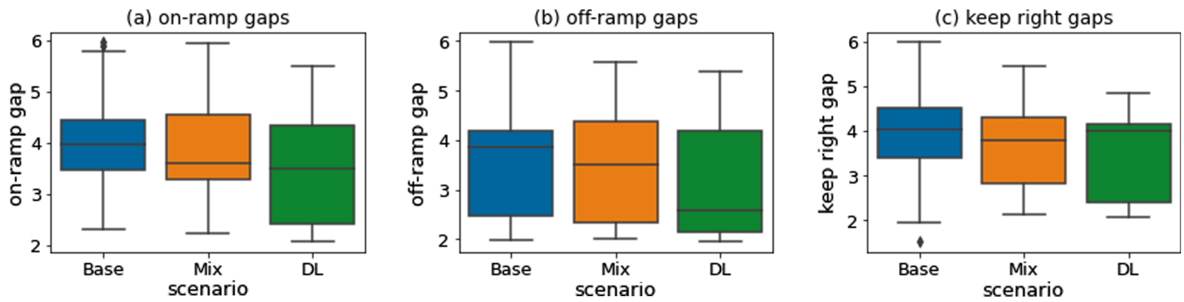

Fig. 9. Boxplots of accepted merging gaps.

3.3. Linear mixed effects models (LMM)

To find out whether or not the differences observed in the boxplots are statistically significant, Linear Mixed Effects Models (LMM) were conducted to compare the THWs and merging gaps across the different scenarios, taking into account the participants' demographics and driving styles derived from the MDSI questionnaire.

The LMM is a widely used method to analyse unbalanced longitudinal data, where individuals may be measured at different time points, or at different number of time points. LMMs are able to consider random effects that cannot be controlled for in the experiment. Random effect models have been widely utilized for this purpose (Wang, Yang, & Hurwitz, 2019; Laird & Ware, 1982; Razmi Rad, Homem de Almeida Correia, & Hagenzieker, 2020).

We have fitted models with two random effects for each participant: a random intercept, and a random slope (with respect to scenario). The random intercept captures correlations between the observations from the same participant. This means that each participant may have a different baseline THW or merging gap due to their characteristics or driving styles. The random slope allows the explanatory variables to have a different effect for each participant. This means that each participant may change the THW or merging gap at a different rate. This is because different drivers may perceive and be influenced differently by the CAV platoons and the dedicated lane. So the rate of behavioural adaptation (if any) may be different for each participant.

In total, five LMMs (car-following THW, critical THW, on-ramp accepted gaps, off-ramp accepted gaps, and keep right accepted gaps) were developed, as shown in Table 2–4. Backward elimination method was used for the selection of variables. First the full independent variables were included in the model, then the most insignificant ones were eliminated until reaching a set of variables that all have a significant influence on the model.

3.3.1. *Car-following behaviour*

In order to compare the car-following behaviour in different scenarios, LMMs were developed considering the THWs equal or smaller than 3 s. The LMMs were performed in two ways: Model (a) only considering the main independent variables without any interactions. Model (b) considering the main independent variables with possible interactions which appeared to be significant in the model.

As it is shown in Table 2, Model (a), in the DL scenario, the participants drove with significantly smaller THWs (0.128 s smaller), compared to the other two scenarios. The results also indicate that younger, male drivers kept smaller THWs in general compared to older female drivers. Finally, drivers with higher education kept larger THWs in general.

Considering Table 2, Model (b), although the THW is shown to be larger on the middle lane in general (0.012 s larger), when considering the interaction between the lane and scenario, the results reveal that THW is significantly smaller in DL scenario and on the middle lane when the participants drove right next to the CAV platoons on the dedicated lane (0.058 s smaller). It should be mentioned that the THWs on the fast lane were not included in LMM analysis since drivers rarely used this lane in Base and Mixed scenario and were not allowed to drive on it in DL scenario. Considering gender and education, we can see the same trend as explained in Model (a). Moreover, interesting results were found regarding age. Model (b) indicated that older drivers keep significantly larger THWs. However, when considering the interaction between age and scenario, it is found that older drivers decrease their car following THW in DL scenario compared to Base (significant at the 10% level), while this has not happened in Mixed scenario. It can be concluded that, older drivers are more likely to adapt their behaviour when driving next to platoons compared to young people.

Next, LMMs were developed for critical car-following behaviour considering THWs equal or smaller than 1.5 s. Table 3, Model (c) and Model (d) show the results of LMM without and with interactions, respectively. Similar to Model (a) shown in Table 2, Model (c) reveals that drivers drive significantly closer to their leaders in DL scenario compared to Base (0.042 s smaller). However, the coefficient indicates that this decrease in critical THW is not as high as the decrease in car-following THW (0.128 s) in Model (a).

In line with the results of the car-following behaviour in Table 2, older drivers and drivers with high education increased their critical THW relative to their leaders. Considering Model (d) including the interactions, it can be seen that drivers decreased their critical THWs on the middle lane in both DL and Mixed scenario. However, the decrease in DL scenario is more than four times larger than in Mixed scenario (0.046 s and 0.011 s decrease in DL and Mixed respectively).

3.3.2. *Lane change behaviour*

Three LMMs were also performed to compare the lane change accepted gaps between the different scenarios. Table 4 illustrates that off-ramp and on-ramp accepted gaps were significantly shorter in DL compared to Base scenario.

In terms of keep right lane changes, scenario turned out to be a significant factor once again. Table 4 indicates that keep right gaps were decreased in Mixed and DL scenario compared to Base. However, the coefficient shows that this decrease is greater in DL compared to Mixed scenario.

Table 2
Linear Mixed Effects Model for car-following (THW $\leq$ 3 s).

Dependent variable		Model (a)			Model (b)		
		Coefficient	p-value	Z	Coefficient	p-value	Z
Intercept		1.337	<0.001	7.047	1.304	<0.001	6.805
Scenario	DL (vs. Base)	−0.128	0.029	−2.187	Not significant in the model		
	Mix (vs. Base)	Not significant in the model			Not significant in the model		
Gender	Female (vs. Male)	0.158	0.061	1.871	0.157	0.062	1.866
Lane	Middle (vs. Slow)	0.056	<0.001	37.776	0.012	<0.001	5.217
Age		0.048	0.003	3.015	0.060	0.001	3.356
Education		0.086	0.033	2.130	0.088	0.029	2.180
Lane * Scenario	Middle (vs. Slow), DL (vs. Base)				−0.058	<0.001	−17.141
	Middle (vs. Slow), Mixed (vs. Base)				0.249	<0.001	66.543
Age * Scenario	Middle (vs. Slow), DL (vs. Base)				−0.033	0.084	−1.730
	Middle (vs. Slow), Mixed (vs. Base)				Not significant in the model		
Statistics							
Number of observations		748,866			748,866		
Number of groups		51			51		
Log-likelihood		−536450.24			−532901.1		
AIC		1072912.48			1065818.2		
BIC		1072981.64			1065910.41		

Table 3
Linear Mixed Effects Model for critical car-following (THW ≤ 1.5 s).

Dependent variable		Model (c)			Model (d)		
		Coefficient	p-value	Z	Coefficient	p-value	Z
Intercept		1.029	<0.001	17.284	1.020	<0.001	17.038
Scenario	DL (vs. Base)	−0.042	0.038	−2.072	Not significant in the model		
	Mixed (vs. Base)	Not significant in the model			Not significant in the model		
Age		0.016	0.003	2.979	0.017	0.003	3.013
Education		0.044	0.001	3.291	0.044	0.001	3.259
Lane	Middle (vs. Slow)				0.023	<0.001	15.319
Lane * Scenario	Middle (vs. Slow), DL (vs. Base)				−0.046	<0.001	−22.875
	Middle (vs. Slow), Mixed (vs. Base)				−0.011	<0.001	−4.625
Statistics							
Number of observations		285,542			285,542		
Number of groups		51			51		
Log-likelihood		110241.43			110523.29		
AIC		−220472.86			−221034.58		
BIC		−220420.05			−220971.21		

Table 4
Linear Mixed Effects Models for off-ramp, on-ramp, and keep right accepted gaps.

Dependent variable		Off-ramp			On-ramp			Keep right		
		Coef.	p-value	Z	Coef.	p-value	Z	Coef.	p-value	Z
Intercept		3.524	<0.001	28.941	4.019	<0.001	39.469	3.961	<0.001	29.437
Scenario	DL (vs. Base)	−0.383	0.026	−2.230	−0.578	<0.001	−4.068	−0.431	0.028	−2.199
	Mix (vs. Base)	Not significant in the model			Not significant in the model			−0.361	0.026	−2.223
Statistics										
Number of observations		181			300			194		
Number of groups		45			51			45		
Log-likelihood		−254.28			−416.77			−263.00		
AIC		512.56			837.54			530		
BIC		518.96			844.95			536.54		

Lane changes which were performed in order to overtake were also studied. No specific trend was found in these type of lane changes.

It should also be mentioned that driving styles derived from MDSI were not statistically significant in any of the LMM models.

4. Discussion

In this section, the results are summarized and discussed according to the expectations proposed in the introduction.

4.1. Behavioural adaptation in Mixed situation

The first expectation was that behavioural adaptation would be negligible in a mixed traffic of CAVs and MVs at moderate PRs. One of the scenarios in the experiment was to drive on a freeway with mixed traffic of MVs and CAVs while the PR of CAVs was 43% (Mixed scenario). The objective was to compare the car-following and critical THWs (THW ≤ 3 s and THW ≤ 1.5 s respectively) and lane change gaps in mixed scenario with Base when there were no CAVs around (representative of the current situation) with the same traffic flow per lane as the Mixed scenario. LMM compared the THWs in both situations and revealed that there is no significant difference in car-following THWs between the two scenarios. This shows that the few number of platoons which were scarce on the freeway did not influence the car-following behaviour of MV drivers. Regarding the lane change gaps, the comparison of Base and Mixed scenario showed that no significant changes happened in on-ramp and off-ramp gaps when driving next to few platoons for a short time.

In fact the exposure time (the time when the ego vehicle was driving next to a platoon) was too short to influence the behaviour of MV drivers (Gouy et al., 2014). Moreover, in the current experiment the number of platoons and the platoon size were kept very low to represent the PR of 43%. So, the conspicuity of the platoons was not high enough to influence the car-following and lane changing behaviour of MV drivers. This confirms the conclusions obtained by Gouy et al. which indicated that exposure time and conspicuity of platoons are important factors in behavioural adaptation of MV drivers (Gouy et al., 2014). They also indicated that there was no carry over effect in behavioural adaptation from the situation when car-following happened next to platoons keeping short THW (0.3 s) to long THW (1.4 s). This supports the fact that driving next to a platoon for a few seconds cannot influence the car-following behaviour for the entire drive.

On the other hand, considering the keep right manoeuvres, LMM revealed that merging gaps decreased significantly in Mixed scenario compared to Base. Keep right gaps were not significantly different between DL and Mixed scenario. However, because Base was always the first scenario to drive, the participants might have gotten used to the simulator environment and feel more comfortable to accept shorter gaps when they drove in Mixed and DL scenarios.

4.2. Behavioural adaptation when driving next to dedicated lanes:

The second expectation stated that with concentrating CAV platoons on one lane (the DL), the car-following THWs (Expectation 2a) and lane change gaps (Expectation 2b) will decrease significantly due to behavioural adaptation. To test this expectation, participants were asked to drive on a freeway with one dedicated lane to CAV platoons. The comparison between Base and DL scenario showed that MV drivers significantly decreased their car-following THW and critical THW in DL scenario, especially when they were driving on the lane adjacent to DL where platoons drive. In fact, when platoons were concentrated on one lane, their exposure time and conspicuity was increased to the extent that it influenced the car-following behaviour of MV drivers. This is in line with the results of previous experiment when participants were asked to drive next to continuous access DL and limited access DL with buffer (Schoenmakers et al., 2021). This also confirms the other two experiments of Gouy et al. with no dedicated lane (Gouy et al., 2013; Gouy et al., 2014). Although there was no dedicated lane proposed in those experiments, the fast lane of the freeway was in practice used as a dedicated lane since all CAVs were driving on that lane.

It has been concluded from a previous study that MV drivers tend to show more "radical behaviour" by greater steering magnitude and steering velocity when they change lanes into a CAV lane (Lee, Oh, & Hong, 2018). Similarly, in this study, it appeared that MV drivers accept shorter gaps when changing lane for on-ramps, off-ramps and keep right manoeuvres (Expectation 2b confirmed). Given that the traffic flows were equal per lane for all scenarios, accepting smaller gaps could be a result of imitating the behaviour of CAVs and is unlikely to be affected by the offered gaps in traffic.

4.3. Behavioural adaptation and the impacts of demographics and driving style:

Expectation 3 indicated that participants' demographics and driving styles play important roles in behavioural adaptation in car-following and lane changing. The results of LMM for car-following THW showed that male drivers follow their leaders keeping smaller THWs. This is in line with the results from the literature which revealed a positive correlation between being a male driver and close car-following (Rajalin et al., 1997). However, gender impact was not seen in critical THWs.

Furthermore, driver education turned out to be a significant predictor in car-following behaviour. Drivers with high education followed their leaders with larger THWs in all scenarios and did not adapt their car-following behaviour in DL scenario even when they drove on the lane adjacent to CAV platoons. This can be explained by the fact that people with higher education usually are more aware of the new technologies and may be more familiar with CAV behaviour and can distinguish the difference between CAVs and own capabilities in relation to close car-following. Moreover, some of the participants with higher education who participated in the experiment were students of the same department who worked directly in the fields related to CAVs.

Finally, younger drivers kept smaller THWs in car-following. This is in line with the findings of Rajalin et al. which showed that younger drivers tend to follow their leader more closely (Rajalin et al., 1997). Moreover, examining the interaction between age and scenario revealed that older drivers adapt their behaviour more than younger ones when driving on a highway with a dedicated lane to CAV platoons. This was shown by a significant (at 10% level) decrease in car-following THW in DL scenario compared to the other two scenarios. However, this decrease was not seen in critical THW which shows that unwanted behavioural adaptation may occur to older drivers in car-following but not to the extend which leads to risky behaviour (at least at moderate PRs of CAVs). Thus research on the impacts of age on behavioural adaptation is recommended to further support these results.

Furthermore, driving style did not influence the behavioural adaptation of MV drivers in car-following and lane changing. Similar findings can be seen in the study of Hoedemaeker & Brookhuis (1998) which revealed that driving style made little difference to the behavioural adaptation of drivers. This may indicate that other factors like the infrastructure, exposure time, and conspicuity of the CAV platoons in addition to driving style, determine the behaviour of drivers in car-following and lane changing.

5. Conclusions and future work

This study investigated the behavioural adaptation of drivers of MVs in car-following and lane changing when driving in a mixed traffic with CAV platoons as well as driving on separate lanes but adjacent to the CAV dedicated lane at a moderate PR (43%). Based on the results, MV drivers are not likely to adapt their behaviour in car-following and lane changing in mixed traffic situation at moderate PR of CAVs. However, at the same PR, implementing a DL would increase the density of CAVs on one lane and consequently increases the exposure time and conspicuity of CAV platoons. So, MV drivers could see the CAV platoons keeping very short THWs more often. This leads to a situation where MV drivers tend to imitate the behaviour of CAV platoons by following a lead car more closely and accepting shorter gaps in lane changing.

Behavioural adaptation is not necessarily considered negative as long as it is not leading to risky manoeuvres which a human driver is not able to control. In fact, adopting shorter THWs (in manageable range by a human) in car-following could increase the capacity of a freeway. So, if MVs are equipped with systems such as collision avoidance to avoid close car-following by the time we accommodate CAV platoons on our road network, risky manoeuvres can be avoided. However, it requires time and budget to replace the entire vehicle fleet with vehicles equipped with collision avoidance systems. This way we can avoid the potential unsafe consequences of behavioural adaptation and exploit the smoothness of the traffic flow generated by CAVs.

This study further gave insights regarding the impacts of demographics and driving styles of MV drivers on their behavioural adaptation. Age, gender, and education turned out to be significant factors in car-following as expected based on literature. More interestingly, it was observed that older drivers are more prone to behavioural adaptation in car-following but not to the extend which leads to critical or risky behaviour. Moreover, drivers with higher education showed no behavioural adaptation when driving next to CAV platoons. This could be because of their higher information regarding CAV technology. Therefore, it would also be important to investigate whether human drivers still imitate the behaviour of CAVs after they are educated about the differences between human driver and CAV capabilities.

Due to both technical and ethical reasons, it was not possible to perform a field test, therefore, a virtual reality environment was used to investigate the study research question. This brings along questions regarding real-world behavioural adaptation of MV drivers. Therefore, future pilot field tests would be needed to validate the results. Moreover, behavioural adaptation was measured over a limited time and at only one PR (43%). Thus, future research is needed on the long-term effects of behavioural adaptation and at different PRs.

CRediT authorship contribution statement

Solmaz Razmi Rad: Conceptualization, Methodology, Investigation, Software, Formal analysis, Data curation, Writing – original draft. **Haneen Farah:** Methodology, Supervision, Writing – review & editing, Funding acquisition, Project administration. **Henk Taale:** Methodology, Supervision, Writing – review & editing, Funding acquisition. **Bart Arem:** Supervision, Writing – review & editing. **Serge P. Hoogendoorn:** Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

This study was funded by Rijkswaterstaat (part of the Dutch Ministry of Infrastructure and Water Management and responsible for the design, construction, management, and maintenance of the main infrastructure facilities in the Netherlands), grant agreement n. 31137019, under the label of ITS Edulab.

References

Bener, A., & Crundall, D. (2008). Role of gender and driver behaviour in road traffic crashes. *International Journal of Crashworthiness, 13*(3), 331–336. https://doi.org/10.1080/13588260801942684.

Fagnant, D. J., & Kockelman, K. (2015). Preparing a nation for autonomous vehicles: Opportunities, barriers and policy recommendations. *Transportation Research Part A: Policy and Practice, 77*, 167–181. https://doi.org/10.1016/j.tra.2015.04.003.

Farah, H. (2011). Age and Gender Differences in Overtaking Maneuvers on Two-Lane Rural Highways. *Transportation Research Record: Journal of the Transportation Research Board, 2248*(1), 30–36. https://doi.org/10.3141/2248-04.

Farah, H., Bekhor, S., Polus, A., & Toledo, T. (2009). A passing gap acceptance model for two-lane rural highways. *Transportmetrica, 5*(3), 159–172. https://doi.org/10.1080/18128600902721899.

Gouy, M., Diels, C., Reed, N., Stevens, A., & Burnett, G. (2013). Do drivers reduce their headway to a lead vehicle because of the presence of platoons in traffic? A conformity study conducted within a simulator. *IET Intelligent Transport Systems, 7*(2), 230–235. https://doi.org/10.1049/itr2.v7.210.1049/iet-its.2012.0156.

Gouy, M., Wiedemann, K., Stevens, A., Brunett, G., & Reed, N. (2014). Driving next to automated vehicle platoons: How do short time headways influence non-platoon drivers' longitudinal control? *Transportation Research Part F: Traffic Psychology and Behaviour., 27*, 264–273. https://doi.org/10.1016/j.trf.2014.03.003.

Grontmij. (2015). Capaciteitswaarden Infrastructuur Autosnelwegen, 149. Retrieved from http://publicaties.minienm.nl/documenten/capaciteitswaarden-infrastructuur-autosnelwegen-versie-4-handboek-cia-versie-4.

Hoedemaeker, M., & Brookhuis, K. A. (1998). Behavioural adaptation to driving with an adaptive cruise control (ACC). *Transportation Research Part F: Traffic Psychology and Behaviour, 1*(2), 95–106. https://doi.org/10.1016/S1369-8478(98)00008-4.

Ivanchev, J., Knoll, A., Zehe, D., Nair, S., & Eckhoff, D. (2017). Potentials and Implications of Dedicated Highway Lanes for Autonomous Vehicles, 1–12. *Retrieved from*. http://arxiv.org/abs/1709.07658.

Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness. *The International Journal of Aviation Psychology, 3*(3), 203–220. https://doi.org/10.1207/s15327108ijap0303_3.

Kennedy, R., Stanney, K., Harm, D., Compton, D., Lanham, D., & Drexler, J. (2003). Con.gural Scoring of Simulator Sickness, Cybersickness and Space Adaptation Syndrome. In Virtual and Adaptive Environments (pp. 247–278). https://doi.org/10.1201/9781410608888.ch12.

Kockelman, K., Avery, P., Bansal, P., Boyles, S. D., Bujanovic, P., Choudhary, T., … Stewart, D. (2016). Implications of Connected and Automated Vehicles on the Safety and Operations of Roadway Networks: A Final Report Implications of Connected and Automated Vehicles on the Safety and Operations of Roadway Networks: A Final Report. Fhwa/Tx-16/0-6849-1, 7. https://doi.org/FHWA/TX-16/0-6849-1.

Laird, N. M., & Ware, J. H. (1982). Random-Effects Models for Longitudinal Data. *Biometrics, 38*(4), 963. https://doi.org/10.2307/2529876.

Lee, Seolyoung, Oh, Cheol, & Hong, Sungmin (2018). Exploring lane change safety issues for manually driven vehicles in vehicle platooning environments. *IET Intelligent Transport Systems, 12*(9), 1142–1147. https://doi.org/10.1049/itr2.v12.910.1049/iet-its.2018.5167.

Lumiaho, A., & Malin, F. (2016). Road Transport Automation Road Map and Action Plan 2016–2020, https://www.doria.fi/bitstream/handle/10024/123375/lts_2016-19eng_978-952-317-263-0.pdf?sequence=4. Retrieved from https://julkaisut.liikennevirasto.fi/pdf8/lts_2016-19eng_road_transport_web.pdf.

Madadi, Bahman, Van Nes, Rob, Snelder, Maaike, Van Arem, Bart, & Keyvan-Ekbatani, Mehdi (2021). Optimizing Road Networks for Automated Vehicles with Dedicated Links, Dedicated Lanes, and Mixed-Traffic Subnetworks. *Journal of Advanced Transportation, 2021*, 1–17. https://doi.org/10.1155/2021/8853583.

McDonald, S. S., & Rodier, C. (2015). Envisioning Automated Vehicles within the Built Environment: 2020, 2035, and 2050 (pp. 225–233). Springer, Cham. https://doi.org/10.1007/978-3-319-19078-5_20.

Milakis, D., Snelder, M., Arem, B. Van, Wee, B. Van, & Correia, G. H. D. A. (2015). Development and transport implications of automated vehicles in the Netherlands: scenarios for 2030 and 2050. European Journal of Transport & Infrastructure Research, in press(1), 63–85. Retrieved from http://pure.tudelft.nl/ws/files/11926128/2017_01_03.pdf.

Next Generation Simulation: US101 Freeway Dataset. (2007). Retrieved April 26, 2021, from https://ops.fhwa.dot.gov/trafficanalysistools/ngsim.htm.

Pasanen, E., & Salmivaara, H. (1993). Driving speeds and pedestrian safety in the City of Helsinki. *Traffic Engineering and Control, 34*(6), 308–310.

Rahmati, Y., Khajeh Hosseini, M., Talebpour, A., Swain, B., & Nelson, C. (2019). Influence of Autonomous Vehicles on Car-Following Behavior of Human Drivers. *Transportation Research Record: Journal of the Transportation Research Board, 2673*(12), 367–379. https://doi.org/10.1177/0361198119862628.

Rajalin, S., Hassel, S. O., & Summala, H. (1997). Close-following drivers on two-lane highways. *Accident Analysis and Prevention, 29*(6), 723–729. https://doi.org/10.1016/S0001-4575(97)00041-9.

Razmi Rad, Solmaz, Farah, Haneen, Taale, Henk, van Arem, Bart, & Hoogendoorn, Serge P. (2020). Design and operation of dedicated lanes for connected and automated vehicles on motorways: A conceptual framework and research agenda. *Transportation Research Part C: Emerging Technologies, 117*, 102664. https://doi.org/10.1016/j.trc.2020.102664.

Razmi Rad, S., de Almeida, Homem, Correia, G., & Hagenzieker, M. (2020). Pedestrians' road crossing behaviour in front of automated vehicles: Results from a pedestrian simulation experiment using agent-based modelling. *Transportation Research Part F: Traffic Psychology and Behaviour, 69*, 101–119. https://doi.org/10.1016/j.trf.2020.01.014.

SAE. (2018). Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles. Retrieved from https://www.sae.org/standards/content/j3016_201806/ https://www.sae.org/standards/content/j3016_201806/.

Schoenmakers, M., Yang, D., & Farah, H. (2021). Car-following behavioural adaptation when driving next to automated vehicles on a dedicated lane on motorways: A driving simulator study in the Netherlands. *Transportation Research Part F: Traffic Psychology and Behaviour, 78*, 119–129. https://doi.org/10.1016/j.trf.2021.01.010.

Seabold, S., & Perktold, J. (2010). Statsmodels: Econometric and Statistical Modeling with Python. *PROC. OF THE 9th PYTHON IN SCIENCE CONF. Retrieved from*.

Shladover, S. E. (2005). Automated vehicles for highway operations (automated highway systems). Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering, 219(1), 53–75. https://doi.org/10.1243/095440705X9407.

Taubman-Ben-Ari, O., Mikulincer, M., & Gillath, O. (2004). The multidimensional driving style inventory - Scale construct and validation. *Accident Analysis and Prevention, 36*(3), 323–332. https://doi.org/10.1016/S0001-4575(03)00010-1.

Taubman – Ben-Ari, Orit, Eherenfreund – Hager, Ahinoam, & Prato, Carlo Giacomo (2016). The value of self-report measures as indicators of driving behaviors among young drivers. *Transportation Research Part F: Traffic Psychology and Behaviour, 39*, 33–42. https://doi.org/10.1016/j.trf.2016.03.005.

TRB. (2010). Highway Capacity Manual 2010 (HCM2010) | Blurbs New | Blurbs | Main. Retrieved from http://www.trb.org/Main/Blurbs/164718.aspx.

Tsao, H. S. J., Hall, R., & Hongola, B. (1995). Capacity Of Automated Highway Systems: Effect Of Platooning And Barriers. https://escholarship.org/uc/item/53h589sb.

Van Arem, B., Van Driel, C.J.G., Visser, R. (2006). The impact of Cooperative Adaptive Cruise Control on traffic flow characteristics. Intelligent Transportation Systems, IEEE, 7(4), 429–436.

Vander Laan, Z., & Sadabadi, K. F. (2017). Operational performance of a congested corridor with lanes dedicated to autonomous vehicle traffic. *International Journal of Transportation Science and Technology, 6*(1), 42–52. https://doi.org/10.1016/j.ijtst.2017.05.006.

Wang, X., Yang, M., & Hurwitz, D. (2019). Analysis of cut-in behavior based on naturalistic driving data. *Accident Analysis and Prevention, 124*(January), 127–137. https://doi.org/10.1016/j.aap.2019.01.006.

Williams, B., Onsman, A., & Brown, T. (2010). Exploratory factor analysis: A five-step guide for novices. *Journal of Emergency Primary Health Care, 8*(3), 42–50. https://doi.org/10.1080/09585190701763982.

Witmer, B. G., Jerome, C. J., & Singer, M. J. (2005, June 13). The factor structure of the Presence Questionnaire. Presence: Teleoperators and Virtual Environments. MIT Press 238 Main St., Suite 500, Cambridge, MA 02142-1046 USA journals-info@mit.edu . https://doi.org/10.1162/105474605323384654.

Xiao, Lin, Wang, Meng, & van Arem, Bart (2020). Traffic Flow Impacts of Converting an HOV Lane into a Dedicated CACC Lane on a Freeway Corridor. *IEEE Intelligent Transportation Systems Magazine, 12*(1), 60–73. https://doi.org/10.1109/MITS.511764510.1109/MITS.2019.2953477.

Yang, M., Wang, X., & Quddus, M. (2019). Examining lane change gap acceptance, duration and impact using naturalistic driving data. *Transportation Research Part C: Emerging Technologies, 104*(April), 317–331. https://doi.org/10.1016/j.trc.2019.05.024.