Investigating drivers’ car-following behaviour after automated driving

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Tyron Louw
Mina Torrao
Rafael Goncalves
Rafael Goncalves
Vishnu Radhakrishnan
Natasha Merat

Pablo Puente Guillen
Jorge Lorente Mallada

Study aim

- Investigate if the time headway adopted by an automated vehicle during car-following situations influences driver behaviour in subsequent manual driving.

We investigated the effect of:

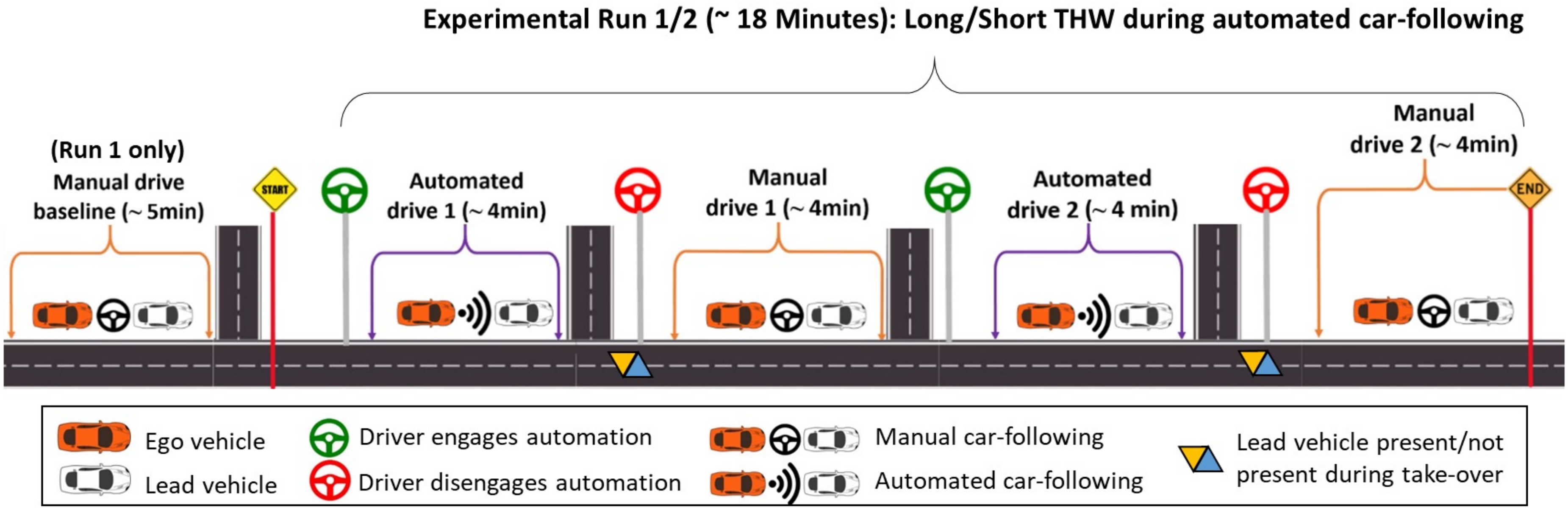
- Level of automation
- Time headway in automation

ON:

Driver behaviour and state

- During automation
- During take-overs
- During subsequent car-following

Experimental order



2-lane urban road with low-density oncoming traffic
(no traffic in own lane except in car-following situation)

Condition: Level of automation

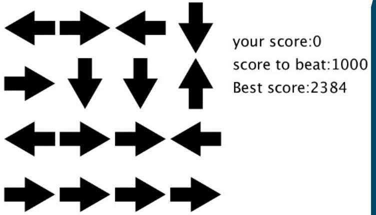
Separate groups

Level 2

Level 3

L2: Looked up and around

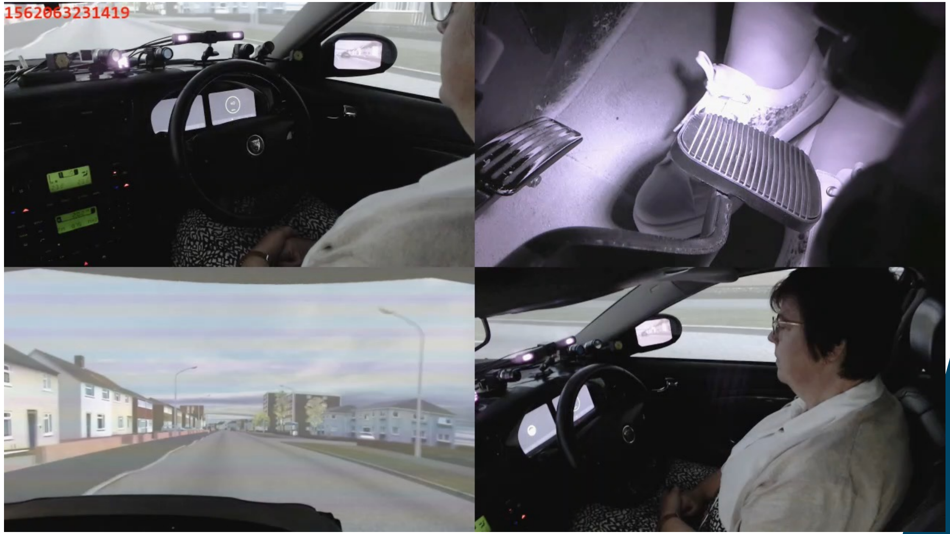
L3: Visual search task (Arrows task)



Condition: Take-over type

Will catch up to a lead vehicle to follow

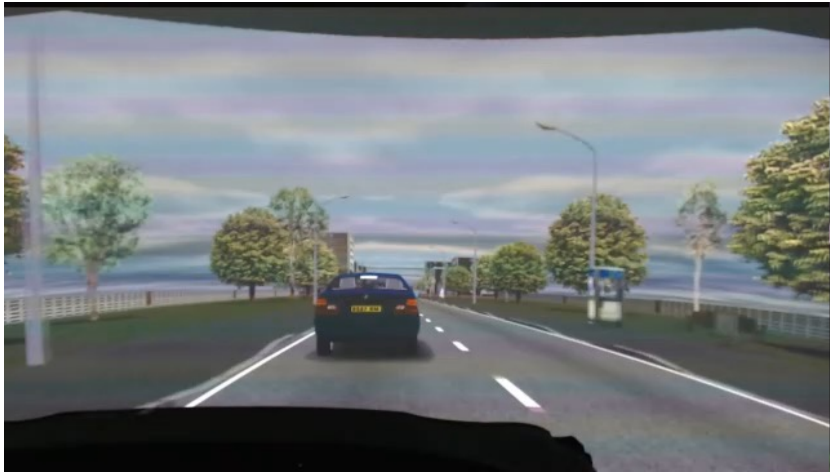
With lead vehicle | **Without lead vehicle**



Non-critical take-overs due to faded road markings

Condition: Time headway during automation

Short: 0.5 s



Long: 1.5 s

Research Questions

1. Do drivers change their car-following behaviour in manual driving after experiencing car-following in automated driving?
   i. Is this influenced by the time headway adopted by the automated driving system?
   ii. Is this influenced by engaging in a visual non-driving task during automation?
   iii. Is this influenced by whether drivers resume control in the presence of a lead vehicle?

Participant demographics

- 28 participants:
  - Average age of 39 years (SD=14)
  - Gender: 68% Males and 32% Females
  - Average miles travelled annually: 8922 (SD=6439)
  - Average years of driving experience: 18 (SD=13)

What is the impact of ADF use on **manual driving behaviour**?

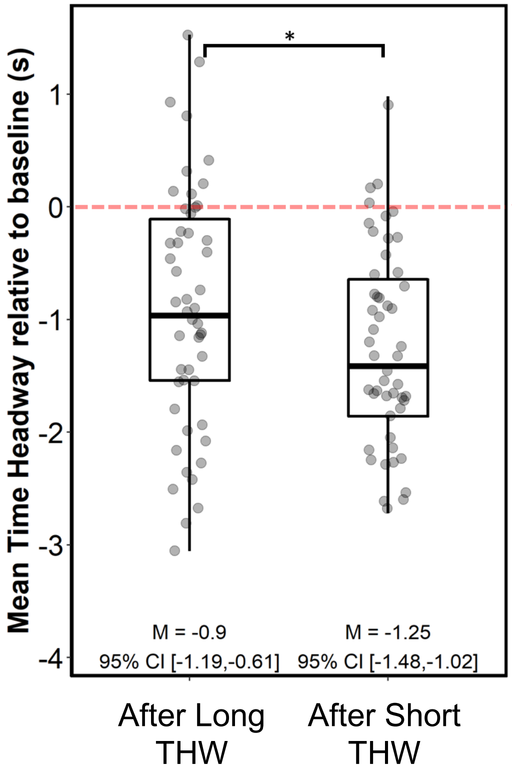
- Drivers **reduced** their **time headway** after experiencing automation, across all conditions.

- Standard deviation of time headway was also **lower after automation**.

- Drivers **adapt THW** after the first automated drive and repeat similar behaviour after the second automated drive.

What is the impact of ADF use on **manual driving behaviour**?

- There was a greater **reduction** in THW after they had experienced a short (0.5 s) THW during automated car following.
- Whether drivers were in L2 or L3 did not appear to influence the change in mean THW.



Mean Baseline Manual THW: 4 s

4 s THW is higher than real-world values, but the focus is on relative differences between conditions

Subjective responses

- Drivers' evaluation of the **system's** behaviour:
  - 0.5 s (short) THW during automation was generally **perceived to be unsafe.**
  - 1.5 s (long) THW during automation was **generally acceptable** to drivers.
  - No differences between those in L2 and L3 conditions.

Example of Likert scale

		Strongly agree	Agree	Neutral	Disagree	Strongly disagree
		1	2	3	4	5
CDB01	During the automated drive, the system kept a safe distance from the car in front.					

Subjective responses

- Drivers’ evaluation of their **own** behaviour:
  - **No major differences** between L2 and L3.
  - Generally, drivers were **neutral** about whether their **behaviour changed** after experiencing automation.
  - Drivers in the short THW condition during automation did not think they kept the same headway as in automation.

Example of Likert scale

		Strongly agree	Agree	Neutral	Disagree	Strongly disagree
		1	2	3	4	5
CDB01	During the automated drive, the system kept a safe distance from the car in front.					

L3Pilot Driving Automation

Evaluation

Outlook

- The system in use should be designed in a way that **limits negative behavioural adaptation**.

  e.g. system should adopt a more conservative THW.

- Drivers should receive explicit **training** about the potential effects that automation use may have on their manual driving.

  e.g. warn drivers that their THW might shorten after using automation.

- Drivers should be **warned** when their behaviour exceeds certain safe boundaries of operation.

  e.g. warn drivers during manual driving that their THW has shortened compared to either their normal driving style or a safe standard.

Comparing an Ambient Light HMI and Auditory HMI in Automated Driving

UNIVERSITY OF LEEDS

Tyron Louw
Yee Mun Lee
Ruth Madigan
Natasha Merat

Cinzia De Marco
Jorge Lorente Mallada

Study aims

The aim of this study was to evaluate whether, compared to an Auditory HMI, an ambient peripheral light display (Lightband HMI) can:

1. Improve drivers' trust in L3 automated driving.
2. Facilitate effective transitions of control.

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TOYOTA

L3Pilot Driving Automation

Co-funded by the European Union

Take-over response: Drivers' hands-on-wheel time and automation disengagement time

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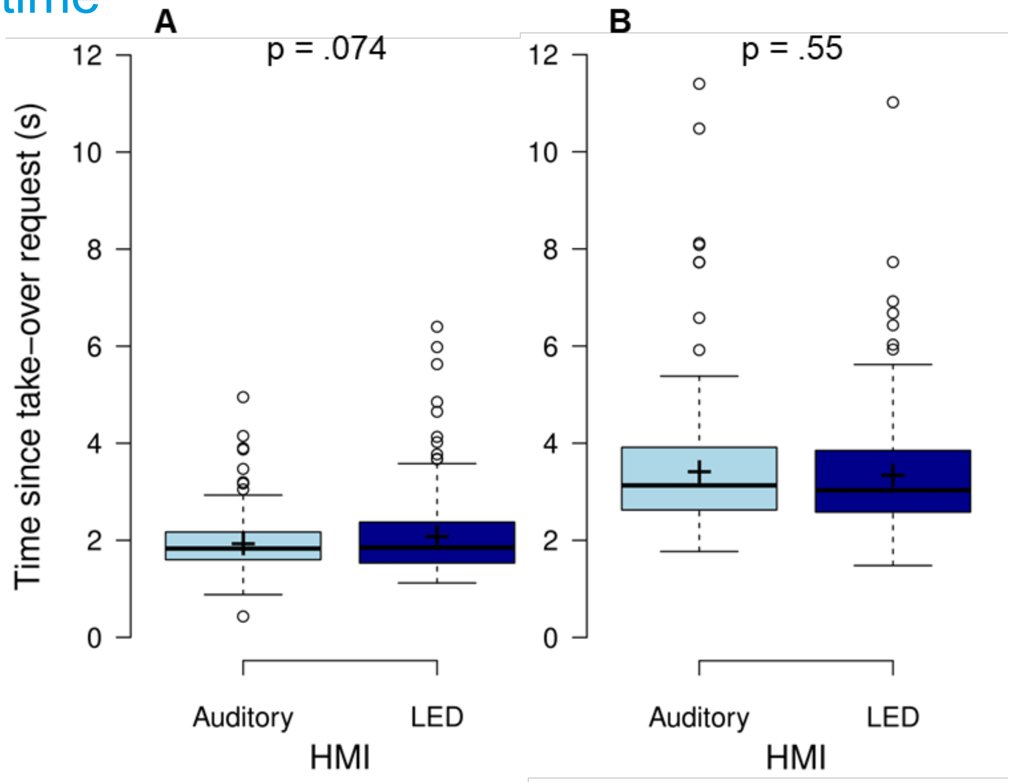
- During the take-overs, participants had marginally **faster hands-on wheel time** when using the Auditory HMI, compared to the Lightband HMI.

- However, there was **no difference** in terms of **automation disengagement** time.



Time taken from when take-over request was issued to A) both hands on wheel, and B) automation disengagement, for each HMI.

Drivers’ ratings of safety, trust, and HMI acceptance

- Slightly more participants preferred the Auditory HMI, but tended to prefer the HMI they experienced first.
- Overall, participants **trusted the vehicle to drive safely** while they did the Arrows task, but there was no difference between HMIs.
- Overall, participants **felt safe during automated driving**, but there was no significant difference between HMIs.
- The van der Laan scale results showed that participants rated the **Auditory HMI as significantly more useful** compared to the Lightband HMI, though **no more satisfying**.

Conclusions

- Neither HMI **improved drivers' perception of safety or trust** in the automated driving system during automation, compared to their baseline ratings.
- The **Auditory HMI may be slightly more effective** in terms of encouraging people to re-take control from L3 automation.
- **More research** incorporating different types of take-over requests is required to gain a further understanding of this issue.
- Further analysis required to understand whether Lightband HMI improves comfort and trust during automated driving.

Full paper links

1. Louw, T., Goncalves, R., Torrao, G., Radhakrishnan, V., Lyu, W., Guillen, P. P., & Merat, N. (2020). Do drivers change their manual car-following behaviour after automated car-following?. Cognition, Technology & Work, 1-15.
2. Gonçalves, R., Lyu, W., Torrão, G., Puente Guillen, P., Louw, T., & Merat, N. (2020). Development of an algorithm to identify stabilisation time for car-following after transitions of control from vehicle automation. 12th International Conference on Methods and Techniques in Behavioral Research. Krakow, Poland, October 15-18 2021.
3. Lyu, W., Gonçalves, R., Guo, F., Torrão, G., Radhakrishnan, V., Puente Guillen, P., ... & Merat, N. (2020). Applying Entropy to Understand Drivers' Uncertainty during Car-following. 12th International Conference on Methods and Techniques in Behavioral Research. Krakow, Poland, October 15-18 2021.
4. Louw, T., Madigan, R., Lee, Y. M., De Marco, C., Mallada, J. L., & Merat, N. (2021, September). Don't Worry, I'm in Control! Is Users' Trust in Automated Driving Different When Using a Continuous Ambient Light HMI Compared to an Auditory HMI?. In 13th Int

Full results reported in Deliverable 7.2