Institute for Transport Studies

UNIVERSITY OF LEEDS

Drivers have impaired working memory under high cognitive load and visual distraction:

Safety Implications for transitions of control from vehicle automation

Dr. Rafael C. Goncalves
Hao Qin
Dr. Jonny Kuo
Prof. Mike Lenné
Prof. Natasha Merat

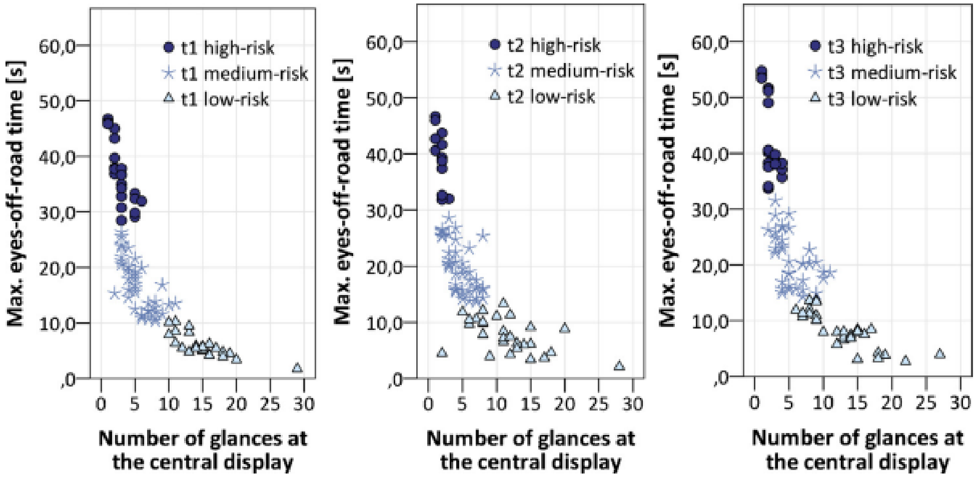
seeingmachines

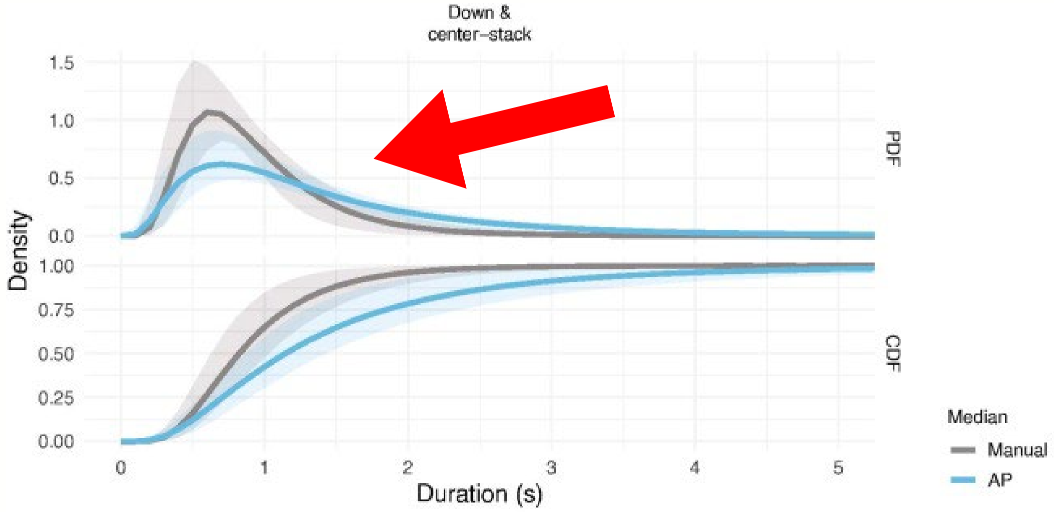
Background

UNIVERSITY OF LEEDS

Visual distraction: "Tasks that require the driver to look away from the roadway to visually obtain information" (NHTSA, 2017)

- Strong correlation between **off-road glances/visual distractions and crash risk** (Liang et al., 2012; Tian et al., 2013; Seppelt et al., 2017).
- Especially during hands-free Level 2 automation, **drivers are more likely to look away from the forward roadway for long periods of time** (Morando et al., 2021; Louw & Merat., 2017; Gershon et al., 2021).





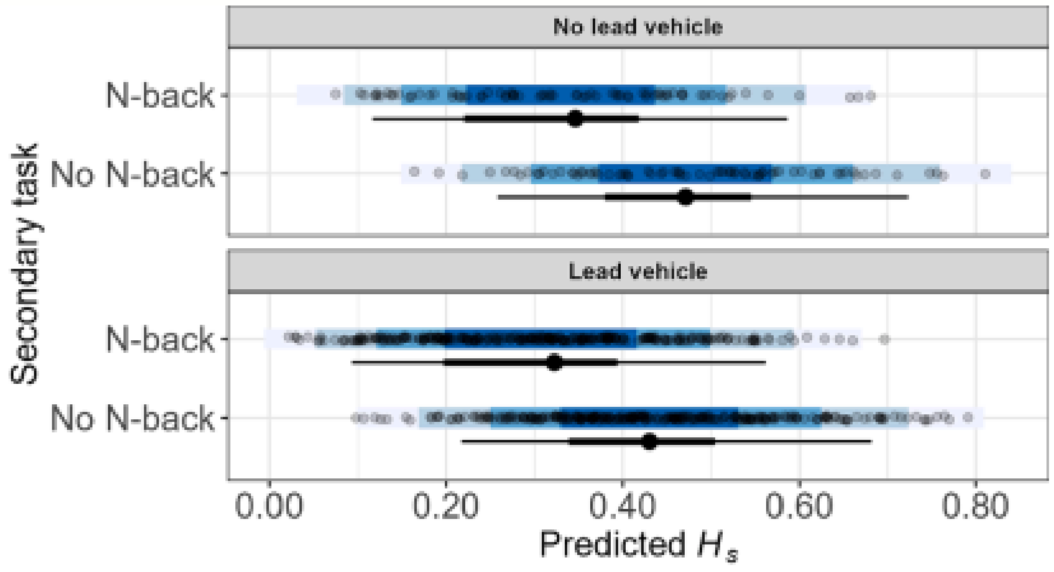
Background

UNIVERSITY OF LEEDS

Cognitive Distraction: "Diversion of mental resources allocated to the driving task towards competing demands from secondary activities" (Lee et al., 2009)

- Studies reported detrimental effects of cognitive load on drivers' gaze dispersion (Wilkie et al., 2019; Gold et al., 2016) and peripheral event detection (Yang et al., 2022a; van Winsum et al., 2019).

- Other says that the effect of cognitive load on drivers' gaze is strongly affected by inter-participant variability (Goodridge et al., 2024; Yang et al., 2022b).



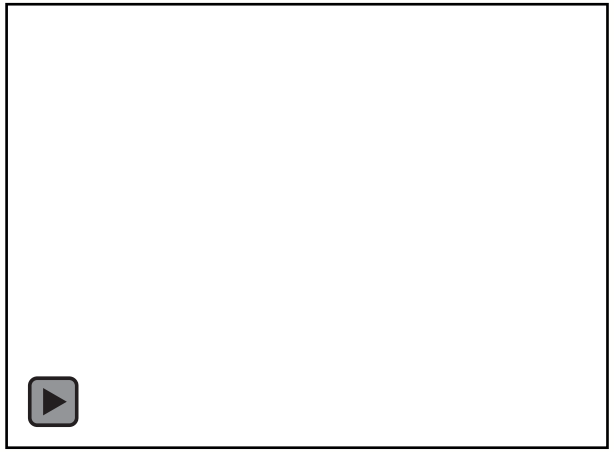
Lack of understanding on how cognitive load may affect drivers' takeover performance and visual scanning behaviour

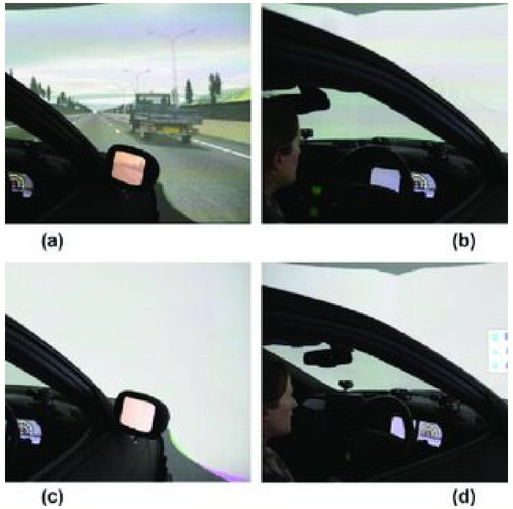
Background

UNIVERSITY OF LEEDS

- **Even less is known about how the effects of cognitive load may interact with additional impairments caused by visual distraction!**

- Previous driving simulator studies **on manual drive** by Liang and Lee (2010) found that cognitive load and visual distractions **affected different aspects of the drivers' performance.**





- Their experimental setup do **not relate to a partial automation context**, where drivers are still required to monitor the environment.

Research overview

UNIVERSITY OF LEEDS

Evaluate the effect of both **cognitive load** and **visual occlusion** on drivers' **attention management**, and subsequent **takeover performance** on an L2 automated drive.

1. What are the effects of **drivers' cognitive load and visual occlusion** on drivers' **attention management** strategies in L2 automation?

   ↑ **Cognitive Load** ↓ **Visual Search** > ↑ **Visual Occlusion** ↑ **Visual Search**

2. What are the effects of **drivers' cognitive load and visual occlusion** on drivers' **takeover performance** in L2 automation?

   ↑ **Individual Impairment** ↓ **Takeover Performance** < ↑ **Combined Impairment** ↓ **Takeover Performance**

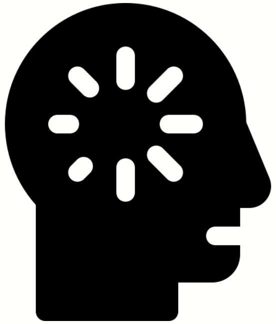
Experimental Design

UNIVERSITY OF LEEDS

3X1 Repeated measures design.

3-Lane motorway scenario, with surrounding traffic.

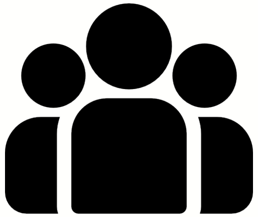
Drivers just needed to engage the automation and monitor the environment.



2-Back

Occlusion

Combined



N = 31 (13 F 18 M)

22 to 56 years old (M = 38.02, SD = 12.03)

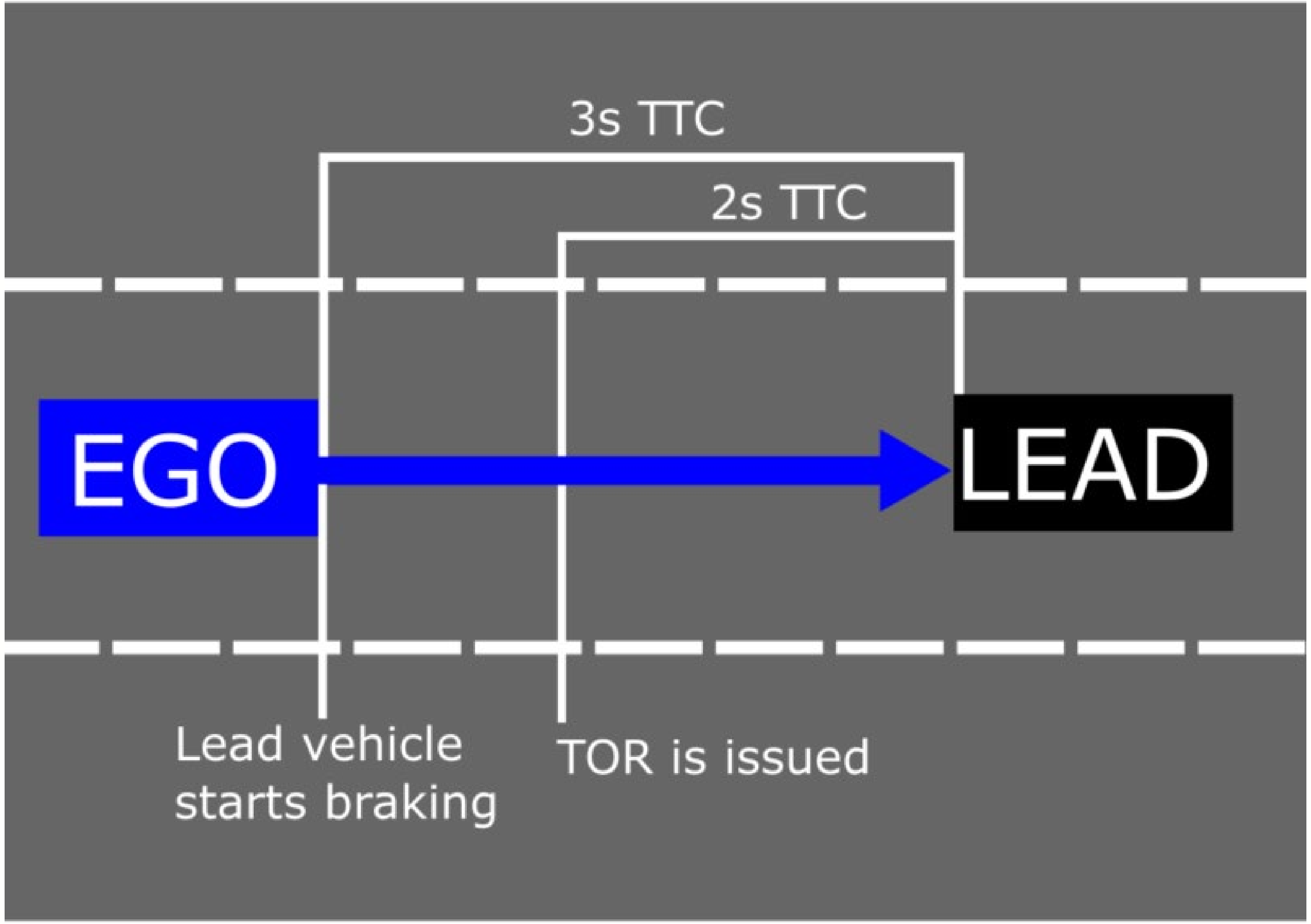
3+ years of driver experience

Habitual drivers (drive at least 2x a week).

No prior experience with vehicle automation

Experimental Design

UNIVERSITY OF LEEDS



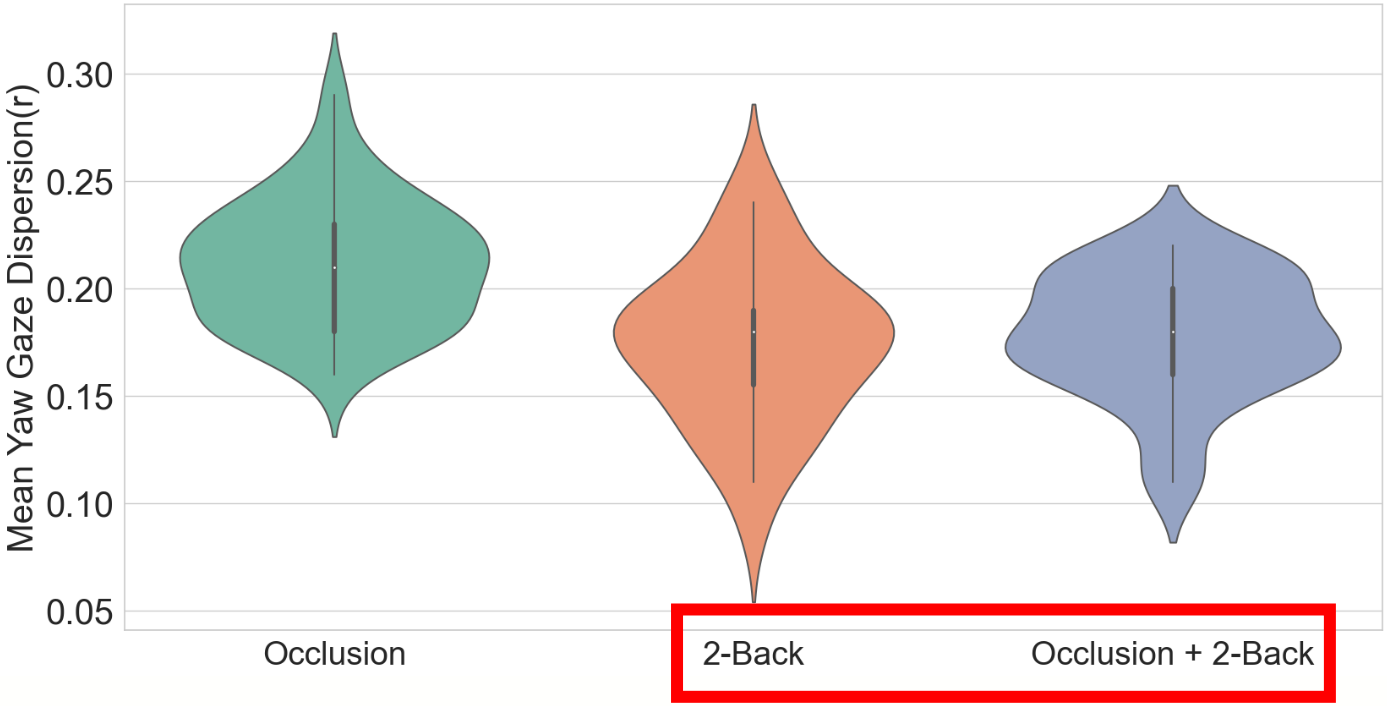
- Lead's hard brake (~$4m/s^2$), that the **automation fails to deal with.**
- The driver **can see the brake lights** from the beginning of the event.
- **The TOR is issued whenever the TTC of the incoming collision reaches 2s.**
- There **were no surrounding vehicles in the side lanes** during the event, so drivers were **free to make evasive manoeuvres**.

Results: Attention Management

UNIVERSITY OF LEEDS

Yaw gaze dispersion:

- Significant effect of event conditions on drivers' Yaw dispersion [F (4, 104)= 7.816, p = .006), η_p^2 =.072].
- Post-hoc tests show that the **Occlusion task alone caused significantly higher yaw dispersion.**



↑ **Cognitive Load** ↓ **Lateral Scanning**

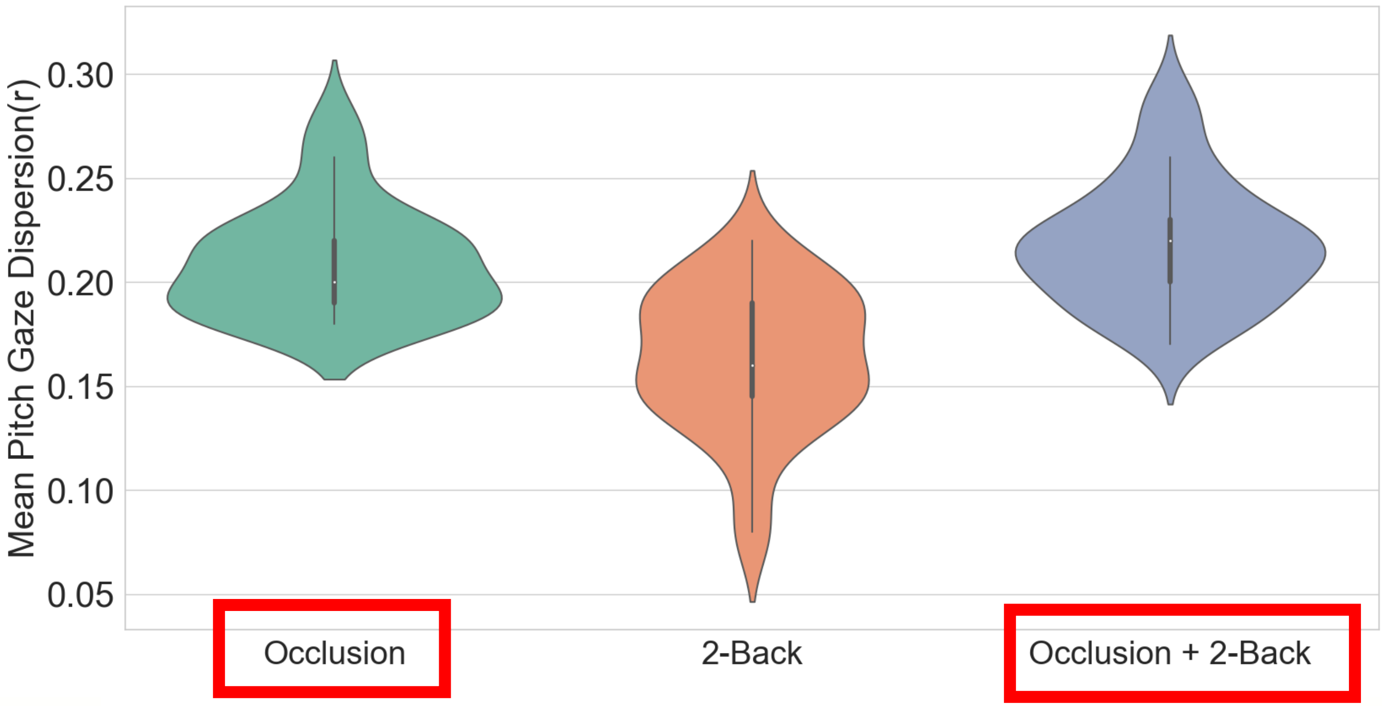
Results: Attention Management

UNIVERSITY OF LEEDS

Pitch gaze dispersion:

- Significant effect of event conditions on drivers' Pitch dispersion [F (4, 104)= 2.536, p = .045), η_p^2 =.092].

- Post-hoc tests show that **2-back task alone have significantly lower gaze Pitch dispersion.**



Visual Occlusion

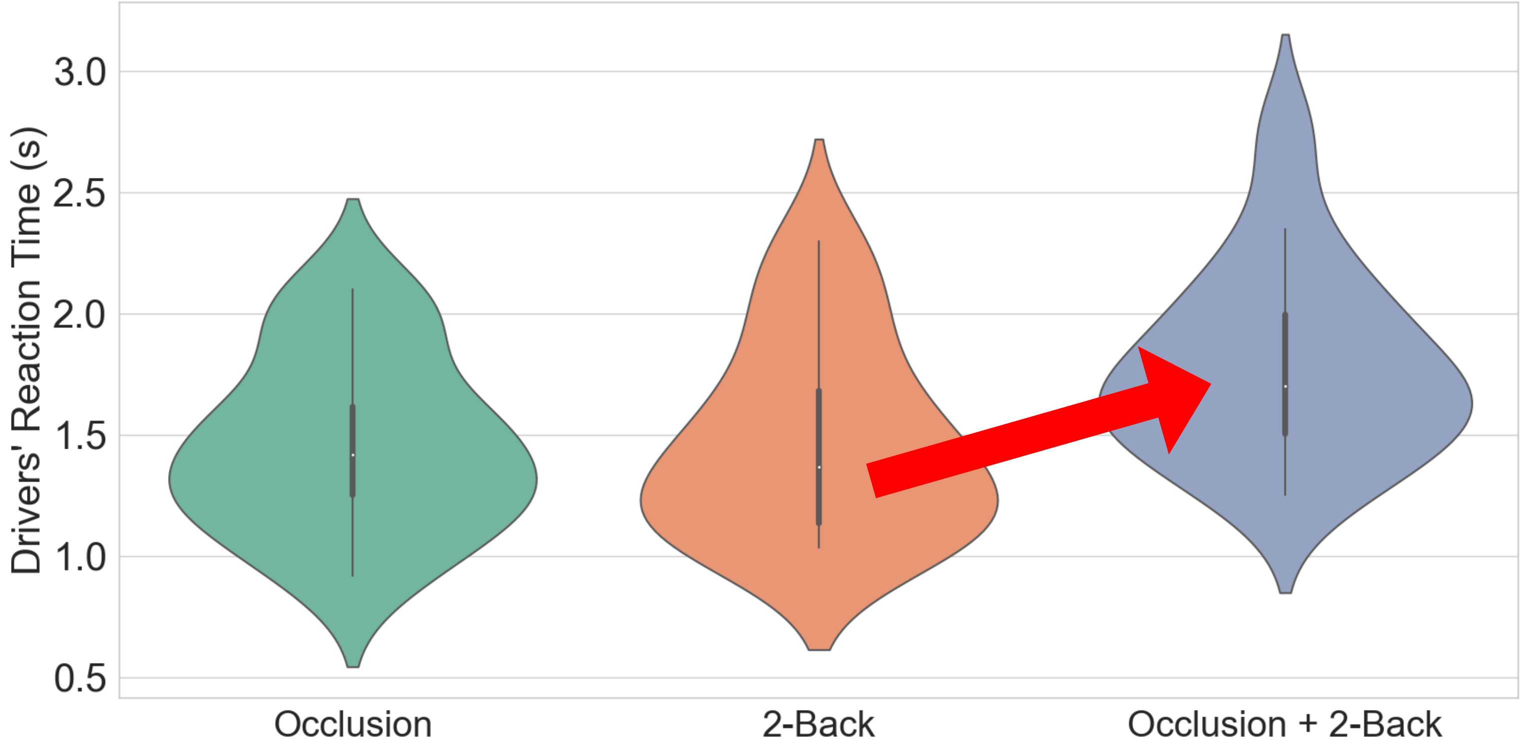
Vertical Scanning

Results: Driver Performance

UNIVERSITY OF LEEDS

Reaction time:

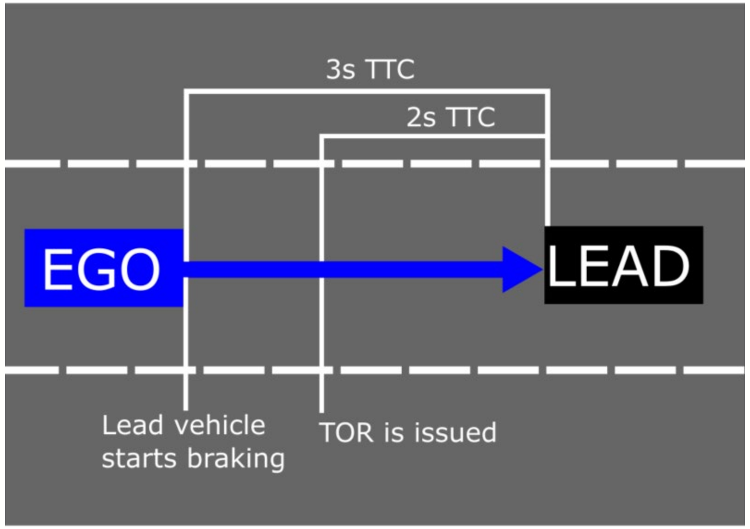
- Significant difference between conditions [F (4, 104) = 3.475, p = .019), η_p^2 =.197], where the **"Occlusion + 2-Back"** condition presented a **significantly higher reaction time than the other two conditions.**



Results: Driver Performance

UNIVERSITY OF LEEDS

- Drivers were able to react to the critical event before the TOR.
- Drivers were able to see the lead vehicle's brake lights.
- Response to brake lights affected by driver state (Engstrom et al., 201).
- To confirm whether or not drivers were successfully monitoring their environment, **we compared the likelihood for drivers to react before the TOR was issued across the 3 conditions.**



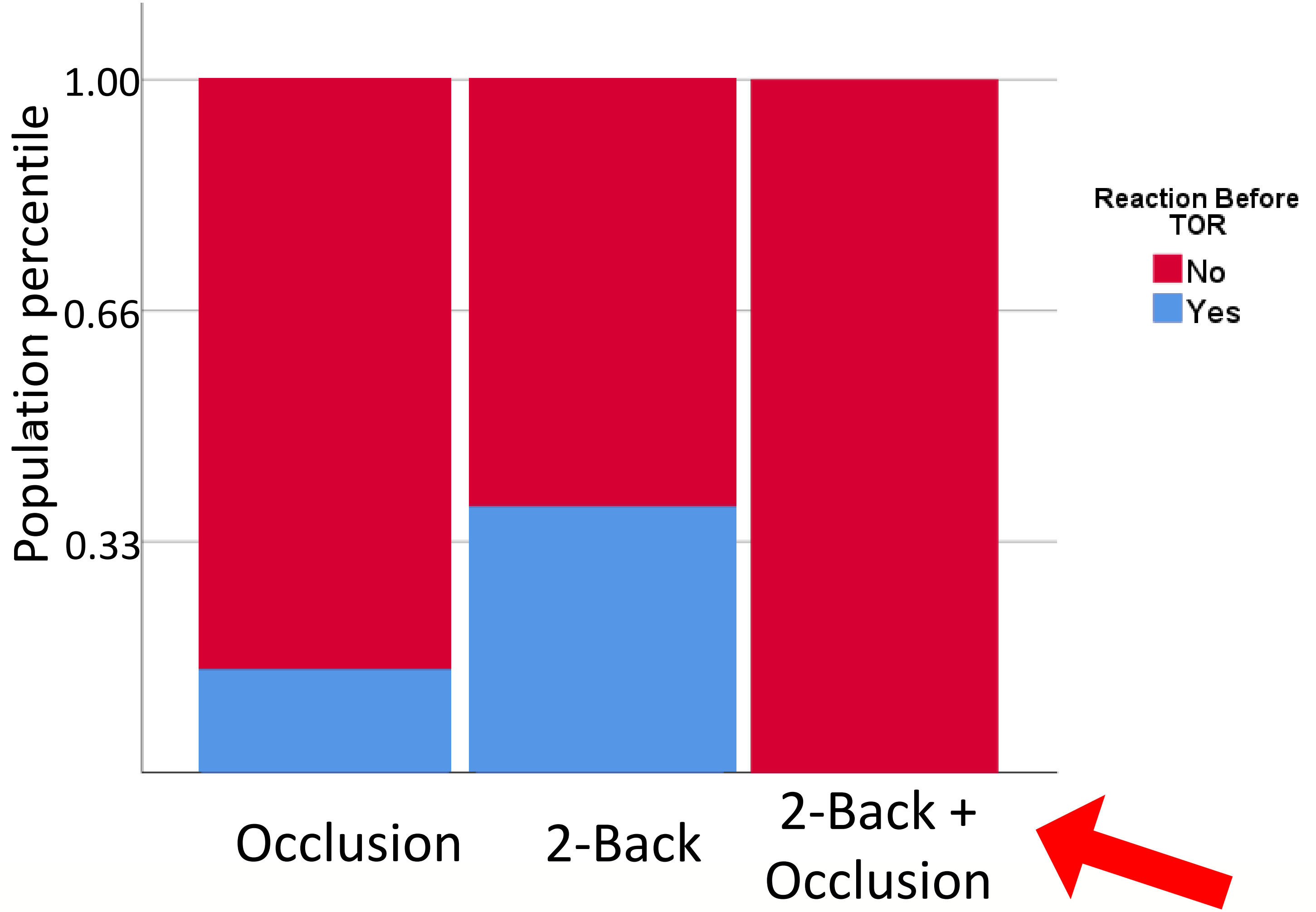
Results: Driver Performance

UNIVERSITY OF LEEDS

Probability to react before TOR:

- Significant difference on the likelihood for drivers to react before the TOR is issued [X^2 (2, 93) = 14.63, p=.001].

- It is worth noting that **no driver was able to react** by simply monitoring the scenario under the **"Occlusion + 2-Back" condition.**



Discussion

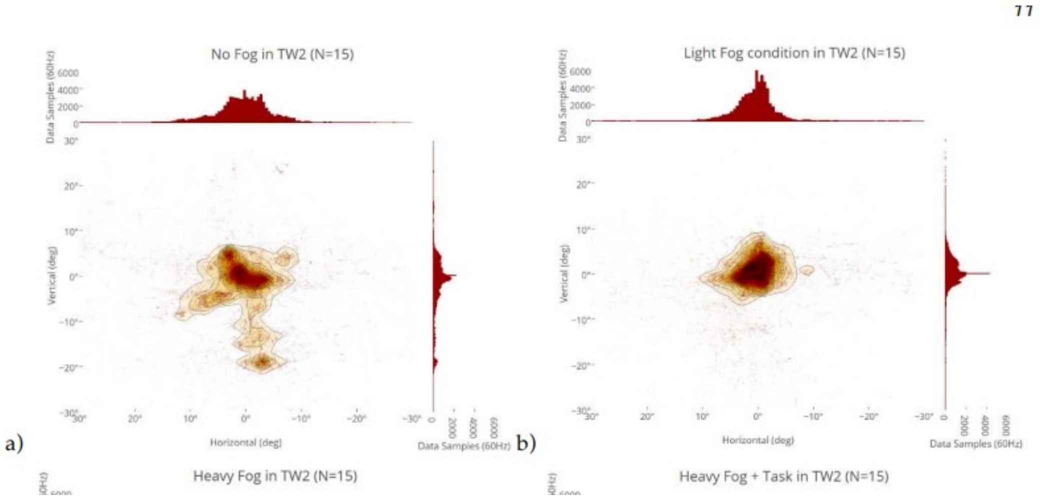
UNIVERSITY OF LEEDS

- It seems like drivers try to compensate for their “temporary blindness” by **quickly checking the environment and recover situation awareness** (similar results from Garthenberg, 2014).
- It is argued here that this process **may tax drivers’ working memory**, as drivers need **store visual information** of the status of the driving environment during the occlusion periods (see Polani, 2011; Klyubin et al., 2007).

Discussion

UNIVERSITY OF LEEDS

- Gaze dispersion analysis have shown that drivers under the effect of a cognitive-loading task (2-back) have the **range of their gaze scanning patterns diminished**, in line with previous studies (e.g. Broadbent et al., 2023; Louw & Merat, 2017).
- Increased cognitive load is associated with **slower response to brake lights**, together with limited gaze dispersion (Engstrom et al., 2017).



Discussion

UNIVERSITY OF LEEDS

- The **combination** of a cognitive demanding task with the constant occlusion of their field of view seems to **compromise their reaction time** to a hazardous situation.

EURO NCAP

- Based on the results on the gaze data, we believe that the **impairments on event detection and information acquisition** caused by the **cognitive load** are **enhanced** by the **taxation of drivers' working memory**, caused by the **visual distraction**.

- This assumption is also reinforced by statements of the participants, during the debriefing periods of the experiment, like: *"I was not able remember what was going on when everything was blank. I was too busy paying attention to the numbers".*

THANK YOU!