The influence of cognitive load on driver performance in automated driving contexts: a scoping review in progress

Hao Qin[1], Natasha Merat[1], Rafael Cirino Gonçalves[1]
[1] Institute for Transport Studies, University of Leeds

UNIVERSITY OF LEEDS
Correspondence: tshq@leeds.ac.uk

DDI2024 MICHIGAN

Introduction

- Typically, **cognitive distraction** occurs when drivers divert their cognitive resources away from driving to competing activities, while **cognitive load** refers to the amount of cognitive resources demanded from drivers by activities[1,2]
- The **influence of cognitive load caused by non-visual-manual activities** (e.g., hands-free phone call) on driver performance has aroused much debate.
- Research on manual driving suggests that cognitive load impairs driver performance relying on **cognitive control**, but leaves **automatic performance** unaffected[2]
- The influence of **cognitive load** on driver performance in the automated driving context is less understood and there lacks a review of available literature.

Objectives

- Identify the **gap** within the literature about the influence of cognitive load on driver performance in the automated driving context.
- Focus on drivers' **attention and takeover performance** in SAE **Level 2** and **Level 3** automation context[3].

Methods

Database Searching

- Follow the guidance for conducting systematic scoping reviews[4]
- **Database** (Jan-May 2024) **-** Scopus, IEEE Xplore, ACM Digital Library, and SAE Mobilus
- **Search terms** (in title, abstract and keywords) - *("Automation" OR "" Automated" OR "Autopilot" OR "Autonomous) AND ("Driving" OR "Driver") AND ("Cognitive" OR "Mental") AND ("Load" OR "Workload" OR "Distraction" OR "Demand")*
- **Requirements** - peer reviewed journal article, conference paper and technical paper, written in English and without year limit.

Methods

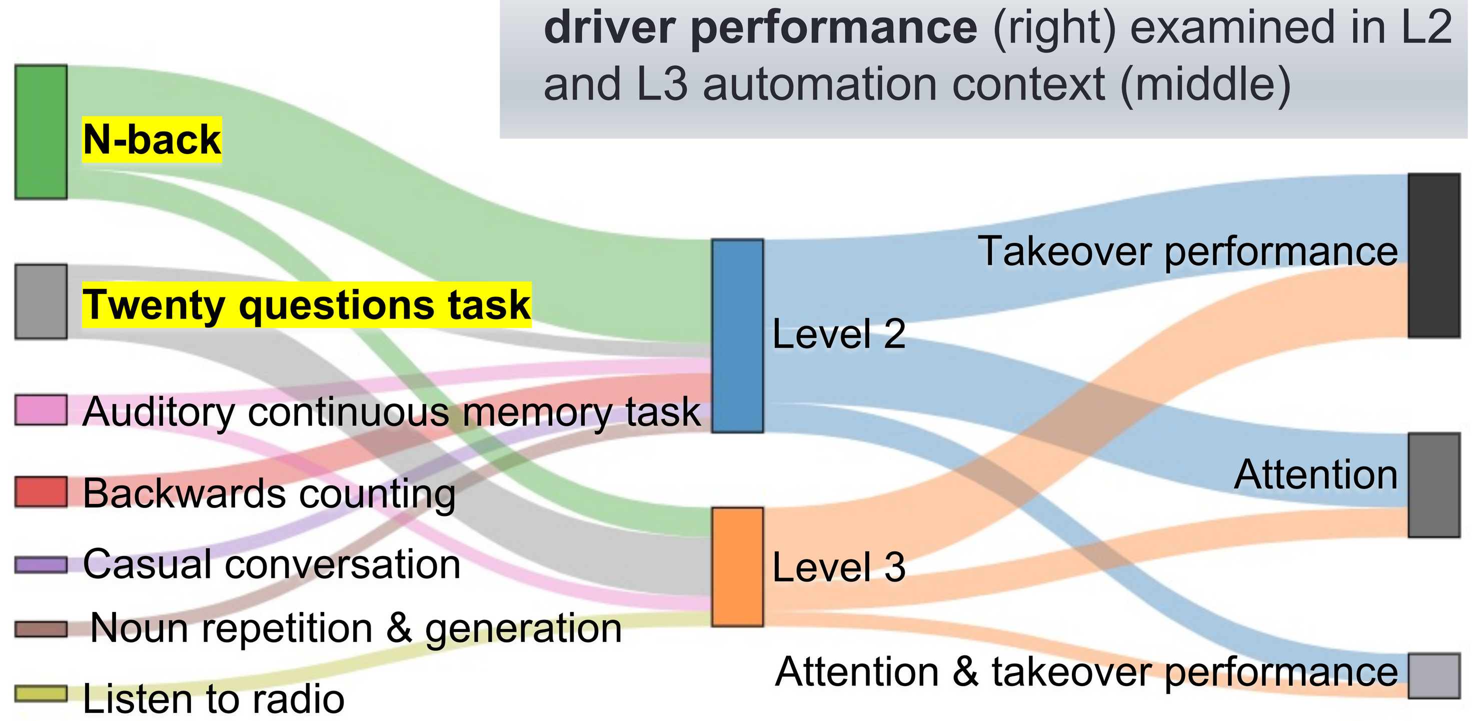
Inclusion Criteria	Exclusion Criteria
I. Analysis of **human participant data**	I. Review, work in progress, theoretical paper etc.
II. Focus on **SAE L2 or L3** automation	II. Focus on manual driving, UAV, other automation etc.
III. Focus on the **impact of cognitive load** (as independent variable)	III. Consider cognitive load as dependent variable (e.g., interface assessment)
IV. Focus on cognitive load from **non-visual-manual** tasks	IV. Examine cognitive load of visual-manual task
V. Compare conditions with and without cognitive load	V. No comparison with no-cognitive load baseline
VI. Focus on drivers' **attention and takeover performance**	VI. Focus on subjective measurements etc.

Review Process

Identification	Screen & Eligibility		Included
Records identified through **database searching** Scopus(n=505), IEEE (n=471), ACM (n=131), SAE (n=93)	Records after **duplicates** removed (n=1076)	Records screened and assessed for **eligibility** (n=1076)	Literature **included** (n=20)

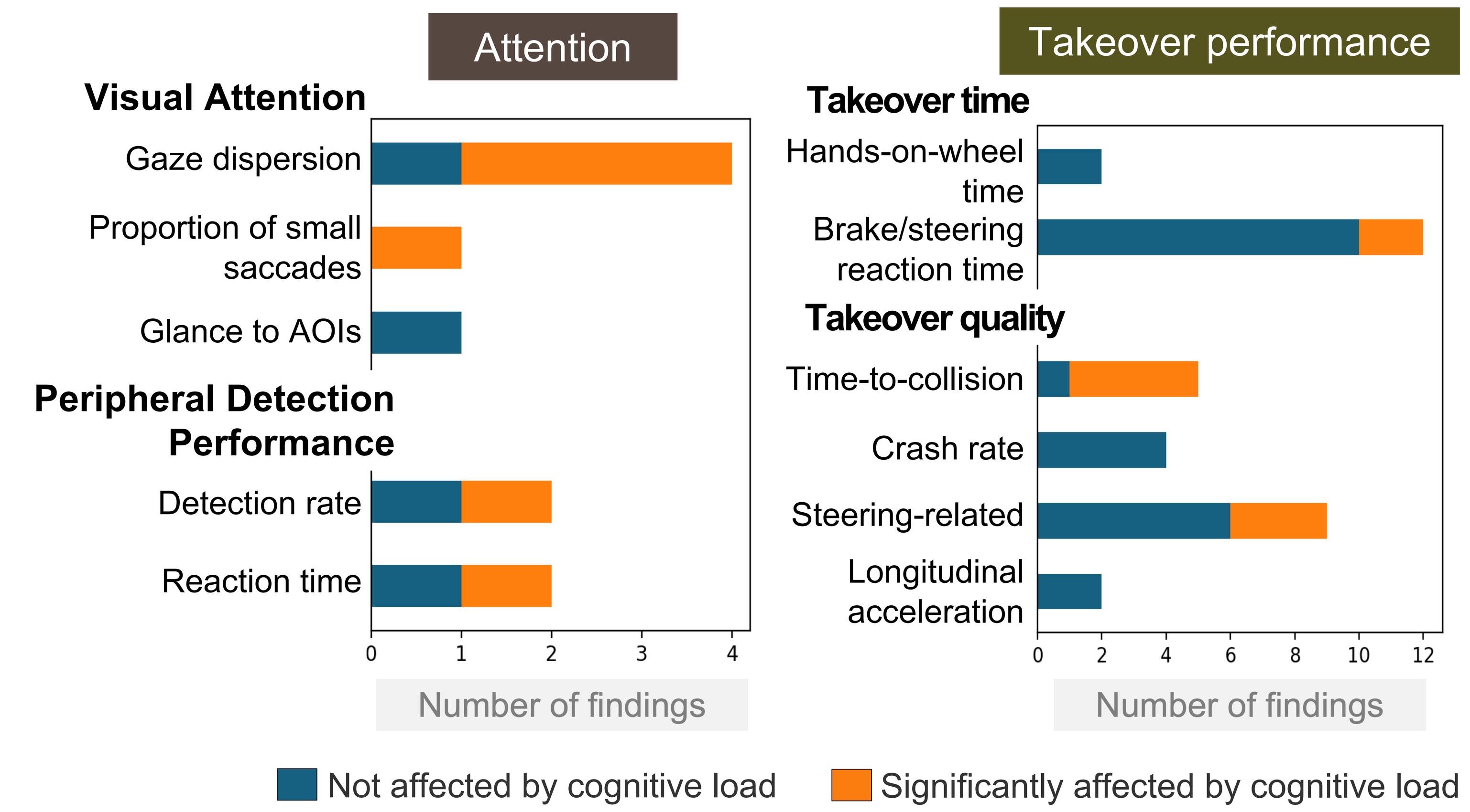
Results

Cognitive load task (left) employed and **driver performance** (right) examined in L2 and L3 automation context (middle)



* The width of the bands represents the amount of relevant literature.

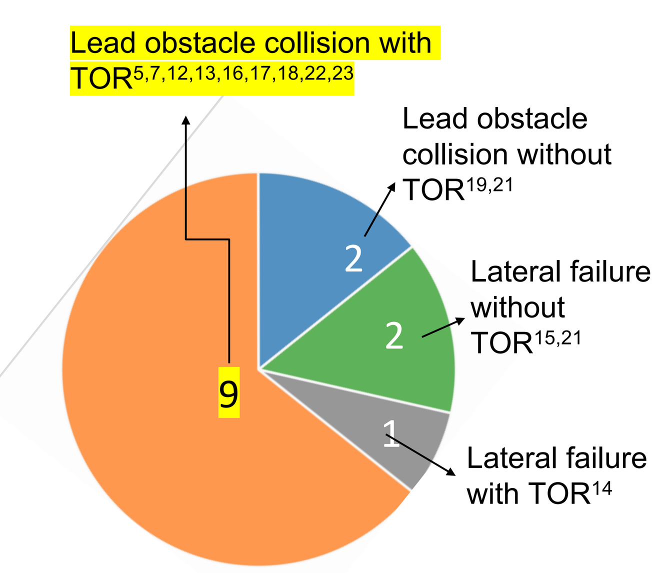
Results & Conclusions



- Cognitive load **narrows drivers' visual attention**[5,6,7] and **impairs detection of peripheral targets**[8,9,10] during automated driving.
- Cognitive load causes **lower TTC**[7,11,12] and **reduced steering response**[13,14,15] during takeover (e.g., the standard deviation and maximum value of steering wheel angle become lower)
- Cognitive load barely affects reaction time[5,7,12,13,15,16,17,18,19,20], longitudinal / lateral acceleration[7,11] and crash rate[7,12,15,21] during takeover.

Research opportunity

- Takeover scenario focused on **lead obstacle collision with takeover request (TOR)**, which is likely to induce automatic reaction and may underestimate the influence of cognitive load[2]
- More research in different takeover scenarios is warranted (e.g., silent failure without TOR, overtaking scenario)



Takeover scenario employed

Acknowledgement

- The first author is funded by a China Scholarship Council-University of Leeds Joint Scholarship.

References

1. Engström, J., Monk, C. A., Hanowski, R. J., Horrey, W. J., Lee, J. D., McGehee, D. V., Regan, M., Stevens, A., Traube, E., Tuukkanen, M., Victor, T., & Yang, C. Y. D. (2013). A conceptual framework and taxonomy for understanding and categorizing driver inattention. European Commission. Directorate General for Communications Networks, Content & Technology.
2. Engstrom, J., Markkula, G., Victor, T., & Merat, N. (2017). Effects of cognitive load on driving performance: The cognitive control hypothesis. Human Factors, 59(5), Article 5.
3. SAE International. (2021). Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles.
4. Peters, M. D. J., Godfrey, C. M., Khalil, H., McInerney, P., Parker, D., & Soares, C. B. (2015). Guidance for conducting systematic scoping reviews. International Journal of Evidence-Based Healthcare, 13(3), 141–146.
5. Wu, Y., Kihara, K., Takeda, Y., Sato, T., Akamatsu, M., & Kitazaki, S. (2019). Assessing the Mental States of Fallback-Ready Drivers in Automated Driving by Electrooculography. 2019 IEEE Intelligent Transportation Systems Conference (ITSC), 4018–4023.
6. Radlmayr, J., Fischer, F. M., & Bengler, K. (2019). The Influence of Non-driving Related Tasks on Driver Availability in the Context of Conditionally Automated Driving. Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018) (Vol. 823, pp. 295–304).
7. Gold, C., Körber, M., Lechner, D., & Bengler, K. (2016). Taking Over Control From Highly Automated Vehicles in Complex Traffic Situations: The Role of Traffic Density. Human Factors: The Journal of the Human Factors and Ergonomics Society, 58(4), 642–652.
8. Yang, S., Wilson, K., Roady, T., Kuo, J., & Lenné, M. G. (2022). Beyond gaze fixation: Modeling peripheral vision in relation to speed, Tesla Autopilot, cognitive load, and age in highway driving. Accident Analysis & Prevention, 171, 106670.
9. Van Winsum, W. (2019). Optic Flow and Tunnel Vision in the Detection Response Task. Human Factors, 61(6), 992–1003.
10. Heikoop, D. D., de Winter, J. C. F., van Arem, B., & Stanton, N. A. (2018). Effects of mental demands on situation awareness during platooning: A driving simulator study. Transportation Research Part F: Traffic Psychology and Behaviour, 58, 193–209.
11. Körber, M., Gold, C., Lechner, D., & Bengler, K. (2016). The influence of age on the take-over of vehicle control in highly automated driving. Transportation Research Part F: Traffic Psychology and Behaviour, 39, 19–32.
12. Choi, D., Sato, T., Ando, T., Abe, T., Akamatsu, M., & Kitazaki, S. (2020). Effects of cognitive and visual loads on driving performance after take-over request (TOR) in automated driving. Applied Ergonomics, 85, 103074.
13. Wilkie, R., Mole, C., Giles, O., Merat, N., Romano, R., & Makkula, G. (2019). Cognitive Load During Automation Affects Gaze Behaviours and Transitions to Manual Steering Control. Proceedings of the 10th International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design: Driving Assessment 2019, 426–432.
14. Mole, C., Pekkanen, J., Sheppard, W., Louw, T., Romano, R., Merat, N., Markkula, G., & Wilkie, R. (2020). Predicting takeover response to silent automated vehicle failures. PLOS ONE, 15(11), e0242825.
15. Guo, L., Xu, L., Ge, P., & Wang, X. (2023). How Resource Demands of Nondriving-Related Tasks and Engagement Time Affect Drivers' Physiological Response and Takeover Performance in Conditional Automated Driving. IEEE Transactions on Human-Machine Systems, 53(3), 600–609.
16. Louw, T., Madigan, R., Carsten, O., & Merat, N. (2017). Were they in the loop during automated driving? Links between visual attention and crash potential. Injury Prevention, 23(4), 281–286.
17. Louw, T., Madigan, R., Carsten, O., & Merat, N. (2017). Were they in the loop during automated driving? Links between visual attention and crash potential. Injury Prevention, 23(4), 281–286.
18. Lu, G., Zhai, J., Li, P., Chen, F., & Liang, L. (2021). Measuring drivers' takeover performance in varying levels of automation: Considering the influence of cognitive secondary task. Transportation research part F: traffic psychology and behaviour, 82, 96-110.
19. Merat, N., Jamson, A. H., Lai, F. C. H., & Carsten, O. (2012). Highly Automated Driving, Secondary Task Performance, and Driver State. Human Factors: The Journal of the Human Factors and Ergonomics Society, 54(5), 762–771.
20. Müller, A. L., Fernandes-Estrela, N., Hetfleisch, R., Zecha, L., & Abendroth, B. (2021). Effects of non-driving related tasks on mental workload and take-over times during conditional automated driving. European Transport Research Review, 13(1), 16.
21. Lee, J., Hirano, T., Hano, T., & Itoh, M. (2019). Conversation during Partially Automated Driving: How Attention Arousal is Effective on Maintaining Situation Awareness. 2019 IEEE International Conference on Systems, Man and Cybernetics (SMC), 3718–3723.
22. Louw, T., Markkula, G., Boer, E., Madigan, R., Carsten, O., & Merat, N. (2017). Coming back into the loop: Drivers' perceptual-motor performance in critical events after automated driving. Accident Analysis & Prevention, 108, 9–18.
23. Meteier, Q., Capallera, M., De Salis, E., Angelini, L., Carrino, S., Abou Khaled, O., Mugellini, E., & Sonderegger, A. (2023). Effect of Obstacle Type and Cognitive Task on Situation Awareness and Takeover Performance in Conditionally Automated Driving. Proceedings of the 34th Conference on l'Interaction Humain-Machine, 1–12.
24. Janssen, C. P., van der Heiden, R. M. A., Donker, S. F., & Kenemans, J. L. (2019). Measuring susceptibility to alerts while encountering mental workload. Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications: Adjunct Proceedings, 415–420.
25. Xu, L., Guo, L., Ge, P., Wang, X., & Qin, Z. (2022). Effects of Non-Driving-Related Tasks with Different Resource Demands on Driver Gaze Behavior. 2022 IEEE 25th International Conference on Intelligent Transportation Systems (ITSC), 1440–1445.