Abstract and Motivation
Driver drowsiness is a major cause of severe accidents, many of which involve a single vehicle lane departure. The objective of this experiment is to determine the relationships between drowsiness, lane departure events (LDE) and effects of a warning system.
For reasons of safety (and reproducibility), a laboratory-based driving simulator is used. The experiments were conducted with a cohort of 63 healthy male subjects aged 22 to 27 driving for about 2.5 hours in a stimulus-deprived scenario with a six-fold repetition. Several hundreds micro-sleep episodes were identified in 53 successful trials; more than 800 lane departure warnings (LDW) occurred in the assisted sub-cohort of 17 drivers.

The analysis of LDE with and without LDW system shows significant reduction in number, time, departure length and out-of-lane area for the assisted subjects. The timing and design of the warning could prevent more than 85% of the lane departure events caused by sleepiness.

Simulation Scenario
Baseline 6 km, good visibility, gentle, no traffic
Control 9 km, frequent and strong change in curvature and slope, lively traffic, partly fog
Induction 114 km, (6 repeats), fog, gentle curves and slopes, little traffic, speed limit 50 km/h
Test same as Control

LDW: Event Description

Lane Departure Events & Warnings
Group F2 in foggy drowsiness induction repetitions:
- 145 LDE-Events detected, only 26 after a warning
- 215 LDW-Warnings issued, only 26 LDE followed (intersection in Figure right).

Efficacy of warning design after micro-sleep:
- only 6 LDE-Events occur after 37 LDW-Warnings (pink in Table below)

<table>
<thead>
<tr>
<th>number</th>
<th>LDE total</th>
<th>25 LDE after LDW</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>215</td>
<td>37</td>
</tr>
<tr>
<td>LDE after LDW</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>LDE / LDW [%]</td>
<td>16.2</td>
<td></td>
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<tr>
<td>F2</td>
<td>6</td>
<td>145</td>
</tr>
<tr>
<td>LDE (LDW-sleepy)</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>LDE (LDW-rest)</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>LDE (no alarm)</td>
<td>120</td>
<td></td>
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<tr>
<td>F1</td>
<td>5</td>
<td>635</td>
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<tr>
<td>max LD [cm]</td>
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<tr>
<td>max Area [cm²]</td>
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<tr>
<td>max time [s]</td>
<td>2.4</td>
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Experimental Equipment
- Fixed-base Simulator (Steim);
- Physiological measuring system (Biopac);
- Stereo camera eye-tracking system (faceLAB);
- Video-split;
- External observer with video and audio link

LW System (LDWS)
- 813 Lane Departure Warnings (LDW) issued
- 286 LDW after micro-sleep
- 1615 non assisted Lane Departure Events (LDE)
- 153 LDE after Warning

Cohort
- 268 rejected (participant, glasses, smokers, etc.)
- 63 trials
- 11 declined
- 3 reserved
- 36 valid with LDW
- 36 valid without LDW

Distribution of lane departures
- 18% LDE after LDW
- 82% LDE total

Two distinct groups can be easily identified: 14 drivers with few warnings (F2) and 3 drivers with many (F1) (Figure left). The same applies to the number of LDE for both the assisted and the non-assisted cohorts. The latter (Figure below) splits into 29 drivers with few LDE (F1) and 7 drivers with many LDE (M1).

Trial Statistics

Conclusions
Different perspectives on the Lane Departure Events and Lane Departure Warnings yield a coherent picture of what happens before, while, and after a micro-sleep event. We show that the LDWS strongly reduces the number and severity of the lane departure events even in case of a micro-sleep episode. System limits and the critical issue of habituation will be further addressed.