Analyzing Driver Eye Movements to Investigate the Impact of Distraction on Driving Behavior

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Introduction - Driving Distractions

- While several factors affect driving performance, distracted driving has been emphasized as a critical safety issue across the globe [1].

- **Texting while driving** is a form of mobile-phone distraction and can engage drivers visually, auditorily, physically & cognitively.

- **Texting while driving can deteriorate driving performance** through, for instance, a higher reaction time, speed reduction, poor lane keeping, and fewer glances ahead to compare with non-distracted driving conditions [2-4].

- Texting while driving is associated with **a high risk of being involved in safety-critical events** [5].

Figure source: The Christian Science Monitor

Introduction - Driving Simulator Experiments

- Driving simulator studies are popular means to investigate driving behavior in a controlled environment and **test safety-critical events**.

- Driving simulators along with the corresponding equipment and technologies (e.g., dash cameras, wearables, heart rate monitoring systems, mobile-phone applications) have the potential to identify **physiological driver state** indicators and **driving performance characteristics**.

Introduction - Eye Movement Data

- Eye-tracking devices have been used frequently **to measure drivers' eye movements** and **visual attention** and **investigate the effect of distraction on driving performance.**

- Eye movements and gaze data can provide **insight into drivers' cognitive processes and intended actions**, and thus, a more thorough understanding of their behavioral patterns.

Figure source: Tobii Pro Website

Research Objectives

- While previous studies aimed to understand the impact of distraction and used eye-tracking data to investigate distraction, there is limited research studying **the impact of interventions on driving performance**.

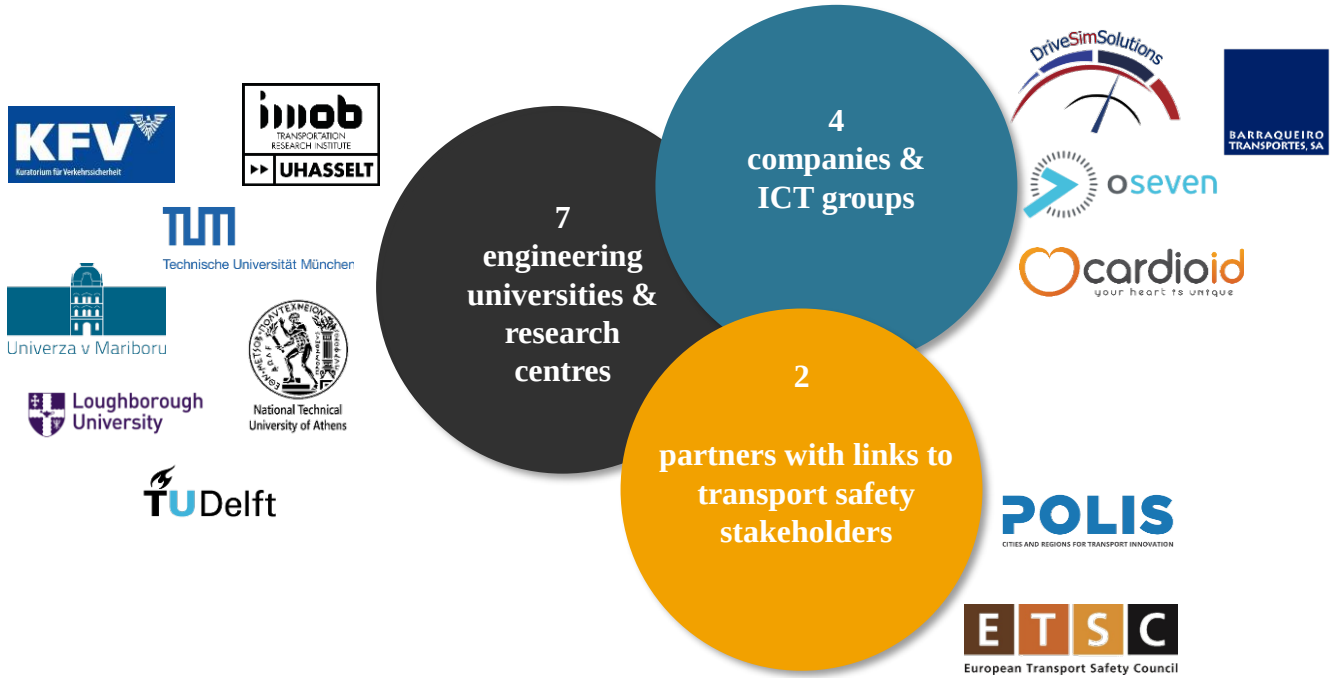
- This study uses a driving simulator experimental design **to test driving performance under a variety of conditions**.

- This study investigates driving behavior by **observing drivers' eye movements** under the various driving conditions.

- **Different risky events** are designed to investigate the driver response under the various driving conditions.

i-DREAMS Project

- This study is a part of the i-DREAMS project that aims to define, develop, test and validate a context-aware safety envelope for driving in a **'Safety Tolerance Zone' (STZ)**.



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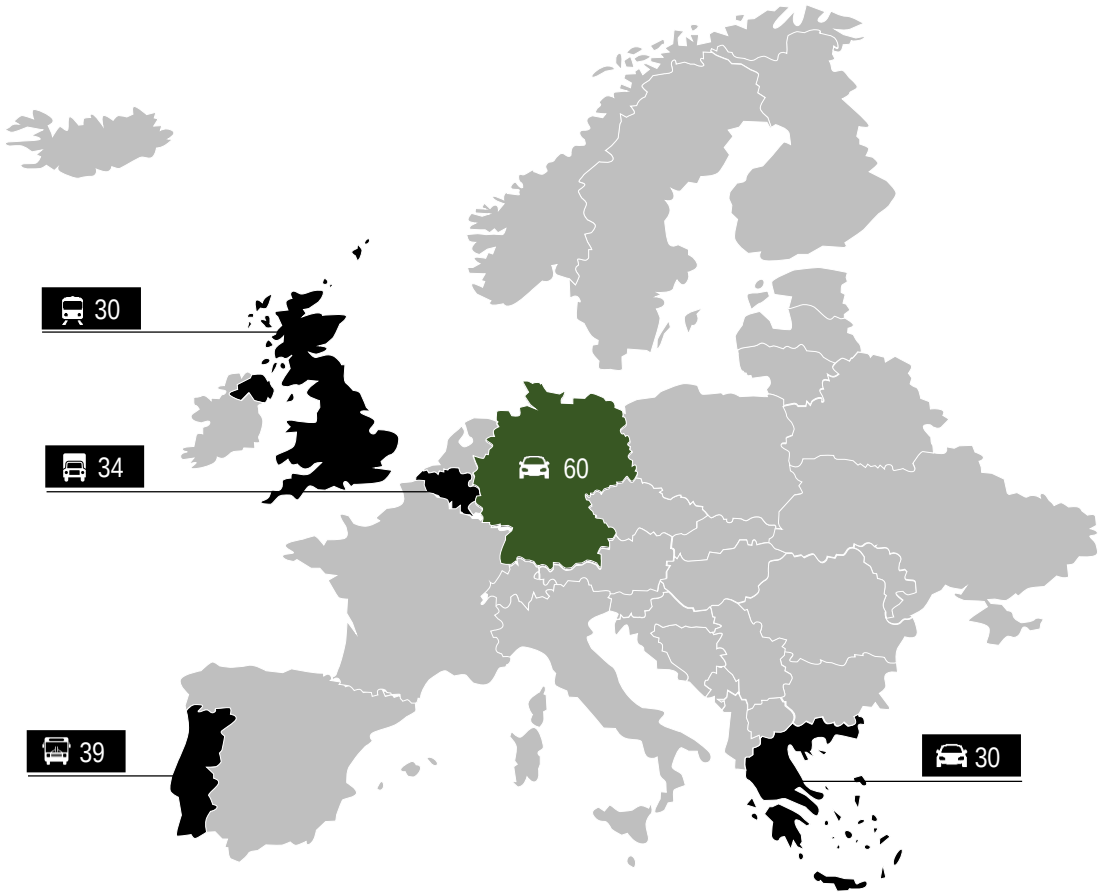
i-DREAMS Project

STAGE 1 — SIMULATOR

STAGE 2 — PILOT STUDY

STAGE 3 — BASELINE MEASURMENT

STAGE 4 — IMPLEMENTING INTERVENTIONS



Methodology - Driving Simulator Experiment

- The experiment was held at the chair of Transportation Systems Engineering, Technical University of Munich using a custom simulator developed by **DriveSimSolutions.**

- The simulator uses fully customizable **STISIM Drive 3 software**, allowing for the creation of custom scenarios and data collection at every simulation frame.

Methodology - Driving Simulator Experiment

- **Tobii Pro Glasses 2** were used to collect gaze data.

- Tobii Pro Glasses 2 is equipped with two cameras for using Tobii's 3D eye model to **run eye tracking studies in dynamic environments**.

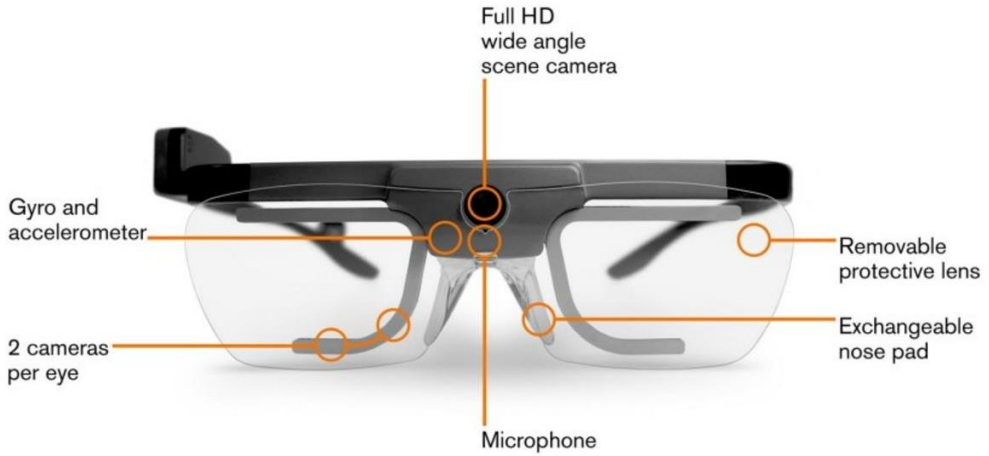


Fig.1. Tobii Pro Glasses 2 (Source: manufacturer's website)

Methodology - Application of Safety Interventions

Customized interventions were proposed during the intervention scenarios.

These included **real-time and in-vehicle warnings** (i.e., audio, visual) in safety-critical situations (i.e., close to the boundary of the STZ) and with respect to:

- **Lane departure warning**
- **Headway warning**
- **Forward collision warning**
- **Pedestrian collision warning**
- **Mobile phone distraction warning**

Methodology - Application of Safety Interventions

The two intervention scenarios were designed:

- **First intervention scenario**: there was a focus on fixed timing thresholds (audio & visual in-vehicle warnings),
- **Second intervention scenario**: to assess the impact of certain conditions on driving behavior (i.e., distraction) and by optimizing the intervention thresholds (by using dynamic or time-variable thresholds).

Methodology - Equipment

Multiple sources of data collection were used during the simulator runs:

Tab.1. Data collection sources utilized in the simulator experiments. Source: [6]

Data Source	Purpose
Mobileye	Forward Collision Warning, Lane Departure Warning, etc.
PulseOn wearable	Cardiovascular data, such as inter-beat interval.
CardioGateway	i-DREAMS real-time interventions, such as headway warning.
Questionnaires	To assess driver background factors, technology acceptance and feedback, etc.
Simulator log files	Measurement of driving performance variables.
Tobii Pro Glasses 2	Eye movement data of participants.

Methodology - Driving Sessions

The selected risk factors were used for scenario designs for the simulator trials, and examined through **three sessions** [7]:

- **The first session (drive-1: ~15min):** monitoring drive without interventions,
- **The second session (drive-2: ~15min):** an intervention drive with fixed timing warnings,
- **The third session (drive-3: ~15min):** an intervention drive with interventions based on task completion capability including the risky conditions.

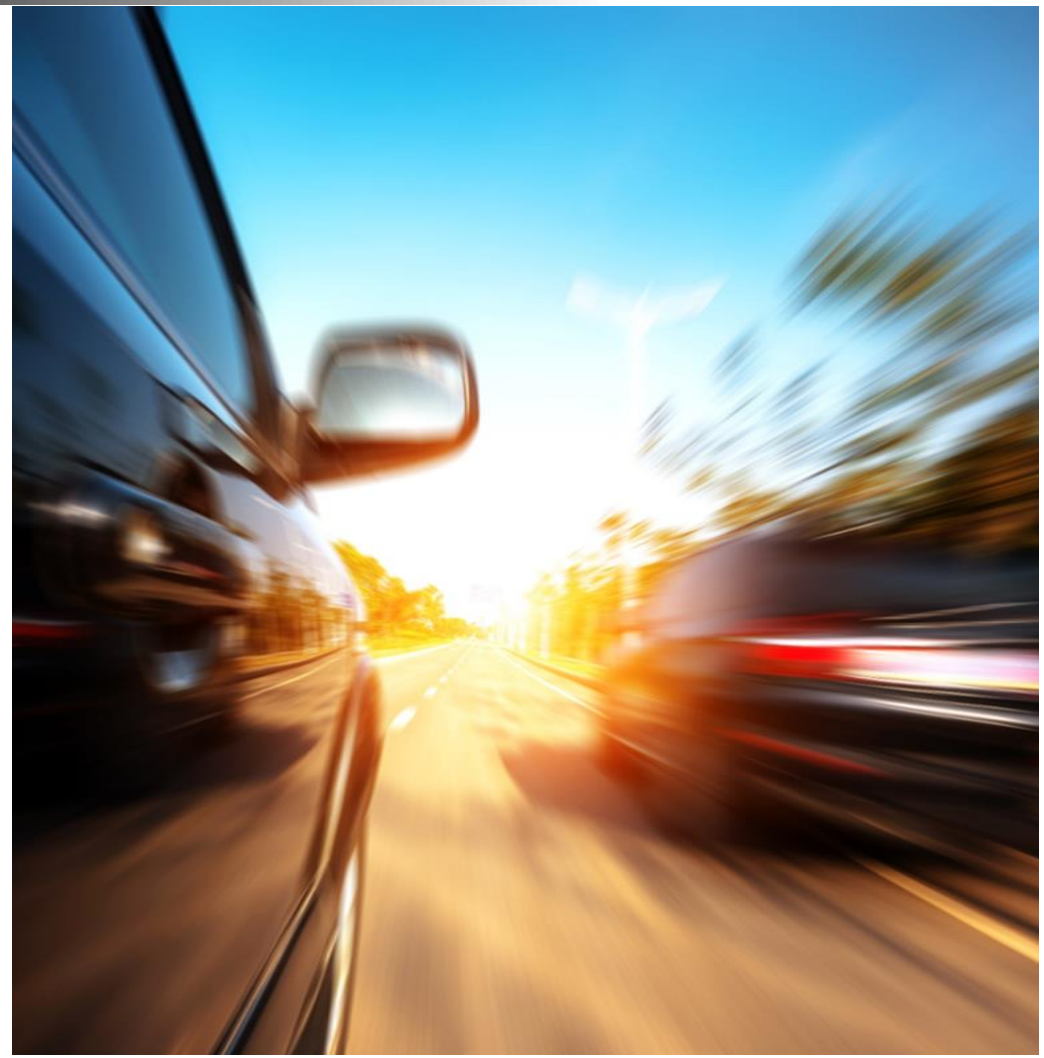
Each risk factor was captured by several separate events.

Methodology - Risk Scenarios Design

The content of the simulator scenarios focused on specific target risks. To reach the scope of the i-DREAMS project, several risk factors were measured for the simulator experiment, including:

- **Tailgating,**
- **VRU collision,**
- **Driver distraction,** as an additional driving condition.

Risk factors were investigated through a series of risky events (CEs) during all scenarios [7].



Methodology - Risk Scenarios Design

The **tailgating** behavior was explored through a low-speed lead vehicle in front of the driver that imposes the events (Fig. 2).

Fig. 2. Examples of the designed risky events of tailgating

Methodology - Risk Scenarios Design

The **VRU collision** was investigated by triggering three crash prone events between pedestrian and vehicle (Fig. 3):

Fig. 3. Examples of the designed risky events of VRU collision

Methodology - Risk Scenarios Design

- In total, **eight text messages (TM)** were sent by the operator to the participants during the **drive-3 trial**.

Tab.2. Example of distraction design in drive-3 scenario. Source:[7]

Distraction	Event	Complexity level	Content of the text message	Length (character)
Reading & replying to TM	CE 2 - Tailgating	complex	“Can you name two cities you want to visit?”	question: 42 answer: max. 25
Reading a TM	CE 3 - Pedestrian collisions	simple	“50% off on online orders! Today only!”	34
Reading & replying to TM	CE 1 - Tailgating	complex	“27+30=?”	question: 7 answer: max. 2

Methodology - Risk Scenarios Design

- Several **‘neutral’ events (NEs)** were embedded to create a realistic driving scenario and minimize confounding effects (e.g., order / learning effects).

- Three scenarios were designed using similar components, but with different order of events to **minimize learning effects**.

- A **Balanced Latin Square method** was applied to equally distribute the scenarios between the participants.

Methodology - Data Collection

- A total of **60 participants** were recruited for the driving simulator experiment.
- The entire data collection process was **fully anonymized**.
- The participants were remunerated with a **25 EURO voucher** at the end of the experiment.
- Two participants, with an incomplete recording of data, were removed from the data analysis.
- **58 participants** with complete recording of data were selected for analysis.

Data Analysis - Eye Movement Data

The eye movement data were analyzed during all distraction events:

- **A time of interest (TOI)** was defined for logging each distraction event.
- **Areas of interest (AOI)** were created to specify different regions boundaries.

  - ➢ AOI varied with session drives.
  - ➢ All AOI were constantly adjusted.

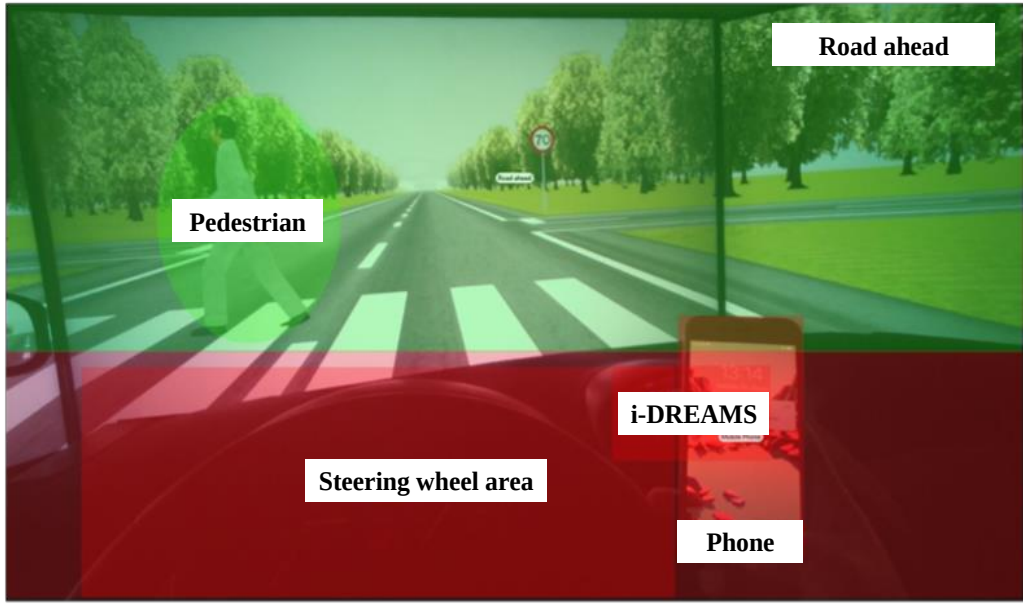


Fig. 4. An example of the AOI created for intervention scenarios.

Data Analysis - Eye Movement Data

Two measures of eye movement, obtained after applying fixation metrics, were selected for analysis:

- **The average fixation duration** which records the elapsed time between the first and the last gaze points in the sequence of gaze points.

- **The number of fixations** that occurred during the TOI and within the targeted AOI.

Data Analysis - Driving Simulator Data

The outputs of driving data are generated at the completion of the simulation runs.

A set of parameters was scrutinized during the logged TOI in all scenarios to investigate the impact of distraction on driving performance:

- **Lateral positioning**
- **Longitudinal acceleration rate**
- **Lateral acceleration rate**

Statistical Analysis Results

- A **Shapiro-Wilk test** was applied to determine if the distribution of data comes from a normally distributed population.

- Since the Shapiro-Wilk test failed to reject the null hypothesis, a **Kruskal-Wallis test** was performed for the statistical test.

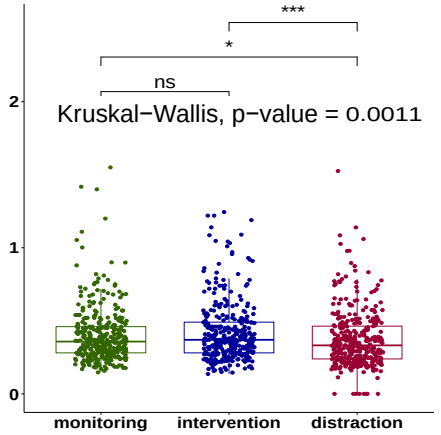
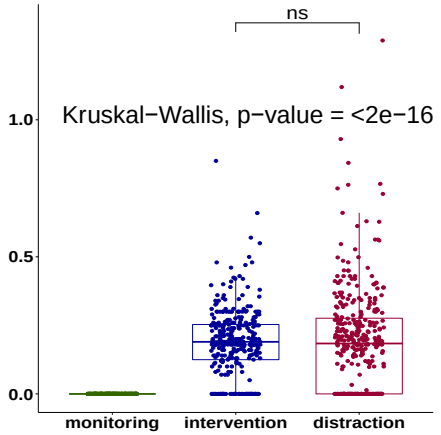
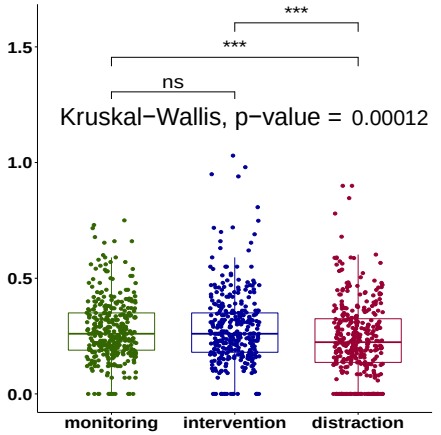
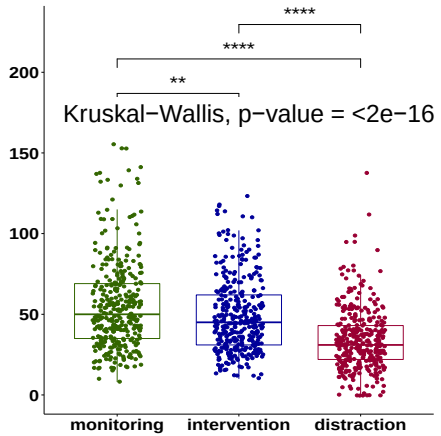
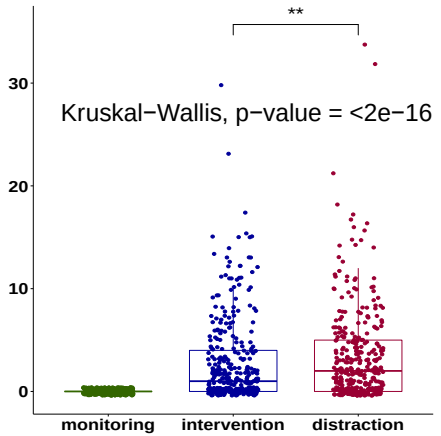
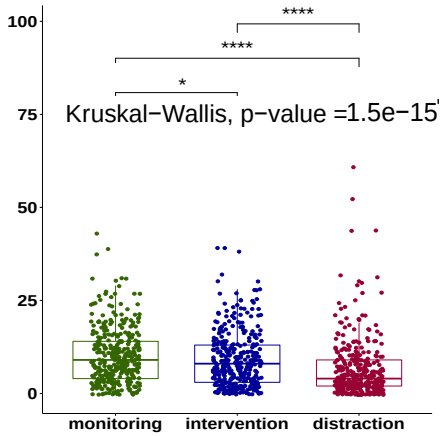
  - If **p-value ≤ 0.05**, a *Post Hoc analysis of the Dunn's test* was used to determine which groups differed from other groups.

  - If **p-value > 0.05**, *Post Hoc analysis of the Dunn's test was* no longer performed.

Statistical Analysis Results – Eye Movement Measures (CEs)

Fixation Duration (Avg.)

Fixation Count

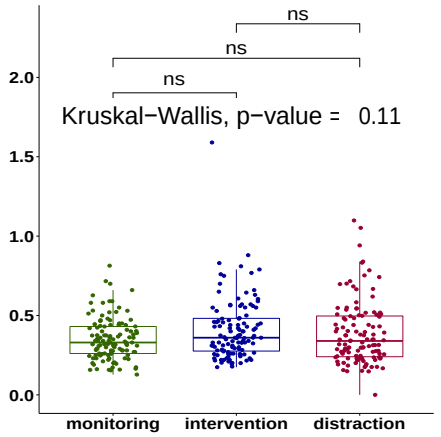
	Road Ahead	i-DREAMS Display	Dashboard Area
Fixation Duration (Avg.)			
Fixation Count			

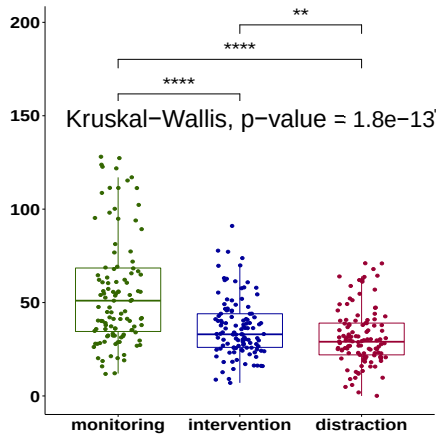
Statistical Analysis Results – Eye Movement Measures (NEs)

Fixation Duration (Avg.)

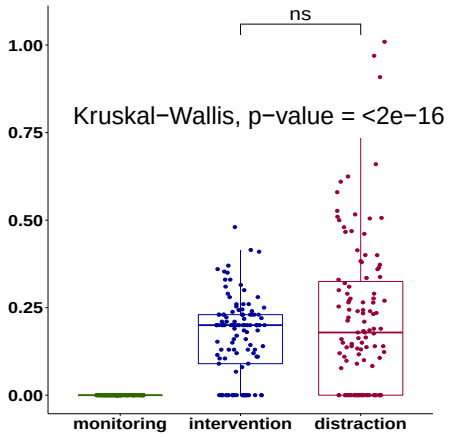
Fixation Count

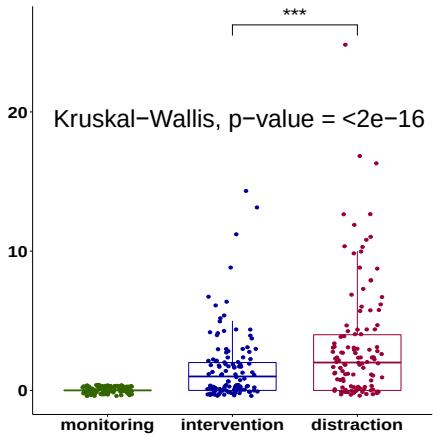
Road Ahead



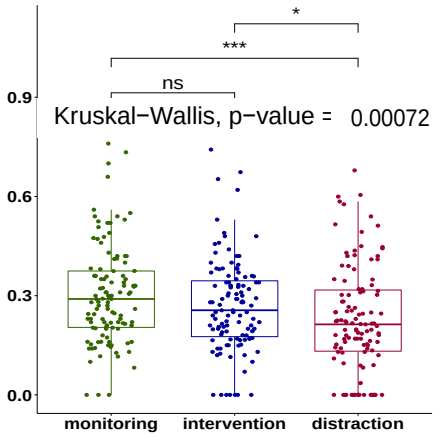


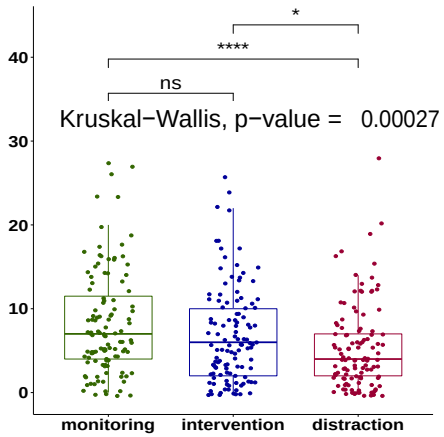
i-DREAMS Display



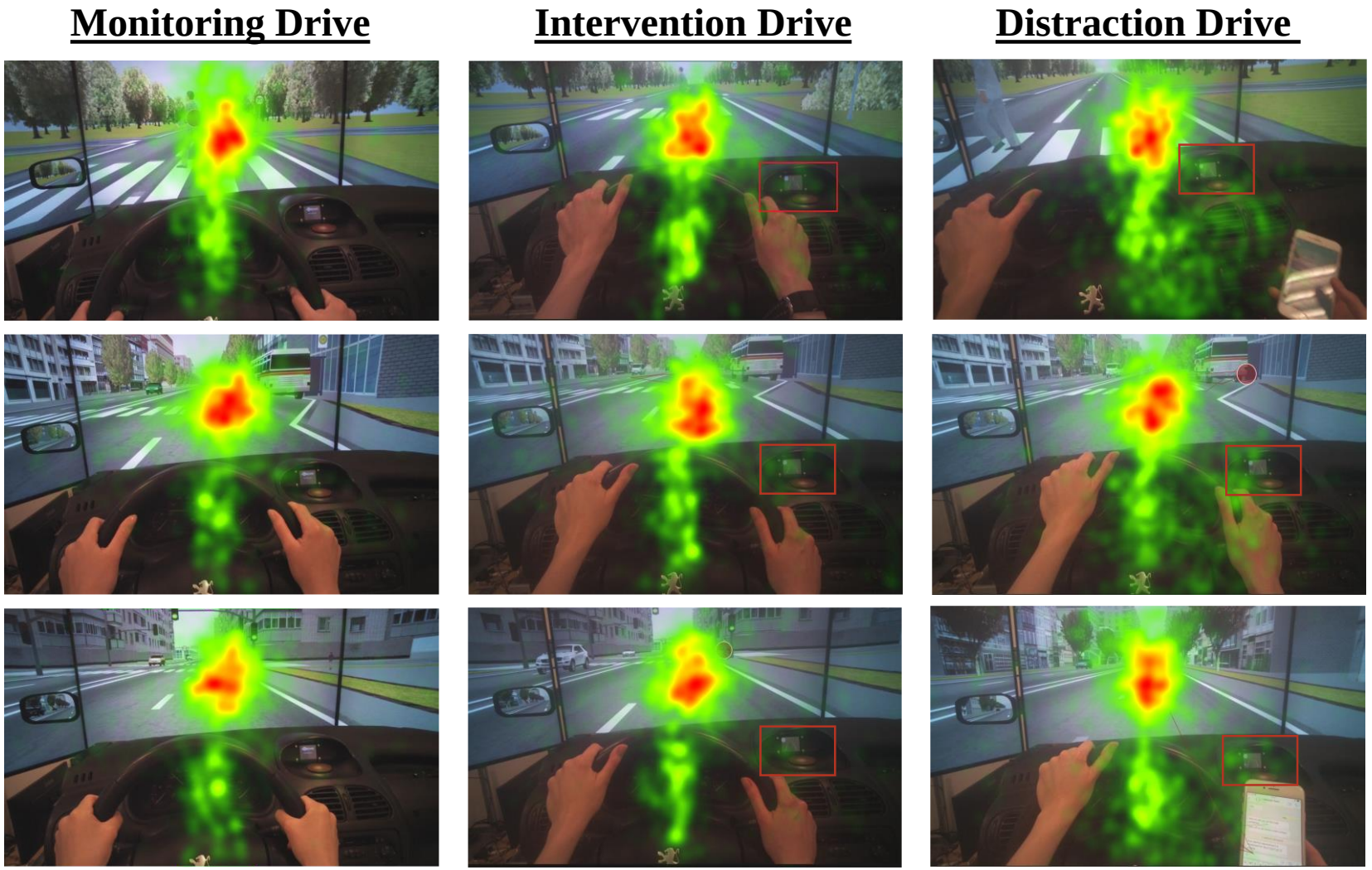


Dashboard Area





Statistical Analysis Results – Eye Movement Behavior

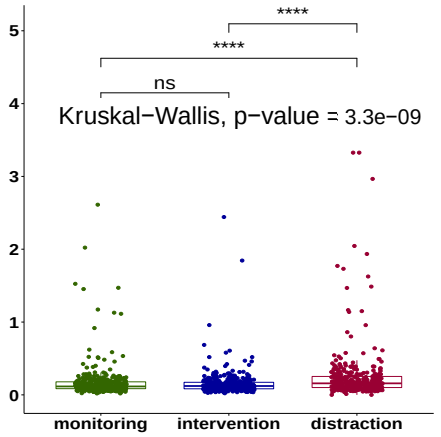


Statistical Analysis Results – Driving Performance Measures

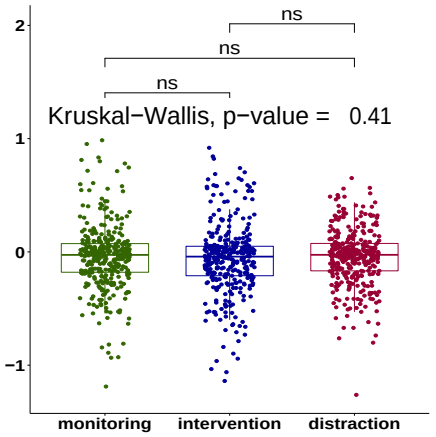
CEs

NEs

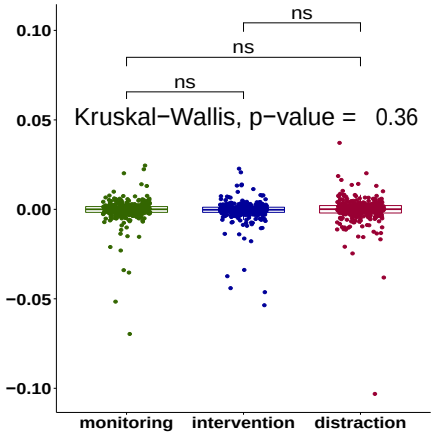
Lateral Position - std. dev.

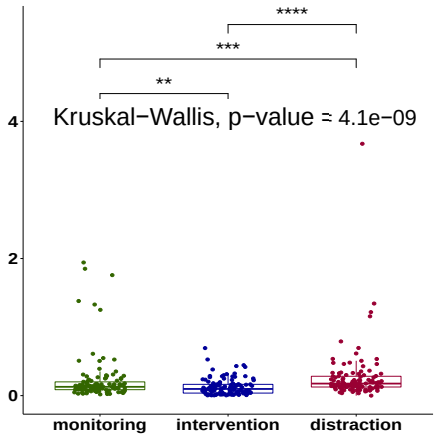


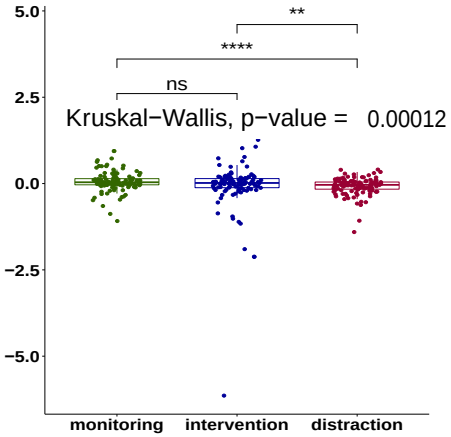
Longitudinal Acc. - Mean

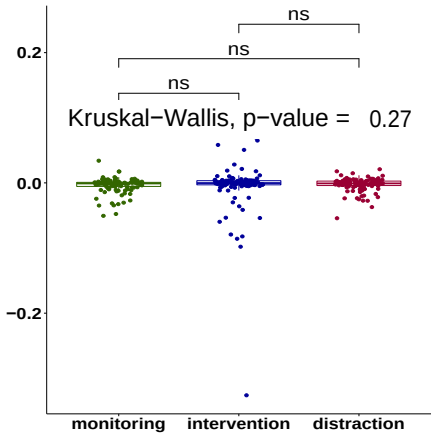


Lateral Acc. - Mean









Conclusions & Future Work

- The results suggest that **driver gaze patterns significantly change while drivers are distracted**, with **a significant increase towards the i-DREAMS intervention display**.

- This results suggest that drivers may have **more reliance on the intervention system while distracted** and check the i-DREAMS intervention system more frequent.

- The overall statistical analysis on driving performance measures reveals **a similar impact on driver behavior, with a higher deviation of lateral positioning and lower longitudinal acceleration rates during the distracted driving**.

Conclusions & Future Work

- In future work, **a broader range of driving performance and eye movement measures** will be utilized to further explore driver behavior.

- Information collected through the **questionnaires** (e.g., driver background factors, demographics) will be considered in studying driver behavior in future work.

- Further study should be performed to investigate **whether the i-DREAMS intervention display adds to the visual distraction sources available for drivers** or brings them back to the driving task and understand if visual interventions offer a higher benefit than cost towards safety compared to other types of interventions (e.g., auditory-only, physical).

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