Multidisciplinary Development of a Driving Simulator with Autostereoscopic Visualization for the Integrated Development of Driver Assistance Systems

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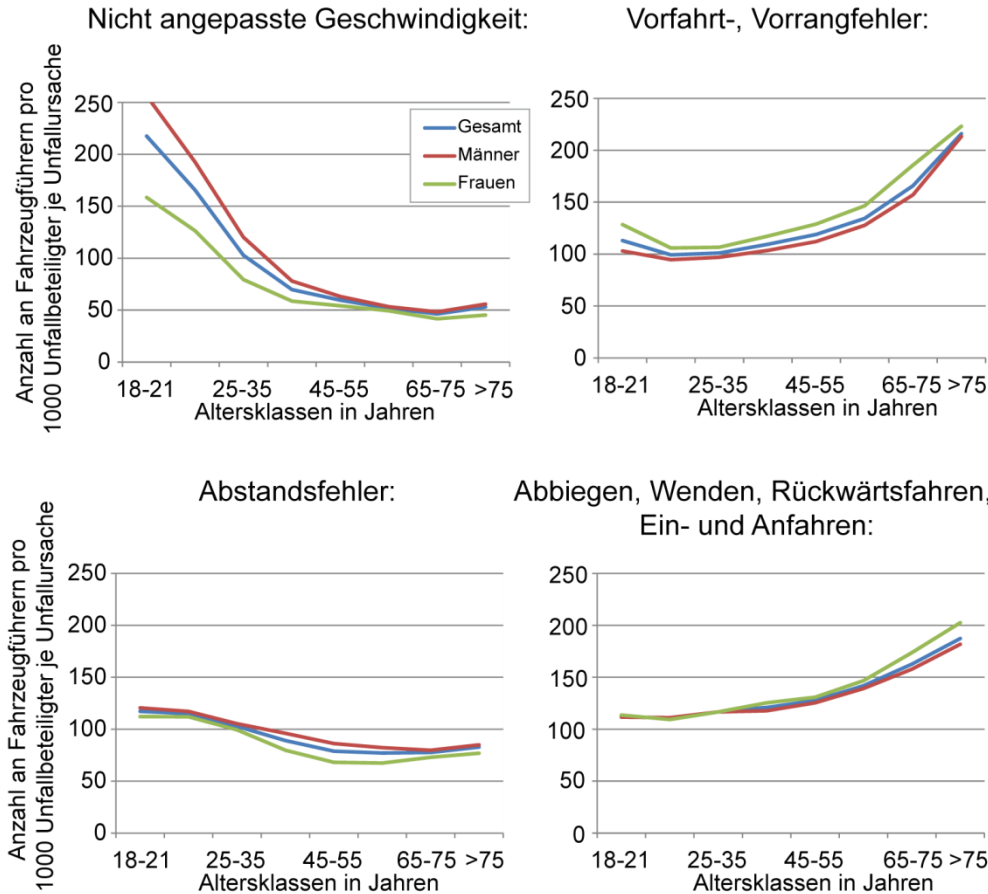*[2]Fraunhofer Austria Research GmbH, Visual Computing, Austria*

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Agenda

- Motivation

- Development of driving simulator
    - Visualization (3D effect by parallax barrier)
    - Sound simulation
    - Force feedback simulation (FFB)
    - Driver interaction

- Validation study

- Conclusion

Motivation - age and gender specific differences in accident causation

Nicht angepasste Geschwindigkeit:

Vorfahrt-, Vorrangfehler:

Abstandsfehler:

Abbiegen, Wenden, Rückwärtsfahren, Ein- und Anfahren:

- Speeding typical for **young male** drivers
- Risk for accidents in *turning* and *giving way* related to age and gender. **Elder women** at higher risk.

Source: DESTATIS 2012

Motivation – Research Questions

- Are there differences regarding age and gender in driver behaviour in different driving situations?

- Can comfort and safety be improved by adaptations of advanced driver assistance systems **(ADAS)** to the driver behaviour?
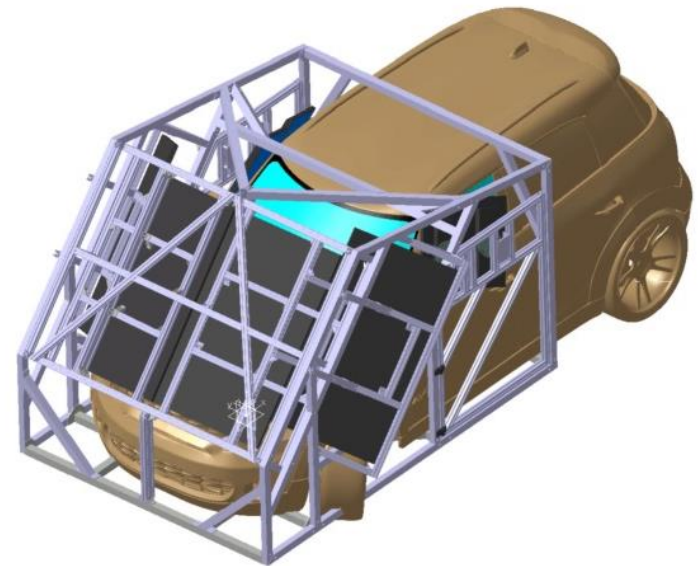
Selected ADAS:

→ Adaptive Cruise Control **(ACC)** (Full Range)

→ Automated Emergency Braking (**AEB**) (City, Urban, Pedestrian)
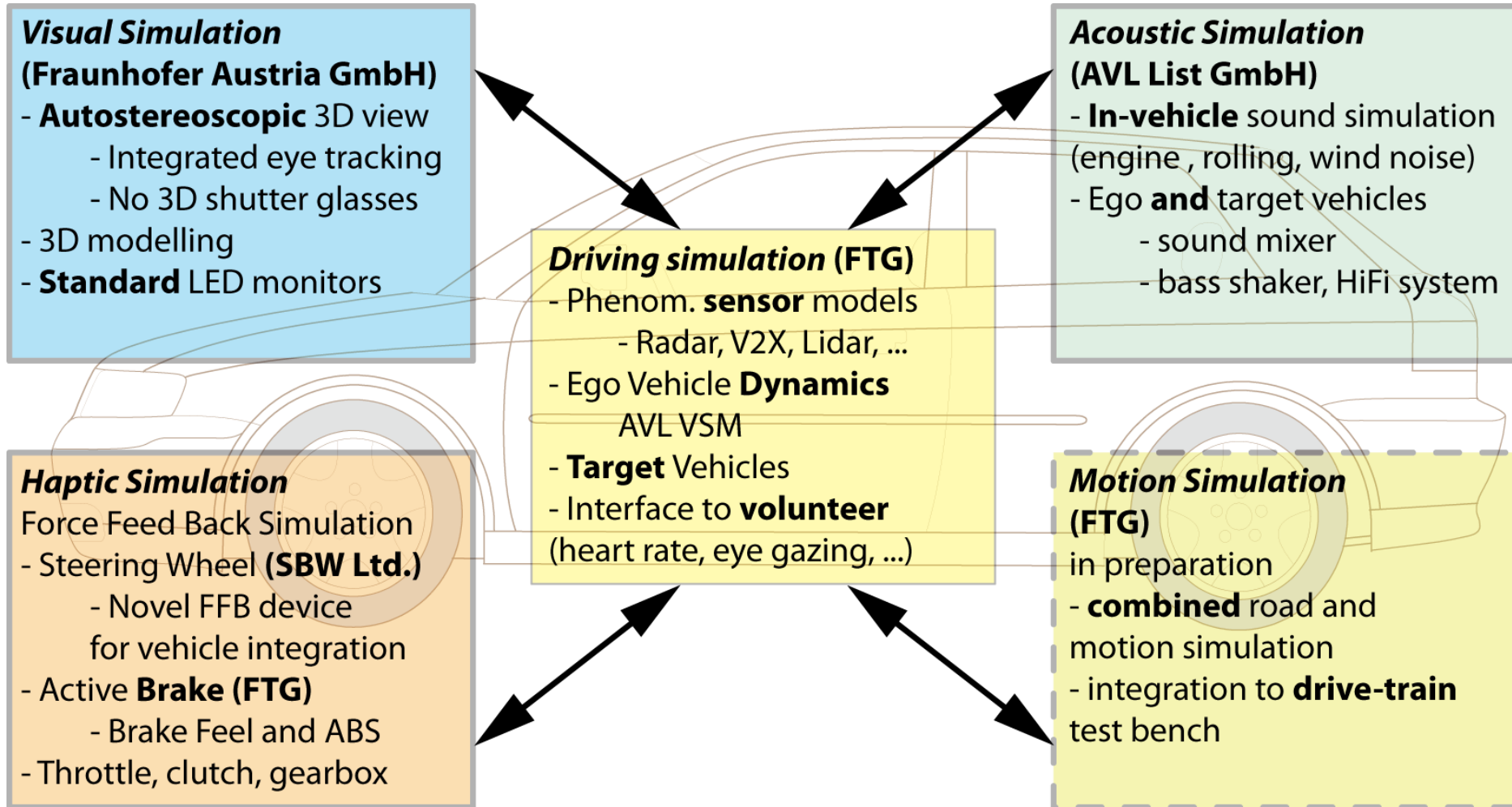
Method:

→ Comparison of natural driving study to simulator pre-study (validation)

→ Main driving simulator study with 100 participants (ongoing)

Driving simulator features

- Full vehicle (Mini Countryman chassis)

- Autostereoscopic visualization (Fraunhofer Austria)

- Detailed in-vehicle sound simulation (AVL List)

- Detailed force feedback **(FFB)** simulation
  - Active steering wheel FFB (for in-vehicle integration), (SBW Technology)
  - Active Brake FFB
  - Passive throttle, clutch, gearbox

- Integrated eye tracking

- Configurable HMI

- Prepared for motion platform

Modular architecture

Visual Simulation
(Fraunhofer Austria GmbH)
- **Autostereoscopic** 3D view
    - Integrated eye tracking
    - No 3D shutter glasses
- 3D modelling
- **Standard** LED monitors

Acoustic Simulation
(AVL List GmbH)
- **In-vehicle** sound simulation
(engine , rolling, wind noise)
- Ego **and** target vehicles
    - sound mixer
    - bass shaker, HiFi system

Driving simulation (FTG)
- Phenom. **sensor** models
    - Radar, V2X, Lidar, ...
- Ego Vehicle **Dynamics**
    AVL VSM
- **Target** Vehicles
- Interface to **volunteer**
(heart rate, eye gazing, ...)

Haptic Simulation
Force Feed Back Simulation
- Steering Wheel **(SBW Ltd.)**
    - Novel FFB device
    for vehicle integration
- Active **Brake (FTG)**
    - Brake Feel and ABS
- Throttle, clutch, gearbox

Motion Simulation
(FTG)
in preparation
- **combined** road and
motion simulation
- integration to **drive-train**
test bench

Visualization

- Autostereoscopic visualization **without** 3D shutter glasses by parallax barrier

- **Optimized monitor configuration** for maximum field of view (180 degrees) and minimum package

- Standard LCD monitors: four 55" monitors for front window, four 23" monitors for side windows

- Integrated **eye tracking** for head position compensation
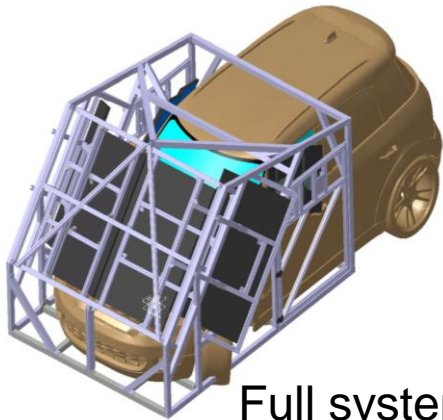

Full system
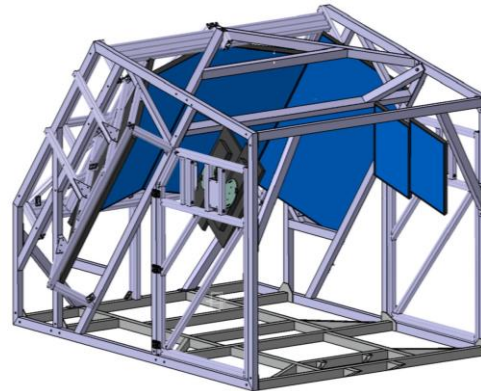
Monitors

Visualization

Monitor test setup:

Full system:
(2D)

Parallax barrier

- Separated pixels for left and right eye by parallax barrier (Pixels are blocked individually for each eye)

- Different picture for left and right eye gives the 3D effect (in optimal configuration)

- Integrated eye tracking for head position compensation

- Optimized design of each barrier for maximum resolution for each monitor

Monitors

Barrier

Left eye (blue) Right eye (red)
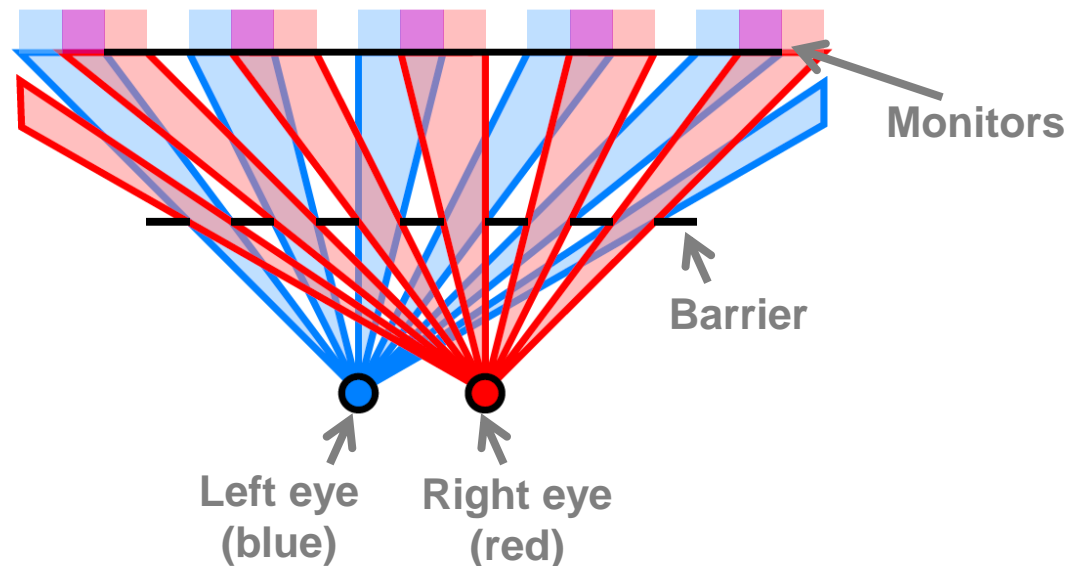
Sound simulation

- Interior sound
  - Bass shakers (engine compartment, beneath front seats)
  - Vehicle HiFi system

- Sound generation
  - Engine noise
  - Road noise
  - Wind noise
  - Multiple vehicles

- Input from vehicle dynamics simulation:
  - Vehicle velocity, engine speed, gear information, throttle position
  - Relative position of all simulated vehicles

# Haptic force feedback steering wheel

- Patented FFB device (SBW Technology) with innovative gearbox and BLDC motor

- On-board power supply 12/24V with energy recuperation

- Integrated controller

- Steering torque generated by vehicle dynamics simulation, respecting tire and steering system dynamics
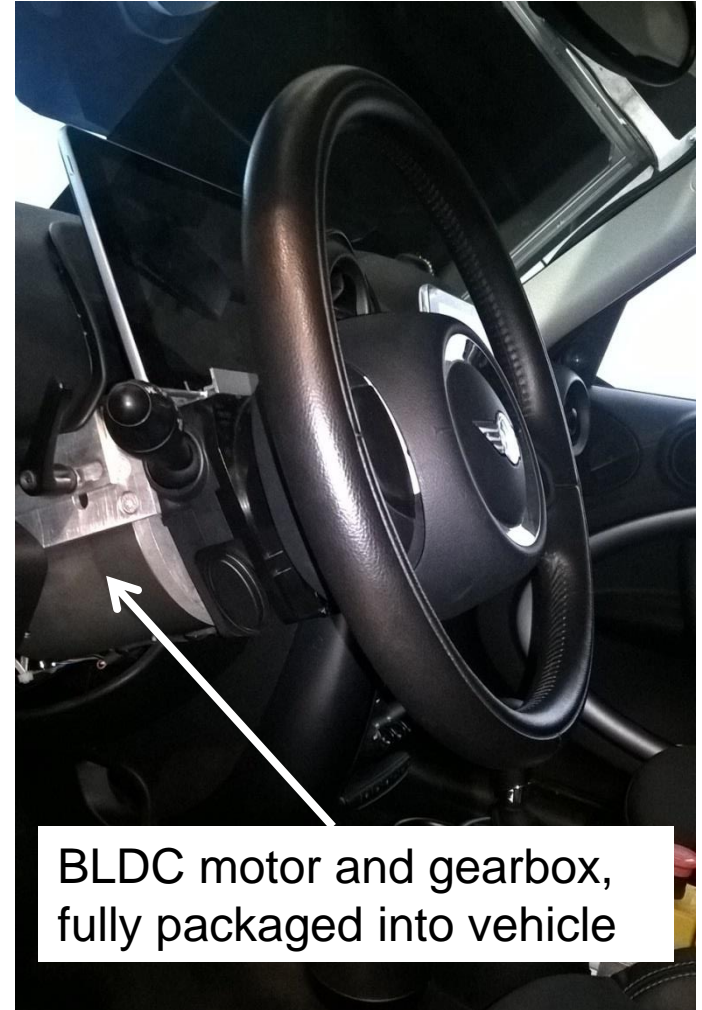
BLDC motor and gearbox, fully packaged into vehicle

Haptic FFB brake and throttle, clutch, gearbox

- Active brake pedal with gear mechanism from motor to brake pedal

- Electric motor and controller by Infranor (minimum torque ripple)

- Brake characteristic parametrized using measurements from real cars

- Passive FFB solutions for throttle, clutch and gearbox with spring mechanisms

FTG
Fraunhofer
AUSTRIA
AVL
SBW
TECHNOLOGY
TU
Graz
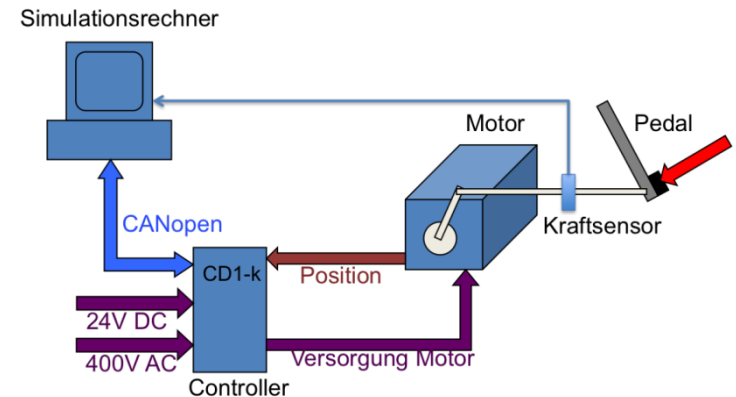
Driver interaction

- Configurable HMI
- Measurement of eye:
    - Position
    - Blinks
    - Gaze vector
- Heart rate monitoring
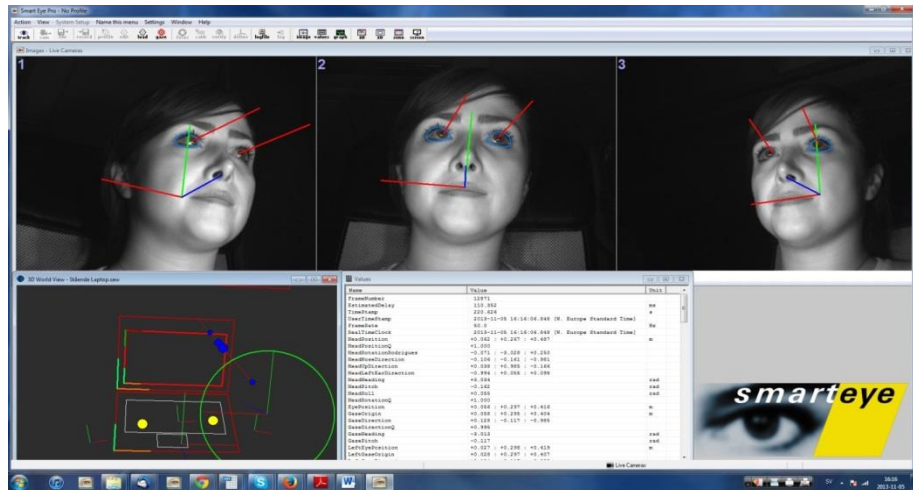
Validation study

Goal: Comparison of results from real driving study and simulator study, using **subjective data** (driver questionnaires) and **objective data** (distances between vehicles, vehicle velocities and accelerations)

Natural driving study:
- conducted in November 2013
- 10 male and 10 female drivers for each ACC and AEB tests, matched by age and driving experience

Driving simulator study:
- conducted in May 2015
- 10 male and 10 female drivers (matched)
- all participants from natural driving study
- same maneuvers like natural driving study

ACC test setup

- **Ego vehicle** with Full-Range ACC
    - Objective measurements: Dewetron CAPS
    - Vehicle data (CAN)
- **Target vehicle 1**
    - Objective measurements: Dewetron CAPS
    - Vehicle data (CAN)
- **Target vehicle 2**
    - for cut-in maneuvers

- Natural driving study on public Austrian highway near Graz (three lanes)
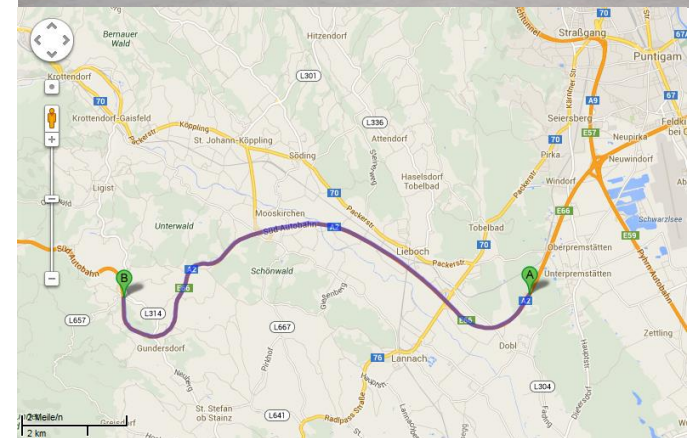
AEB test setup

- **Ego vehicle** with AEB (City, Urban, Pedestrian)
  - Objective measurements: Dewetron CAPS
- **Targets**
  - Euro-NCAP balloon car
  - 4AE Pedestrian Adult Dummy

- Closed test track

AEB Pedestrian tests

Selected results of validation study

Dependent measures were:

- Subjective estimations of safety, comfort and trust

- Ratio of subjective to objective minimal distance to forward vehicle (target vehicle)

**Results for subjective estimations (ACC Tests):**

ACC Tests were performed with time gaps 1 and 1.8 seconds, ACC following a vehicle or a third vehicle cutting in

- Driver's ratings of safety, comfort and trust were significantly lower in the simulator than in reality at time gap 1

- For time gap 1.8, the results did not reach statistical significance

Selected results of validation study

Results for ratio of subjective to objective minimal distance (ACC Tests):

- Again for time gap 1.8, the results did not reach statistical significance
- For time gap 1, the ratios were lower in the simulator than in real conditions (see means and 95% confidence interval below)
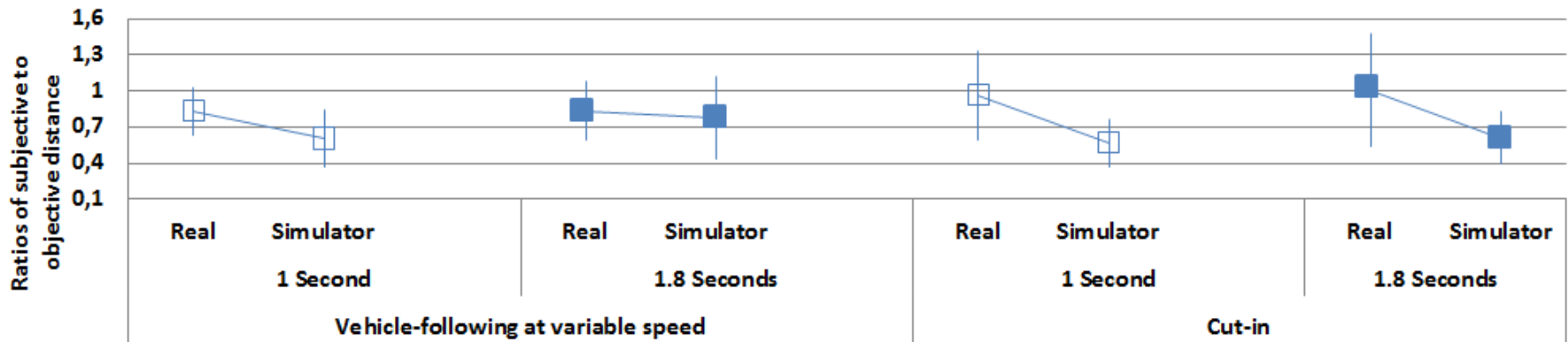
Selected results of validation study

Simulator sickness:

- Simulator Sickness Questionnaire (SSQ) by *Kennedy, Lane, Berbaum and Lilienthal 1993*

- Participants score 16 symptoms of 3 main categories (nausea, oculomotor, disorientation)

- 4 points scale (0-3)

- For comparability, values for Virtual 2D (non-stereoscopic) and Virtual 3D (shutter techniques) are taken from *Häkkinen et al. 2006*:

|	Parallax Barrier	Virtual 2D	Virtual 3D
nausea	34.9	11.8	29.9
oculomotor	49.8	14.0	26.9
disorientation	79.5	21.1	41.1

Conclusion

- Natural driving studies are limited in number of participants and driving manoeuvres

- Simulations are more or less abstract models of the reality, knowledge on the influence of human cognition and behaviour is required to understand driving simulator results

- Comparison of natural driving study to driving simulator study shows some differences in subjective evaluation of trust, comfort and safety as well as the ratio of subjective to objective distance to a forward vehicle

- Because of high values for simulator sickness, the 3D barrier was not used during the main study (with 100 participants)

Outlook

- 3D parallax barriers show a lot of potential:
  However, the barriers have to be adapted (thickness and colour of stripes) in order to reach lower simulator sickness values

- Further investigation on influence of simulation on human cognition is required

- Main study is ongoing, research goals:

  - gender and age specific differences in driving behaviour

  - influence of road condition on driver's perception of trust, safety and comfort in different driving situations with ADAS intervention

- Long-term goal: Adaptation of ADAS interventions to **driver**, **driving situation** and **road condition**

Thank you for your attention!
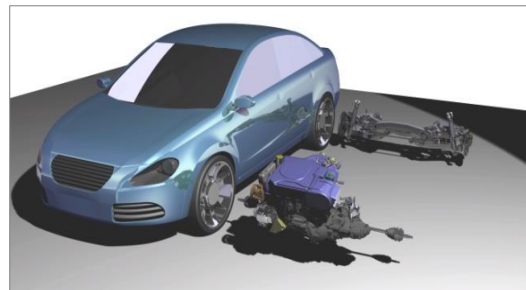
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Publications

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Driving simulator applications

Current

- Full Vehicle Integration of **ADAS** Advanced Driving Assistance Systems

- Evaluation of Human Driving Behavior

- **HMI** (Human-Machine-Interface) development and validation

- Steer-by-Wire integration

- Development of new ADAS

Future

- Operation strategies for electrical and hybrid drive train

- Comfort und rough road investigations

- …