ANALYSIS OF AN ADVANCED DRIVER-ASSISTANCE SYSTEM TO IMPROVE SAFETY OF CYCLISTS OVERTAKING BY DRIVER CHARACTERISTICS

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* DICEA - University of Naples Federico II
** IMOB - University of Hasselt

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Motivation (1)

- Cycling is a sustainable and affordable transport mode with demonstrated health, environmental, and economic benefits.
- Cyclists are particularly vulnerable because they must frequently share the same infrastructures as motorized vehicles.
- Sharing the same lane, cars typically need to overtake cyclists, creating dangerous interactions.
- These interactions often result in severe injuries or even fatalities, especially on rural roads, due to the large difference between speeds of the car and the bicycle.
- The risk for cyclists during the overtaking consist on:
  - A direct impact with vehicles (a rear-end collision or sideswipe)
  - Loss of stability and control due to the aerodynamics forces created by the passing vehicle
Minimum passing distance laws have been introduced to reduce the dangers to cyclists from motor vehicles passing too close but failure to follow traffic regulations, distracted driving, and an inability to determine passing distance accurately can happened. We propose an ADAS system able to support drivers as they overtake cyclists avoiding or mitigating crashes. Study aims are:
- To evaluate if the system succeeds in effectively reducing the aerodynamic forces experienced by the cyclists
- To investigate the effect of socio demographic background factors (age and gender) on the effectiveness of the system.
Experiment: Car-To-Cyclist Overtaking Warning System (1)

- A new ADAS system was designed to support drivers during cyclist passing manoeuvre helping them to maintain safe lateral distance from cyclist.
  - Multistage warning strategy
  - Multimodal systems (both visual and audio signals)

- Three warning phases were defined: (1) normal driving, (2) danger phase, and (3) avoidable accident phase.

<table>
<thead>
<tr>
<th>Signal</th>
<th>Normal driving</th>
<th>Danger phase</th>
<th>Avoidable accident phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual</td>
<td><img src="Visual" alt="Diagram" /></td>
<td><img src="Danger" alt="Diagram" /></td>
<td><img src="Avoidable" alt="Diagram" /></td>
</tr>
<tr>
<td>Audio</td>
<td>No acoustic signal</td>
<td>Single Beep</td>
<td>Double high-pitched beep</td>
</tr>
</tbody>
</table>

Mauriello F., Brijs T., Montella A., Galante F., Brijs K., Ross V. Analysis of an advanced driver-assistance system to improve safety of cyclist overtaking by driver characteristics
Experiment: Car-To-Cyclist Overtaking Warning System (2)

- The activation criterion of the three warning phases during car-cyclist overtaking is based on a combination of the lateral clearance (LC) and time-to-danger (TTD) threshold values.
  - LC: minimum lateral distance between the vehicle and the cyclist during overtaking
  - TTD: time taken for the vehicle to laterally align its front bumper with the rear wheel of the cyclist

<table>
<thead>
<tr>
<th>Lateral Clearance</th>
<th>Time to Danger</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4.5 s &gt; TTD ≥ 3 s</td>
</tr>
<tr>
<td>LC ≥ 1.5 m</td>
<td>Normal driving</td>
</tr>
<tr>
<td>1.5m &gt; LC ≥ 1.0 m</td>
<td>Normal driving</td>
</tr>
<tr>
<td>LC &lt; 1.0 m</td>
<td>Normal driving</td>
</tr>
</tbody>
</table>
Experiment: Study Design (1)

- The study was conducted on the IMOB driving simulator (Hasselt University)

- Experimental road
  - A two-lane rural highway
  - 3.0 m wide lanes, no shoulders
  - 10 tangents (1,000 m long)
  - 9 circular curves (radius of 400 m, d.a. of 35°)
  - Spiral curves (55 m long)
  - Posted speed limit of 70 Km/h
  - No separated cycle lanes
  - No marks to warn of cyclists' presence on the road
  - Occasional traffic in opposite direction
- **Experimental scenario**
  - Three events were tested during the experiment and took place in tangent.
  - Each event was repeated three times along the experimental road.
  - Cyclists had a constant speed of 18 Km/h.

  **Event 1 (E1)**
  - Overtaking a cyclist riding normally with a constant lateral position.

  **Event 2 (E2)**
  - Overtaking a cyclist manoeuvring from the edge to the center of the lane.

  **Event 3 (E3)**
  - Overtaking two cyclists riding in parallel position.
Experiment: Study Design (3)

- Participants
  - 48 subjects (final sample)
  - No simulator sickness observed

<table>
<thead>
<tr>
<th>Driver characteristics</th>
<th>Categories</th>
<th>N</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gender</strong></td>
<td>Female</td>
<td>27</td>
<td>56.25%</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>21</td>
<td>43.75%</td>
</tr>
<tr>
<td><strong>Age</strong></td>
<td>18-25</td>
<td>11</td>
<td>22.92%</td>
</tr>
<tr>
<td></td>
<td>26-35</td>
<td>22</td>
<td>45.83%</td>
</tr>
<tr>
<td></td>
<td>&gt;36</td>
<td>15</td>
<td>31.25%</td>
</tr>
</tbody>
</table>

- To prevent confounding errors, the sequence in which subjects encountered each event through the route was balanced and was determined randomly.
- Each participant drove twice the same experimental route, first without (A0) and then with (A1) the ADAS cyclist overtaking system.
- During each drive, each participant was engaged in nine car-to-cycle overtaking events resulting from the three-time repetition of each basic event (E1, E2 and E3).
Maximum aerodynamic forces ($\Delta F_{f0}$) acting on the cyclist during car overtaking (Gromke et Ruck; 2021)

Rapid flip over from pressure to suction load. The flip over begins when the vehicle front is passing the bottom bracket and ends when the inclined windscreen is next to it.

$$
\Delta F_{f0} = c_1 V_{veh}^2 \\
c_1 = 0.016 \times A_{lc} \times LC^{-1.33}
$$

$A_{lc} =$ projected lateral area;
Three safety measures were extracted and analyzed at the point of load of maximum pressure:

- Lateral clearance (LC)
- Vehicle speed
- Maximum aerodynamic force ($\Delta F_{f0}$)

T-student tests were carried out to evaluate the effect of drivers’ gender and age on the effectiveness of the ADAS system.
ADAS vs Drivers Gender: LC

**Analysis of an advanced driver-assistance system to improve safety of cyclist overtaking by driver characteristics**

**Not active (A0)**
- Female drivers exhibited shorter LC from the cyclist than male drivers (1.52 m vs. 1.70 m)
  
  **Women's greater risk perception of possible head-on crashes**

**Active (A1)**
- Statistically significant increase in LC for female drivers (23%, p-value $<0.001$)
  
  - Statistically significant increase in LC for male drivers (10%, p-value = 0.001)
  
  - No significant gender difference in LC
Both in A0 and in A1, the male drivers drove approximately 5 km/h faster than female drivers (p-value<0.01).

Active (A1)
- Slight decrease of the average total speed (0.81 km/h for female drivers and 0.31 km/h for male drivers)
- Not statistically significant speed reduction for both the genders
ADAS vs Drivers Gender: $\Delta F_{f0}$

- Statistically significant reduction in $\Delta F_{f0}$ for female drivers (1.33 N, p-value <0.001);
- Statistically significant reduction in $\Delta F_{f0}$ for male drivers (1.15 N, p-value = 0.001)

Both in A0 and in A1, significant gender differences were not found in the aerodynamics forces.
Analysis of an advanced driver-assistance system to improve safety of cyclist overtaking by driver characteristics
Not active (A0)
- Statistically significant reduction of LC with the age.

Active (A1)
- Statistically significant increase of LC for drivers older than 26, equal to 0.25 m (p-value < 0.001) for drivers aged between 26 and 35 years and 0.38 m (p-value < 0.001) for drivers older than 35 years
### ADAS vs Drivers Age: Speed

**Active (A1)**
- A statistically significant reduction in speeds only for drivers older than 35 years (4.051 km/h, p-value < 0.001)

<table>
<thead>
<tr>
<th></th>
<th>No active (A0)</th>
<th></th>
<th></th>
<th></th>
<th>Active (A1)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[18; 25]</td>
<td>[26; 35]</td>
<td>&gt;35</td>
<td>Total</td>
<td>[18; 25]</td>
<td>[26; 35]</td>
<td>&gt;35</td>
<td></td>
</tr>
<tr>
<td>No active (A0)</td>
<td>1</td>
<td>0.004</td>
<td>0.871</td>
<td>0.591</td>
<td>0.032</td>
<td>0.079</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>&lt; 0.001</td>
<td></td>
<td>0.418</td>
<td>0.003</td>
<td>0.011</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active (A1)</td>
<td>1</td>
<td>0.005</td>
<td>0.012</td>
<td>0.003</td>
<td>0.012</td>
<td></td>
<td>0.426</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

**Not active (A0)**

<table>
<thead>
<tr>
<th>Speed [km/h]</th>
<th>[18; 25]</th>
<th>[26; 35]</th>
<th>&gt;35</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No active (A0)</td>
<td>79.303</td>
<td>72.985</td>
<td>79.678</td>
<td>76.532</td>
</tr>
<tr>
<td>Active (A1)</td>
<td>80.946</td>
<td>74.316</td>
<td>75.627</td>
<td>76.134</td>
</tr>
</tbody>
</table>

**Analysis of an advanced driver-assistance system to improve safety of cyclist overtaking by driver characteristics**

Mauriello F., Brijs T., Montella A., Galante F., Brijs K., Ross V.

8th RSS (Athens 2022)
**ADAS vs Drivers Age: $\Delta F_{f0}$**

Active (A1)
- Statistically significant reduction of $\Delta F_{f0}$:
  - -2.518 N (45%, p-value<0.001) for drivers older than 35 years
  - -0.856 N (24%, p-value <0.001) for drivers aged between 26 and 35 years
Analysis of an advanced driver-assistance system to improve safety of cyclist overtaking by driver characteristics

$\Delta F_{f0}$ vs LC: Drivers Age

- No active ADAS (A0):
  - [18; 25]
  - [26; 35]
  - $>$35

- Active ADAS (A1):
  - [18; 25]
  - [26; 35]
  - $>$35
Discussion & Conclusions (1)

- The proposed ADAS system tested had significant positive effects on driver behavior during a cyclist overtaking maneuver:

  - LC was affected significantly with active ADAS system (+0.25 m, +15.45%), reducing side crashes.
  - $\Delta F_{fo}$ decreased by 28%, remaining below 17 N (FHWA tolerance limit), increasing cyclist’ safety and comfort.
  - The ADAS system was more effective in helping the female drivers to improve the safety of overtaken cyclists (+23% of LC, -32% of $\Delta F_{fo}$).
  - The ADAS system showed maximum effectiveness for drivers older than 35 years (+25 of LC, -45% of $\Delta F_{fo}$) and positive effects for drivers aged between 26 and 35 years (+15% of LC, -24% of $\Delta F_{fo}$).
Discussion & Conclusions (2)

- Under normal driving conditions with not active ADAS system, significant gender and age differences were found in driver performance during a cyclist overtaking maneuver:
  - Male drivers pass keeping a greater LC and higher speed than female drivers
  - Young drivers overtake leaving a greater LC than older drivers

- Limitations
  - Traditional caveats of laboratory research (driver motivation, level of perceived risk, etc.)
  - Repeated exposure and habituation
Discussion & Conclusions (3)

- Implications
  - Support the designers of ADAS systems
  - Tune future ADAS systems to drivers’ characteristics
  - Better implement and address policies, campaigns, and training programs to improve road safety for cyclist

- Future studies
  - Extend to other vulnerable road users, such as scooters, e-steps, etc.
  - Take account for oncoming traffic during car-to-cyclist overtaking
Thank you for your attention

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