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Eye, steering, and hands on wheel behaviors indicating driver engagement in assisted driving

Session: 9 Automation

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Introduction

Session 3 – Automation

Thomas Streubel

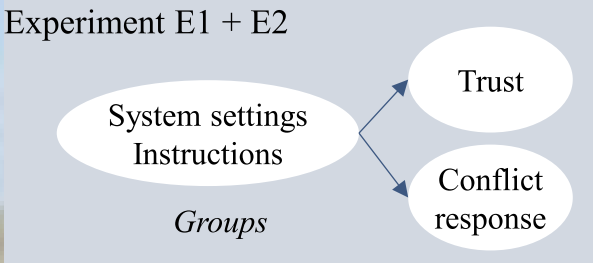
Conflict response after assisted driving with hands on or off wheel and different steering wheel torque settings

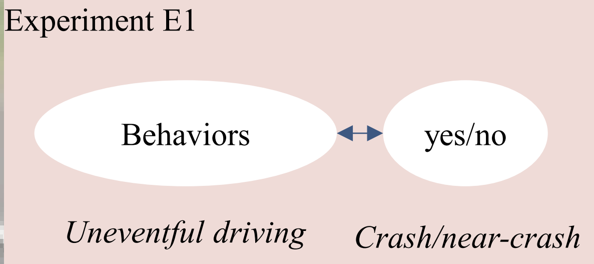
Session 9 – Automation

Emma Tivesten

Eye, steering, and hands on wheel behaviors indicating driver engagement in assisted driving

30 min car-following → conflict event





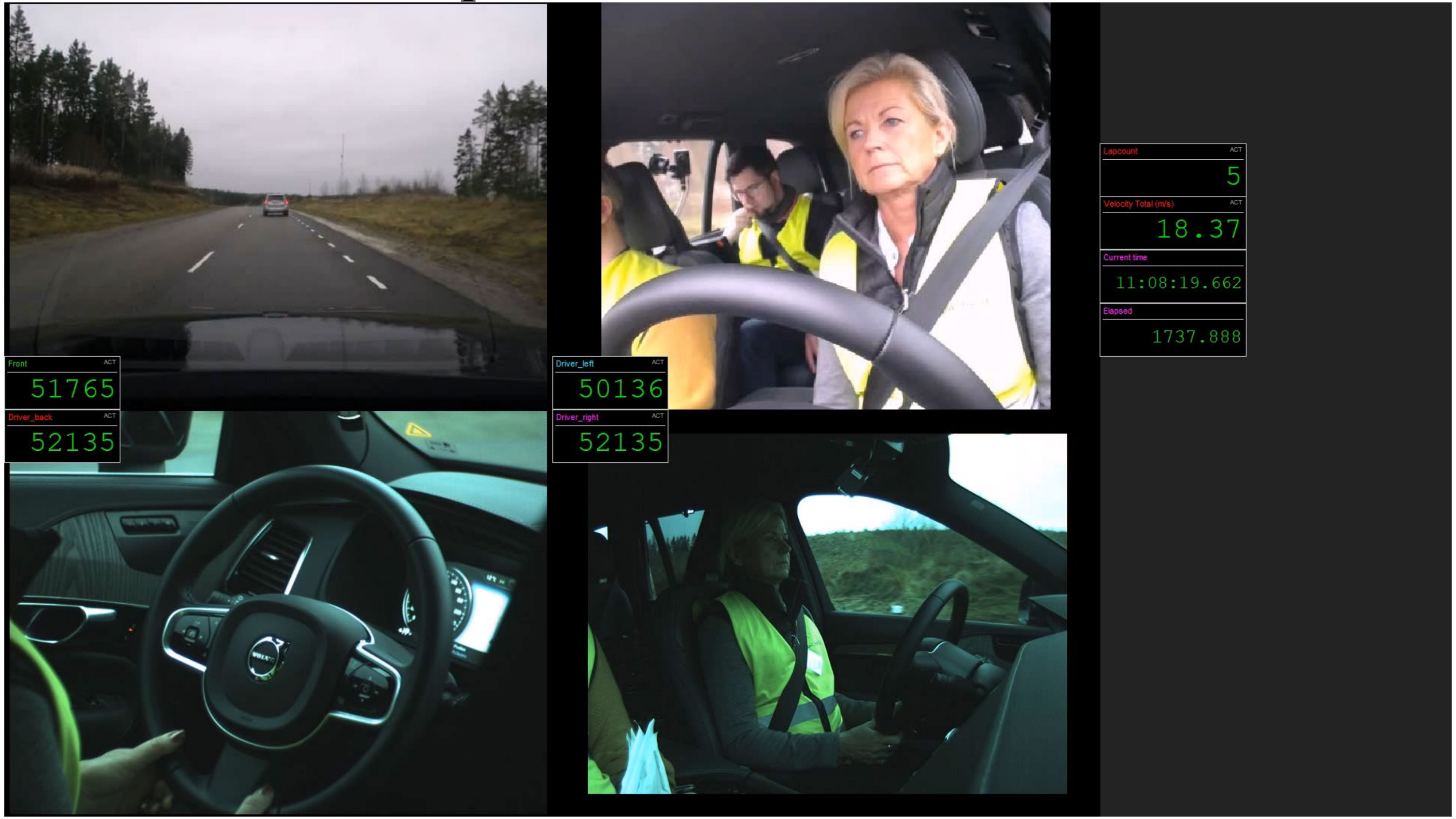
Aim:

Investigate if there are behaviors during the uneventful part of the drive that can distinguish participants that had a crash or a near-crash from the ones that had an early conflict response.

Example: Early conflict response

With explicit consent from the test participant

Example: No conflict response



With explicit consent from the test participant

Introduction: Assisted (level 2) systems effect on safety

Compared to manual driving:

- Increase safety margins in routine driving (e.g., increased time headway)
- Increased secondary tasks & eyes off road in naturalistic driving
  - The driver still needs to supervise and respond to any event the system cannot handle
- Limited understanding of the effect on crash rates, and distribution of crash types
  - Need to consider to what extent and when these systems are being used

Introduction: Assisted (level 2) systems effect on safety

- Driver assistance systems are becoming more reliable in terms of operational control

- Irony of automation – when humans supervise a partially automated processes, the better the automation gets, the harder it is for the operator to maintain vigilance and resolve unexpected situations

- Passive supervision → Driver disengagement (2nd tasks, reduced vigilance, delayed/no response to conflicts).

How can we recognize and prevent driver disengagement in assisted driving?

Introduction: Previous studies – Same test set-up & different L2 systems

Torque needed to override lane centering

Very high/firm lane centering *Low*

AD behavior

Reminders

No

N/A

ADEST:

- A lot of extreme visual distraction
- 10% extreme sleepiness
- Autobrake at conflict

AR

AR & HoW

28%

- Less extreme visual distraction
- No extreme sleepiness
- 28% crashed
    - independent of hands on/off
    - all had eyes on conflict

Victor et al (2018). Automation Expectation Mismatch..... https://doi.org/10.1177/0018720818788164
Gustavsson et al (2018). What were they thinking? ... DDI 2018
Tivesten et al (2019) Out-of-the-loop crash prediction ... doi: 10.1049/iet-its.2018.5555.
Pipkorn et al (2020) Driver conflict response during supervised automation ... DOI: 10.13140/RG.2.2.32222.46401

Introduction: Previous studies – Same test set-up & different L2 systems

Torque needed to override lane centering

Very high/firm lane centering
AD behavior

Low

Reminders

No

AR
AR & HoW

HoW torque
(10 – 30 s)

ADEST

N/A

28%

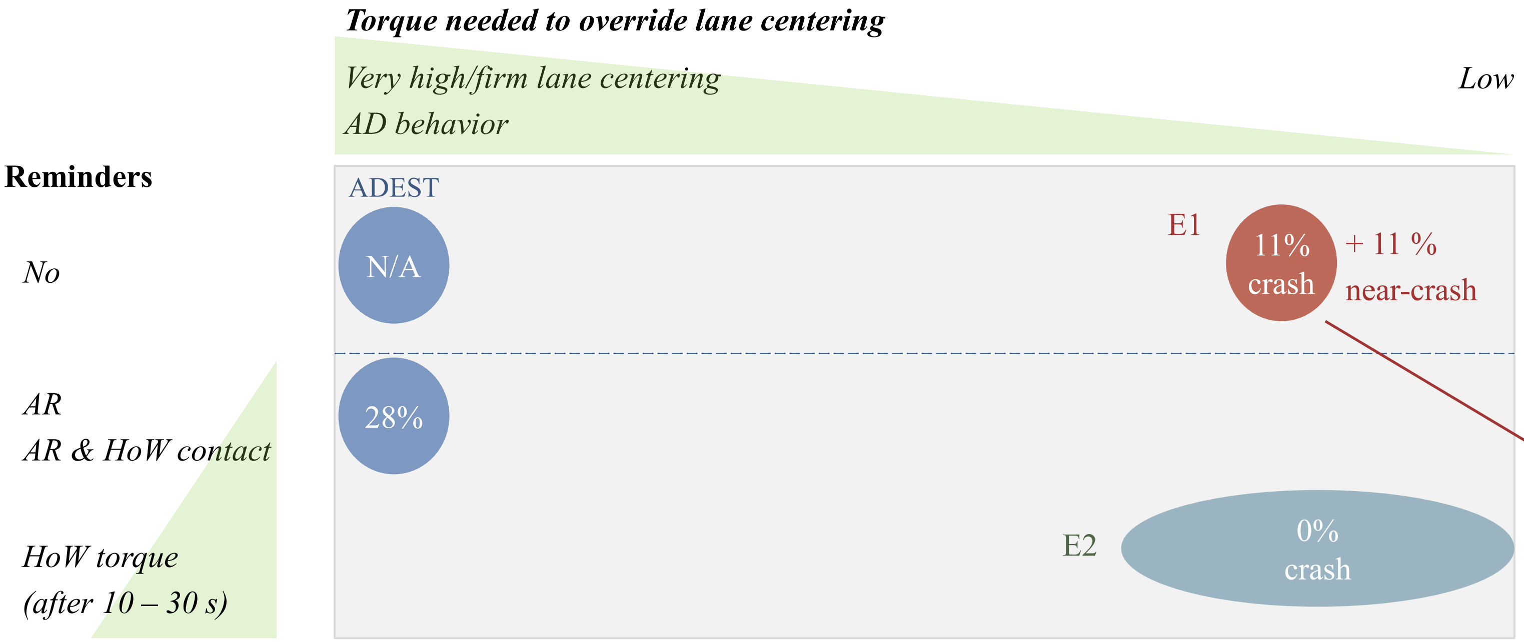
E2

0%
crash

Early conflict response with steering reminders

Session 3 – Automation, Thomas Streubel, ***Conflict response after assisted driving with hands on or off wheel and different steering wheel torque settings***

Introduction: Selected dataset from Experiment 1



54 participants with visible eyes included in present analysis

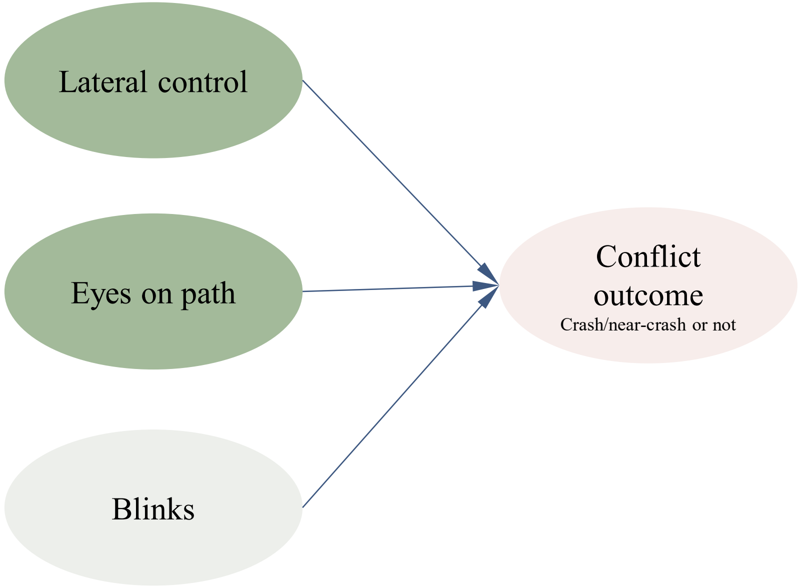
- Same system – varying instructions
- Glance behavior similar to manual naturalistic driving
- No extreme sleepiness
- Crash/near-crashes and hands off driving present in all groups

Session 3 – Automation, Thomas Streubel, ***Conflict response after assisted driving with hands on or off wheel and different steering wheel torque settings***

Time series data from complete drive

- *Distance to lane center (vehicle signals)*
- *Steering wheel torque (vehicle signal)*
- *Hands on/off wheel (coded from video)*

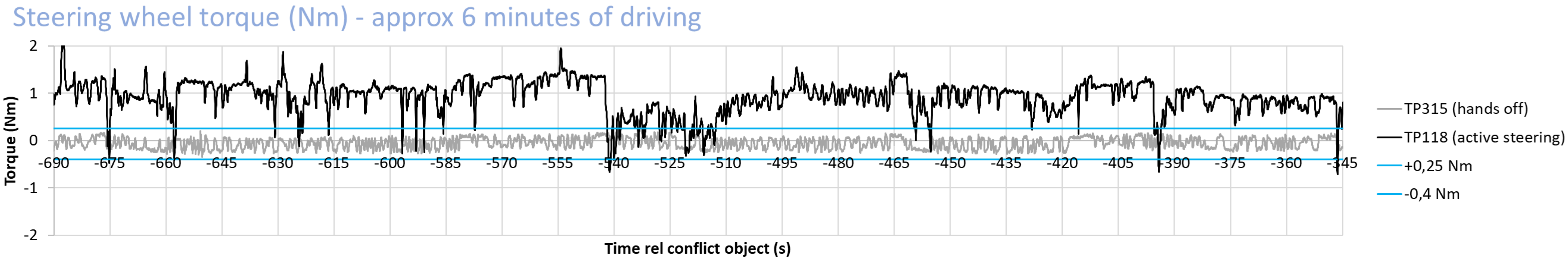
- *Eyes on/off path (coded from video)*



Time series data from complete drive

Lateral control

- *Driver active steering (yes/no) = steering wheel torque outside corridor*



Time series data from complete drive

Eyes on path

PRC4-buffer — *<65% Visual time sharing[1]*

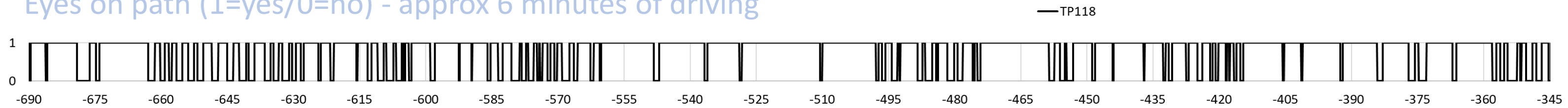
<30% extreme visual inattention[2]

PRC60-buffer — *>92% gaze concentration[1,2]*

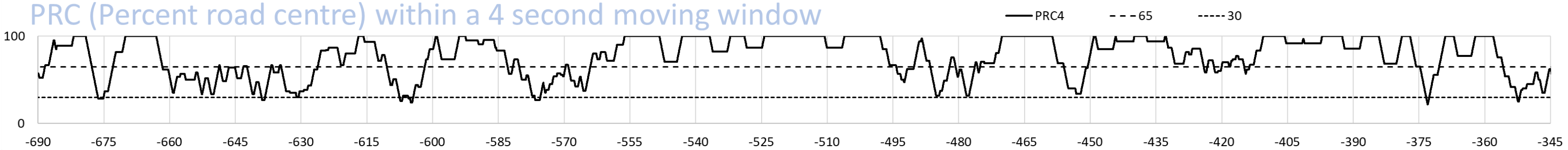
1 = Multi distraction detection algorithm (MDD)

2 = Increased risk of crashing in the ADEST studies (Tivesten et al, 2019)

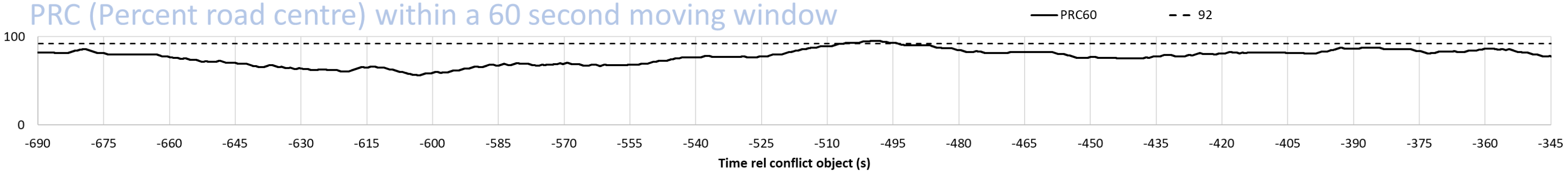
Eyes on path (1=yes/0=no) - approx 6 minutes of driving



PRC (Percent road centre) within a 4 second moving window

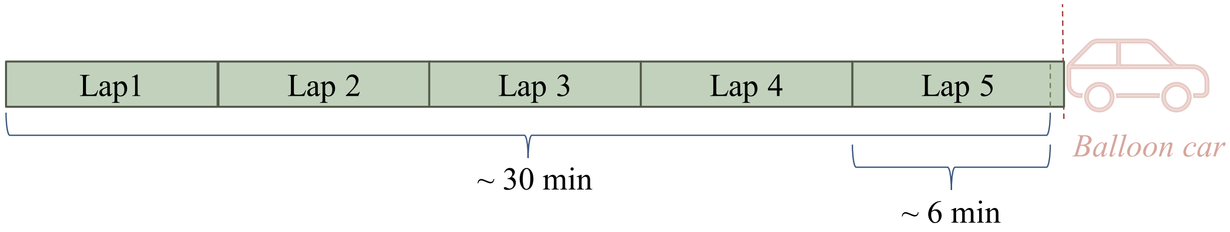


PRC (Percent road centre) within a 60 second moving window

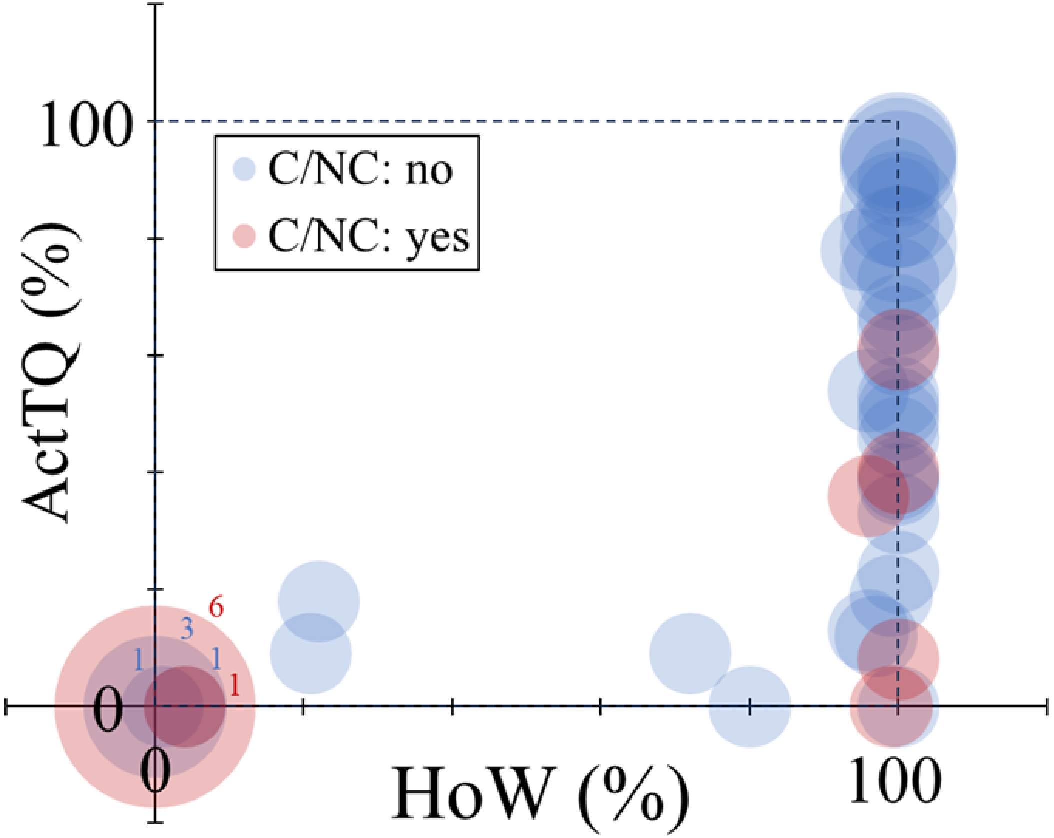


Example of investigated metrics

	Metric	Unit	Defined for complete drive & last lap	
				Drivers actively steering results in
Lateral control	SDLP	cm	Standard deviation of lateral position	high SDLP
	ActTQ	%	Percentage of time with driver active steering	high ActTQ
	HoW	%	Percentage of time with hands on wheel	high HoW
				Gaze behavior
Eyes on path	GD2	N/h	Number of off-path glances longer than 2 seconds per hour of driving	long off-path glances
	PRC4<65	%	Percentage of time the PRC4-buffer drops below 65%	visual time sharing
	PRC60>92	%	Percentage of time the PRC60-buffer exceeds 92%	gaze concentration



Correlation between metrics (last lap)

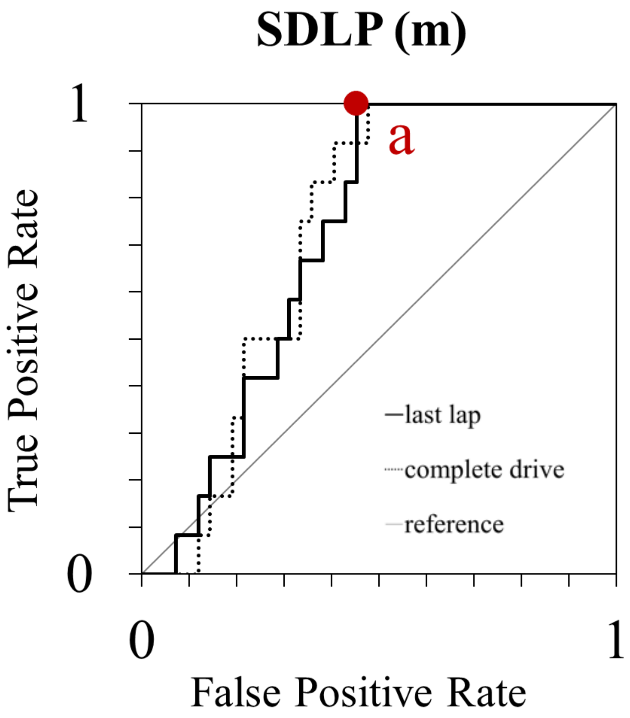


Participants tend to drive either

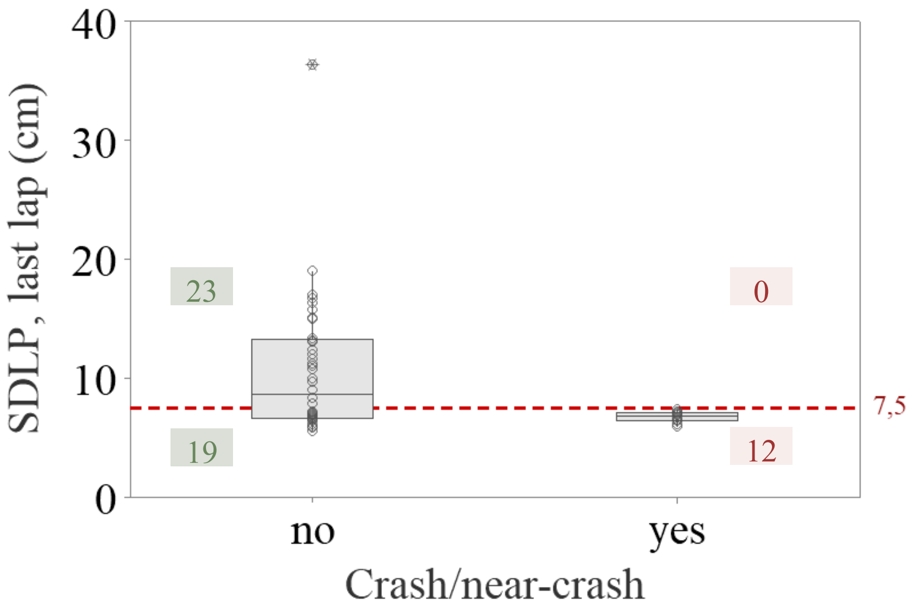
- fully hands off & no active steering,
- fully hands on & 0-100% of the time with active steering input

ActTQ correlation with HoW:
$r_s = 0.804$, $p < 0.001$

ROC curve



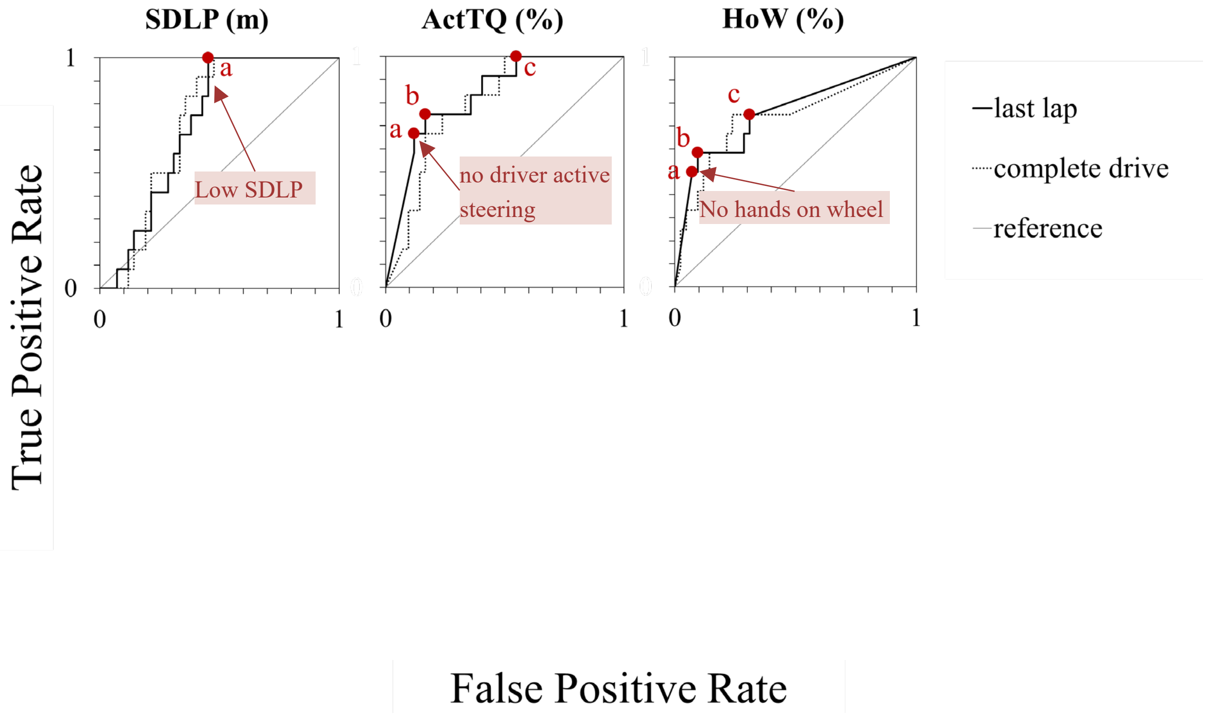
Metric	Unit	Threshold	FPR	TPR	Accuracy
SDLP	cm	a ≤ 7,5	0,452	1,000	0,648



SDLP correlation with C/NC:
$r_s = -.312, p < 0.05$

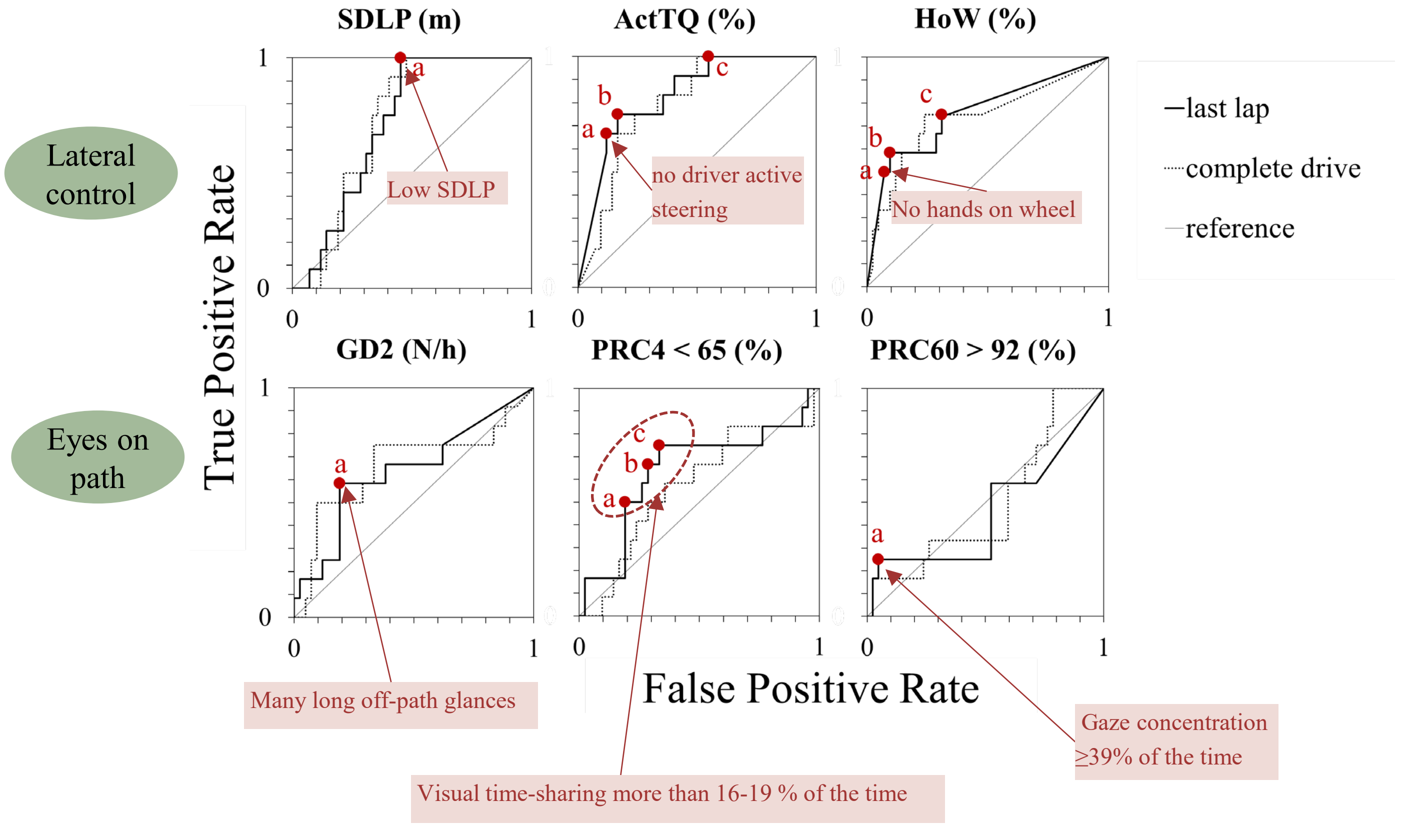
ROC curves

Lateral control



Metric	Unit	Threshold
SDLP	cm	a ≤ 7,5
ActTQ	%	a ≤ 0,022
	%	b ≤ 8
	%	c ≤ 62
HoW	%	a = 0
	%	b ≤ 3,9
	%	c < 99.1

ROC curves



Metric	Unit	Threshold
SDLP	cm	a ≤ 7,5
ActTQ	%	a ≤ 0,022
	%	b ≤ 8
	%	c ≤ 62
HoW	%	a = 0
	%	b ≤ 3,9
	%	c ≤ 99,1
GD2	N/h	a ≥ 32,8
PRC4	%	a ≥ 19,4
	%	b ≥ 17,2
	%	c ≥ 16,4
PRC60	%	a ≥ 39

Combination of behaviors

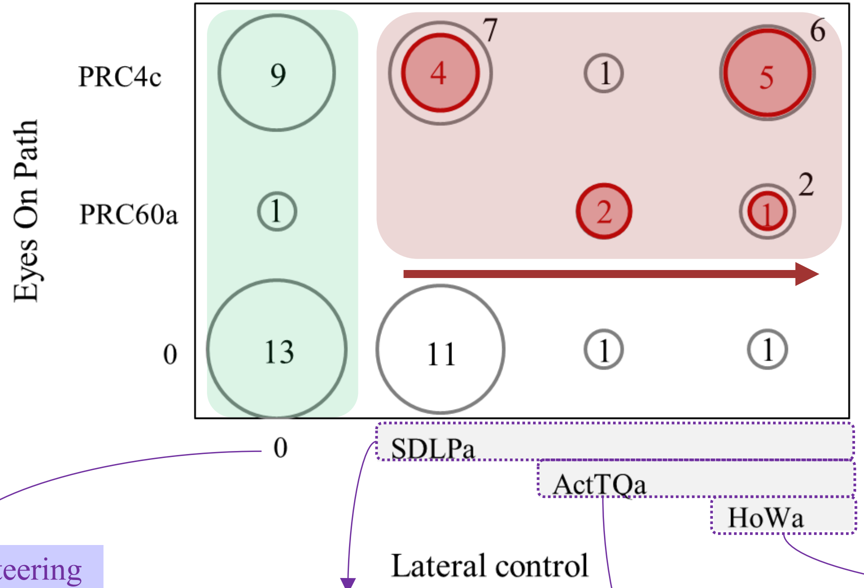
Total number of participants & Number crash/near-crash participants

○ Tot (N) ● C/NC: yes (N)

High visual time sharing
PRC4>65 ≥ 16,4 % of the time

Gaze concentration
PRC60>92 ≥ 39 % of the time

Active/attentive visual pattern



- Driver active steering → early to the conflict – even with high visual time sharing, or gaze concentration
- All crash/near-crash participants all have less ideal glance behavior combined with low or no active steering
- Risk of crash/near-crash increase with no active steering, and fully hands off driving

Driver active steering
SDLP > 7,5 cm

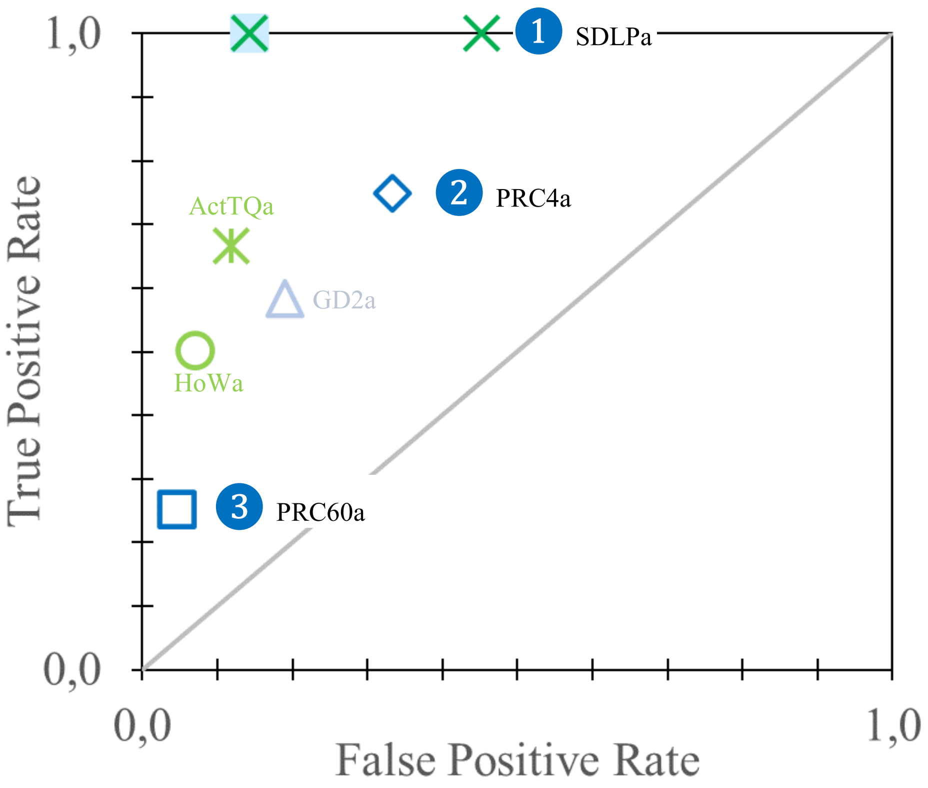
Low or no driver active steering
SDLP ≤ 7,5 cm

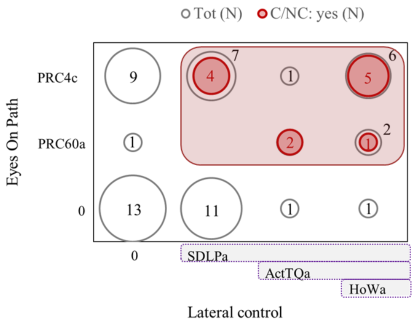
No driver active steering
ActTQ ≤ 0,022% of the time

No hands on wheel
HoW = 0 %

Combination of behaviors

1 and (2 or 3)





100% of crash/near-crash participants (n=12/12) and 14% of the remaining participants - All had

1 Low standard deviation of lane position (≤ 7.5 cm)

- Low SDLP associated with low or no active driver steering

In combination with *either*:

2 Visual time sharing more than 16% of the time

- Low PRC4-buffer

or

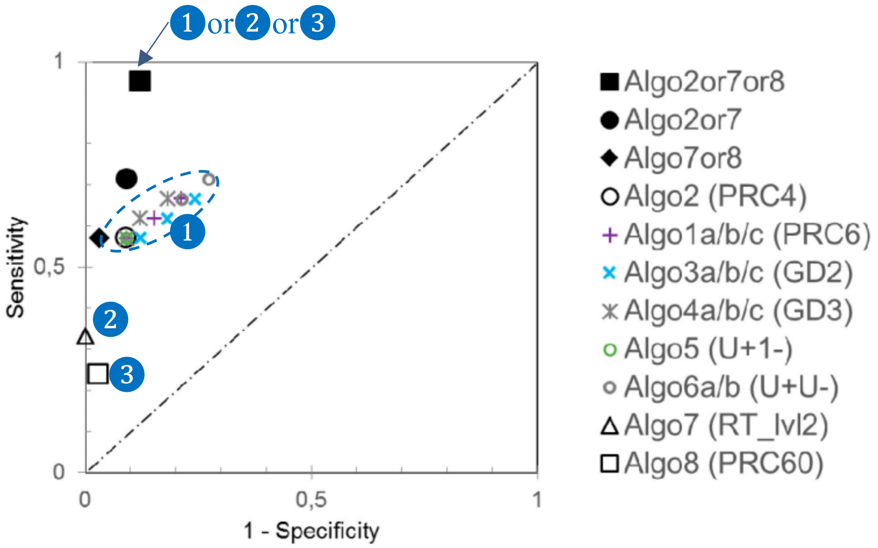
3 Gaze concentration more than 39% of the time

- High PRC60-buffer

Similar analysis using ADEST data

28% crash

ADEST: Behavioral patterns indicating driver disengagement during uneventful driving?



95% of crashes (n=20/21) and 12% of the non-crashers either had:

1. Low levels of eyes on path
   - Low PRC4 – buffer
   - Many off-path glances longer than 2 & 3 s

2. Long visual response time to attention reminders
   - Visual response time to display + sound > 0.9 s

3. Gaze concentration
   - High PRC60-buffer

Tivesten et al (2019) Out-of-the-loop crash prediction ... doi: 10.1049/iet-its.2018.5555.

Conclusion: Detecting driver disengagement depends on system design

1) If systems are designed for shared operational control

Eye, steering, and hands on wheel behavior can be combined to detect driver disengagement with higher accuracy

2) If systems are designed for traded operation control

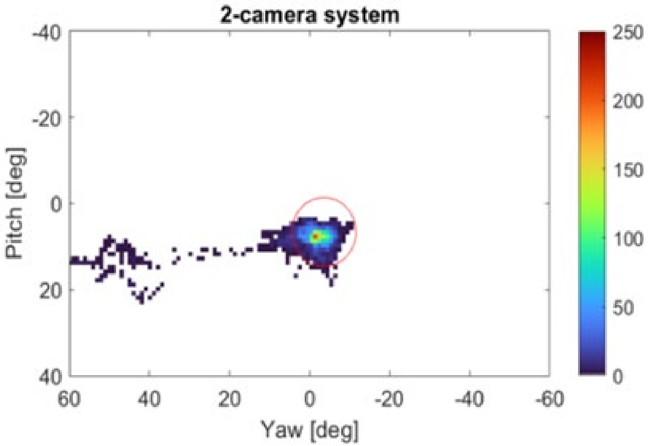
a) Very firm lane centering (ref. ADEST)

b) or Drivers are allowed and decides to drive fully hands off

Eye behavior (visual time sharing, gaze concentration, etc) is the only available indicator

Implications: Sensing capabilities for detecting driver disengagement

- Steering wheel torque & lane position
- Hand to steering wheel contact
- Eye tracking & methods for on-path estimation
  - *Using windshield as on path estimation is not enough to capture gaze concentration*



Images from master thesis report Djerf & Ryckenberg, 2023

Implications - principles that could increase driver engagement

1. Driver state dependent feedback

    Attention, hands on wheel, steering reminders

    Variable lane keeping behavior

2. Keep drivers involved in the steering control loop

3. Investigate how maximum allowed time without hands on wheel & driver steering impact driver engagement.

    10 – 30 s seems ok

    30 minutes seems too long without any driver feedback

Thank you!

DDI 2024, 22-24 October, Emma Tivesten, emma.tivesten@volvocars.com

Correlation between metrics (last lap) (r_s)

Lateral control: SDLP, ActTQ, HoW

Eyes on path: GD2, PRC4<65, PRC60>92

	SDLP	ActTQ	HoW	GD2	PRC4<65	PRC60>92
SDLP	1					
ActTQ	0.754***	1				
HoW	0.502***	0.804***	1			
GD2	-.224	-.315*	-.281*	1		
PRC4<65	-.016	-.051	-.123	0.605***	1	
PRC60>92	-.021	-.049	-.019	-.262	-.726***	1

*(*** p< 0.001; ** p<0.01, * p<0.05)*

$\lvert r_s \rvert > 0.7$
$\lvert r_s \rvert > 0.5$
$\lvert r_s \rvert > 0.2$

- High correlation between the metrics in each group.
  - except for long off path glances that is highly correlated with the visual time sharing, while weakly negatively correlated with both gaze concentration and the lateral control metrics.