Enlightening Communication – An Exploratory Study on Light-Based Signals in Automated Driving

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Abstract

One of the key questions arising in the context of automating our traffic system is: Which strategies will be implemented for the communication between automated vehicles (AVs) and surrounding traffic participants, such as pedestrians? In this context, external human-machine interfaces (**eHMIs**; e.g., light signals) are discussed as important communication cues, which could enhance communication, especially if implicit messages (e.g., vehicle trajectory; [1]) are insufficient [2]. A total of *N* = 38 participants evaluated **three different light signals and three different light colours**, implemented via a light bar placed on a test vehicle's roof, in a realistic setting. Besides the visibility and appropriateness of the signal colours, participants assessed comprehensibility and perceived usefulness of the light signals. Results imply that the displayed **signals are rather unintuitive without prior information**. After receiving information about the intended meaning of the signals, participants assessed them to be medium to high usefully and comprehensibly. **Generally**, light signals were evaluated to be **useful to communicate AVs' states and planned manoeuvres**. Based on the results, participants' ratings revealed a **clear ranking of visibility of signal colours** (**purple > cyan > white**). In sum, results underline the relevance of an intuitive and comprehensible design for the communication between AVs and other road users.

Method

Participants

- *N* = 38; 18 men, 20 women
- Age: *M* = 50 years (*SD* = 23.5)
- Vision: 20% normal vision, 80% corrected visual impairment (glasses or contact lenses)

Apparatus

- Black Ford Tourneo Connect with light bar (eHMI) on top (Fig. 1).

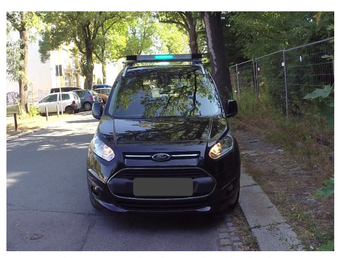
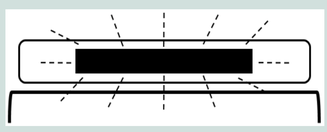


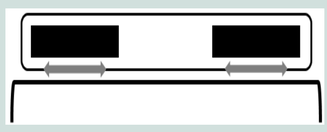
Fig 1. The test vehicle with a light bar as an eHMI on top (signal: Automation mode, colour: Cyan).

eHMI: Light signals

Automation mode:
Steady light
(AV in automated mode)



Starting mode:
Flashing light
(AV approaches)



Crossing mode:
Sweeping light
(VRU could cross in front of AV)

eHMI: Signal colours

WHITE | CYAN | PURPLE

Questionnaire

- Visibility of signal colours (light signal kept constant at 'automation mode'; test vehicle was parked at 4 defined distances away from the participant: 100m, 50m, 20m, 5m),
- Comprehensibility,
- Usefulness of the presented light signals,
- General usefulness of light signals as eHMIs in AVs

Interview

- Comprehensibility and meaning of the presented light signals (without prior information)

Results

Without information about the meaning of the signals

- **Visibility of light colours:** Clear ranking of visibility of colours for all distances: Purple > Cyan > White; significant differences for all colours and distances ($p > .001$, $\eta_p^2 = .68 - .83$; Fig. 2)
- **Intuitive comprehensibility of light signals:** Without prior information about the context (automated driving) and meaning of the signal, it was hard for participants to deduce the light signals' meaning solely from visual impression

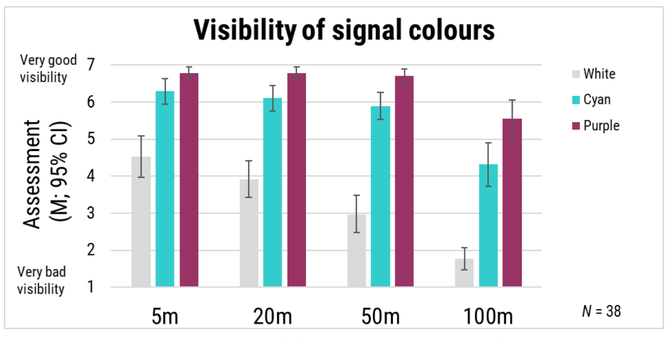


Figure 2. Participants' ratings of visibility of signal colours for 4 different distances (constantly for signal automation mode).

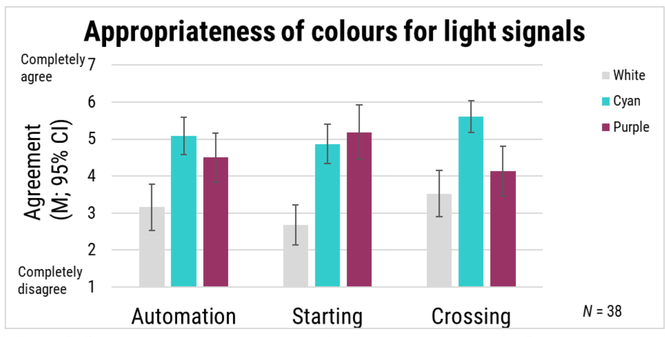


Figure 3. Participants' ratings for appropriateness of colour for the 3 light signals.

With information about the meaning of the signals

- **Appropriateness of signal colour:** Best ratings for Cyan; significant differences between the signal colours ($p \leq .001$, $\eta_p^2 = .20 - .34$; Fig. 3)
- **Usefulness:** Presented signals were assessed to be rather useful with no significant differences between signals ($F = 0.50$, $p \leq .606$, $\eta_p^2 = .01$); general usefulness of signals (independently from presentation format) was assessed significantly better ($F = 31.16$, $p < .001$, $\eta_p^2 = .46$; Fig. 4)
- **Comprehensibility:** Participants rather agreed that the presented light signals are comprehensible (automation mode: *M* = 5.03, *SD* = 1.95, starting mode: *M* = 5.05, *SD* = 1.82, crossing mode: *M* = 5.11, *SD* = 1.80) with no significant differences between light signals ($F(2, 74) = 0.03$, $p = .976$, $\eta_p^2 < .01$).

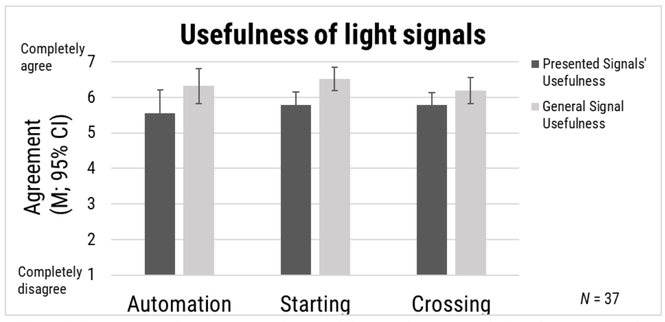


Figure 4. Participants' assessment for usefulness of presented signals vs. general usefulness of signals independently from presentation format..

Discussion

- **Visibility of investigated signal colours follows a clear ranking: Purple > Cyan > White**, which in parts supports findings by others [3]. The question about **an optimal visibility** of an eHMI for the communication between AVs and pedestrians in specific traffic situations still remains open.
- **Appropriateness of signal colour is a relevant aspect of signal interpretation and meaning**; the results further support **Cyan as an appropriate colour** for the communication of AVs [4].
- Investigated light signals were assessed as **rather unintuitive without prior information**, implying some **learning effort for rather abstract eHMIs** [5].
- **After informing** about the signals' meaning, participants assessed the investigated signals to be **comprehensible and useful**, revealing light signals to be a **suitable communication option** in automated driving and indicating specific **advantages of rather abstract light signals** as eHMIs (e.g., no language skills required [3]).

References

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Meet the research group at Chemnitz University of Technology.