Pedestrian Attitudes to Shared-Space Interactions with Autonomous Vehicles – A Virtual Reality study

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Abstract. The automotive industry is steadily moving towards fully autonomous vehicles, and it is becoming important to understand attitudes towards them. This study is an aspect of the www.ukautodrive.com project with Jaguar-Land Rover, RDM Automotive, and The University of Warwick's Warwick Manufacturing Group (WMG). Uniquely, we used a prototype fully autonomous vehicle, and were interested in pedestrian attitudes towards this vehicle manoeuvring in close proximity. Using virtual reality (VR) cameras, we filmed 18 manoeuvring scenarios and presented them using VR equipment. Participants answered four short rating-scale questions after each exposure, and self-reported less trust and safety when the vehicle was faster and closer. This work has implications both for real-world autonomous vehicles, and for further use of VR technology. That the VR environments seemed sufficiently convincing to evoke consistent responses from volunteers represents a considerable opportunity across a variety of experimental domains, and can improve further with advances in this technology.

Keywords: Trust · Safety · Autonomous Vehicles · Human Factors ·

1 Introduction

There is a growing body of research among the Automotive User Interface community to understand aspects of user interaction with autonomous vehicles [1]. A number of challenges and questions are frequently discussed but still need to be addressed, including those surrounding the ergonomics of users' interaction with a vehicle, situational awareness, acceptance, trust and ethical issues [2]. Early tests have been performed with autonomous vehicles (AVs) to transport passengers at low speed and short distances [3],[4], and on how these vehicle should communicate intention to pedestrians and cyclists via external human-machine interaction [5]. Given the potential physical risks surrounding automotive research with human participants (i.e. experimental vehicles can suffer various malfunctions which could be physically unsafe), safer methods to study the interaction between people and vehicles are of interest [6],[7]. Virtual Reality (VR) is an immersive technology where users experience simulated environments through visual and auditory inputs. The immersion is created via a head-mounted display which tracks the user's head orientation to update a rendered viewpoint within a video-recorded or simulated environment with stereo sound to improve sensory immersion. VR environments are often used to test aspects of the user interaction with technology in a variety of scenarios, especially in situations which could be physically dangerous [8].

VR can induce a stronger sense of "presence" compared to traditional non-immersive virtual environments (VEs) such as a standard computer with a monitor screen. Presence is defined as the subjective experience of being immersed in a virtual space and environs [9],[10]. VR simulations can better control most variables and ensure that participants have an objectively similar experience, which is typically harder to do in real-world conditions. VR can also simulate situations which could be too hazardous or infeasible to implement in real life. Software-rendered 3D VEs have also been used to understand pedestrian behaviours with autonomous vehicles; e.g. investigating how people negotiate the space with autonomous cars during road crossings and the feedback given by an autonomous vehicle when it indicated that it was about to stop or to move off [11]. Another study using a VR environment had vehicles driving past a pedestrian crossing and evaluated the impact of vehicle's external lights on the user experience [12], while VR has also been used to simulate AVs with 'eyes' on the headlights that 'see' pedestrians and indicate intention to stop [13]. Very few studies, however, investigate the perceptions of acceptance or trust when people have to share the same areas as vehicles [5], and it is unclear the distances and speeds at which autonomous vehicles should drive in these scenarios in order to improve perceptions of safety. The present study examined if the speed of an autonomous vehicle and its lateral distance from road users affected acceptance and trust, especially in a semi-pedestrianized area.

Autonomous vehicles are characterized according to six increasing levels of automation from level 0 to 5 [14], with level 5 vehicles being fully self-driving and self-navigating across nearly all potential driving situations. However, increases in public acceptance of AVs is hindered by media coverage of incidents or even fatalities which involve AVs, which are often caused by a mixture of misuse, human error, and imperfect systems [15],[16]. Over-trust in AVs could result in higher chances of accidents as any AVs with automation up to level 3 require the driver to intervene and regain control of the vehicle when necessary [18]. Some proportion of accidents involving AVs are inevitable, caused by imperfect automated systems which cannot infallibly react appropriately to e.g. poor weather or visibility conditions, as well as in scenarios where the interaction between the AV and other road users make predictive calculations prone to inaccuracy [19]. There is also evidence [20] that peoples' acceptance and experience of AVs decreases as the level of automation increases. The reluctance in acceptance and trust in AVs is perhaps mediated by the public knowledge that AVs are still in development and there is still a long way to go until we reach a widespread adoption of level 4 or 5 AVs.

2 Methods

2.1 Participants

13 participants (4 females) were recruited for this study, aged between 21 to 58 (M =36.69, SD =12.3). Participants were recruited through posters placed on common areas within the International Digital Lab building, University of Warwick. Participation was entirely voluntary, and no financial incentives were given. Participants required only normal or corrected-to-normal vision to participate.

2.2 Design

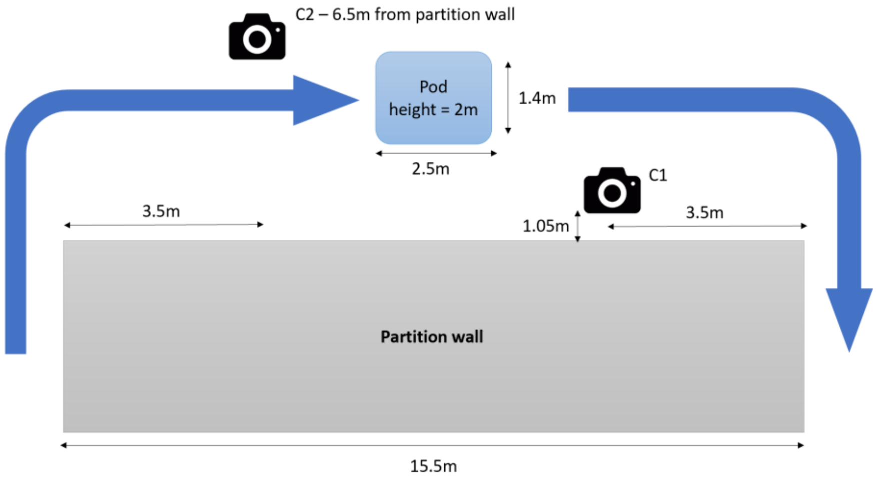

Fig. 1.

This study was a within-subjects multifactorial design. Three independent variables included camera positions (C1, C2), AV distance from camera positions (1m, 2m, 3m), and AV speeds (1.75m/s, 2.25m/s, 3m/s). All 18 AV passing scenarios were recorded using a Kodak PixPro 360 camera positioned 1.48m off the ground using a tripod.We used an electric LSATS (Low-speed autonomous transport system) PodZero AV with dimensions of 1.4m(w) x 2.5m(l) x 2m(h); images of the pod can be found at <http://rdmgroup.co.uk/>. Each scenario featured the AV travelling around a corner, driving past the camera then turning a second corner, out of the camera's field of vision. The 18 VR videos were 13-20 seconds in length and presented in a randomised order, and edited such that the starting viewpoint was aimed towards the corner where the pod would emerge. Participants watched the videos using an Oculus Rift VR system connected to an Alienware 17 R5 laptop.

Questionnaires were administered using Google Forms. After each interaction, participants were asked to rank their experience using four questions on a 7-point Likert-type scale:

1. What do you think about the speed of the vehicle? (1 Unsafe speed > Safe speed 7)
2. What do you think about the distance between you and the vehicle? (Unsafe distance > Safe distance)
3. What is your general feeling of safety at this speed and distance? (Unsafe > Safe)
4. What is your general feeling of trust in the vehicle at this speed and distance? (Distrust > Trust)

The Simulator Sickness Questionnaire (SSQ) [21] was used to monitor if participants experienced any cybersickness effects during the VR simulations. Cybersickness refers to a condition which is specifically induced by exposure to VR environments, whereas simulator sickness is used in the context of flight, driving, or other training simulators. The SSQ contains 27 symptoms on the axes of nausea, oculomotor discomfort and disorientation, each rated on a nominal scale of 'None', 'Slight', 'Moderate', and 'Severe' to denote the severity of the symptom experienced.

2.3 Procedure

The scenarios were briefly explained to participants, and informed consent was obtained after questions were addressed. Participants were asked to complete the pre-simulation SSQ. A still image of the simulation was presented from the perspective of the specific camera position of their first allocated condition and participants were given a few minutes to familiarize themselves with the headset. They were reminded that they could adjust the headset for comfort using straps on the sides of the headset, and to check that they could see objects in the simulation reasonably clearly. Then, each of the 18 simulations were presented to the participant, in a randomized order and participants responded to the 4-item questionnaire. When the participants completed all 18 simulations and subsequent questionnaires, they completed a post-simulation SSQ. Afterwards, semi-structured interview was conducted, but this data will be presented elsewhere and is not analysed as part of this study. Finally, the participants were debriefed and any questions addressed. The duration of the experiment was around 30-35 minutes per participant.

3 Results

3.1 Cybersickness (SSQ)

No participants reported any noteworthy discomfort or sensations associated with simulator sickness at any point in the study. Individual total scores ranged from zero to 76.32 points on the scale, where the maximum achievable score is at 2437.9. Although SSQ mean scores rose across all three intervals where it was measured (pre-test; =7.48, mid-test=7.192, and post-test=9.206), there were no significant differences in SSQ Total score ($F(2,24)=0.329$, p=N.S.), nor any of the sub-scales for Nausea ($F(2,24) = 0.618$, p=N.S.; Occulomotor disturbances ($F(2,24)=0.625$, p=N.S.), or Disorientation ($F(2,24) = 0.178$, p=N.S.). No participant reported any subjective or anecdotal discomfort.

3.2 Safety Questionnaire

Rating responses to each question in turn after each passing scenario were analysed via repeated-measures 4-way ANOVAs using IBM SPSS Statistics 24. The ANOVA comprised Camera position (2 positions) x Distance (1m, 2m, 3m) x Speed (1.75m/sec, 2.25m/sec and 3m/sec) x 3 groups – “Prior experience with VR” (4 individuals), “Prior experience with LSATS” (4 individuals) and “Have owned a vehicle with autonomous features” (3 individuals) for a 2x3x3x3 design. All pairwise comparisons were conducted using SPSS’s Least Significant Difference (LSD) method.

Only two tests of a single between-subjects factor (“Have owned a vehicle with autonomous features”) produced significant results, (for Q1, $F(1,9)=5.493$, $p<0.047$, and for Q4, $F(1,8)=5.603$, $p<0.045$), but subsequent post-hoc tests produced no further discrimination in scores.

The pod’s passing distance exerted a main effect across all 4 questions - on pod speed and safety ($F(2,16) = 10.175$, $p<0.001$), on pod passing distance ($F(2,16)= 25.956$, $p<0.0001$), on general feelings of safety in the scenario ($F(2,16)=26.7$, $p<0.0001$), and on participants’ self-reported trust in the vehicle ($F(2,16) = 23.668$, $p<0.0001$). In all cases, as pod passing distance increased, participants reported significant increases in self-reported safety.

Table 1. Summary of significant main effects

Question	Distance main effect	Speed main effect
Q1 - Pod speed and safety	$F(2,16) = 10.175$, $p<0.001$	$F(2,16) = 15.047$, $p<0.0001$
Q2 - Distance from participant	$F(2,16)= 25.956$, $p<0.0001$	$F(2,16) = 1.566$, p=N.S.
Q3 – General feeling of safety	$F(2,16)= 26.7$, $p<0.0001$	$F(2,16) = 7.514$, $p<0.005$
Q4 – General trust in vehicle	$F(2,16) = 23.668$, $p<0.0001$	$F(2,16) = 25.948$, $p<0.0001$

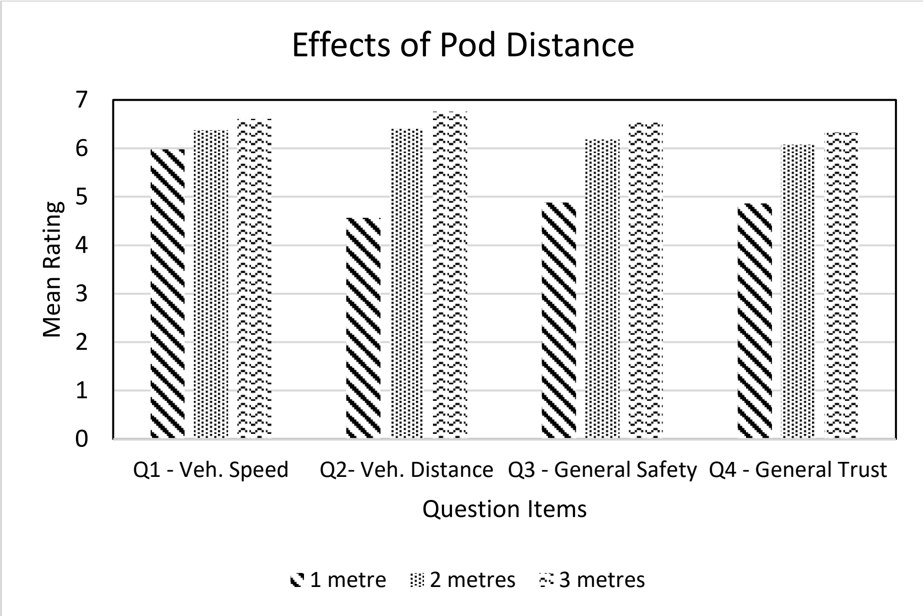

Fig. 2 – Mean ratings for pod distance effects per question. In every case, as pod passing distance increased, participants self-reported greater safety and trust, with LSD significance levels indicating all variables as significantly different from each other as stance increased (Table 2).

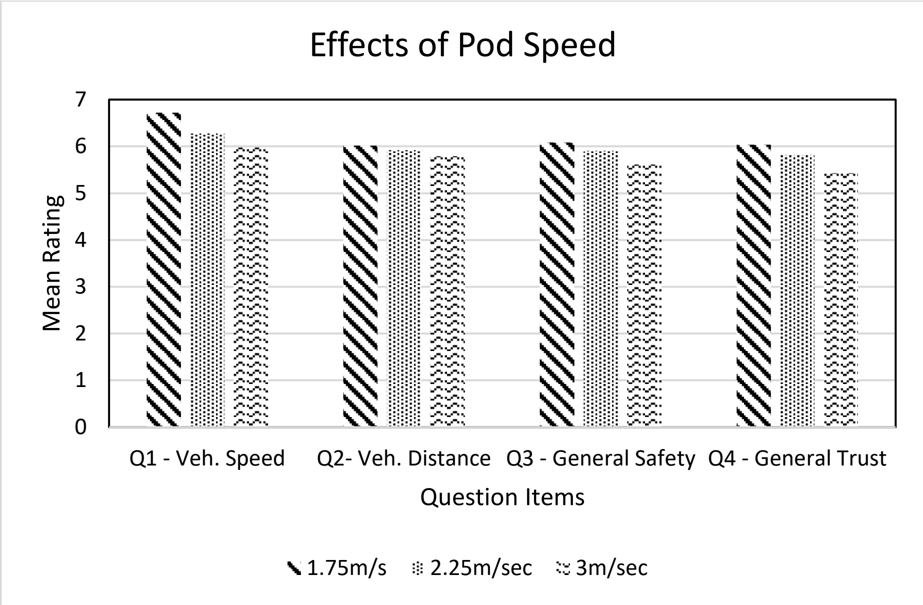

Fig. 3 – Mean ratings for pod speed effects. For Q1, Q3 and Q4, increasing speed showed increasingly lowered self-reported safety and trust in the vehicle. No effects were recorded Q2. For Q3 (general safety) participants' self-reported safety did not distinguish between speeds of 1.75m/sec and 2.25m/sec where they did in Q1 and Q4. Participants felt least safe when the pod was at 3m/sec.

Table 2. Summary of significant post-hoc contrasts (LSD pairwise)

Q1	Distance	Mean	Q1	Speed	Mean
	1m	5.983		1.75m/sec	6.719
	2m	6.378		2.25m/sec	6.278
	3m	6.611		3m/sec	5.975

Q2	Distance	Mean	Q2	Speed	Mean
	1m	4.564		1.75m/sec	6.019
	2m	6.403		2.25m/sec	5.922
	3m	6.764		3m/sec	5.789

Q3	Distance	Mean	Q3	Speed	Mean
	1m	4.886		1.75m/sec	6.083
	2m	6.183		2.25m/sec	5.903
	3m	6.531		3m/sec	5.614

Q4	Distance	Mean	Q4	Speed	Mean
	1m	4.867		1.75m/sec	6.039
	2m	6.083		2.25m/sec	5.819
	3m	6.333		3m/sec	5.425

(Mean values **with no significant post-hoc contrasts** of at least $p<0.05$ are *underlined*, after the method described in [22])

4 Discussion

Humans can estimate speeds and distances from visual observation, variously referred to as *tau* [23], relying largely on physiological retinal effects, or the newer *time-to-contact* concept (e.g. [24]) incorporating cognitive as well as biological phenomena. These mental faculties operate as there is an obvious survival value in knowing whether a moving object in the world (e.g. a vehicle) poses any physical relevance to one's person. Pedestrians have also been shown to simultaneously underestimate approaching vehicles' speeds and stopping distances [25]; a potentially hazardous combination. Similarly, it has been found that pedestrians base their road-crossing decisions "mainly...on the distance between them and the oncoming vehicle", as well as the perceived time-to-contact which can be "easily misjudged" [26], perhaps due to underestimations of vehicle speed. In brief, pedestrian estimations of the risk posed by oncoming vehicles are not readily modelled with great accuracy, can be highly subjective, and can be influenced by a host of variables including their age, estimations of their own speed of mobility, cognitive function, choice reaction time and more [27].

With these phenomena in mind, it is relatively unsurprising that participants generated self-reports in line with logical expectations and established theory, although importantly this also indicates that the virtual experience we presented was naturalistic and convincing. Pod passing distance alone exerted a consistent effect among participants; when the pod was relatively further away (3m), participants reported they felt safer and more trusting of the pod than when it passed by at any speed. Main effects of pod speed were nuanced. Consistent with the main effects of pod passing distance, participants seemed to focus more on *the distance between the pod and themselves than their estimation of the pod's speed*. When asked specifically about their safety due to pod passing distances (Q2), there were no main effects of speed. Participants reported feeling least safe when the pod passed at 3m/sec, and did not feel more or less safe at the pod's two other passing speeds. Participants also self-reported significantly less general trust in the AV as its passing speed increased. Although our camera positions altered participants' visual perception of the vehicle - position C1 gave participants a slightly longer exposure time to view the pod as it passed, while position C2 gave a view of the pod as it turned the corner before proceeding along the straight - neither position exerted any effects on participant self-reports. In summary, when the pod was closer to the camera (down to 1m separation) and travelling faster (up to 3m/sec, or approximately 6pmh), participants reported feeling less safe and less trusting of the pod. This is noteworthy given that the pod is capable of travelling more than twice as fast, around 15mph. It seems clear that during the introductory phases of autonomous transport vehicles in a locale, autonomous vehicles should be *segregated from pedestrians such that they are clearly not a potential collision hazard*, perhaps avoiding shared spaces entirely until bystanders become accustomed to them. Our volunteers clearly did not feel completely safe when in simulated proximity to the pod, although perhaps some of this insecurity is explained by a natural caution around vehicles arising from decades of exposure to road-traffic and pedestrian safety information.

The absence of any noteworthy cybersickness is a positive sign for continued use of VR as a stimulus presentation method. Although the scenarios themselves were brief, the experiment in total lasted approximately 30 minutes, yet participants self-reported little in the way of motion- or simulator-related sickness. This is likely due to our use of a static recording location – although participants could turn their head to follow the path of the AV, they could not "move" within the environment, similar to a pedestrian standing at a fixed location at a roadside. In contrast, using a fully rendered virtual environment simulating road-crossing behaviours, participant drop-outs of approximately 15% have been reported [6], the majority of which occurred within minutes of the study commencing. Our results were consistent with using a randomised presentation methodology and a relatively small sample size, indicating that contemporary, mainstream VR equipment has reached a stage where it is sufficiently convincing to the (mostly visual) senses to serve as a research tool where real-world, *in vivo* experimentation would be problematic or impossible. This is additionally interesting given that the scenarios we presented to participants were non-interactive video clips, where participants literally viewed events "from the sidelines". Regarding our methodology, relatively inexpensive commercially available VR technology appears to have reached a level of fidelity where convincing sensory experiences (supported by statistical evidence) can apparently evoke genuine feelings and attitudes in participants in the absence of physical risk, opening up whole new avenues of research possibilities for vehicular and other research.

This study was part of the UK Autodrive project, a flagship, multi-partner project, focusing on the development of the Human Machine Interface (HMI) strategies and performing real-world trials of these technologies in low-speed AVs (http://www.ukautodrive.com).

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