Vehicle Movement and its Potential as Implicit Communication Signal for Pedestrians and Automated Vehicles

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ABSTRACT

An important challenge for automated vehicles will be the coordination of their own actions with the behaviour of other road users such as pedestrians. A possible solution for pedestrian-automated vehicle interaction could be explicit interfaces that convey additional visual or auditory signals (e.g., by projection). However, it is argued that light and weather conditions could significantly affect the functionality of such interfaces. Implicit communication signals such as the movements of a vehicle are already used by pedestrians, so that they are able to cross the street without any further communication. Thus, the study addresses the question of which parameters influence the recognition and classification of vehicle movements into acceleration, deceleration and constant speed driving. Therefore, we implemented an experimental video simulation in which the independent variables vehicle speed (20 and 40 km/h), daylight (morning, dusk, evening), onset of the movement change (early, late) and acceleration rate (positive, negative, none) were varied. The task of the participants (n = 33) was to indicate by pressing a button when they had detected changes in the approaching car movement. Further, they had to decide what kind of movement it was (deceleration/acceleration). In the results we expect answers to which parameters or parameter combinations have a positive or negative influence on the recognition of deceleration, acceleration or constant speed driving. First exploratory analyses reveal an influence of speed and deceleration rate on detection time. The influence of daytime and the onset of deceleration seems to be rather subordinate or not clear yet.

Keywords: implicit communication, communication pedestrian and automated car, recognition of vehicle movement.

1 INTRODUCTION

The transport systems of the future will be determined by an ever-increasing proportion of automated vehicles (AV). Current market predictions forecast 21 Million AV sales by 2035 (IHS Automotive, 2016). In addition to this promising outlook on the future of automated driving, there are still many challenges, like for example the regulation of autonomous behaviours in terms of legal issues (Gasser, 2016). A further challenge which AVs has to face is how to communicate with other road users, like pedestrians, where there is still comparatively little research (Pillai, 2017; Rasouli, Kotseruba & Tsotos, 2017). One approach to configure communication between pedestrians and AVs is to incorporate external interfaces, often in terms of visual communication via LED displays or projections (see for example Lagström & Malmsten Lundgren, 2015; Nilsson, Thill & Ziemke, 2015). In complex, busy traffic environment with sometimes bad weather or light conditions, it is questionable whether the comprehensibility of such external interfaces is ensured in any case (Pillai, 2017; Rasouli et al., 2017; Risto, Emmenegger, Vinkhuyzen, Cefkin & Hollan, 2017). In current traffic, the assessment of vehicle movement seems to be an implicit and functional strategy for cooperative communication among vehicles and pedestrians (Müller, Risto & Emmenegger, 2016; Pillai, 2017; Rasouli et al., 2017). Implicit communication is familiar to the involved interaction partners and also visible from different perspectives. This allows pedestrians to cross a road without having a direct communication with the driver, such as at night (Rothenbücher, Li, Sirkin, Mok & Wu, 2016). The observational findings of Rothenbücher et al. (2016) and Risto et al. (2017) suggest that different types of vehicle decelerations or accelerations in front of the pedestrian lead to behavioural adjustments, such as sidestepping of the pedestrian. Pillai (2017) conducted a virtual reality experiment to investigate several types of deceleration and pedestrian's feeling of interaction comfort. Most comfortable deceleration types where characterized by smooth speed reduction that starts rather further away from the pedestrian. Deceleration types with a mixture of deceleration and acceleration were assessed to be most uncomfortable. One question imposed at this point is, on which parameters do people determine vehicle movement at all, before a behaviour change or a comfort evaluation can take place? Beggiato, Witzlack, Springer and Krems (2017) published a video simulation study, where they investigated the effect of daytime and speed of the approaching car on participant's assessment of the latest moment for crossing the street comfortably. Indirectly it could be concluded, at which time the participants would expect a brake initiation of the vehicle. Results indicate, there is no "one-fits-all" solution for comfortable braking, but this study revealed the two important parameters vehicle speed and daytime. A study which specifically dealt with the identification of vehicle braking, examined the deceleration rate (5 m/s² vs. 3.5 m/s²) in addition to different vehicle speeds (50 km/h vs. 30 km/h) to have an impact on detection time (Petzoldt, Schleinitz & Banse, 2018). The authors found that participants had shorter detection time for lower speed and higher deceleration rate. The present study therefore focuses on the detection of vehicle movement. New here is the investigation of different parameters and their combinations in a common experimental setup. The aim was to investigate which parameters an parameter settings have an influence on the detection performance. In addition, the nature of the vehicle movement was investigated by including both deceleration, acceleration and constant driving in the experiment. We chose to include vehicle acceleration and constant driving to investigate every possible way of vehicle behaviour concerning speed. Further, we also addressed acceleration to explore, whether these type of movement could be useful as implicit communication signal.

2 METHOD

2.1 Participants

A total of 33 persons participated in the study. The sample consisted of 22 women and 11 men ranging from 18 to 47 years (*M* = 23 years, *SD* = 5.38) who were all students at Chemnitz University of Technology. Slightly less than half of the subjects had normal vision (45 %), the remainder used glasses or contact lenses to correct vision (55 %). Participants managed their daily routes, primarily on foot (76 %) or by public transport (45 %), especially in case of shorter distances between one and 20 kilometres (79 %).

2.2 Study Design

This experimental study was based on a video-simulation using a within-subject design. We varied the independent variables speed (20 km/h vs. 40 km/h) of the approaching vehicle. Furthermore, the independent variable acceleration had seven degrees which had positive, negative and neutral values (+/- 5, 3.4, 1.5 and 0 m/s²; based and extended from Petzoldt et al., 2018). We could simulate three types of motion by that, namely acceleration, deceleration and constant driving. The third independent variable was the onset of adjusted vehicle movement. Here, we implemented an early onset (between 3.5 and 4.5 s before reaching the target position) and a late onset (between 2 and 3 s before reaching the target position; both time gaps were based on findings by Beggiato et al., 2017). We preferred these onset time gaps over fixed points of onset, because we were able to reduce the subject's probability to guess the right answer. The target position was a yellow line on the street surface, which we used to calculate distances for the acceleration onset and profiling (Figure 1). This line was not visible to the participants during the simulation. As fourth independent variable, we used the daylight which was varied between in the morning, dusk and evening light condition. We measured the reaction time between onset of the acceleration or deceleration and detecting the movement of the vehicle as dependent measure. Furthermore, we recorded the answer of the participants which kind of movement they recognized. In total, there were 2x7x2x3 = 84 trials which were shown in a randomized order.

Figure 1 – Recording perspective and yellow line

2.3 Video Material and Simulation Software

The experiment included prerecorded real-world videos on a public parking area at Chemnitz University of Technology. All videos were recorded at exactly the same place and one day, between 11:13 AM and 19:25 PM. These two time stamps represent the daylight conditions in the morning and dusk. The daylight condition in the evening was generated by darkening the video at 19:25 PM using the software VirtualDub. The recording was done using a GoPro Hero 4 camera with Full HD resolution of 1920×1080 pixels and 120 frames per second. The camera was placed at a height of 1.60 m and 50 cm left of the roadside (Figure 1). This position was assumed to be similar to the perspective of a pedestrian intending to cross the street. The oncoming vehicle was a small passenger car (white smart electric drive), driven by an investigator at a constant speed of 20 km/h. To ensure precise vehicle speed in the videos, markers like the yellow line, were placed at the street surface. For the video recording session it was made sure that no other moving objects such as other vehicles or pedestrians passed the scene. The scenes were shot in calm weather, so no movement of the trees and plants in the video can cause irritation. Using the markers and the video editing software LabVIEW 2015, all videos were accelerated or decelerated to get an exact and constant speed, acceleration rate and acceleration onset depending on the experimental condition. Due to these precautionary measures, vehicle speed, acceleration rate and onset of accelerations could exactly be manipulated without artificial side-effects in the simulation software by regulating the playback speed of the videos. Using LabVIEW 2015, the videos, instructions and messages were presented and the detection time and responses of the subjects were recorded.

2.4 Procedure

Before the start of the simulation, all participants were informed about the scope and procedure of the study and anonymity was guaranteed. Thereafter, socio-demographic and pedestrian behaviour information were collected (based on Papadimitriou, Yannis & Gilou, 2009). The instruction was to press a defined key, when the participant noticed the kind of vehicle movement. They were instructed to press the key, when they were as sure as possible in their decision about the vehicle movement. Further, they were instructed not to press the key, when the vehicle is driving with constant speed. After pressing the key or watching the video to the end, they were asked to decide what kind of vehicle movement they recognized (Figure 2). After the instruction, two test trials were presented. Subsequently, the 84 experimental trials were presented in randomized order. After each trial, a dialog message with an OK Button was shown to give participants control over the start of the next trial whenever they were ready.

Figure 2 – Participant's view on video simulation and answer screen

3 RESULTS

As part of the data preparation, a subject was removed due to instructional adverse behavior. Only those data were included in the calculations for which both the vehicle movement was correctly detected and whose detection time was not prior to the initiation of the respective change in movement. Since there is no reaction time for the condition with constant speed, this condition was not included in the analyses.

3.1 Detection of Acceleration and Deceleration

In a first step, we analysed the proportion of false responses for both types of vehicle movement. A high amount of participants gave wrong answers in the acceleration condition (on average per trial, only 13 participants gave correct answers) in comparison to the deceleration condition (on average per trial, 27 participants gave correct answers). For that reason, all data regarding the acceleration condition were excluded from further analyses. But, a closer look at the deceleration condition also revealed problematic trials. Those trials were characterized by higher speed (40 km/h), a low deceleration rate (1.5 m/s²) and a late deceleration onset time (between 2 and 3 s). In that trial, only about 13 percent of participants gave the correct answer, independent from daytime. For that reason, we decided to describe our results in an explorative way first. Within the first steps of analyse, we focused on general tendencies among our parameter. Thus, we found almost no impact of daytime, which is presented as first result, followed by vehicle speed, onset of deceleration and deceleration rate.

3.2 Daytime

We averaged here the trials for each daytime condition separated by speed (Table 1) across all deceleration trials. When comparing the mean detection time, it becomes obvious that daytime seems to have probably not a big impact, but rather speed.

Table 1 – Mean detection times separated by daytime and speed (standard deviation enclosed in brackets)

	Morning	Dusk	Evening
20 km/h	1.59 s (0.43)	1.72 s (0.64)	1.63 s (0.57)
40 km/h	2.72 s (0.71)	2.65 s (0.86)	2.51 s (0.52)

3.3 Vehicle Speed

To analyse this parameter, we averaged across all deceleration trials representing the lower (20 km/h) and higher (40 km/h) speed condition. We found shorter reaction times for any trials with lower speed (*Mean* = 1.61 s, *SD* = 0.66) than for higher speed (*Mean* = 2.60 s, *SD* = 0.86). So, it seems as if participants were able to detect deceleration manoeuvres faster, when the car approached with lower speed.

3.4 Onset of Deceleration and Deceleration Rate

Here, we averaged the trials with late and early onset of deceleration with no regard to daytime, but separated by deceleration rate. Because of missing values for the higher speed condition, we only describe results referring to the lower speed condition (20 km/h). Table 2 lists the mean reaction times for deceleration rate in relation to onset of deceleration. Tendencies can be assumed for the impact of deceleration rate; the stronger the deceleration the shorter detection times can be found. The influence of the onset of deceleration seems to be not that stringent. Participants showed shorter reaction times when the vehicle started to decelerate further away from them (3.5-4.5 s), except for the medium deceleration rate.

Table 2 – Mean detection times separated by deceleration rate and onset of deceleration (standard deviation enclosed in brackets)

		Deceleration Rate		
		-1.5 m/s²	**-3.4 m/s²**	**-5 m/s²**
Onset of Deceleration	**2-3 s**	2.60 s (0.96)	1.37 s (0.45)	1.23 s (0.53)
	3.5-4.5 s	2.14 s (0.59)	1.39 s (0.41)	1.18 s (0.45)

4 DISCUSSION

The aim of the study was to identify parameters that describe the detection of vehicle movement and thus can be used as an implicit communication tool for pedestrians and automated vehicles. On the basis of the previous descriptive exploration of the data, it can be assumed that acceleration processes are recognized much worse than braking. The lack of acoustic cues (engine noise), which are primarily noticable when accelerating, might be an explanation here. Alternatively, a method effect could be conceivable, because in the accelerating conditions the absolute duration of the videos was shortened by speeding up the video, which could have been critical in particular for the late onset of acceleration. Further, the difference between the two onset ranges is only 0.5 sec. Thus it might be possible there was not enough contrast between the onset ranges to be perceived as distinct levels. We found tendencies, which confirm the results of Petzoldt et al. (2017), who also found shorter detection times for higher deceleration rates and lower speed. We could not assume daytime to have an unambiguous influence on detection time, contrary to the effects of Beggiato et al. (2017b). Onset of deceleration seems to be an influencing factor on detection time, but probably interacts with other aspects, like deceleration rate. It should be noted that deceleration is the more appropriate implicit communication solution compared to accelerations. This might be confounded by the two-stage response process we conducted. In further experiments, it could be helpful to use two buttons (one for detection of acceleration, one for detection of deceleration), then reaction time and choice can be measured simultaneously. Further analyses must address the characteristics of the individual parameters in order to derive substantiate information regarding algorithm development in AVs.

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REFERENCES

Beggiato, M., Witzlack, C., Springer, S., & Krems, J. (2017b). The Right Moment for Braking as Informal Communication Signal Between Automated Vehicles and Pedestrians in Crossing Situations. In *International Conference on Applied Human Factors and Ergonomics* (pp. 1072-1081). Springer, Cham.

Gasser, T. M. (2016). Fundamental and special legal questions for autonomous vehicles. In *Autonomous Driving* (pp. 523-551). Springer, Berlin, Heidelberg.

IHS Automotive. 2016. Autonomous vehicle sales forecast to reach 21 mil. globally in 2035. (Aug. 2016). Retrieved April 10, 2018 from https://www.ihs.com/country-industry-forecasting.html?ID=10659115737

Lagström, T., & Malmstem Lundgren, V. (2015). *Autonomous vehicles‘interaction with pedestrians. An investigation of pedestrian-driver communication and development of a vehicle eternal interface*. Master Thesis. Chalmers University of Technology. Gothenborg. Sweden.

Müller, L., Risto, M., & Emmenegger, C. (2016). The social behavior of autonomous vehicles. In Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing Adjunct - UbiComp ’16 (pp. 686–689). New York, NY, USA: ACM Press. DOI: 10.1145/2968219.2968561

Nilsson, M., Thill, S., & Ziemke, T. (2015). Action and intention recognition in human interaction with autonomous vehicles. In " *Experiencing Autonomous Vehicles: Crossing the Boundaries between a Drive and a Ride" workshop in conjunction with CHI2015*.

Papadimitriou, E., Yannis, G., & Golias, J. (2009). A critical assessment of pedestrian behaviour models. Transportation research part F: traffic psychology and behaviour, 12(3), 242-255.

Petzoldt, T., Schleinitz, K., & Banse, R. (2018). Potential safety effects of a frontal brake light for motor vehicles. *IET Intelligent Transport Systems*.

Pillai, A. (2017). *Virtual Reality based Study to Analyse Pedestrian Attitude towards Autonomous Vehicles*. Master thesis. Stockholm, Sweden: KTH Royal Institute of Technology.

Rasouli, A., Kotseruba, I., & Tsotsos, J. K. (2017, June). Agreeing to cross: How drivers and pedestrians communicate. In *Intelligent Vehicles Symposium (IV), 2017 IEEE* (pp. 264-269). IEEE.

Risto, M., Emmenegger, C., Vinkhuyzen, E., Cefkin, M., & Hollan, J. (2017). Human-Vehicle Interfaces: The Power of Vehicle Movement Gestures in Human Road User Coordination.

Rothenbücher, D., Li, J., Sirkin, D., Mok, B., & Ju, W. (2016, August). Ghost driver: A field study investigating the interaction between pedestrians and driverless vehicles. In *Robot and Human Interactive Communication (RO-MAN), 2016 25th IEEE International Symposium on* (pp. 795-802). IEEE.