

Investigating drivers' visual scanning patterns under different levels of driving automation across daytime and after dark driving environments

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EPSRC HAROLD project
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Introduction – Literature Background

After Dark Driving



- ↑ % of road traffic collisions (Fotios et al., 2021)
- One of the potential factors: **reduced visibility** in **after dark**, making it **more difficult** for drivers to **detect** and **interpret** relevant information from surrounding traffic environment (Wood, 2020)

Effects on visual scanning patterns when driving after dark

- Later hazard detection (Lee et al., 2026)
- ↓ distributions of fixations across driving scenes (Gruner & Ansorge, 2017)
- ↓ mirror checking (Urwyler et al., 2015)
- Potential compensatory behaviours: ↑ fixation durations to process visual inputs (Konstantopoulos et al., 2010; Urwyler et al., 2015)



Introduction – Differences between manual driving & L2 assisted driving



Manual Driving

Driver → Lateral & longitudinal control of the vehicle from **moment-to-moment basis**
SAE (2026)



- In the loop (Merat et al., 2019)
- Visuo-motor coordination (Land & Horwood, 1995; Wilkie & Wann, 2003)



L2 Assisted Driving

L2 assistance system → Lateral & longitudinal control of the vehicle

Driver → Monitor the driving environment & supervise the system
SAE (2026)
→ Take over manual control if needed to maintain safety



Changes in the driver's role influence how they monitor the driving environment!

- ↓ % of glance time towards road centre (Pipkorn et al., 2024)
- ↑ horizontal gaze dispersion (Louw & Merat, 2017)
- ↓ vertical gaze dispersion (Goncalves et al., 2020)

Research Gap & Research Questions

Research Gap:

- To date, studies on drivers' visual scanning patterns in L2 assisted driving have mainly used **motorway scenarios** and **daytime driving**
- **Urban driving** involves **more frequent peripheral hazards**, placing **greater demands** on visual attention
- **Freed-up resources** from operational control during L2 assisted driving may help **compensate** for the **increased demands** in **after dark urban driving**, but this remains **underexplored**

Research Questions:

1. How do visual scanning patterns differ across levels of driving automation and lighting conditions in a complex urban environment?
2. How does drivers' visual attention allocation towards different urban traffic differ across experimental conditions?
 - Behavioural Prediction Elements (BPEs) (Crundall et al., 2012)
 - Inanimate Objects (IOs)



BPEs



IOs



Participant & Experimental Design

Participant

- **44 participants (20 female; 24 male)** aged between 25 and 63 years old ($M = 40.23$; $SD = 11.19$)
- They are all regular UK drivers who held a **UK driving license** for at least 3 years
- Annual mileage ranged from **3000 to 18000 miles** ($M = 8125$; $SD = 3313$)



Experimental Design

- **2 X 2 within-participants design** (counterbalanced order)
- Participant drove along a two-lane urban roadway (speed limit = 30mph)
- The urban environment was populated with ambient traffic, placed equally on the **left** and **right** of the **periphery**

Independent Variable 1



Independent Variable 2



Manual
Driving



L2 Assisted
Driving

Urban Driving Environment

Daytime



After Dark



Data Analysis & Metrics – RQ1

How do visual scanning patterns differ across levels of driving automation and lighting conditions in a complex urban environment?

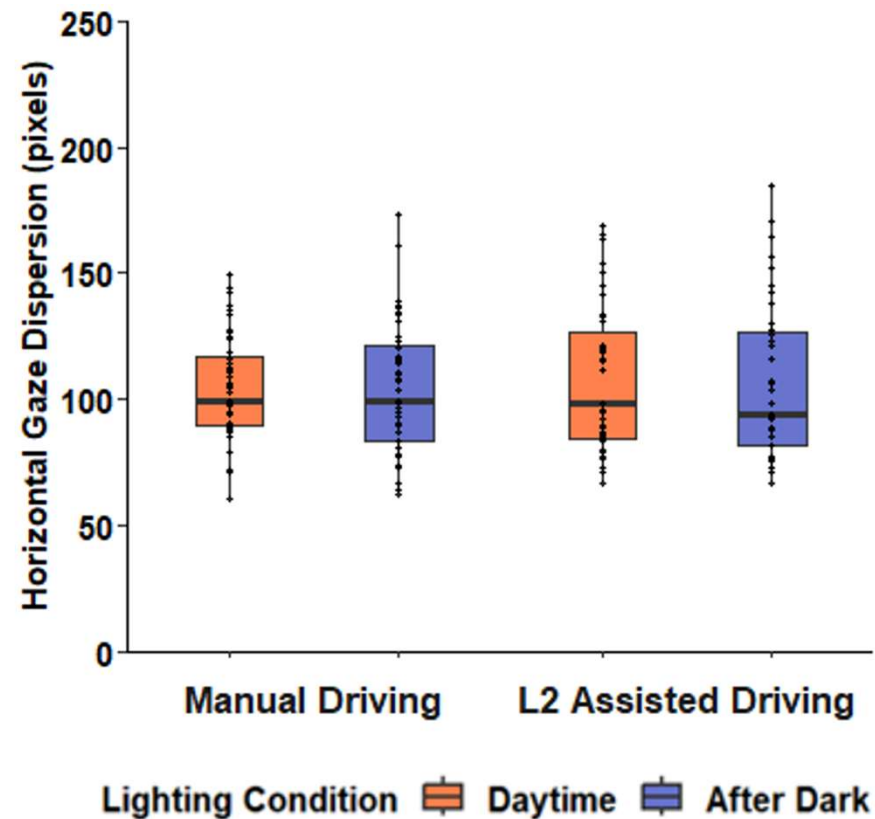
- Focused on gaze data from straight road segments that were populated with ambient traffic



- **Horizontal Gaze Dispersion (px)**
- **Vertical Gaze Dispersion (px)**



Result – Horizontal Gaze Dispersion



No significant main effect of lighting ($F(1, 114.92) = 0.391, p = .533$), automation level ($F(1, 115.39) = 2.380, p = .126$) or interaction effect ($F(1, 114.92) = 0.145, p = .704$)

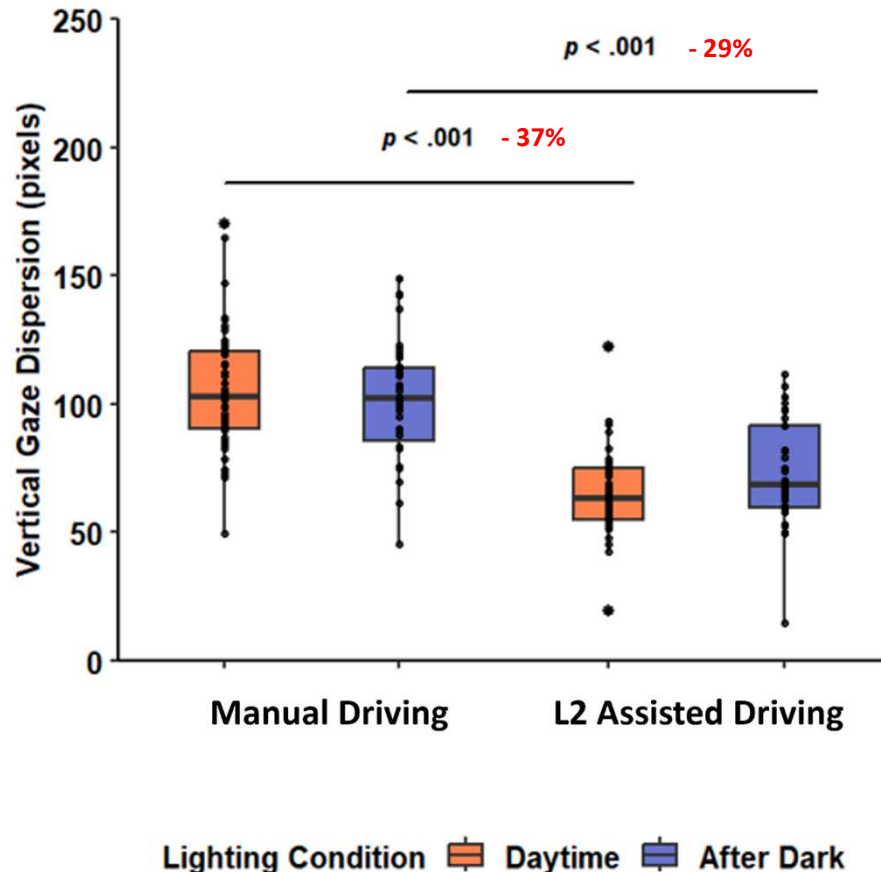


Previous studies with motorways



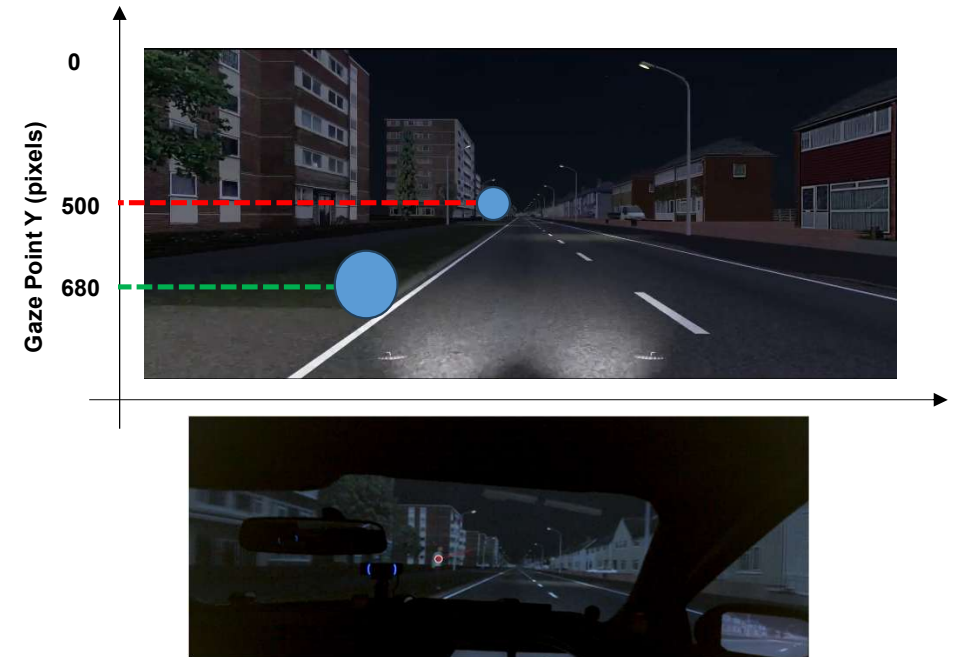
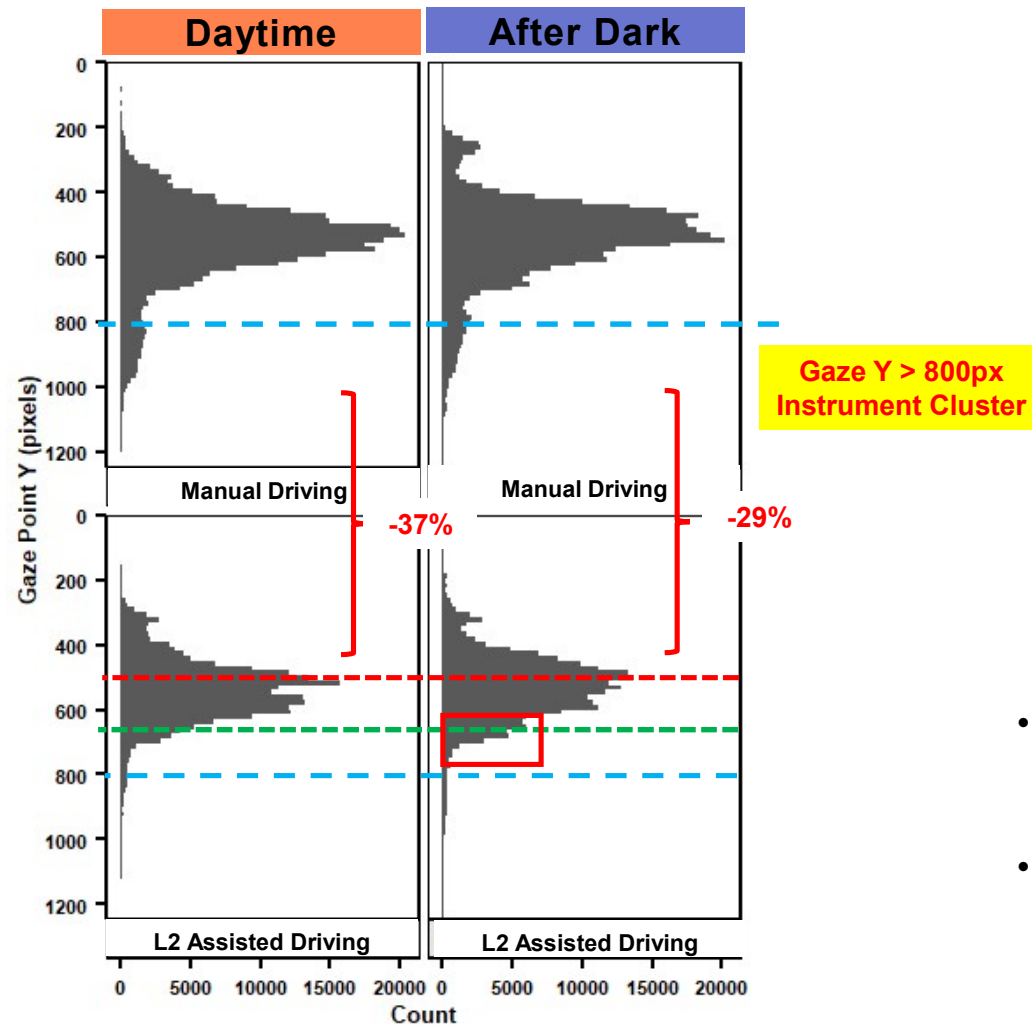
Present Study

Result – Vertical Gaze Dispersion



- No significant main effect of Lighting Conditions
 - $F(1, 118.24) = 0.339, p = .562$
- Significant main effect of Automation Level
 - $F(1, 118.73) = 245.931, p < .001$
 - Vertical gaze dispersion in **L2** was significantly **reduced** by 33.4% relative to **Manual Driving**
- Significant interaction found between Lighting Conditions & Automation Level
 - $F(1, 118.24) = 4.722, p = .032$
 - L2 significantly reduced the vertical gaze dispersion compared to manual driving in both daytime & after dark conditions
 - The **magnitude of reduction** was more **pronounced in daytime (37%)** than observed in **after dark (29%)** conditions

Result – Further exploration on the interaction result on vertical gaze dispersion

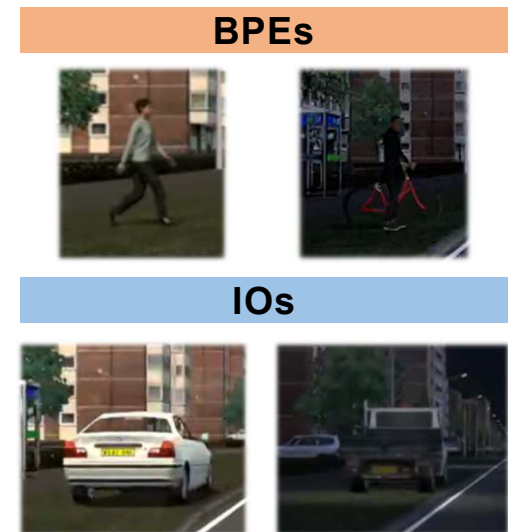


- **Reduced visibility** in **after dark** environment make it **challenging** for the drivers to detect ambient traffic from a **far distance**
- Even though drivers in **L2** **did not** need to direct their gaze **downward to the instrument cluster**, they may still need to shift their gaze **relatively downward** to the regions closer to the ego vehicle monitor surrounding **nearby** traffic.

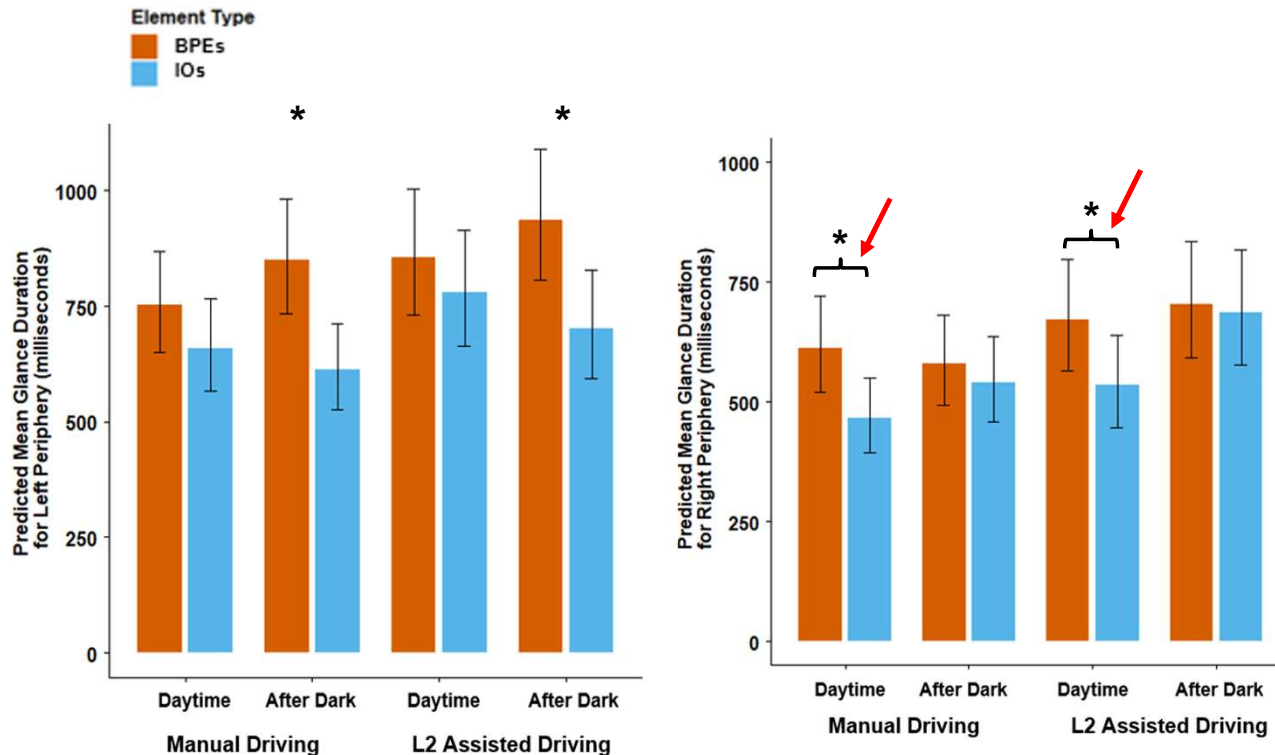
Result – RQ2

How does drivers' visual attention allocation towards Behavioural Prediction Elements (BPEs) & Inanimate Objects (IOs) differ across experimental conditions?

- Focused exclusively on segments where BPEs/IOs present
- Gaze points were mapped onto the left & right peripheries using the Assisted Mapping Tool within Tobii Pro Lab software
- Manual checks and adjustments were conducted to verify correct mapping of gaze data to the correct areas
- **Mean Glance Duration towards the left & right peripheries when the elements were presented (milliseconds)**
 - To capture the amount of visual attention devoted to these areas of the driving scenes when these elements were presented



Result – RQ2



- For both **left & right peripheries**, drivers allocated **greater** visual attention to BPEs than IOs

- Left ($z = 3.86, p < .001$)
- Right ($z = 2.89, p = .004$)



- This effect was **moderated by lighting condition** at the **right periphery**
 - Daytime:** Drivers allocated **greater** visual attention to BPEs than IOs ($z = 3.39, p = .004$)
 - After Dark:** No significant difference found between elements ($p = 1.000$)

Conclusions & Take-home messages

1

Regular presence of **peripheral traffic** consistently **attracted** drivers' **visual attention** across lighting conditions and automation level

2

Reduced visibility in after dark environments make it **challenging** for drivers to detect any peripheral urban traffic from a **far distance**

3

After dark driving may **diminish** drivers' ability to distinguish between **critical** and **non-critical** traffic elements

Final Implications

- Findings from the present study **challenged our current understanding** about the effect of L2 on visual scanning patterns
- Specifically, **daytime gaze behaviour** should **not** be assumed to be **generalised to after dark driving**

CONTEXT MATTERS!!



- Future driver assistance and monitoring systems should be **designed** and **validated** in relatively **more demanding and dangerous contexts**, particularly **urban** and **after dark** environments.

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Thank you for your attention!

Happy to receive any questions!



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ResearchGate



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