Drive safely and comfortably – Gap Acceptance as a Basis for a user-centred Design of Driving Styles in Automated Vehicles

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ABSTRACT

To ensure safety and support drivers' comfort and acceptance, automated vehicles (AVs) need to communicate with other traffic participants. Hence, a user-centred implementation of manual driving behaviour is considered as beneficial in AVs. Currently, manual driving is often coordinated by implicit communication. Thus, specific parameters regarding implicit communication and potential influencing factors need to be further investigated for the implementation in AVs. The present video simulation study investigated the effects of participants' age, vehicle types and vehicles' speed on participants' gap acceptance (GA). Pre-recorded real-world video material displayed a left-turn parking scenario from the drivers' perspective including an overlap of the oncoming vehicles' trajectory. Four different vehicle types (truck, passenger car, scooter, bicycle) approaching with four different speeds respectively (10 - 25 km/h) were presented to N = 42 participants (including two age groups: < 30 years vs. > 45 years). The results showed that time gaps increased by vehicles' size, with smallest gaps for the bicycle and largest for the truck. Despite a similar object size, the selected gaps for the scooter and the bicycle also differed. Moreover, lower time gaps were selected for higher speed levels (i.e., riskier time gaps). Older participants preferred more conservative gaps compared to younger participants (i.e., larger time gaps). Besides safety issues, AVs should particularly consider speed related time gaps to meet human expectations and enhance comfort and acceptance. Age related time gaps could serve as a basis for different automated driving style profiles, e.g., defensive vs. dynamic driving style.

Keywords: automated vehicles, gap acceptance, driving styles, vehicle types, vehicles' speed, age effects.

BACKGROUND

Automated driving relates to the potentials of increased road safety and traffic efficiency; moreover, it offers the capability of enhanced driving comfort (ERTRAC, 2017). However, to benefit from the automation the introduced systems need to be applied by the driver. To enhance the acceptance and thus the usage of vehicles' automation, the human-machine interaction should be considered as a key issue (i.e., a user-centred design). Therefore, existing interaction patterns and forms of communication provide a basis to identify relevant communication parameters between different traffic participants. The identified parameters could prospectively be implemented in automated vehicles (AVs) to provide a safe and natural (i.e., subjectively familiar) driving style that is accepted by the driver (Elbanhawi et al., 2015).

Besides ensuring road safety and traffic flow, communication in transport supports a comfortable interaction between different traffic participants. In manual driving, traffic participants interact via explicit (e.g., braking lights) and implicit communication signals (e.g., trajectory). Implicit communication signals are context-dependent and therefore difficult to interpret (Hölzel, 2008). However, in shared spaces and parking areas implicit communication is particularly relevant due to diverse traffic participants and resulting various speed levels (i.e., vehicles and vulnerable road users) as well as ambiguous encounters (Hamilton-Baillie, 2008). Gap acceptance (GA) could serve as a signal to initiate an implicit communication process. GA could be described as the minimum acceptable time gap to other traffic participants were drivers would still feel safe and comfortable (Yan et al., 2007). According to Summala's Safety Margin Model (2007), safety margins (including GA) are described as an inter-individual varying threshold of driving parameters. Hence, individual safety margins finally result in drivers' comfort (i.e., operating *within* individual safety margins) or discomfort (i.e., operating *beyond* individual safety margins; Summala, 2007). To provide a positive experience with AVs and thus support drivers' comfort and the acceptance of AVs, individual driving parameters (e.g., GA) should be considered (Elbanhawi et al., 2015). Previous research investigated participants' GA and various affecting parameters, for instance a) different vehicle types (e.g., Robbins et al., 2018), b) different speed levels of the oncoming traffic participants (e.g., Schleinitz et al., 2020) and c) the influence of drivers' age on GA (e.g., Beggiato et al., 2017). According to the size-arrival effect (DeLucia, 2013), larger objects are expected to be closer and therefore arriving earlier at an observer's position than smaller objects. Consequently, the minimal accepted time gaps for bigger objects are larger (DeLucia, 2013) to continuously operate within the individual safety margins (Summala, 2007). Several studies that investigated the size-arrival effect in transport, considering the effect of vehicles' size on GA, could show decreased accepted time gaps for smaller approaching vehicles (i.e., riskier time gaps) compared to larger vehicles (Robbins et al., 2018). Regarding the speed level of the approaching vehicle, former studies found smaller accepted time gaps at higher speeds, resulting in riskier behavior (e.g., Schleinitz et al., 2020; Yan et al., 2007). The stable effect could be shown from different perspectives, i.e., the pedestrians' perspective (Beggiato et al., 2017) or the drivers' perspective (e.g., Schleinitz et al., 2020). In a driving simulator study by Yan et al. (2007), participants were instructed to perform left-turn actions with approaching traffic that arrived at two different speed levels. The participants accepted significantly smaller gaps during the higher speed condition compared to the lower speed condition (Yan et al., 2007). Furthermore, previous research (e.g., Beggiato et al., 2017) could show a stable effect of younger participants tending to accept smaller gaps (i.e., riskier time gaps) than older participants. The differences in accepted time gaps between the age groups might be explained by both compensatory behavior due to age-related declines; and the general tendency of incremental conservative behavior with increased age (Beggiato et al., 2017).

OBJECTIVES

To investigate and quantify precise parameters of comfortable communication in transport, the present study examined drivers' GA as a form of implicit communication. The identified parameters could prospectively be implemented in AVs. In contrast to previous studies, which mainly focused on safety issues (e.g., Schleinitz et al., 2020), the current study transferred the paradigm of GA to the issues of driving comfort and automated driving. Since implicit communication is particularly relevant in shared spaces (Hamilton-Baillie, 2008) lower speed levels (up to 25 km/h) were investigated in the current study. Moreover, the applied speed levels were analyzed in higher detail (10-25 km/h in steps of 5 km/h) to be prospectively implemented as a function in AVs. Vehicle types and participants' age groups were included in the experimental design to analyze the respective influence on the function. Therefore, the present study included different a) vehicle types and b) speed levels of the approaching traffic as well as c) two age groups of participants.

METHOD

2.1 Research design

In the study, a 4x4x2 mixed design was applied. The within-subject factors included the type of the oncoming vehicle (truck, passenger car, scooter, bicycle) and the speed levels of the approaching vehicle (10, 15, 20, 25 km/h). Participants' age served as the between-subject factor for two sampled groups a) < 30 years and b) > 45 years. Each condition was presented in a randomized order and was repeated three times in order to avoid missing values, resulting in a total of 48 trials. Participants indicated the last accepted time gap for a left-turn parking scenario by pressing the enter key.

2.2 Material

2.2.1 Video material

The study included pre-recorded real-world video material from the drivers' perspective. The material was recorded by a GARMIN VIRB Ultra 30 in 1920x1080 pixels on Saturday, 30th March 2019 on a parking area of Chemnitz University of Technology. The video material considered an onward left-turn parking scenario resulting in an overlap of the ego-vehicles' and the oncoming vehicles trajectory. To identify size-related differences in participants' accepted time gaps, the type of the approaching vehicle was varied (truck, passenger car, scooter, bicycle). All four oncoming vehicles were driven by the same researcher at a constant speed of about 15 km/h. Recordings showing other moving objects expect the investigated oncoming vehicles (e.g., pedestrians or animals) were excluded as further study material. Therefore, the speed of the oncoming vehicles could be manipulated without any artificial side effects by accelerating or decelerating the videos in a simulation environment to investigate the influence of different speed levels on GA.

2.2.2 Simulation software and apparatus

The video material was presented on a 17" Full HD screen. A simulation environment was programmed in LabVIEW 2015 (National Instruments, 2015) to provide full experimental control during the study including instructions, the randomized order of trials and exact timings, and logging files including response times. A previously generated configuration file for each participant provided specific parameters considering the video material (e.g., randomization of trails).

2.3 Instruction and procedure

At the beginning, participants were welcomed and informed about the scope of the study and informed consent was obtained. The participants required a specific age (i.e., < 30 years or > 45 years) and had to hold a driver's license. Due to a standardized procedure, written instructions were provided by the simulation software. Participants were instructed to press the enter key at the last moment when they would comfortably enter the parking lot performing a left-turn action in front of the oncoming vehicle. To accustom the participants with the simulation environment, five test trails were conducted at the beginning of the study. Moreover, participants always had the opportunity to ask questions if further information was required. Then, 32 experimental trails were conducted in a randomized order in the simulation environment. Afterwards, participants filled in a sociodemographic questionnaire followed by another 16 experimental trails. The entire study lasted about one hour. Participants received 10€ for their attendance.

2.4 Participants

A total of *N* = 42 participants (22 women, 20 men) with a mean age of *M* = 39 years (*SD* = 17.43) and an average annual mileage of *M* = 11 538.10 km (*SD* = 11 629.78) were included in the study. Both age and gender were equally distributed within the two age groups a) < 30 years (*n* = 22, *M* = 24 years, *SD* = 3.11, 12 women) and b) > 45 years (*n* = 20, *M* = 56 years, *SD* = 7.74, 10 women).

RESULTS

Participants' accepted time gaps (in seconds) were examined using mixed ANOVAs. The assumption of sphericity had been violated for the factor vehicles' speed; therefore, Greenhouse-Geisser-corrected degrees of freedom are reported. The accepted time gaps dependent on vehicle type and speed levels as well as age groups are displayed in Figure 1.

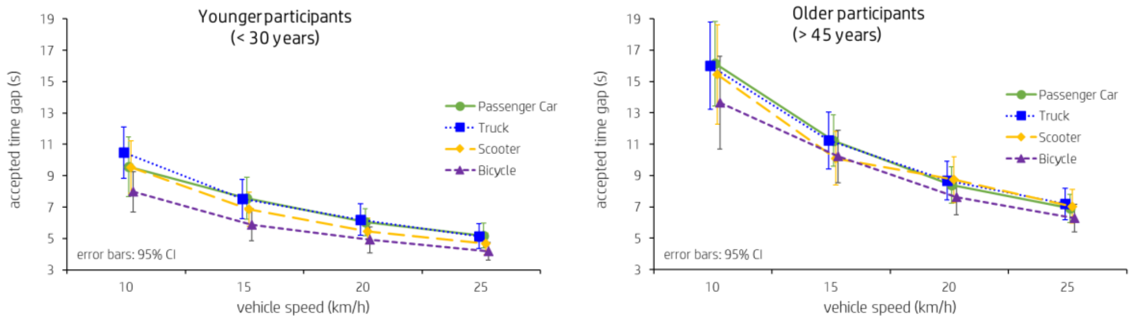

Figure 1 – Accepted time gaps by younger (left) and older (right) participants dependent on vehicle type and vehicles' speed

Generally, both younger and older participants' selected the longest time gaps for the truck (*M* = 8.97, *SD* = 3.39) compared to the passenger car (*M* = 8.79, *SD* = 3.52) and the scooter (*M* = 8.39, *SD* = 3.59). The smallest time gaps were accepted for the bicycle (*M* = 7.50, *SD* = 3.28). Results for the mixed ANOVA revealed a statistical significant main effect for the investigated vehicle types ($F(32,123) = 36.43$, $p < .001$, $\eta^2 = 0.47$). Bonferroni-corrected pairwise comparisons showed a significant difference between the truck and the scooter ($p < .01$). Moreover, the accepted time gaps for the bicycle differed significantly from all the other examined vehicles ($p < .01$, respectively). Furthermore, participants accepted smaller time gaps during higher speed levels of the oncoming vehicles compared to lower speed levels ($M_{10km/h} = 12.21$, $SD_{10km/h} = 5.62$; $M_{15km/h} = 8.74$, $SD_{15km/h} = 3.55$; $M_{20km/h} = 6.94$, $SD_{20km/h} = 2.0$; $M_{25km/h} = 5.77$, $SD_{25km/h} = 2.01$). A main effect for vehicles' speed was also identified by the conducted mixed ANOVA ($F(1.09,44.66) = 110.89$, $p < .001$, $\eta^2 = 0.73$). Significant differences between each speed level were shown by Bonferroni-corrected pairwise comparisons ($p < .001$, respectively). In addition, a significant interaction for vehicle type and vehicles' speed level was found ($F(5.25,215.34) = 3.82$ $p = .002$, $\eta^2 = 0.09$). Overall, younger participants accepted significantly smaller gaps ($M = 6.70$, $SD = 2.25$) than older participants did ($M = 10.30$, $SD = 3.48$; $F(1,40) = 18.37$, $p < .001$, $\eta^2 = 0.32$). There was also a significant interaction between vehicles' speed and participants' age ($F(1.13,45.29) = 18.18$, $p < .001$, $\eta^2 = 0.31$). No interaction was found for vehicle type and participants' age ($F(3,120) = 1.02$, $p = .386$, $\eta^2 = 0.03$).

DISCUSSION AND IMPACT

The scope of the study was to investigate participants' accepted time gaps during a left-turn parking scenario in a shared space setting with particular attention to drivers' comfort. Therefore, different vehicle types and various speed levels were considered. Participants' accepted time gaps increased as vehicles' size increased as shown in previous studies (Robbins et al., 2018). However, the current results also depicted a statistically significant difference between the accepted time gaps for the scooter and the bicycle despite a similar object size. Participants accepted significantly smaller time gaps when interacting with an oncoming bicycle in contrast to an approaching scooter. The results are in line with Schleinitz et al. (2020) who also reported smaller accepted time gaps for bicycles compared to a scooter. Therefore, the authors assumed additional factors, besides vehicles' size, influencing drivers' accepted time gaps (e.g., the anticipated threat of the vehicle in case of an accident; Schleinitz et al., 2020). There was a clear effect of vehicles' speed on GA, in spite of the lower speed levels that were investigated due to the shared space setting. The results are also in line with previous studies that considered GA during higher speed levels (Yan et al., 2007). In detail, participants accepted smaller time gaps during higher speeds of the approaching vehicles, thus resulting in riskier decisions. Moreover, it should be highlighted that a non-linear relationship between vehicles' speed and accepted time gaps could be shown. The results also indicated an effect for participants' age. Despite the relatively low speed levels, older participants selected extended time gaps in front of the oncoming vehicles in contrast to younger participants. The increased GA by older drivers indicated a more conservative driving behavior during parking actions as also shown by Beggiato et al. (2017) from a pedestrians' perspective.

To conclude, the current study emphasized that left-turn actions should be initiated according to oncoming vehicles' speed to provide a familiar driving style of AVs. Due to a difference in accepted time gaps, drivers' age should be considered in automated driving styles. Therefore, it seems recommendable to provide selectable driving style profiles in AVs (e.g., conservative vs. dynamic driving style).

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