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Implicit longitudinal communication: an effective means of communication for oncoming automated vehicles interacting with human drivers in dynamic overtaking situations?

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Background
Driving automation holds great promise for improving traffic safety, however, managing interactions between automated vehicles (AVs) and human drivers in mixed traffic scenarios remains a substantial challenge. In particular, overtaking maneuvers on two-lane rural roads pose significant risks of head-on collisions at high speeds. The inconsistent judgment of available gaps by human drivers underscore the need for a comprehensive understanding of human overtaking behavior to enhance road safety. Advanced overtaking behavior models can enhance our understanding of human gap acceptance, consequently playing a pivotal role in enhancing road safety and the development of AV technology. However, existing studies and models of human overtaking behavior have mostly focused on scenarios with simplistic, constant-speed dynamics of oncoming vehicles, disregarding the potential of AVs to proactively influence the decision-making process of the human drivers via implicit communication. Furthermore, despite numerous studies in other scenarios, so far it remained unknown whether overtaking decisions of human drivers are affected by whether they are interacting with an AV or a human-driven vehicle (HDV).

Aim
This study aims to investigate whether human drivers adapt their gap acceptance behavior when interacting with AVs compared to HDVs, and to what extent AVs' implicit communication can influence the decision-making process.

Method
To investigate the effect of interacting with AV compared to HDV, we manipulated participants' belief of the type of oncoming vehicle they interacted with. To this end, we used a “reverse Wizard-of-Oz'” setup (Figure 1): the participants (n = 30; 15 females) were made to believe that in HDV trials they would interact with the experimenter, while the actual oncoming vehicle was still AV with the same pre-programmed behaviors (Figure 2). The oncoming AV was preprogrammed to perform one of the three behaviors: 1) maintaining a constant speed; 2) decelerating with 2.5 m/s^2 for 2 s soon after appearing in participants' field of view and then accelerating back to its original speed (“weak nudge”); 3) “strong nudge” --- similar to the weak nudge but with deceleration magnitude of 5 m/s^2. A post-experiment questionnaire assessed participants' perceived safety for each interaction partner (AV or HDV).

Figure 1: "Reverse Wizard-of-Oz" experimental setup of the driving simulator. During the sessions involving oncoming "human-driven" vehicles, the experimenter (on the right-hand side) pretended to operate an unconnected driving simulator.

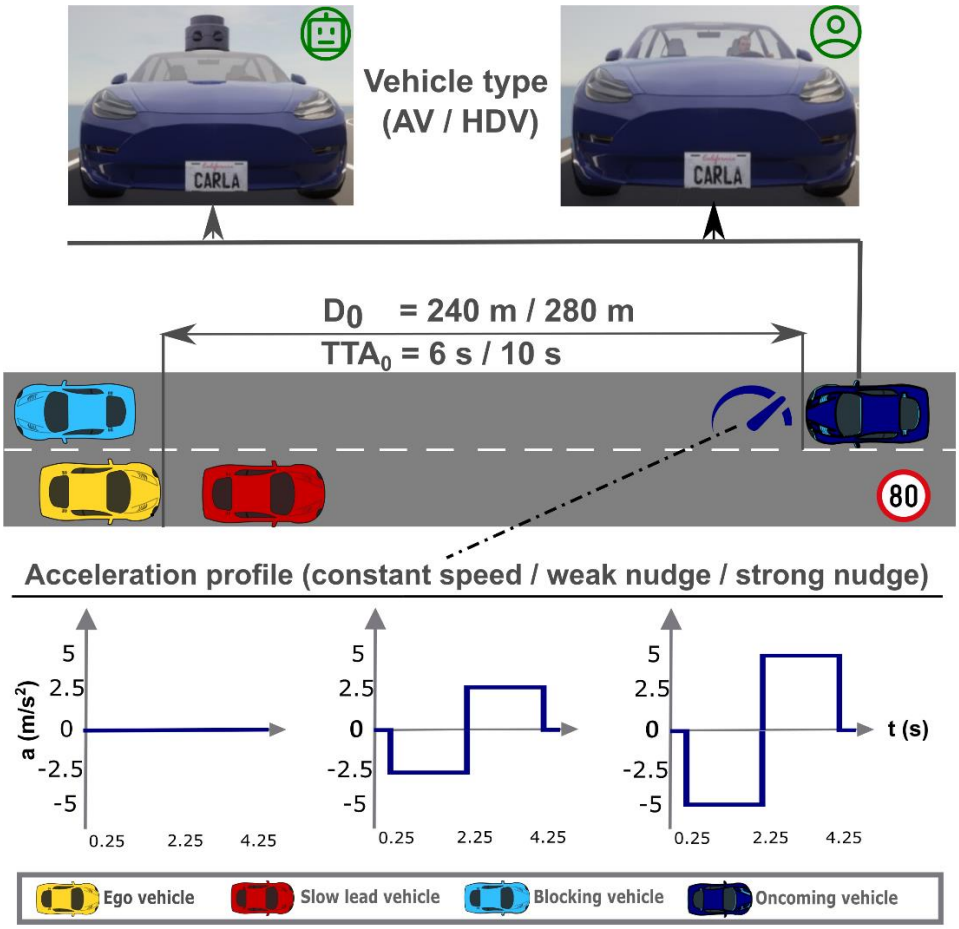

Figure 2: Independent variables manipulated in the experiment: vehicle type, initial distance (D_0), initial time-to-arrival (TTA_0), and acceleration profile of the oncoming vehicle.

Results

On average, participants did not significantly alter their overtaking behavior (decisions and response times) when interacting with oncoming AVs compared to HDVs. Brief decelerations of the oncoming vehicle did not affect participants' decisions or response times. The post-experiment questionnaire indicated similar perceived safety levels for interactions with both AVs and HDVs.

Conclusions

Overtaking behavior models may not need adjustment for interactions with oncoming AVs. Implicit longitudinal communication cues by AVs to indicate yielding behavior are limited in high-speed scenarios. Further research is necessary to determine if these findings hold true for interactions involving vulnerable road users, where speeds and distances are smaller. In such contexts, AVs might need to employ lateral movements and external Human-Machine Interfaces (eHMIs) to effectively communicate intentions. As human exposure to human-AV interactions increases, new behavioral patterns may emerge. Therefore, ongoing empirical and modeling research is needed to understand how human road users' behavior evolves.