TECHNISCHE UNIVERSITÄT CHEMNITZ

Chemnitz University of Technology
Department of Psychology
Cognitive and Engineering Psychology

Federal Ministry of Transport and Digital Infrastructure

InMotion

Light-based communication between automated vehicles and other road users

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Ford

INTENTA
ADVANCED RECOGNITION COMPONENTS

InMotion:

„Development of light-based communication between automated vehicles and other road users “

Federal Ministry of Transport and Digital Infrastructure

Funding: BMVI, Total Budget 1,1 M €

Duration: 10/2017 - 06/2020 (33 Month)

Coordination: TUC (Matthias Beggiato)

Consortium:

- Chemnitz University of Technology (Cognitive and Engineering Psychology + Communications Engineering)
- Ford Werke GmbH (Aachen)
- Intenta GmbH Chemnitz (SME)

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Ford

INTENTA
ADVANCED RECOGNITION COMPONENTS

Aims InMotion

- Development of **light-based communication** between automated vehicles and other road users, particularly Vulnerable Road User (VRU; cyclist and pedestrians)
- Analysis of existing communication procedures as basis
- Develop and test Human-Machine Interfaces as external communication solution (**eHMI**), user centered approach, Wizard-of-Oz study, Field study, Lab studies using augmented video
- Prototypical **Hard- and Software solution and demonstrator vehicle** with sensors, C2X-comm., light-based communication
- Focus on urban setting (low speed), 3 potential use cases:
  1) VRU crossing at crosswalks, mixed traffic environment
  2) Automated valet-parking, communication with user
  3) Communication with passengers of automated taxis

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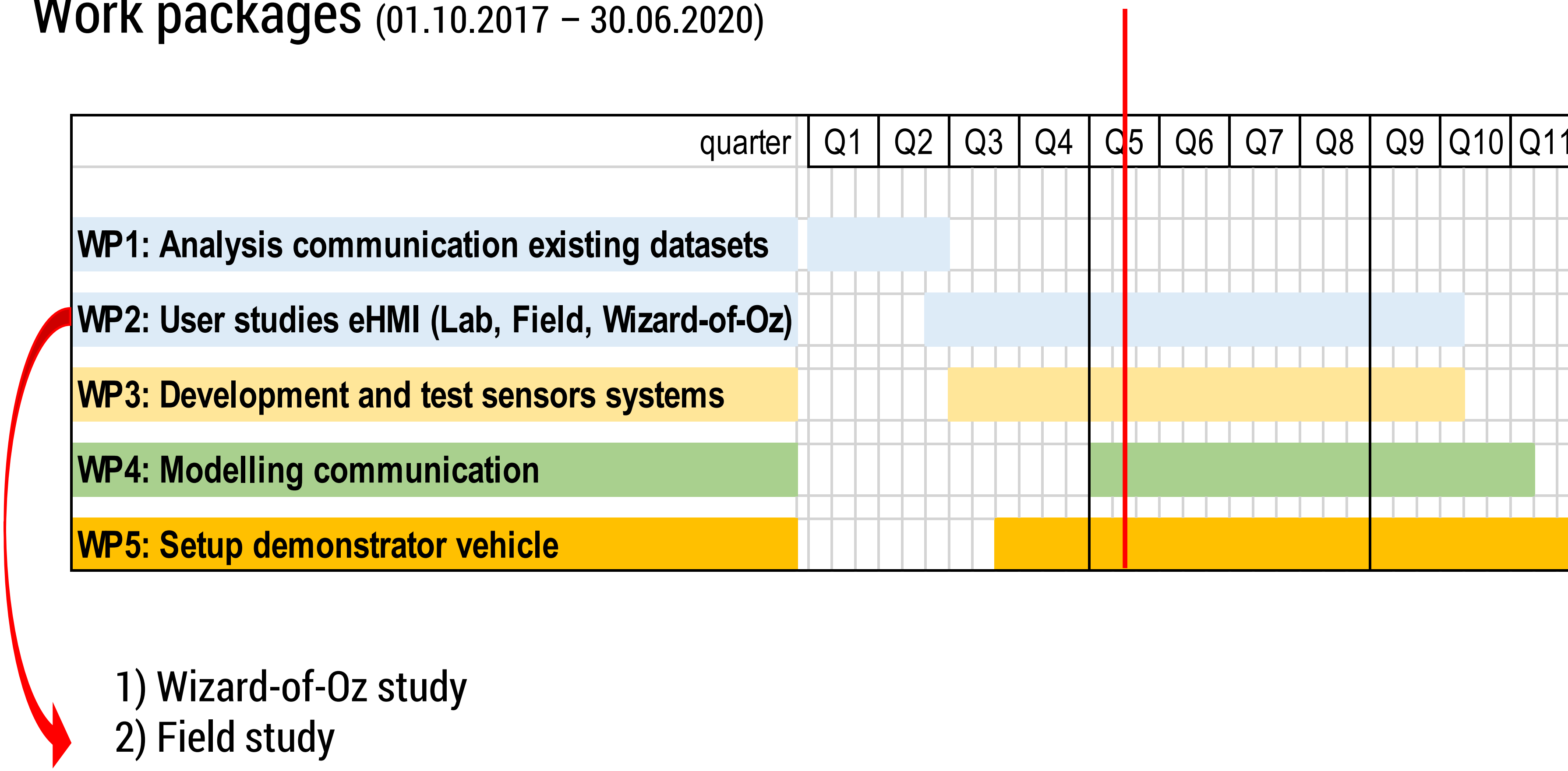
Work packages (01.10.2017 – 30.06.2020)



1) Wizard-of-Oz study
2) Field study

Both with Light Bar Ford as eHMI

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ALLGEMEINE UND ARBEITSPSYCHOLOGIE TU CHEMNITZ

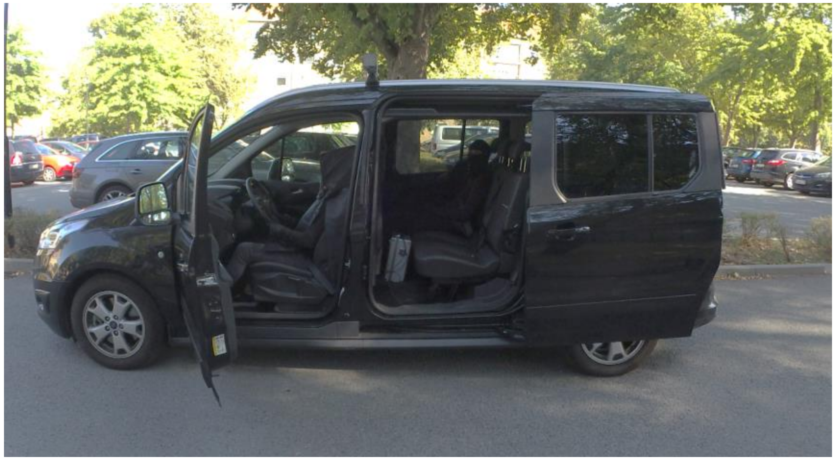
Results WP 2:

Wizard-of-Oz study/ Field study

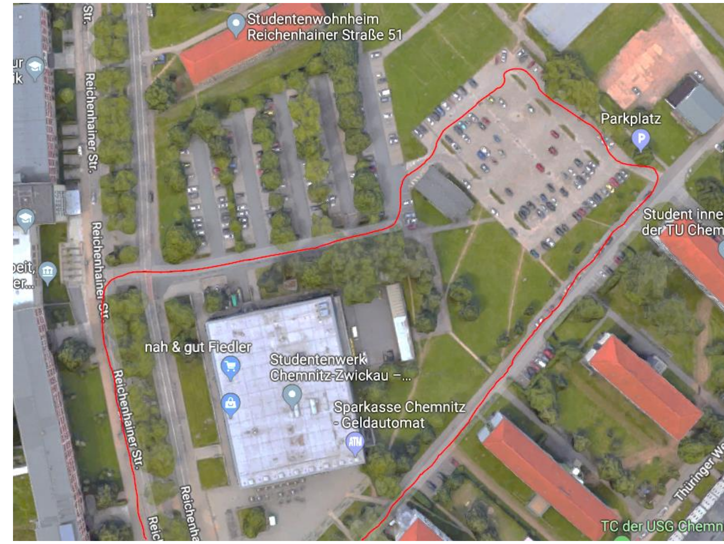
Chemnitz, 19.11.2018

Matthias Beggiato, Isabel Neumann, Ann-Christin Hensch

Wizard-of-Oz study


Method | study design



- Aim: effects of light signals on uninformed passing pedestrians
- Setting: parking area on the campus of Chemnitz University of Technology
- Wizard-of-Oz technique (driver hidden by seat suit); between-subject-design
- Applied methods: questionnaires, interviews, videos

		Use cases (color: turquoise)			
Drivers' visibility		No signal	Automation mode	Crossing mode	Starting mode
	Driver visible	Video data	Questionnaires, Interview data, video data		
	Driver invisible (seat suit)				

Method | use cases

Method | procedure and depended variables

- Demographic data: age, gender
- Scale:
  - [1] „I completely disagree“ to
  - [7] „I completely agree“
- Subjective safety during the interaction with vehicle[1]
- Usefulness of signals*[2]
- Trust in signals*[2]
- Comprehensibility of signals*[2]

1. Drive in respective mode (randomized light signals/ driver visibility)
2. Agreement for interview
3. 1st part of the interview: Uninformed participants
4. 2nd part of the interview: Informed participants

*data also collected in the field study
[1] uninformed
[2] informed

Results | sample and general data

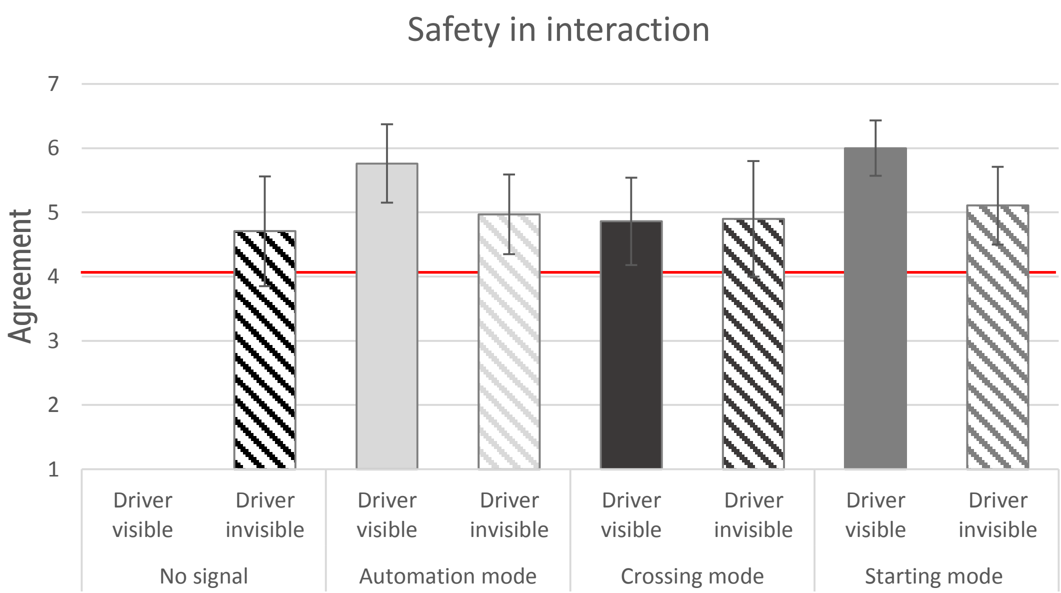
- Video data: 98 drives
  - ≈ 6,5h
  - ≈ 1800 pedestrians

- Interview data: 173 participants
  - 113 (66.1%) men, 58 (33.9%) women
  - Age: M = 29 (SD = 10.65)
  - Completed questionnaires: N = 147

Safety
When interacting with the vehicle I felt safe.

- Regarding subjective safety during the interaction with the vehicle there is no difference between the light signals ($F(3,161) = 1.59$, $p = .193$, $\eta_p^2 = .03$).

- The participants felt **significantly** safer during the interaction with the vehicle when the driver was visible ($F(1,161) = 4.03$, $p = .046$, $\eta_p^2 = .02$).

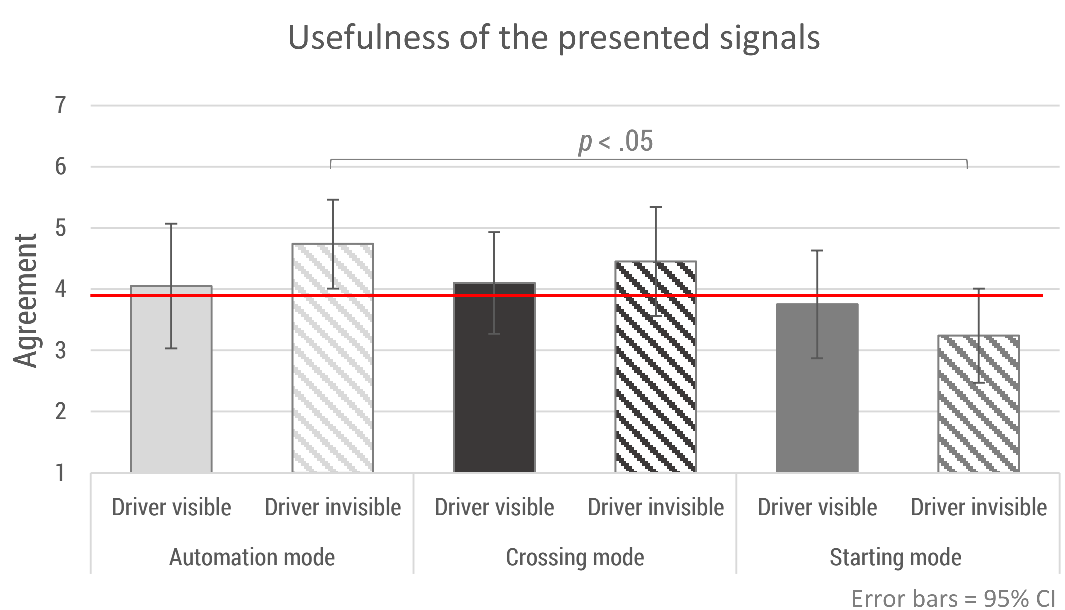


Error bars = 95% CI

$N = 168$

Usefulness
The presented signal is useful.

- The presented light signals were only partially assessed as useful by the participants.
- Regarding the usefulness of the presented light signals there is no difference ($F(2,126) = 2.91$, $p = .058$ $\eta_p^2 = .04$).
- The presented light signals were assessed as equally useful by the participants despite driver's visibility ($F(1,126) = 0.28$, $p = .598$, $\eta_p^2 = .00$).



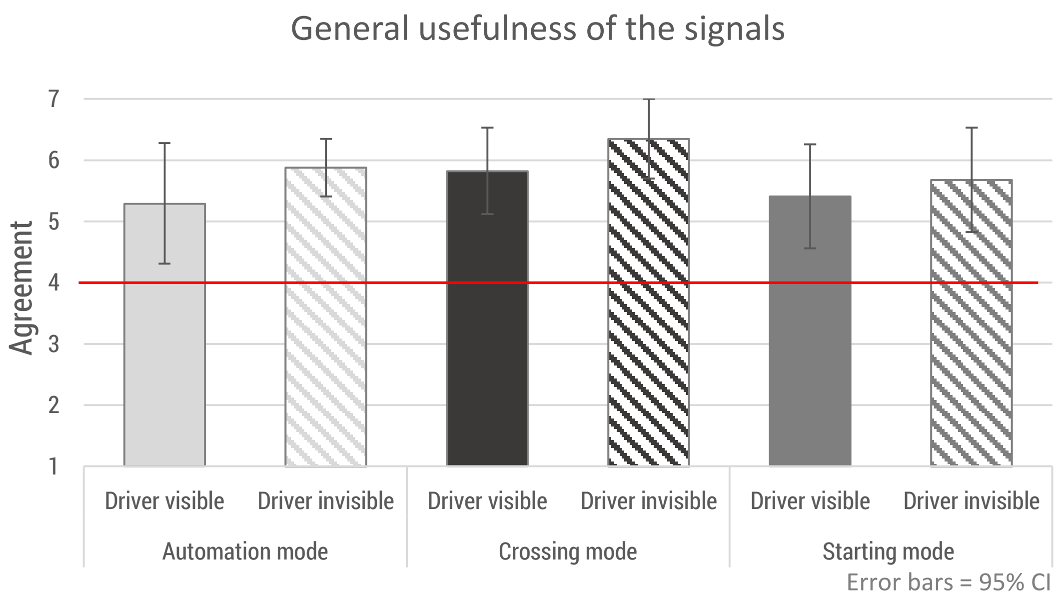
$N = 132$

Usefulness
A Signal that indicates… is generally useful.

- In general light signals as external HMI were assessed as useful by the participants.

- Regarding the usefulness of the general signal use there is no difference between the light signals ($F(2,140) = 1.26$, $p = .286$, $\eta_p^2 = .02$).

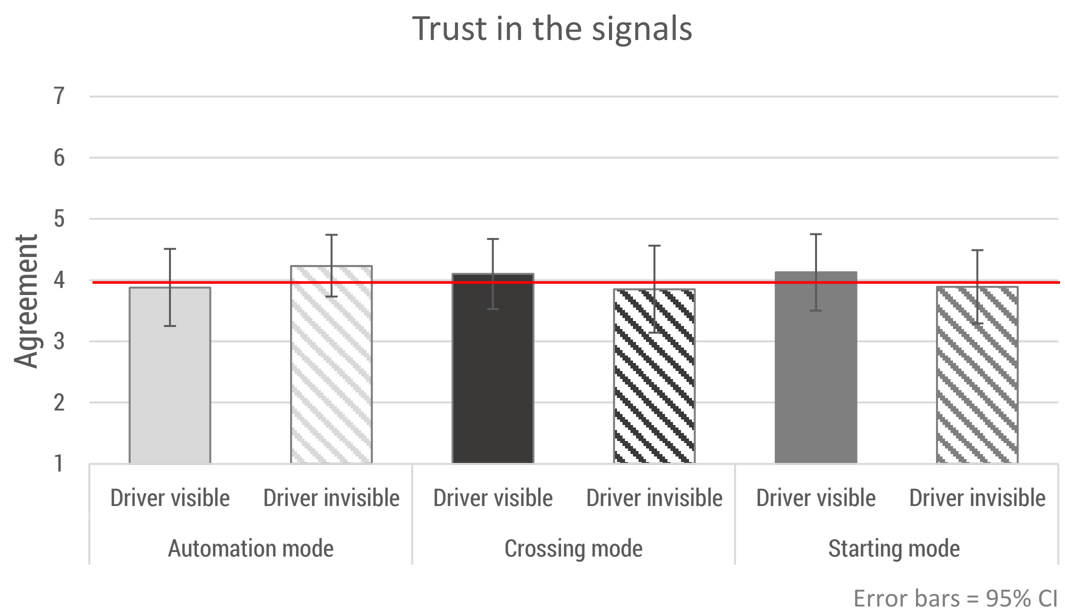
- The general use of the light signals was assessed as equally useful by the participants despite driver's visibility ($F(1,140) = 2.39$, $p = .124$, $\eta_p^2 = .02$).



$N = 146$

Trust – Overall item

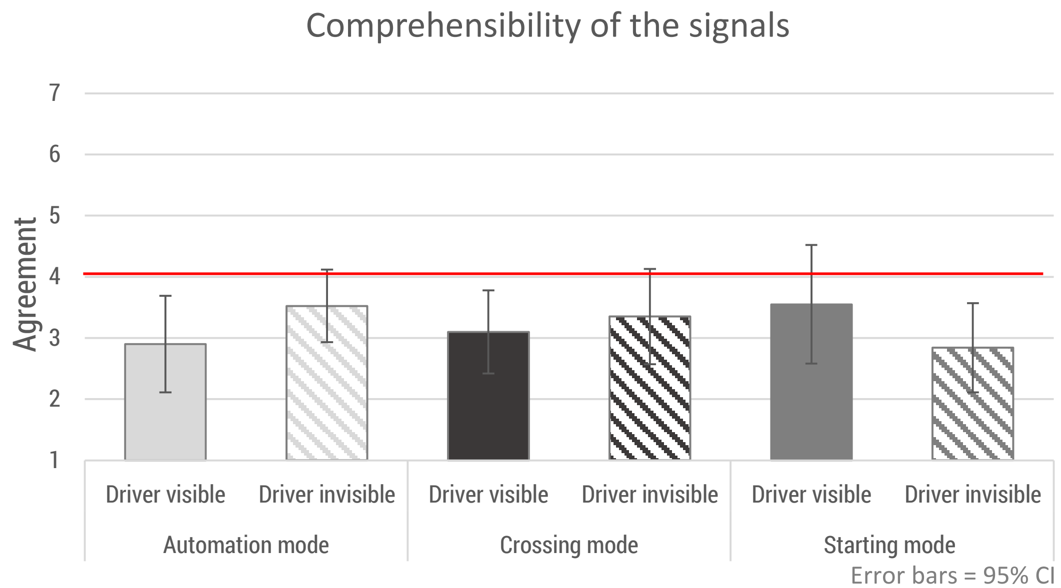
- In general the light signals were only partially assed as trustworthy by the participants.
- Regarding trust there is no difference between the light signals ($F(2,127) = 0.04$, $p = .964$, $\eta_p^2 = .00$).
- The light signals were assessed as equally trustworthy by the participants despite driver's visibility ($F(1,127) = 0.04$, $p = .838$, $\eta_p^2 = .00$).



$N = 133$

Comprehensibility
The signal is comprehensible.

- In general the light signals were assessed as **not comprehensible** by the participants.
- Regarding comprehensibility there is no difference between the light signals ($F(2,126) = 0.00$, $p = .997$, $\eta_p^2 = .00$).
- The light signals were assessed as equally (not) comprehensible by the participants despite driver's visibility ($F(1,126) = 0.03$, $p = .859$, $\eta_p^2 = .00$).



$N = 132$

Interview data
Closed-ended questions

	Yes	No	
Did you perceive the light signal on top of the vehicle?	*N* = 133 (88.7%)	*N* = 17 (11.3%)	

The light signal was perceived by the majority of participants (88.7%).

Do you believe that the light signal was addressed to you?	*N* = 19 (14.3%)	*N* = 114 (85.7%)	*N* = 133

Despite the low spatial distance in the parking area setting the majority of participants (85.7%) did not believe that the light signal was addressed to themselves.

Did you see any driver inside the vehicle?

N = 133

79.2% of participants did **not** see any driver when the **seat suit** was worn.

When the driver was visible 51.6% of participants did see the driver (20.3% were unsure; 28.1% did not see any driver). *N* = 170

Interview data (including all conditions)
Open-ended question: What do you think was indicated by the signal?

Communication to other drivers

No meaning

Illumination

Warning/ caution

Driverless vehicle

Giving right of way

Communication in general

Priority/ precedence/ privilege

Police

Emergency/ rescue vehicle in general

Sensors in general

Mapping

Indicating risks and hazards

Communication to pedestrians

Security transport

Sensor as driver assistance systems

Attention

Detection and tracing of obstacles

No idea

Ambulance

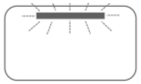
- No information
- Type of vehicle
- Communicaton partner
- Communication message
- Vehicle functions
- Light bar functions

Qualitative data analyzed over all conditions; N = 138

Study 2: Evaluation of light signals

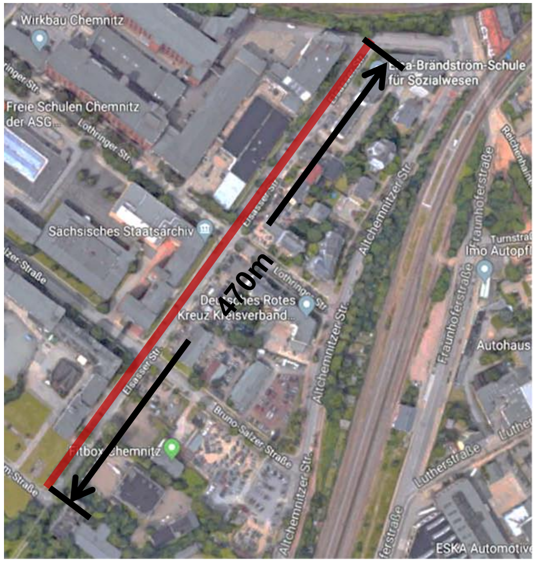
Method | study design

- **Aim:** Evaluation of light signals to communicate between VRU and automated vehicle
- **Setting:** field study (Elsasser Straße, Chemnitz)
- **Independent variables:**

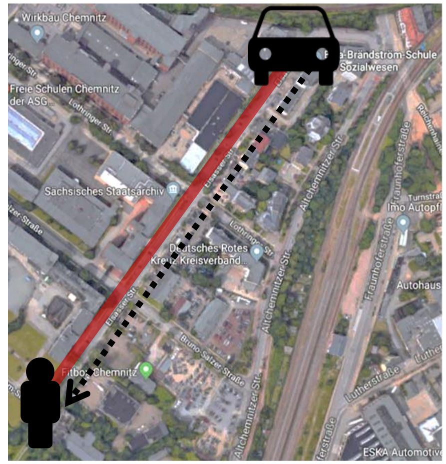
  3 light signals: AUTOMATED,  STARTING,  CROSSING 

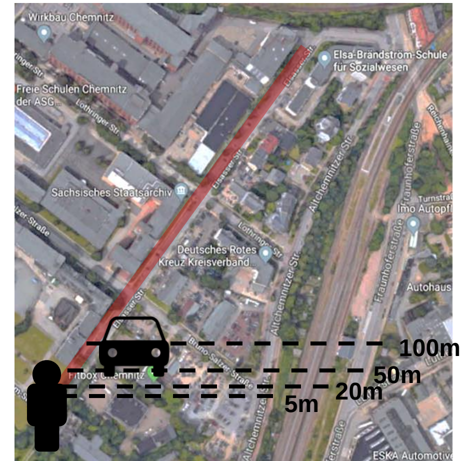
  3 colors: WHITE, TURQUOISE, PURPLE

- **Dependent variables:** visibility and trust, acceptance, comprehensibility of signals, appropriateness of signal colors
- **Applied methods:** questionnaires, interviews, evaluation of visibility
- **Sample:** N = 38 (18 men, 20 women; mean age: 50 years (SD = 23.49))



Method | procedure





- Laboratory (uninformed)
- Test site (uninformed)
- Test site (informed)

1 Welcome and socio-demographics

2 Visibility of colors (distance measurement; 470m condition)

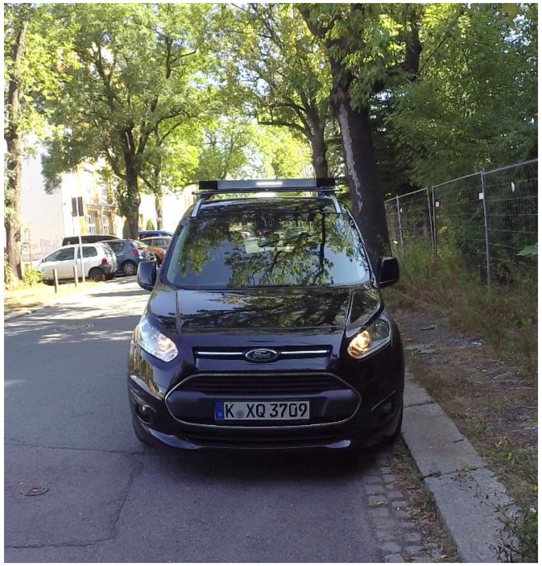
3 Visibility of colors (100m, 50m, 20m and 5m distance)

4 Assumed meaning of light signals (uninformed) — 3 times each

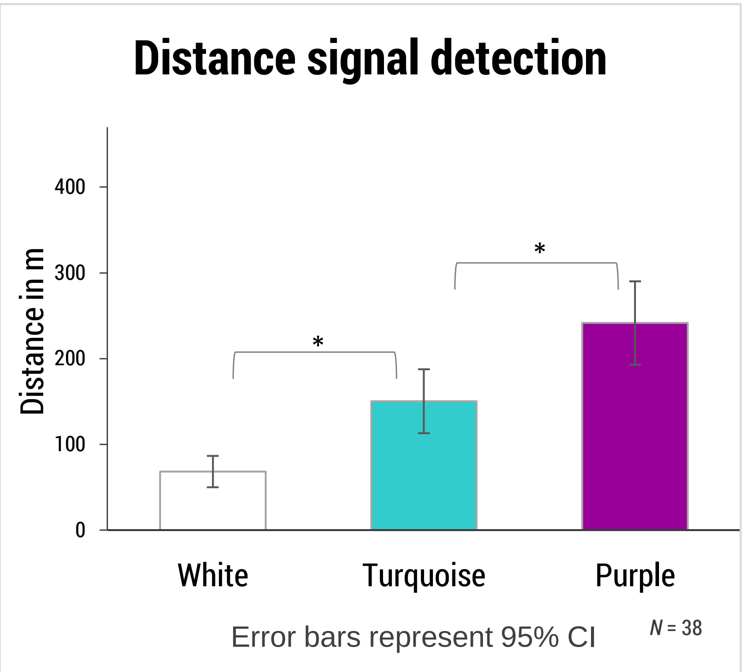
5 Evaluation of light signals; appropriateness of colors (informed) — 3 times each

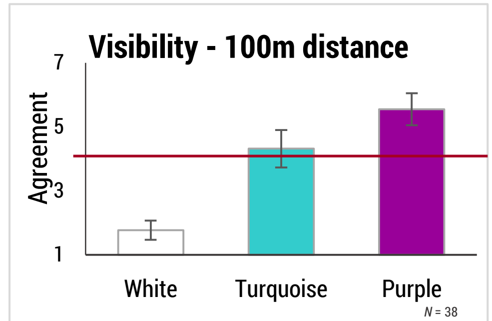
6 Closure and goodbye

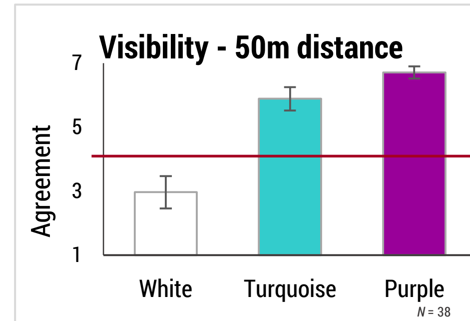
RESULTS I
Visibility of signals depending on color

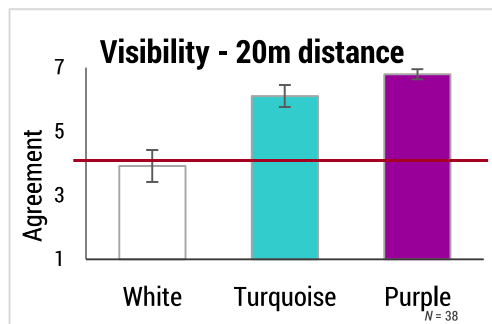


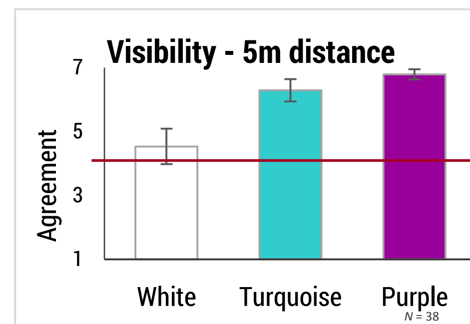
SIGNAL CONSTANT
Visibility of signals depending on color











Participants detected the signal from significant different distances depending on signal color.

Purple > Turquoise > White

(* significant pairwise comparisons)

For all distances analysis of subjective evaluations results in the same ranking:

Purple > Turquoise > White

(Single Item;)

Luminous flux for all conditions: 2 lumen

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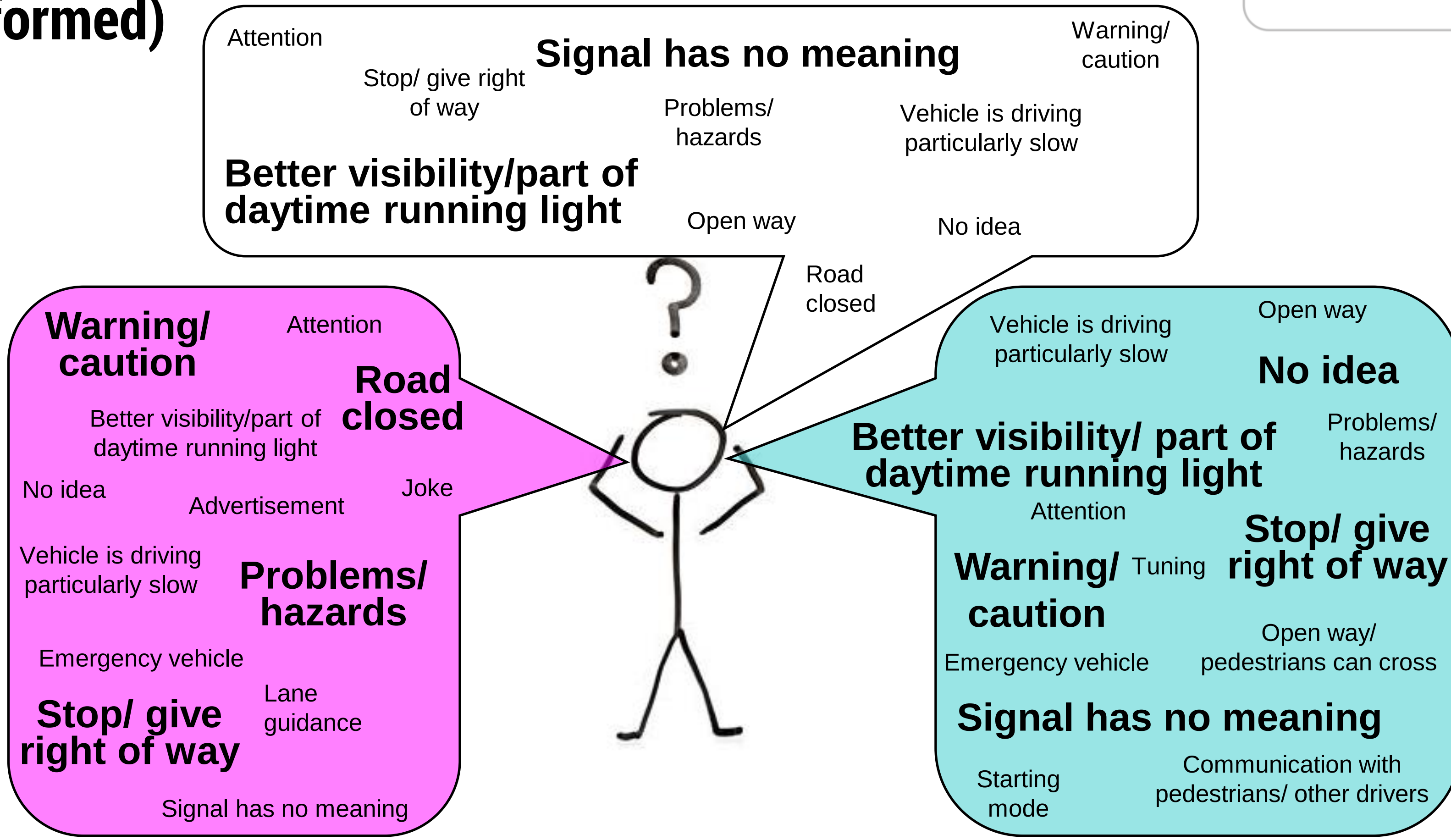
RESULTS II
Evaluation of signals & color

AUTOMATED

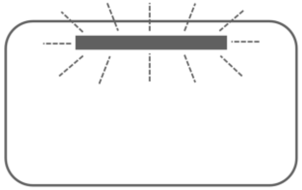
What do you think about the meaning of the signal? (uninformed)

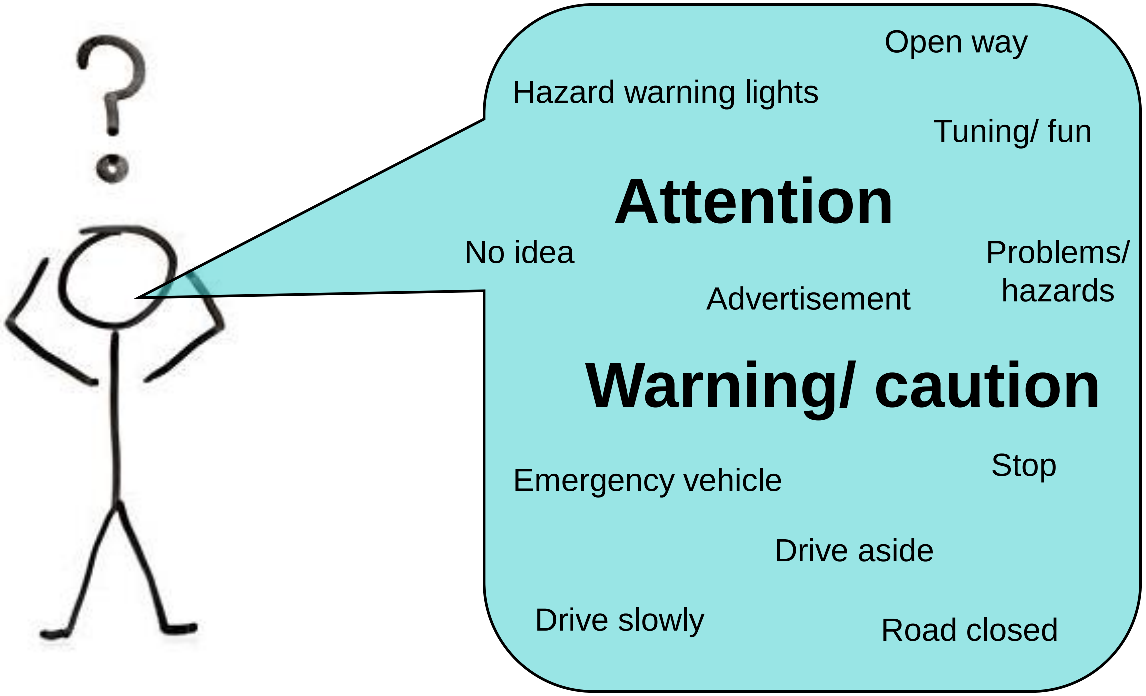


heuristic analysis of interviews, frequent answers bold

STARTING

What do you think about the meaning of the signal? (uninformed)

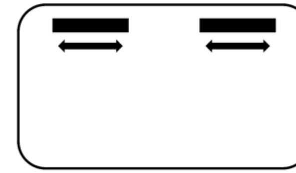


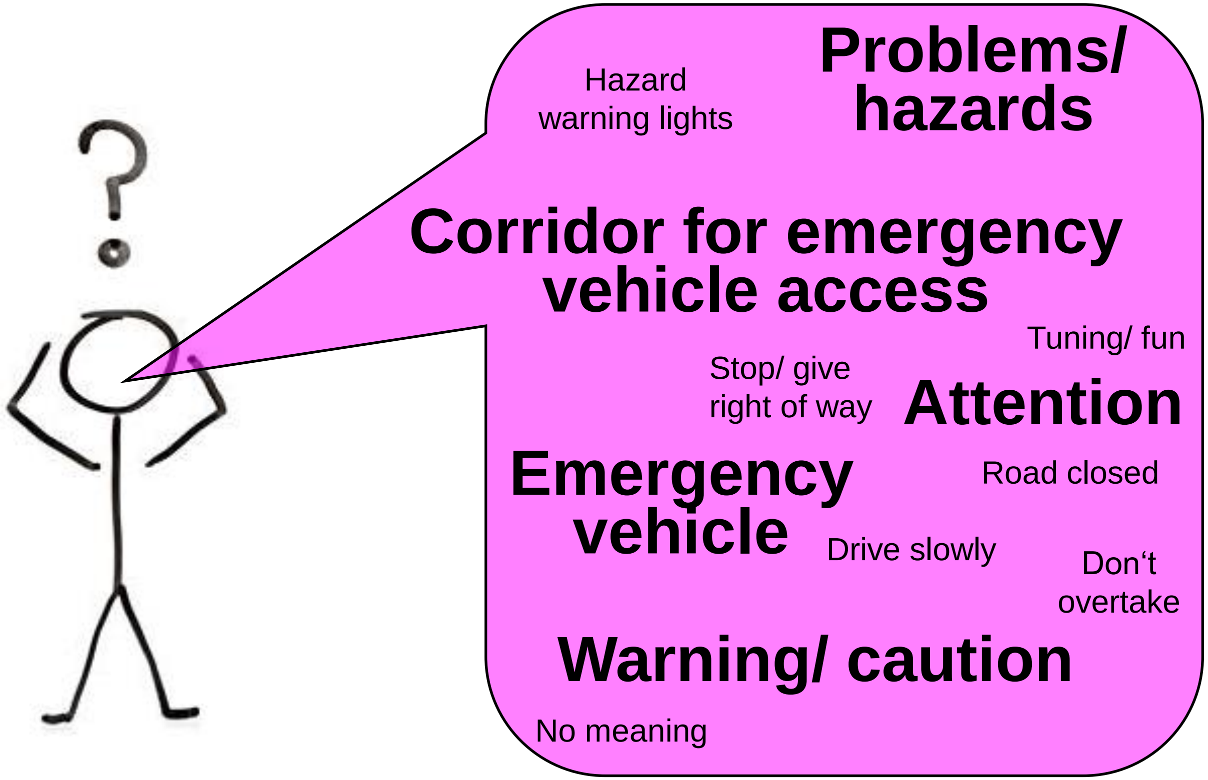


heuristic analysis of interviews, frequent answers bold

CROSSING

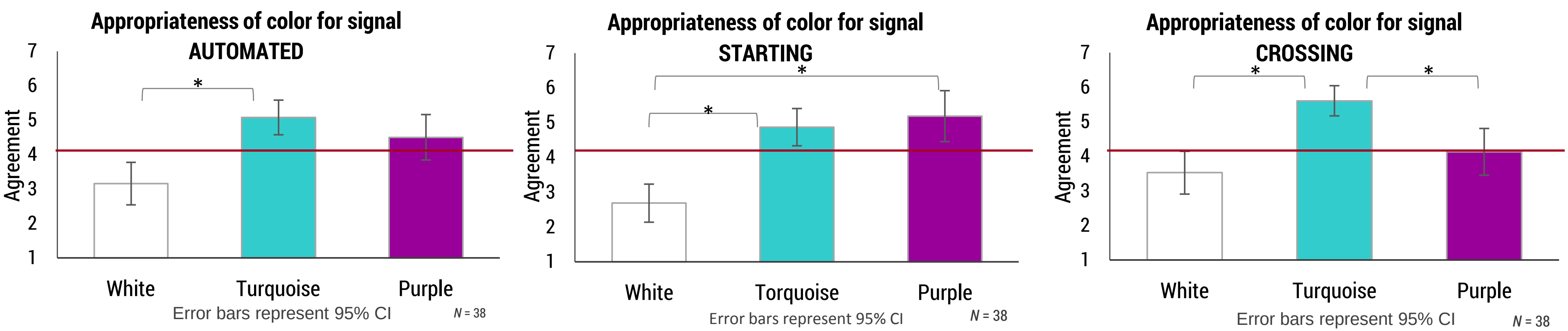
What do you think about the meaning of the signal? (uninformed)





heuristic analysis of interviews, frequent answers bold

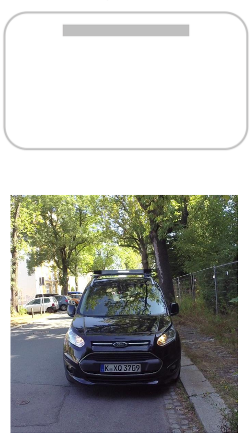
Signal & color
Appropriateness of signal color (informed)

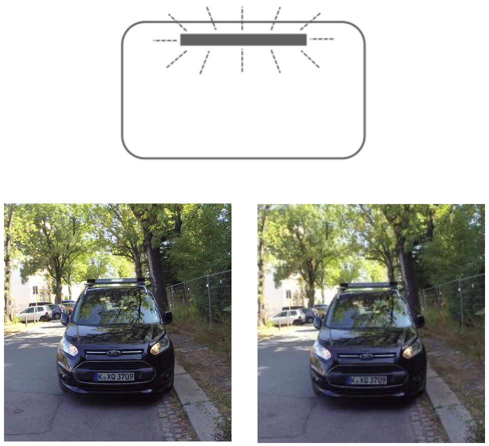


The appropriateness of signal color is evaluated differently for the different signal types.

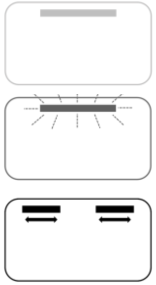
(Single Item, * significant pairwise comparisons)

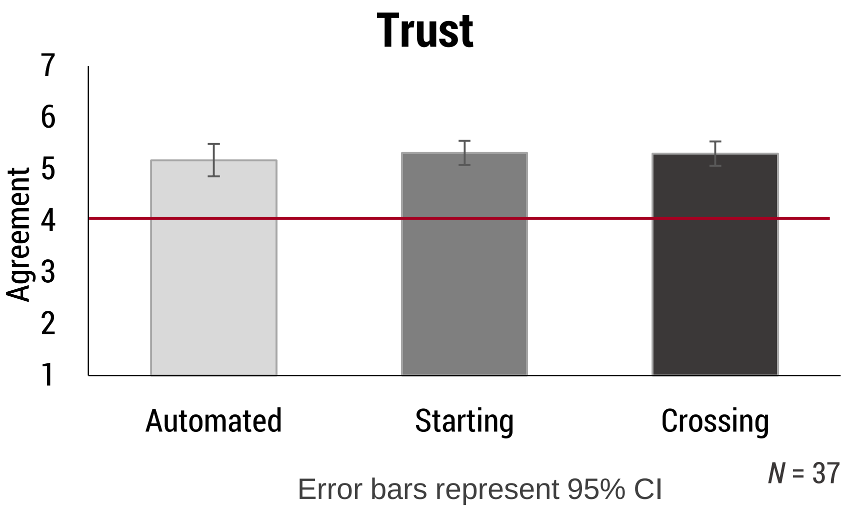
RESULTS III
Evaluation of signals regardless of color

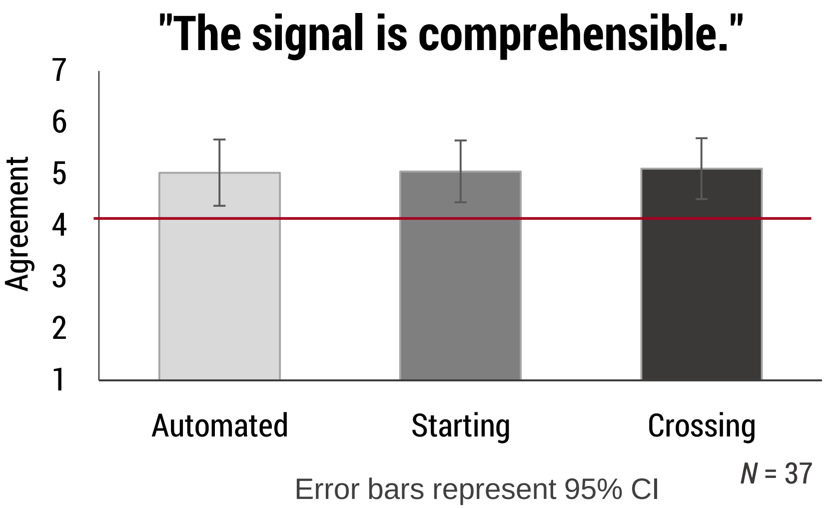




Signals regardless of color
Trust and comprehensibility (informed)







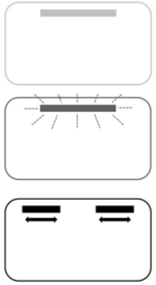
On average participants agree to trust all of the presented signals of automated driving.

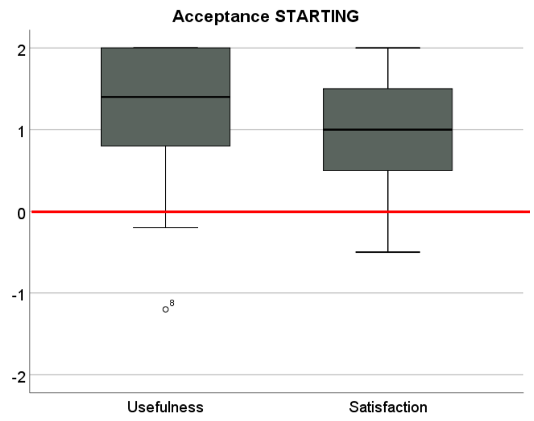
(Trust Scale; Jian, Bisanz & Drury, 2000)

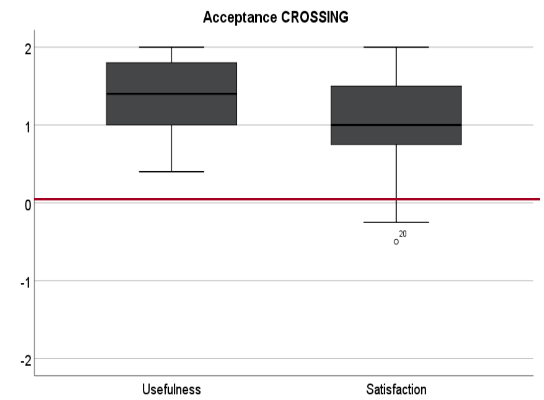
On average participants agree that all signals are comprehensible.

(Single Item)

Signals regardless of color
Acceptance of the signal (informed)







Ratings of participants indicate a rather high acceptance of all presented signals.

(Acceptance Scale, van der Laan, Heino & De Waard, 1997)

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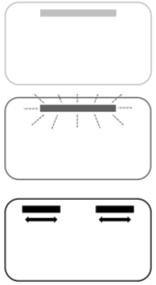
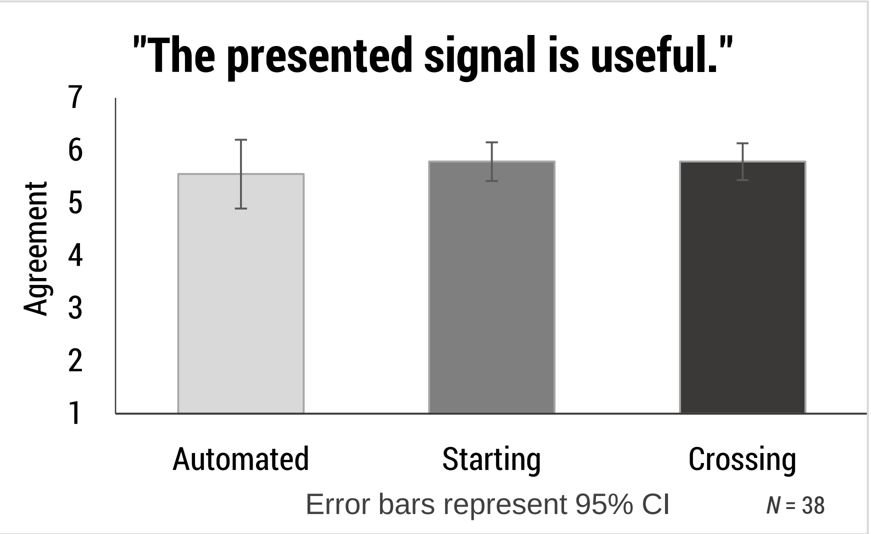
Signals regardless of color
Usefulness (informed)

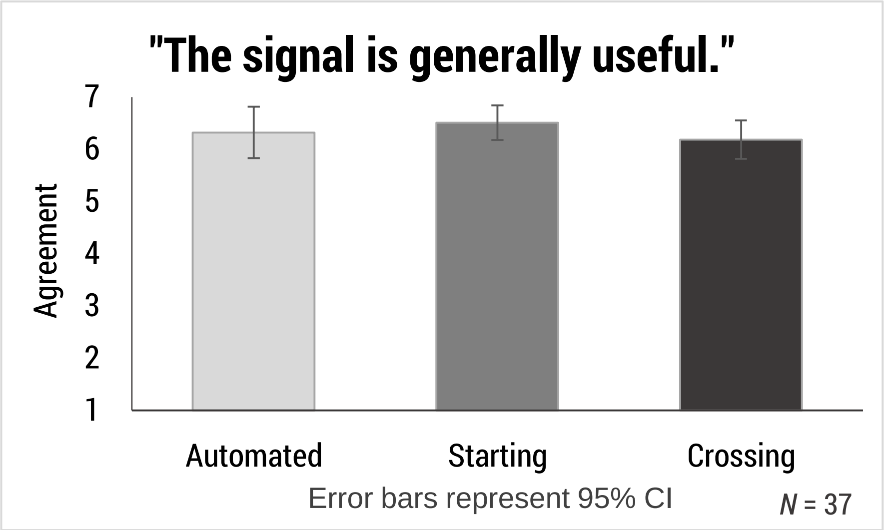




On average participants agree.

Participants assess the presented signals to be useful.

(Single Item)



Results reveal an averaged agreement for all 3 signals.

Participants assess the presentation of signals for automated driving generally as useful.

(Single Item)

Implications

- Differences between passing-by pedestrians and invited participants regarding assessed usability, trust and comprehensibility
  → potential reasons: amount of explanation, directedness

- The presented light signals are not comprehensible by intuition.

- In general, light signals as a form of communication in automated driving is evaluated as useful.
  → possible form of external HMI in automated driving from user perspective

- Visibility: Clear ranking: purple > turquoise > white

  → But: What is an *optimal* visibility in this context?

Priority Program 1835 “Cooperative Interacting Cars” German Science Foundation
KIVI: Kooperative Interaktion mit schwächeren Verkehrsteilnehmern im automatisierten Fahren

KIVI - Cooperative interaction with vulnerable road users in automated driving

Beggiato, M., Witzlack, C., Springer, S. & Krems, J.F.

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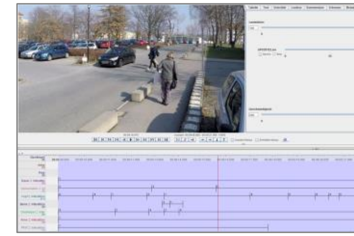
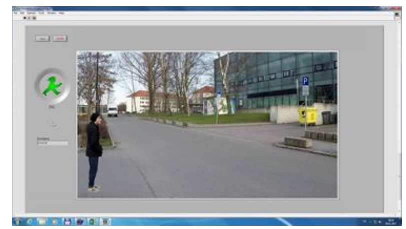
DFG

Priority Program 1835 "Cooperative Interacting Cars" German Science Foundation
KIVI: Kooperative Interaktion mit schwächeren Verkehrsteilnehmern im automatisierten Fahren

- **Observation** of interaction behavior, video labeling and analysis of interaction sequences
  (Witzlack, Beggiato & Krems, 2016)

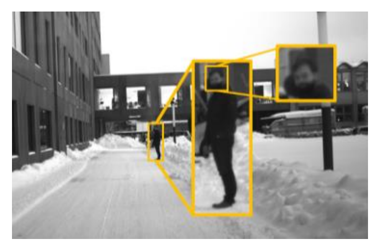



- **Video simulation** studies to identify parameters, e.g. expected moment of braking, perception of deceleration, influencing factors…
  (Beggiato, Witzlack, Springer & Krems, 2017a; 2017b)




- **Focus group** discussions and **video simulation** studies on explicit external communication, e.g. projections, displays...
  (Ackermann, Beggiato, Schubert & Krems, submitted)


- **On-road test** with partner from communication engineering and automated BMW i3
  (summer 2018)




Study design

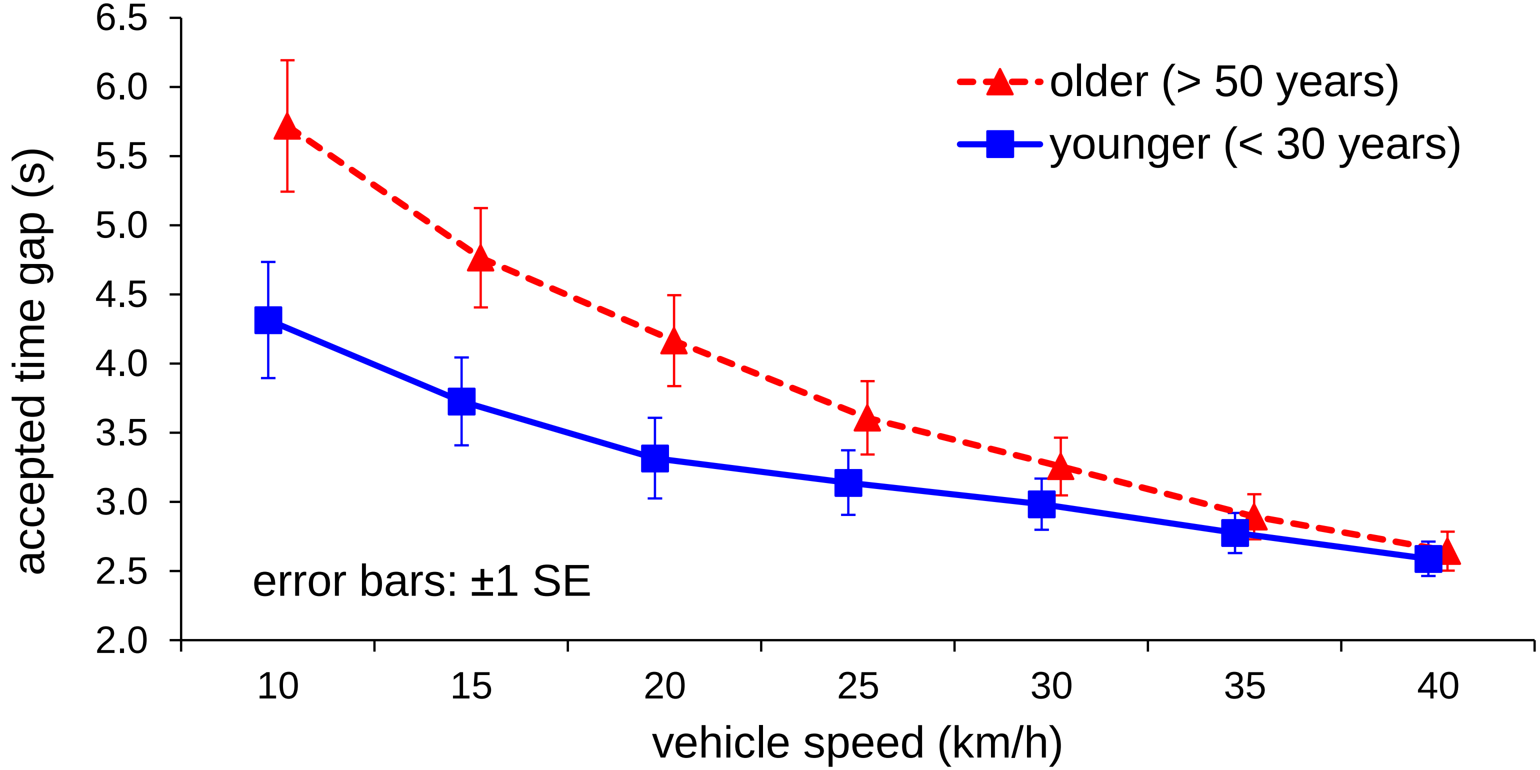
- 7x2x2 mixed design:
- **IV1** within-subject: vehicle speed from 10 to 40 km/h in 7 steps of 5 km/h. Exactly manipulated by accelerating/decelerating video playback speed
- **IV2** within-subject: daytime, midday (11:13 AM) and dusk (19:25 PM at 2nd of April)
- **IV3** between-subject: age, two age groups from 20-30 and 50+ years
- Each of the 14 within-conditions presented in randomized order, 3 repetitions to stabilize results (mean calculated) → 42 trials per participant
- **DV**: last accepted time gap in seconds of the oncoming vehicle, i.e. last moment of crossing comfortably before the vehicle
- **Instruction**: press a defined key at the last moment, when you would cross the street comfortably (without running) before the vehicle.

video midday
(11:13 AM)

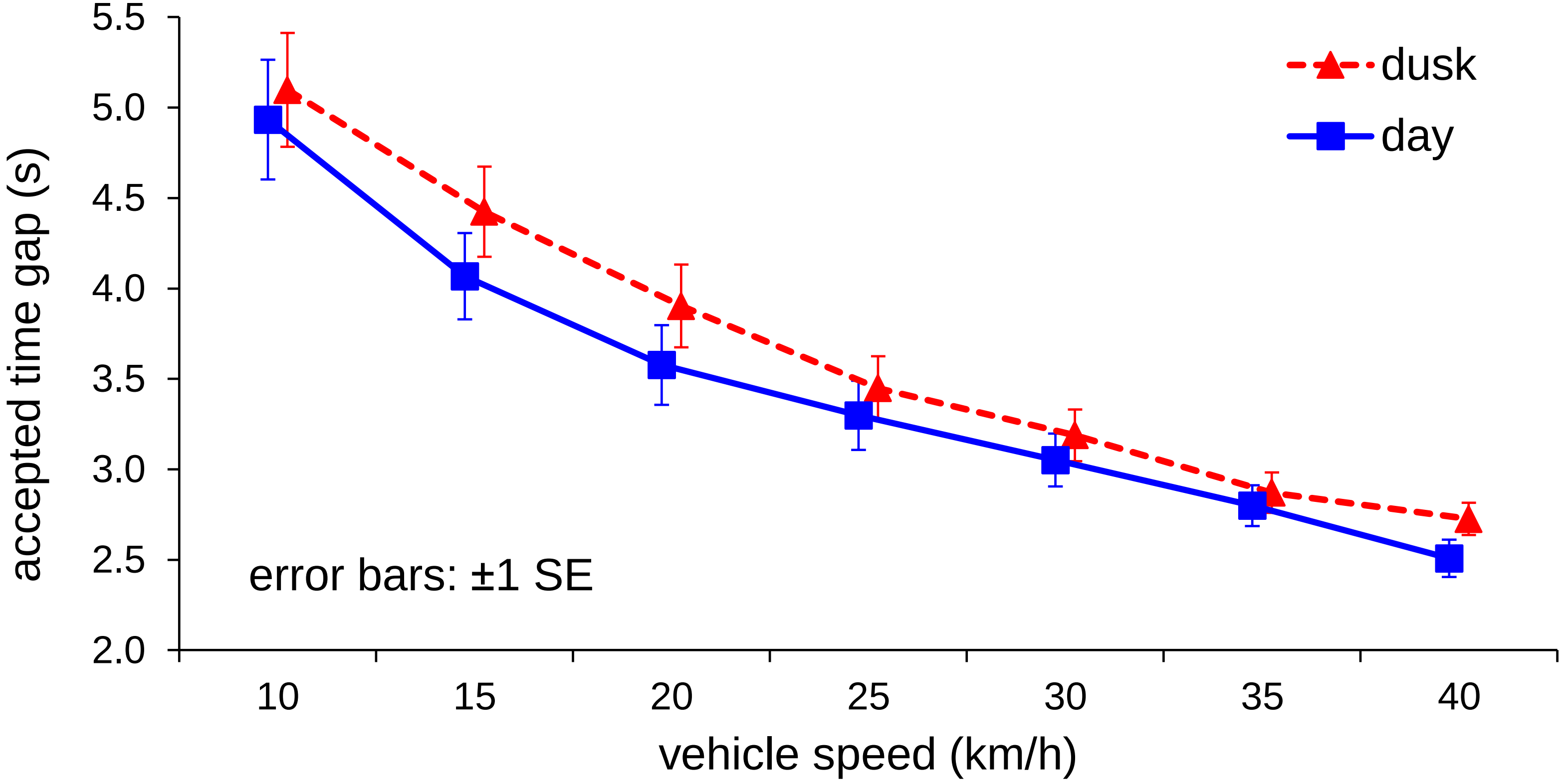
video dusk
(19:25 PM)

Results – speed x age

main effects and interaction	ANOVA		
	F	p	η^2_p
speed	**$F(1.59, 61.84) = 67.22$**	**< .001**	**.633**
age	**$F(1, 39) = 4.46$**	**.041**	**.103**
speed × age	**$F(1.62, 63.32) = 7.95$**	**.002**	**.169**
daytime × age	$F(1, 39) = 0.30$	.590	.008



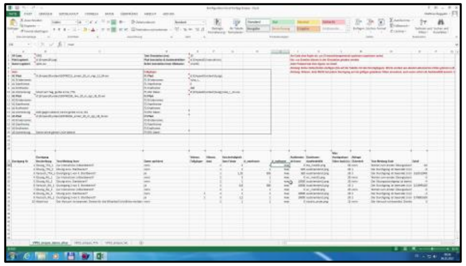
main effects and interaction	ANOVA		
	F	p	η^2_p
speed	**$F(1.59, 61.84) = 67.22$**	**< .001**	**.633**
daytime	**$F(1, 39) = 29.28$**	**< .001**	**.429**
speed × daytime	$F(4.86, 189.55) = 1.63$	.155	.040

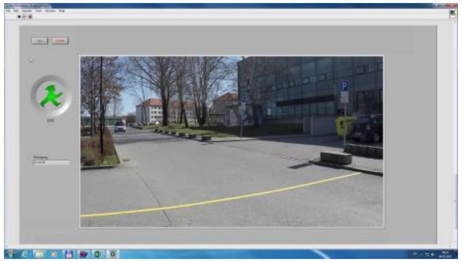


Potential

Dedicated video simulation environment (progr. in LabView)

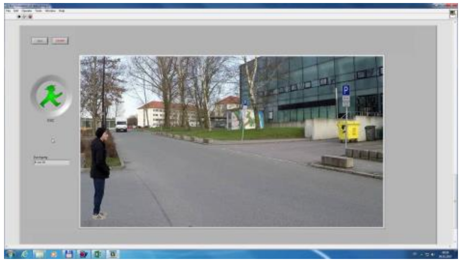
- Exact play rate control of the videos, speed profiles, blanking, pedestrian overlay, logging of participant's reactions, experimental control of instructions, randomized trials, messages etc.
- Easy configuration by separate Excelfiles: videos, instructions, speed, randomization trials, speed profiles… → also used in teaching for bachelor students





Variations of video simulation studies

- Type/size of cars
- TTA estimation by blanking the video (perception / estimation)
- Augmented pedestrian controlled by study participants
- Perception of braking / accelerating → speed profile
- Formal communication / HMI solutions, evaluated by participants



Project publications KIVI DFG

Ackermann, C., Beggiato, M., Schubert, S., & Krems, J. F. (in press). An experimental study to investigate design and assessment criteria: what is important for communication between pedestrians and automated vehicles? *Applied Ergonomics.*

Ackermann, C., Beggiato, M., Blum, L.-F., & Krems, J. F. (2018). Vehicle Movement and its Potential as Implicit Communication Signal for Pedestrians and Automated Vehicles. In N. Van Nes & C. Voegelé (Eds.), *Proceedings of the 6th HUMANIST Conference* (pp. 86-92). Lyon: Humanist Publications. ISBN: 978-2-9531712-5-9.

Beggiato, M., Witzlack, C., & Krems, J. F. (2017). Gap Acceptance and Time-To-Arrival Estimates as Basis for Informal Communication between Pedestrians and Vehicles. In *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI '17)*. (pp. 50-57). New York, NY, USA: ACM. doi:10.1145/3122986.3122995.

Beggiato, M., Witzlack, C., Springer, S., & Krems, J. F. (2017). The Right Moment for Braking as Informal Communication Signal between Automated Vehicles and Pedestrians in Crossing Situations. In N. A. Stanton (Ed.), *Advances in Human Aspects of Transportation. Proceedings of the AHFE 2017 Conference on Human Factors in Transportation, July 17-21, 2017, Los Angeles, California, USA* (pp. 1072–1081). Springer Verlag. doi:10.1007/978-3-319-60441-1_101.

Witzlack, C., Beggiato, M., & Krems, J. F. (2016). Interaktionssequenzen zwischen Fahrzeugen und Fußgängern im Parkplatzszenario als Grundlage für kooperativ interagierende Automatisierung. In VDI (Eds.). *Fahrerassistenz und automatisiertes Fahren, VDI-Berichte 2288* (p. 323-336). Düsseldorf: VDI-Verlag.

Thank you for your attention!

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