Implementation and Evaluation of Lane Departure Warning and Assistance Systems

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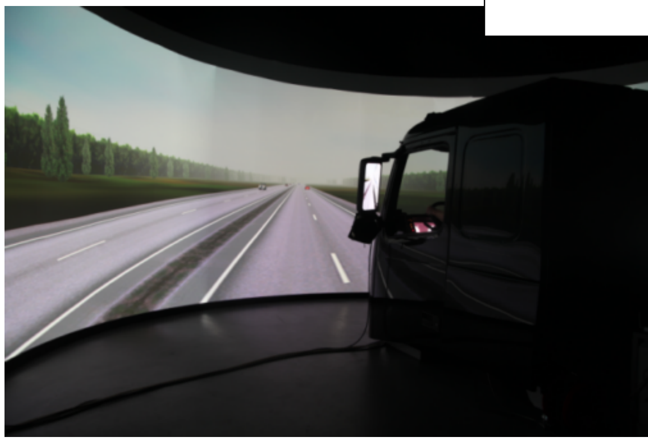
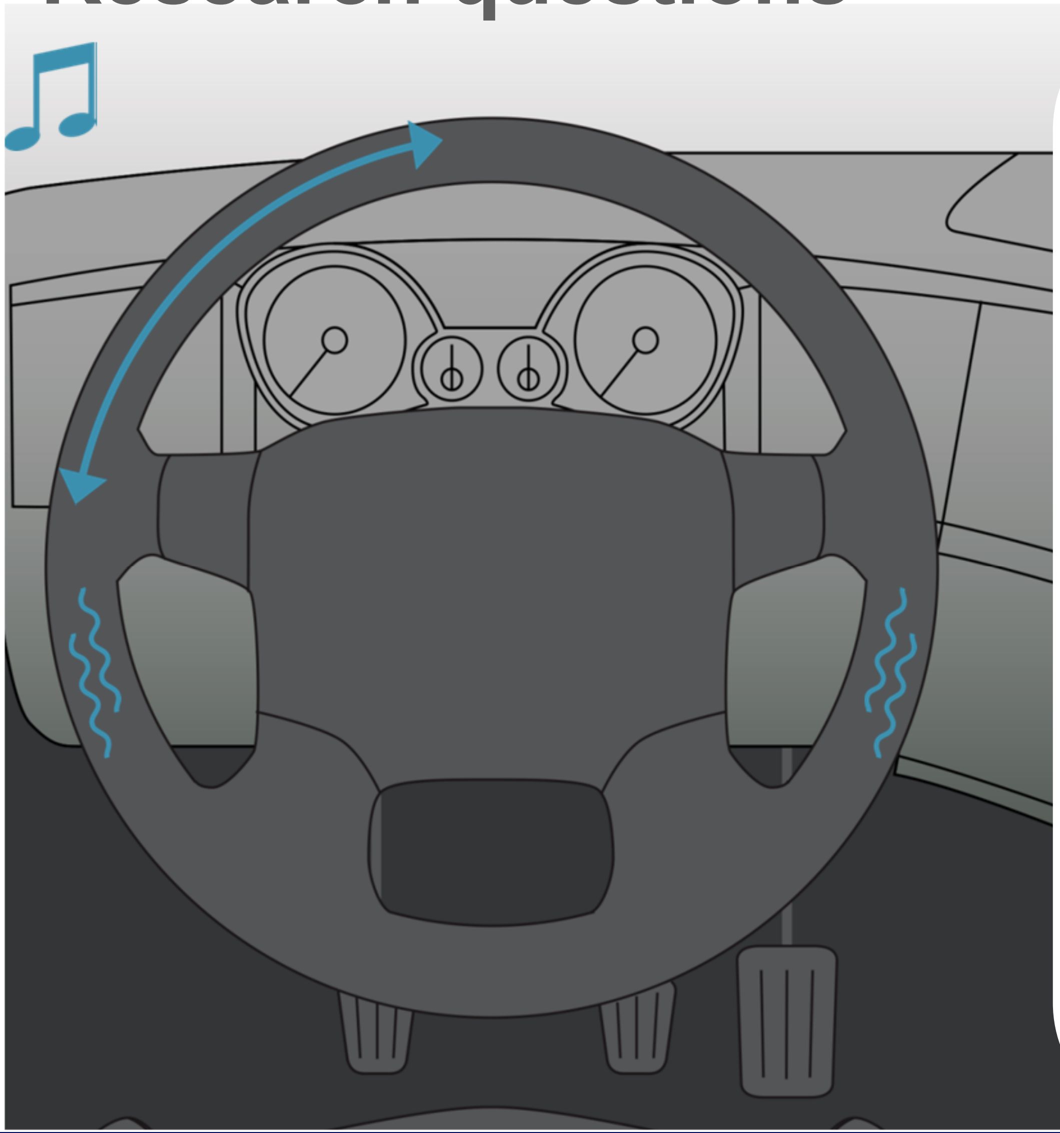


Research questions



- Can **vibrations and/or steering** be an alternative to today's Lane Departure Warning sound in Volvo trucks?

- What, if any, are the differences between alternatives wrt driving performance and driver acceptance?

- **Experiment 1**: comparison between (i) Sound, (ii) Vibration and (iii) Steering
- **Experiment 2**: comparison between (i) Vibration + Steering and (ii) Baseline/no support

Research questions

- ”Bonus” in Exp. 2: evaluation of Lane Change Support
  - There are an increasing number of ADAS introduced in today’s vehicle.
    - Can a **Lane Change Support system** share the same or similar interface with **Lane Keeping Aid system** in order to create a combined lateral support system?
    - Lessen the complexity but still allowing for a fuller lateral support.

Background - Terminology

- Terms used in this presentation:
  - LDW: Lane Departure Warning
  - LKA: Lane Keeping Aid/Assistance
  - LCS: Lane Change Support (“blind spot system”)
- ISO 17361:
  - LDW should detect the lateral position of the subject vehicle relative to the lane boundary and, if the warning condition is fulfilled, warn the driver by either a visual, auditory or haptic warning.
  - LKA: A standard for LKAs is currently not available but under development and will cover systems that provide additional steering torque.

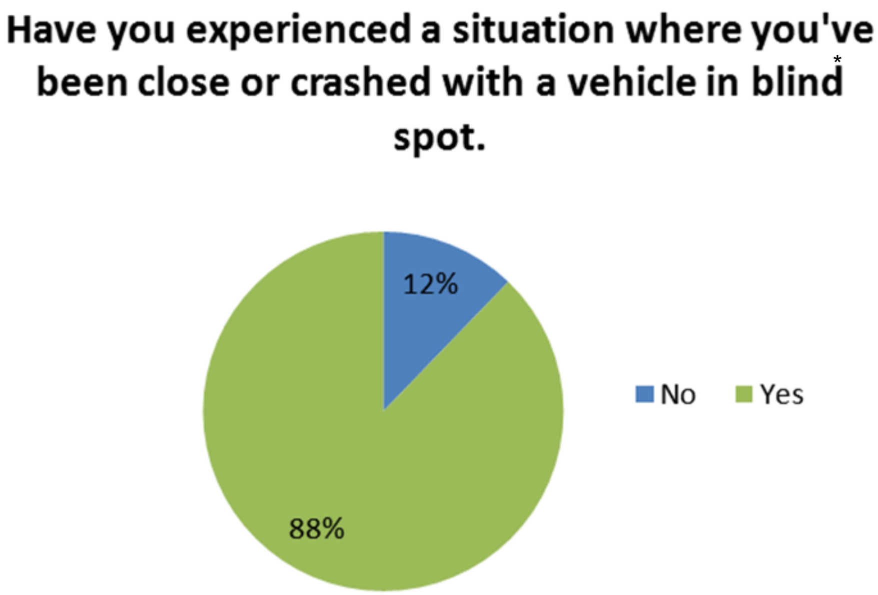
Background - Systems on market

- Personal vehicles:
  - LDW: e.g. Citroën, Mercedes, Volvo and BMW.
  - LKA: e.g. Honda, Audi, Ford, Lexus, Toyota and VW.
- Truck segment:
  - LDW: e.g. Volvo, Renault, Mercedes, MAN, Iveco, Scania
  - LKA: no truck brands were found that offers systems using applied steering wheel torque at the time for this paper/presentation

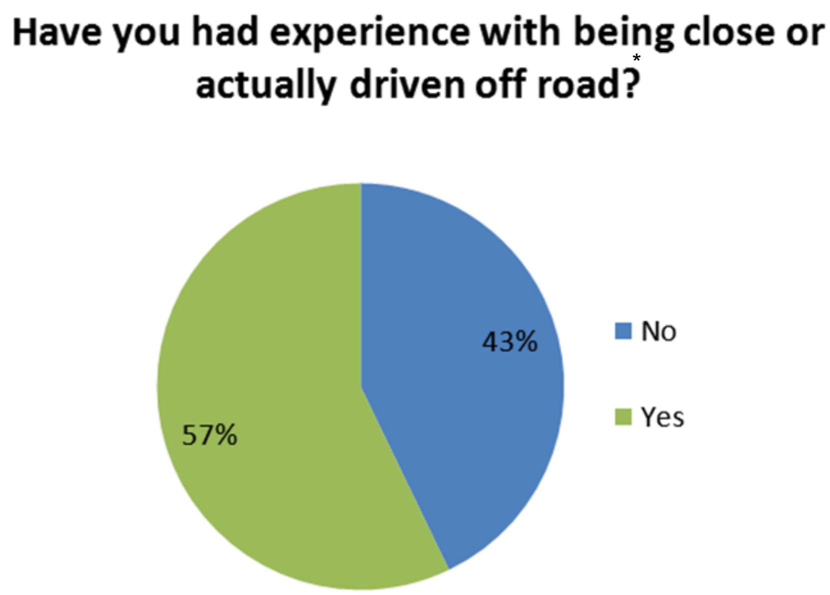
Background

- Drivers' responses (44 drivers in Exp. 2)

Blind Spot situation



Lane departure situation



Experiment 1: method/set up

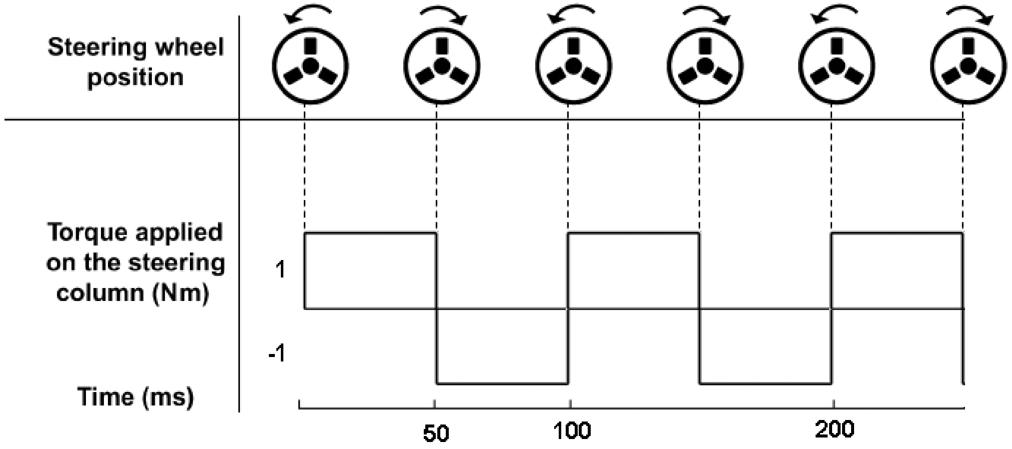
ViP
Virtual Prototyping and
Assessment by Simulation

- Moving base simulator at VTI
- 24 professional truck drivers ranging from novice, medium to experienced. Average age: 37.
- Secondary task (radio) and additional yaw motion introduced to allow for lane departures

Experiment 1: method/set up

- Current sound vs. vibration vs. steering
  - Sound: 70ms long pulses, with a silence of 33ms in between the pulses. The fundamental frequency of the sound was around 133 Hz and the spectrum contained harmonics up to about 4kHz
  - Steering: torque ramped from 0 to 7 Nm. Ramp up time dep. on how truck approached lane marker (e.g. heading angle and speed).

- Vibrations: in the steering wheel, *symmetric* oscillation, with a period of 100 ms and an amplitude of +/-1 Nm:

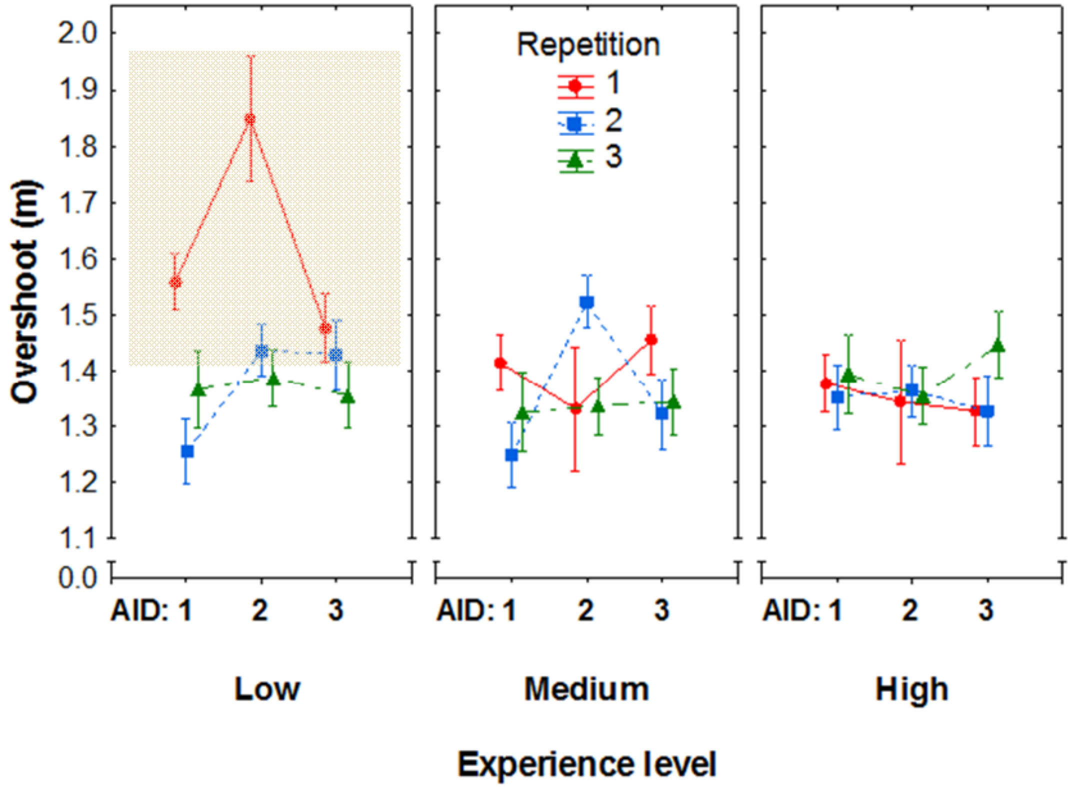


Experiment 1: measures

- Duration of lateral excursion [s]:
  - Time from when vehicle's right/left front wheel crosses the right/left lane marker in the direction from the centre of the driving lane, until vehicle's right/left front wheel crosses the right/left lane marker in the direction towards the centre of the proper driving lane,
- Overshoot [m]:
  - Movement past centre of the right lane after a lateral excursion defined as the distance between the centre of the right lane and the maximum lateral position opposite to the lane departure,
- Peak acceleration of steering wheel motion [degrees/s^2]:
  - Once the subject's recovery steering manoeuvre has started, the sharpness of the steering is given by the maximum acceleration of the steering wheel motion.
- Subjective measures: interview & questionnaire

Experiment 1: objective results

- Overshoots [m]. → Sign. diff. for novice drivers for vibration (larger overshoot for novices)



- Duration of lateral excursion → No diff.
- Peak acceleration of steering wheel motion→ No diff.

AID1: Sound
AID2: Vibration
AID3: Steering

Experiment 1: subjective results

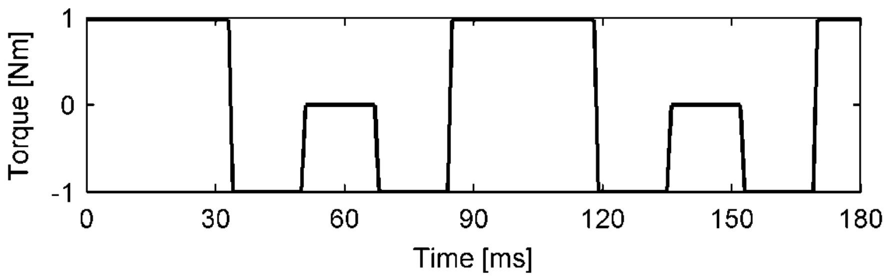
- Steering :
  - Sceptical to **leave control** to the vehicle. Felt scary.
  - Automatically **countersteer** during interventions?
  - The system would really serve its purpose as a **countermeasure**
  - Many **“what if” questions** (e.g. road and load conditions, vehicle configuration)
- Vibrations:
  - Positive comparison w **rumble strips**
  - Might be **annoying**, especially after some time
- Sound:
  - Control issue, some preferred the **passive warning** instead of the guided torque due to this. No risk of counteract as for when vehicle is steering.
  - **Mixed feelings**, assumingly due to the type of sound presented & due to the fact that a warning sound perhaps can be allowed to have some qualities not necessarily comfortable.
  - Some drivers felt that the sound was **not enough** or that the sound volume was too low

Experiment 2: set up

- Static simulator at Volvo
- 43* professional truck drivers ranging from. Average age: 40 years old.
  *Originally 44. One subject removed due to simulator sickness
- Between groups design: 22 subjects drove with system activated, 21 subjects drove with system deactivated
- Secondary task (radio) and yaw motion introduced to allow for lane departures
- Vibrations and Steering triggered at ’lane marking +50 cm’ (in exp. 1 warning and steering was triggered on lane marking)

Experiment 2: set up LKA

- No support vs. support by vibration <u>combined</u> with steering
  - Vibrations: *asymmetric* oscillation, with a period of 85 ms and an amplitude changing between -1, 0 and 1 Nm. The time of the torque was longer in the direction of the lane centre and shorter in the direction of lane departure in order to give a guiding vibration feeling



  - Steering: ramped from 0 to 4 Nm. The guiding direction was opposite the direction of lane crossing
  - Vibrations and Steering triggered at the same time but steering ramped up based on distance from lane markings → feeling of a step wise support strategy

Experiment 2: set up LCS (Lane Change Support)

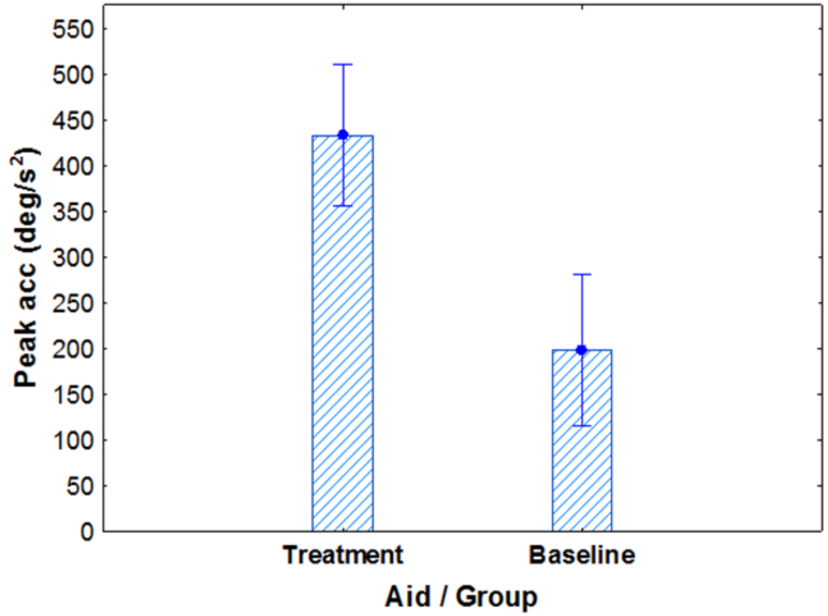
- An additional drive was included for a “LCS situation” (blind spot) with a car following scenario
- Between group design in Experiment 2 due to the need to keep expectancy low for LCS event.
- Steering force applied for treatment group
  - 0 to 5 Nm for the LCS, same vibration settings as for LKA
  - Additional blind spot display located by the right hand A-pillar
  - Triggered based on distance to blind spot vehicle

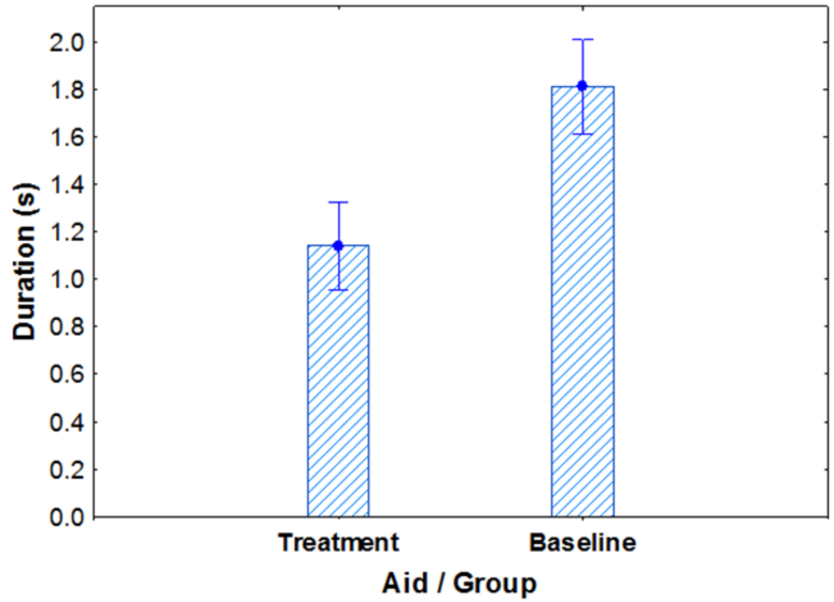
Experiment 2: results

- Same measures as in Experiment 1
- Significant effects on first event for LKA for:
  - Peak acceleration of steering wheel motion (upper pic)
  - Duration of lateral excursion (lower pic)
  - No sign. effects on overshoots

→ With the LKA system drivers (i) steer more hefty and (ii) are back earlier in lane

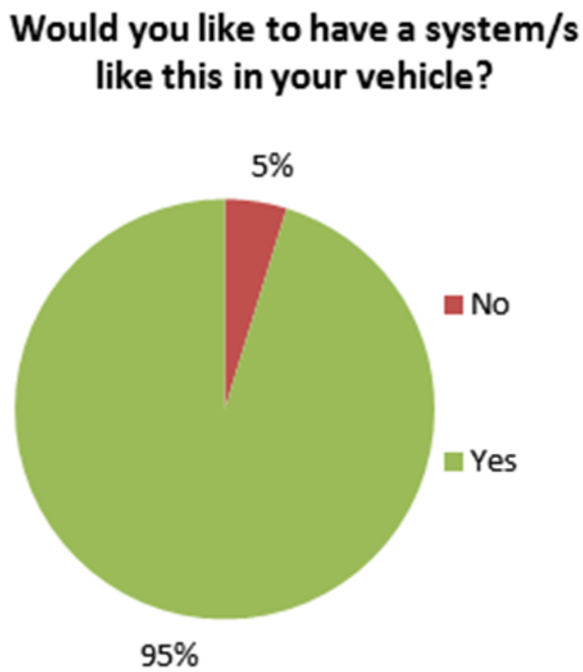
→ No negative unintended effects (overshoots)





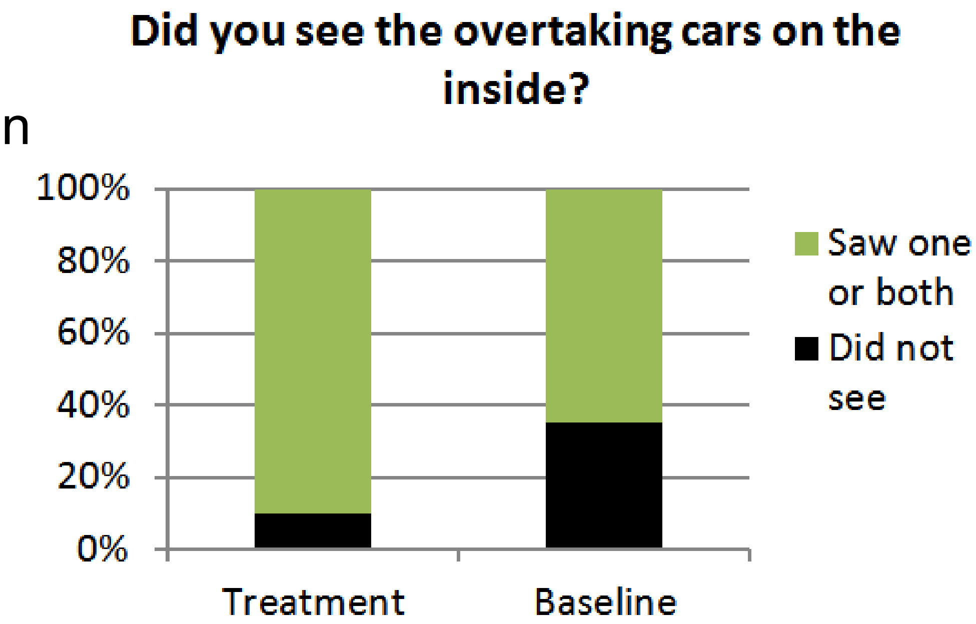
Experiment 2: results

- A majority of the drivers in both baseline and treatment groups said they would like to have a combination of **Lane Keeping Assist and Lane Change Support** systems in their vehicle
- A majority would trust the system
  - still system is considered just a support with drivers as main responsible actor
  - Same questions arised from drivers as in Exp. 1. E.g. instability issues in combination with road surface, heavy load etc.



Experiment 2: results

- Lane Change Support:
  - Most drivers felt the vibration and force *when crossing lane boundaries*. Not so many commented on that they got the warning due to the blind spot vehicle
  - BUT: more drivers with LCS active actually saw the blindspot vehicle



Conclusions

- Experiment 1: ”Only” effect on actual driving was for Overshoots for Vibrations with novice drivers.
- Experiment 1: Quite evenly rated alternatives however, some more scepticism towards vehicle steering:
  - Vibration: coupling to rumble strips
  - Sound: annoying but “safe”
  - Steering:
    - Who’s in control?
    - What happens with heavy loaded trailers, slippery road surface etc (see vehicle dynamics simulations from InteractIVe)

Conclusions

- Experiment 2: Combined vibrations and steering wheel force → positive drivers
- Experiment 2: LCS and LKA with steering wheel input can be combined into one integrated support → drivers find this joint support natural
- Experiment 2: LCS and LKA : vibrations on top of ramped up steering and not just steering is recommended in order to create a feeling of a *system*. Vibrations:
  - are necessary to distinguish intervention from other front axis disturbances
  - raise level of acceptance

Future studies - ideas

- Implement HMI in real truck (on-going in the interactIVe project)
- Validate results in test track and/or on road
- Run experiment with drivers who has larger experience with ADAS
- Run experiment for a longer time, preferrable smaller FOT
- Investigate how system is perceived in different vehicle combinations as well as different load and road surface conditions
- Improve methodology:
  - Secondary task selected. Consider a different task, less ecological valid and w less time sharing opportunities but allowing for longer glances away from road scene…
  - Yaw motion. Investigate if another secondary task can allow for lane changes more easily in order to be able to skip the induced yaw motion…

Acknowledgement & Contact

- Experiment 1: 50% national funding and carried out within the Swedish competence centre ViP, Virtual Prototyping and assessment by simulation (http://www.vipsimulation.se/)

- Experiment 2: 50% EU funding and conducted within the EU project interactIVe (http://www.interactive-ip.eu)

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Thank you for your attention!