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

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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

Motivation (2)

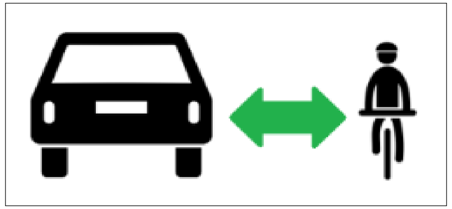
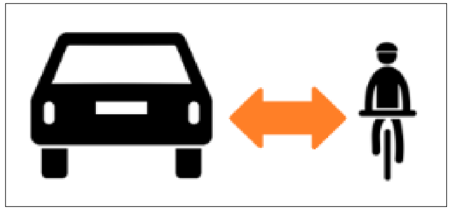
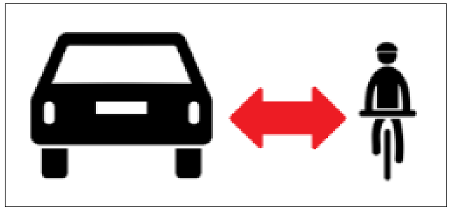
- Minimum passing distance laws have been introduced to reduce the dangers to cyclists from motor vehicles passing too close
- ……but failure to follow traffic regulations, distracted driving, and an inability to determine passing distance accurately can happened

- 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 manouver 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.

Phase / Signal	Normal driving	Danger phase	Avoidable accident phase
Visual			
Audio	No acoustic signal	Single Beep	Double high-pitched beep

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

		Time to Danger		
		4.5 s > TTD ≥ 3 s	3s > TTD ≥ 2 sec	TTD < 2 s
Lateral Clearance	LC ≥ 1.5 m	Normal driving	Normal driving	Normal driving
	1.5m > LC ≥ 1.0 m	Normal driving	Danger	Danger
	LC < 1.0 m	Normal driving	Danger	Avoidable Accident

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

Experiment: Study Design (2)

- 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 costant speed of 18 Km/h

Overtaking a cyclist riding normally with a constant lateral position

Overtaking a cyclist manouvring from the edge to the center of the lane

Overtaking two cyclists riding in parallel position

Experiment: Study Design (3)

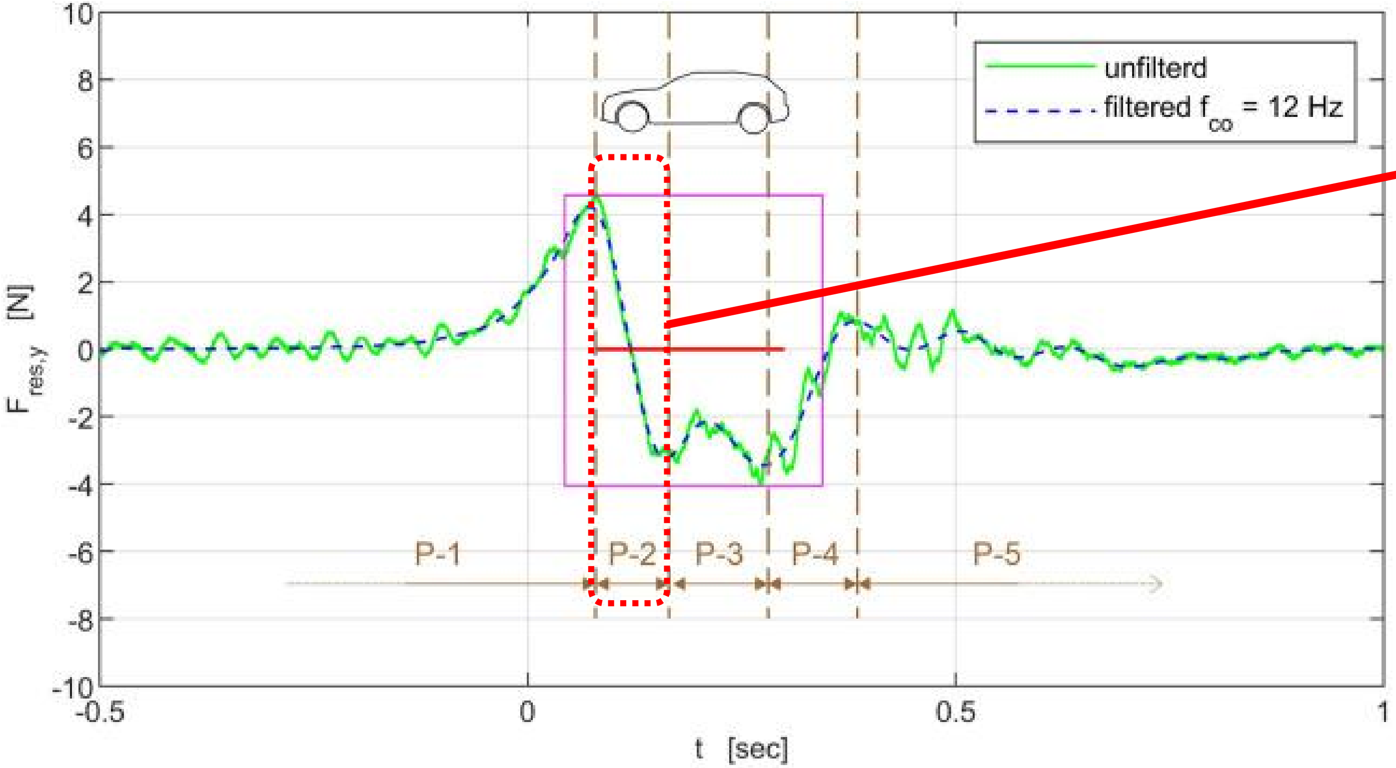
- Participants
  - 48 subjects (final sample)
  - No simulator sickness observed

Driver characteristics	Categories	N	%
Gender	Female	27	56.25%
	Male	21	43.75%
Age	18-25	11	22.92%
	26-35	22	45.83%
	>36	15	31.25%

- 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)

Analysis Methods (1)

- Maximum aerodynamic forces ($\Delta \boldsymbol{F}_{f0}$) 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;

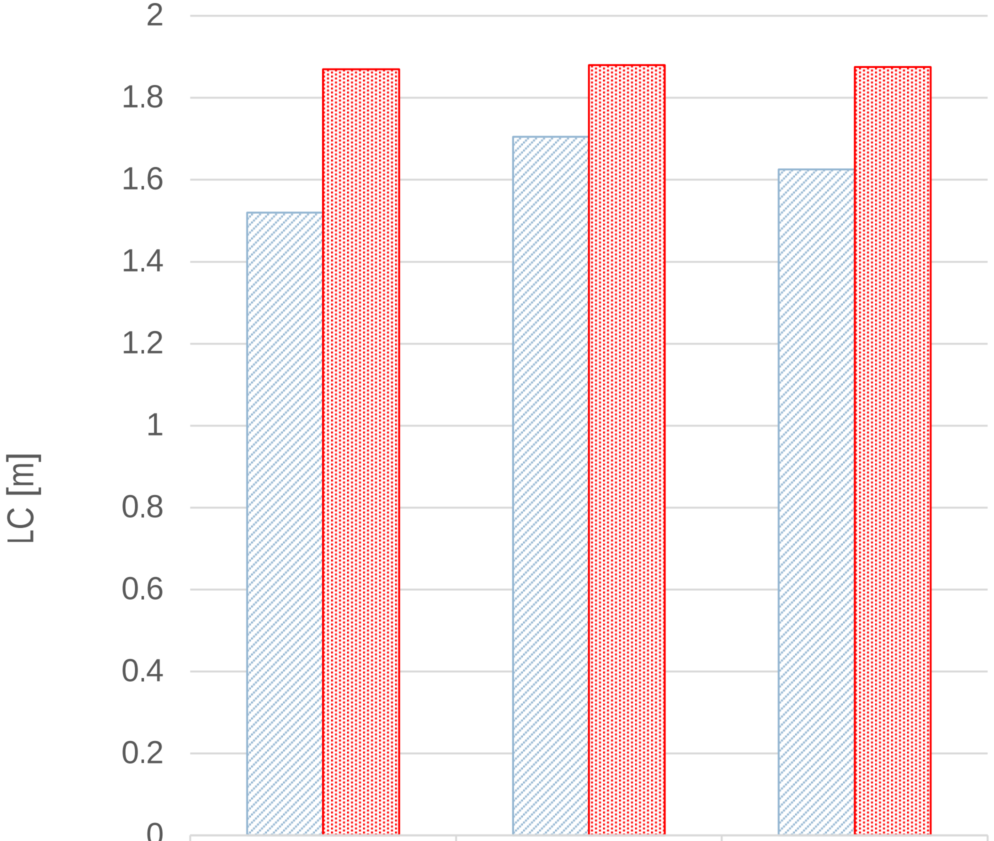
Gromke, C., and Ruck, B., 2021. Passenger car-induced lateral aerodynamic loads on cyclists during overtaking. J. Wind. Eng. Ind. Aerodyn., 209, 104489

Analysis Methods (2)

- Three safety measures were extracted and analyzed at the point of load of maximum pressure
  - Lateral clearance (LC)
  - Vehicle speed
  - Maximum aerodynamic force ($\Delta \boldsymbol{F}_{\boldsymbol{f0}}$)

- 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



	F	M	Total
Not active (A0)	1.52	1.705	1.625
Active (A1)	1.87	1.88	1.875

ADAS	Gender	Not active (A0)		Active (A1)	
		F	M	F	M
Not active (A0)	F	1	0.001	<0.001	<0.001
	M		1	0.002	0.001
Active (A1)	F			1	0.856
	M				1

Not active (A0)

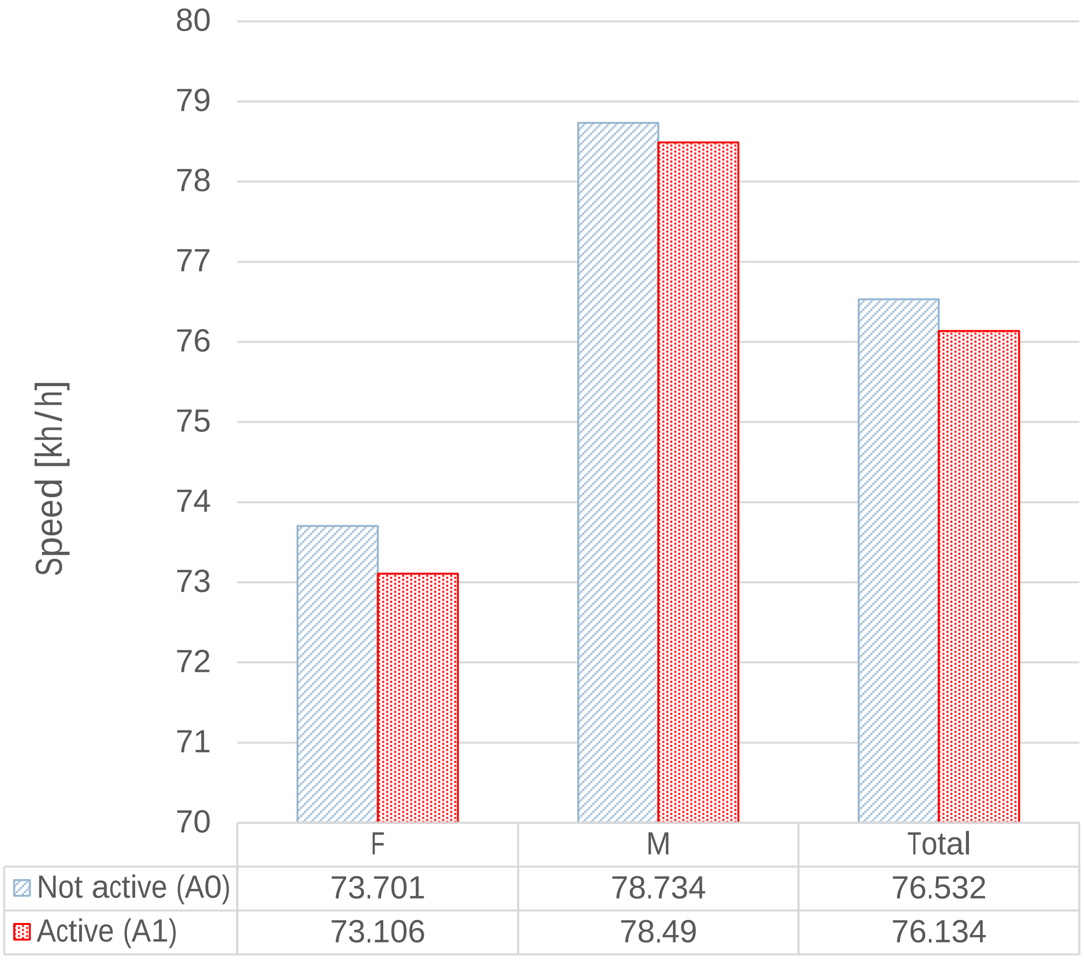
- Female drivers exhibited shorter LC from the cyclist than male drivers (1.52 m vs. 1.70 m)

  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

ADAS vs Drivers Gender: Speed



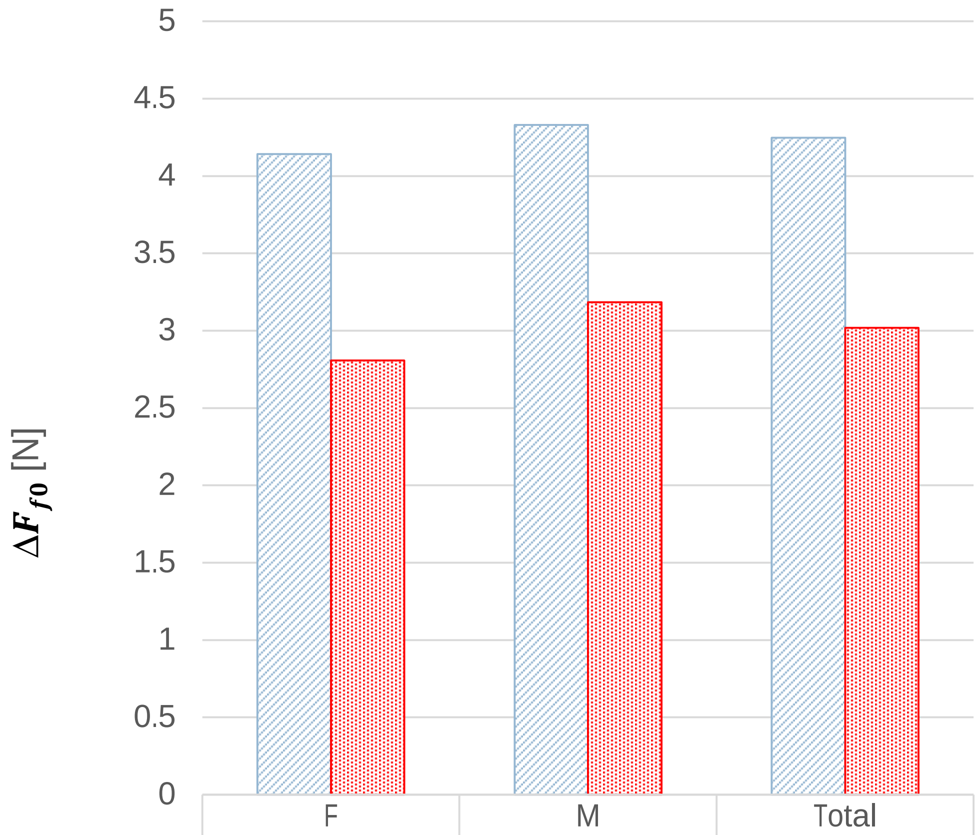
ADAS	Gender	Not active (A0)		Active (A1)	
		F	M	F	M
Not active (A0)	F	1	0.002	0.662	0.004
	M		1	<0.001	0.885
Active (A1)	F			1	0.001
	M				1

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

Both in A0 and in A1, the male drivers drove approximately 5 km/h faster than female drivers (p-value<0.01).

ADAS vs Drivers Gender: ΔF_{f0}



	F	M	Total
Not active (A0)	4.141	4.33	4.248
Active (A1)	2.807	3.184	3.019

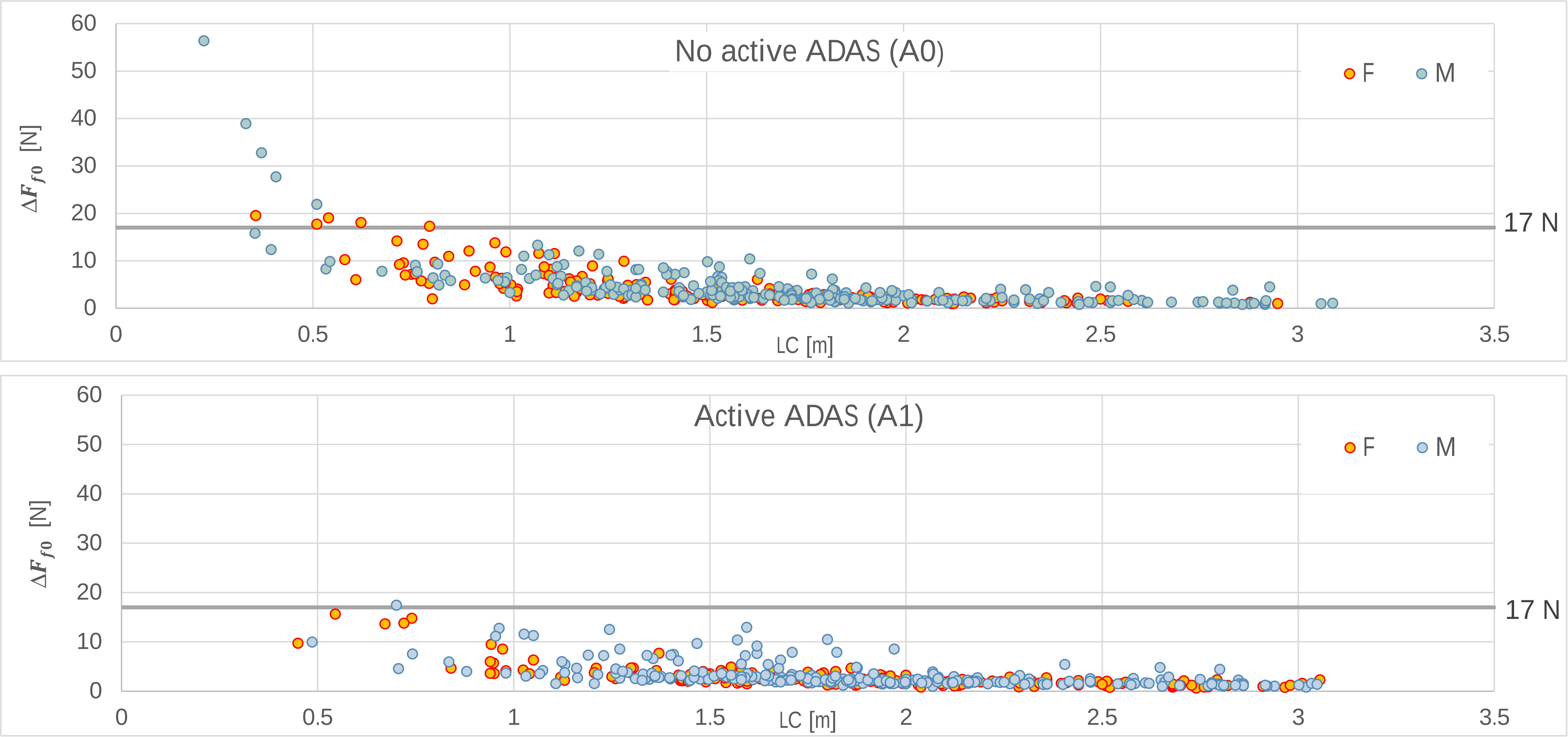
ADAS	Gender	Not active (A0)		Active (A1)	
		F	M	F	M
Not active (A0)	F	1	0.684	<0.001	0.001
	M		1	<0.001	0.003
Active (A1)	F			1	0.104
	M				1

Active (A1)

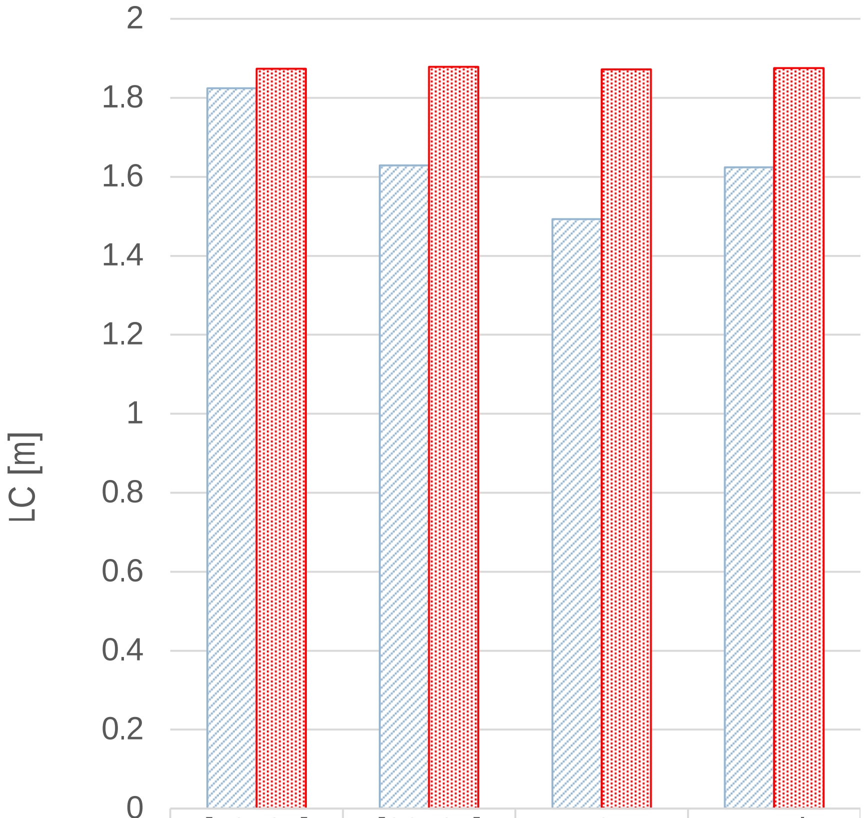
- Statistically significant reduction in ΔF_{f0} for female drivers (1.33 N , p-value <0.001) ;
- Statistically significant reduction in ΔF_{f0} for male drivers (1.15 N, p-value = 0.001)

Both in A0 and in A1, significant gender differences were not found in the aerodynamics forces.

ΔF_{f0} vs LC: Drivers Gender



ADAS vs Drivers Age: LC



	[18; 25]	[26; 35]	>35	Total
Not active (A0)	1.824	1.629	1.493	1.624
Active (A1)	1.874	1.879	1.872	1.875

		No active (A0)			Active (A1)		
		[18; 25]	[26; 35]	>35	[18; 25]	[26; 35]	>35
No active (A0)	[18; 25]	1	0.005	< 0.001	0.492	0.414	0.501
	[26; 35]		1	0.025	< 0.001	< 0.001	< 0.001
	>35			1	< 0.001	< 0.001	< 0.001
Active (A1)	[18; 25]				1	0.949	0.972
	[26; 35]					1	0.910
	>35						1

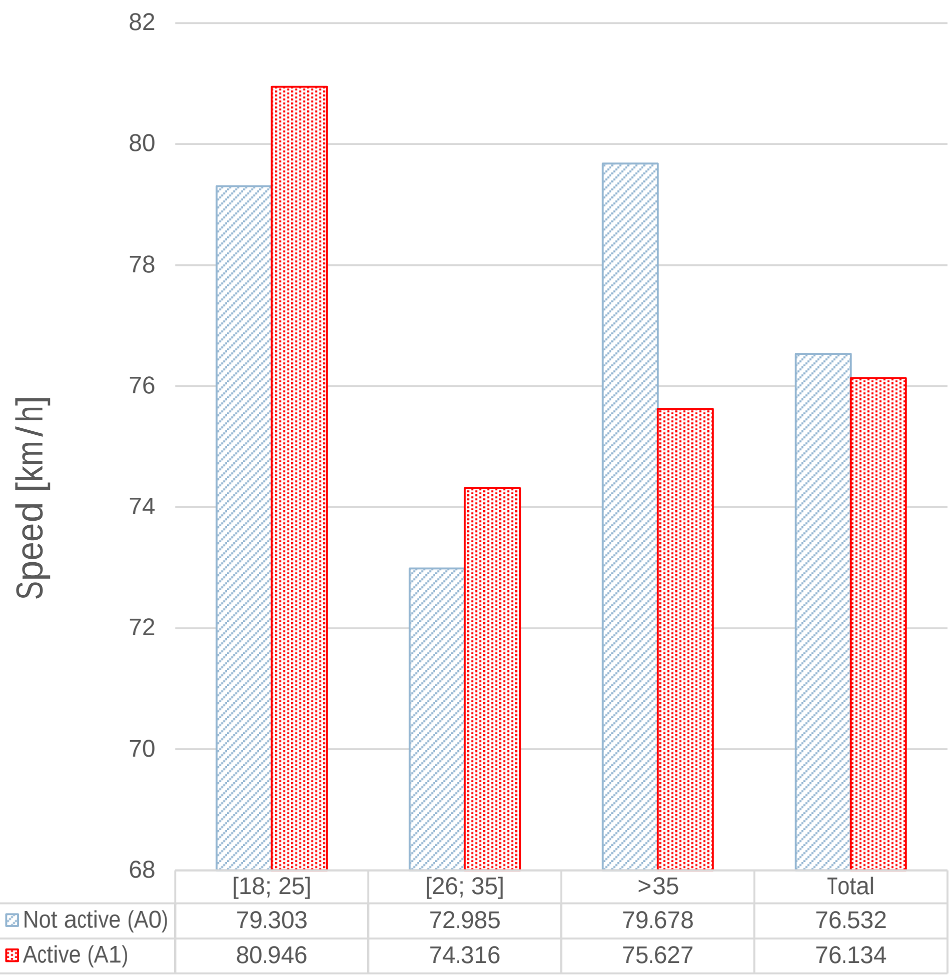
Not active (A0)

- 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

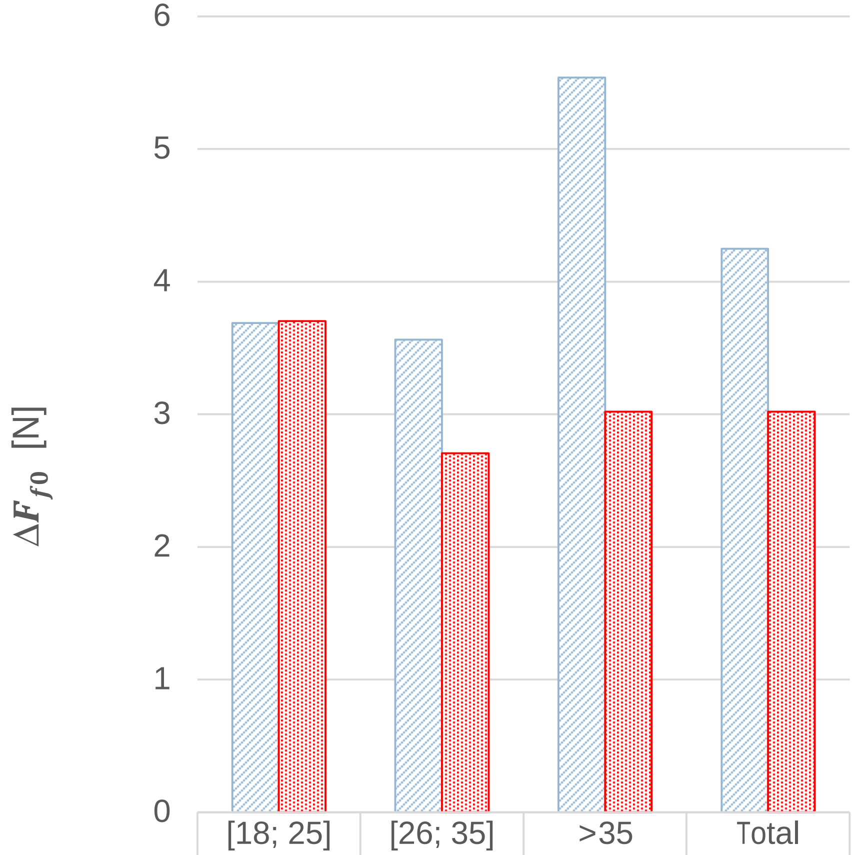


		No active (A0)			Active (A1)		
		[18; 25]	[26; 35]	>35	[18; 25]	[26; 35]	>35
No active (A0)	[18; 25]	1	0.004	0.871	0.591	0.032	0.079
	[26; 35]		1	< 0.001	< 0.001	0.418	0.085
	>35			1	0.587	0.003	0.011
Active (A1)	[18; 25]				1	0.005	0.012
	[26; 35]					1	0.426
	>35						1

Active (A1)

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

ADAS vs Drivers Age: ΔF_{f0}



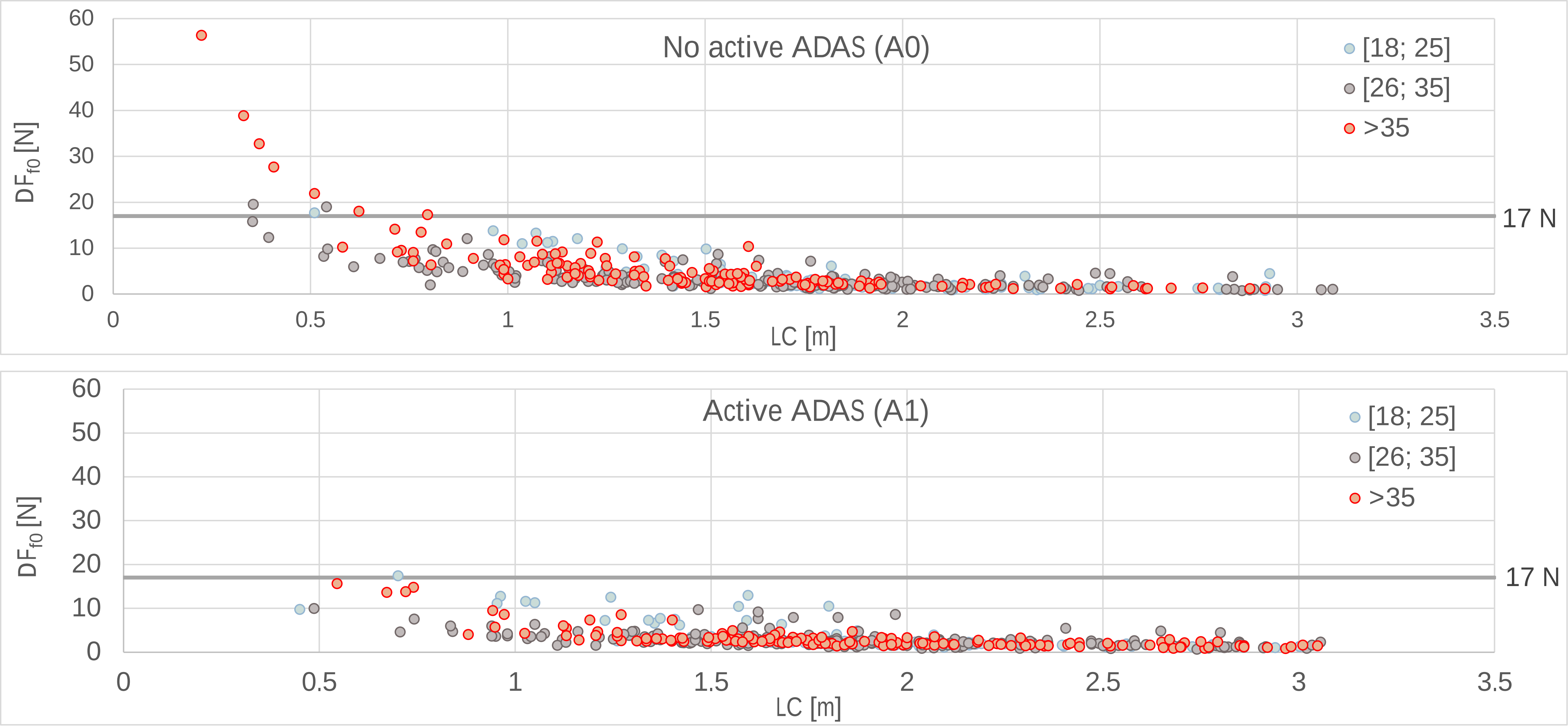
	[18; 25]	[26; 35]	>35	Total
Not active (A0)	3.689	3.563	5.538	4.248
Active (A1)	3.702	2.707	3.02	3.019

		No active (A0)			Active (A1)		
		[18; 25]	[26; 35]	>35	[18; 25]	[26; 35]	>35
No active (A0)	[18; 25]	1	0.742	0.019	0.980	0.001	0.081
	[26; 35]		1	< 0.001	0.718	< 0.001	0.064
	>35			1	0.020	< 0.001	< 0.001
Active (A1)	[18; 25]				1	0.001	0.077
	[26; 35]					1	0.155
	>35						1

Active (A1)

- Statistically significant reduction of ΔF_{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

ΔF_{f0} vs LC: Drivers Age



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.
  - ΔF_{f0} 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 ΔF_{f0}).
  - The ADAS system showed maximum effectiveness for drivers older than 35 years (+25 of LC, -45% of ΔF_{f0}) and positive effects for drivers aged between 26 and 35 years (+15% of LC, -24% of ΔF_{f0})

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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