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Interaction between pedestrians and automated vehicles: A Wizard of Oz experiment

Ana Rodríguez Palmeiro [a,*], Sander van der Kint [b], Luuk Vissers [b], Haneen Farah [a], Joost C.F. de Winter [c], Marjan Hagenzieker [a,b]

[a] Department of Transport and Planning, Delft University of Technology, Stevinweg 1, 2628 CN Delft, The Netherlands
[b] SWOV Institute for Road Safety Research, Bezuidenhoutseweg 62, 2594 AW Den Haag, The Netherlands
[c] Department BioMechanical Engineering, Delft University of Technology, Mekelweg 2, 2628 CD Delft, The Netherlands

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A B S T R A C T

Automated vehicles (AVs) will be introduced on public roads in the future, meaning that traditional vehicles and AVs will be sharing the urban space. There is currently little knowledge about the interaction between pedestrians and AVs from the point of view of the pedestrian in a real-life environment. Pedestrians may not know with which type of vehicle they are interacting, potentially leading to stress and altered crossing decisions. For example, pedestrians may show elevated stress and conservative crossing behavior when the AV driver does not make eye contact and performs a non-driving task instead. It is also possible that pedestrians assume that an AV would always yield (leading to short critical gaps). This study aimed to determine pedestrians' crossing decisions when interacting with an AV as compared to when interacting with a traditional vehicle. We performed a study on a closed road section where participants ($N = 24$) encountered a Wizard of Oz AV and a traditional vehicle in a within-subject design. In the Wizard of Oz setup, a fake 'driver' sat on the driver seat while the vehicle was driven by the passenger by means of a joystick. Twenty scenarios were studied regarding vehicle conditions (traditional vehicle, 'driver' reading a newspaper, inattentive driver in a vehicle with "self-driving" sign on the roof, inattentive driver in a vehicle with "self-driving" signs on the hood and door, attentive driver), vehicle behavior (stopping vs. not stopping), and approach direction (left vs. right). Participants experienced each scenario once, in a randomized order. This allowed assessing the behavior of participants when interacting with AVs for the first time (no previous training or experience). Post-experiment interviews showed that about half of the participants thought that the vehicle was (sometimes) driven automatically. Measurements of the participants' critical gap (i.e., the gap below which the participant will not attempt to begin crossing the street) and self-reported level of stress showed no statistically significant differences between the vehicle conditions. However, results from a post-experiment questionnaire indicated that most participants did perceive differences in vehicle appearance, and reported to have been influenced by these features. Future research could adopt more fine-grained behavioral measures, such as eye tracking, to determine how pedestrians react to AVs. Furthermore, we recommend examining the effectiveness of dynamic AV-to-pedestrian communication, such as artificial lights and gestures.

* Corresponding author.
E-mail addresses: a.rodriguezpalmeiro-1@tudelft.nl (A. Rodríguez Palmeiro), sander.van.der.kint@swov.nl (S. van der Kint), luuk.vissers@swov.nl (L. Vissers), h.farah@tudelft.nl (H. Farah), j.c.f.dewinter@tudelft.nl (J.C.F. de Winter), m.p.hagenzieker@tudelft.nl (M. Hagenzieker).

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1. Introduction

1.1. Mixed traffic of pedestrians and automated vehicles

In Europe, about 26% of road fatalities concern pedestrians (World Health Organization, 2015). Most of these fatalities occur while pedestrians attempt to cross the road in an urban environment (e.g., European Commission, 2016; SWOV, 2010).

Automated vehicles (AVs) may be expected to reduce these accident rates by replacing error-prone drivers with reliable computers. However, in the coming decades, there will be a situation of mixed traffic with both conventional vehicles and AVs driving on the road, giving rise to uncertainty about safety (Sivak & Schoettle, 2015). Unless fully segregated lanes are created, AVs will also be sharing the roads with vulnerable road users such as pedestrians and cyclists. Before AVs are deployed in traffic, pedestrian safety should be assessed and guaranteed.

Currently, many researchers are concerned with the development of computer algorithms that enable the detection of pedestrians using cameras onboard the AV (Ohn-Bar & Trivedi, 2016). Furthermore, ample research is available on how drivers inside the AV take control, for example when a pedestrian enters the road or when another type of impending hazard occurs (e.g., De Winter, Stanton, Price, & Mistry, 2016; Gold, Damböck, Lorenz, & Bengler, 2013). However, research that is focused on the pedestrians themselves is crucial as well, because pedestrians may alter their behavior in response to AVs.

1.2. Interaction challenges between pedestrians and automated vehicles

A model of situation awareness in dynamic decision making developed by Endsley (1995) can be used to reflect on the factors of relevance during an encounter between pedestrians and AVs (Fig. 1).

As seen in Fig. 1, pedestrians' crossing decisions and crossing behavior depend on situation awareness. More specifically, pedestrians predict the behavior of vehicles (Level 3) based on their perception of vehicle and road features (Level 1) and their comprehension of the situation (Level 2). Vehicle features may include speed and distance (Brewer, Fitzpatrick, Turner, Whitacre, & Lord, 2005; Kadali & Vedagiri, 2013; Yannis, Papadimitriou, & Theofilatos, 2013) as well as cues provided by the driver inside the vehicle, such as eye contact and gestures (Habibovic, Andersson, Nilsson, Malmsten Lundgren, & Nilsson, 2016; Keferböck & Riener, 2015; Kitazaki & Myhre, 2015). Situation awareness, crossing decisions, and crossing behaviors of pedestrians are also influenced by environmental and individual factors (see the top of Fig. 1). Individual factors include preconceptions and trust in AVs (Rothenbücher, Li, Sirkin, Mok, & Ju, 2016) as well as knowledge and expectations about the behavior of road users (AVs) (Houtenbos, 2008). In summary, Fig. 1 illustrates that when pedestrians are able to perceive and understand an approaching vehicle's features and the road situation, they are able to make appropriate predictions regarding the behavior of the vehicle. This, in turn, leads to accurate crossing decisions and safe crossing behavior. If, however, pedestrians have inaccurate perception and comprehension about the behavior of the vehicle, this could lead to wrong predictions, a state of elevated confusion and stress, and unsafe crossing decisions (and see George & Dane, 2016; Starcke & Brand, 2012, indicating that stress is associated with decision making).

There are several ways in which pedestrians may make incorrect crossing decisions when interacting with an AV. First, there could be a problem of perception or comprehension, as pedestrians might be unable to distinguish whether they are interacting with a traditional vehicle or with an AV. One of the drawbacks of AVs is that communication between pedestrians and drivers is

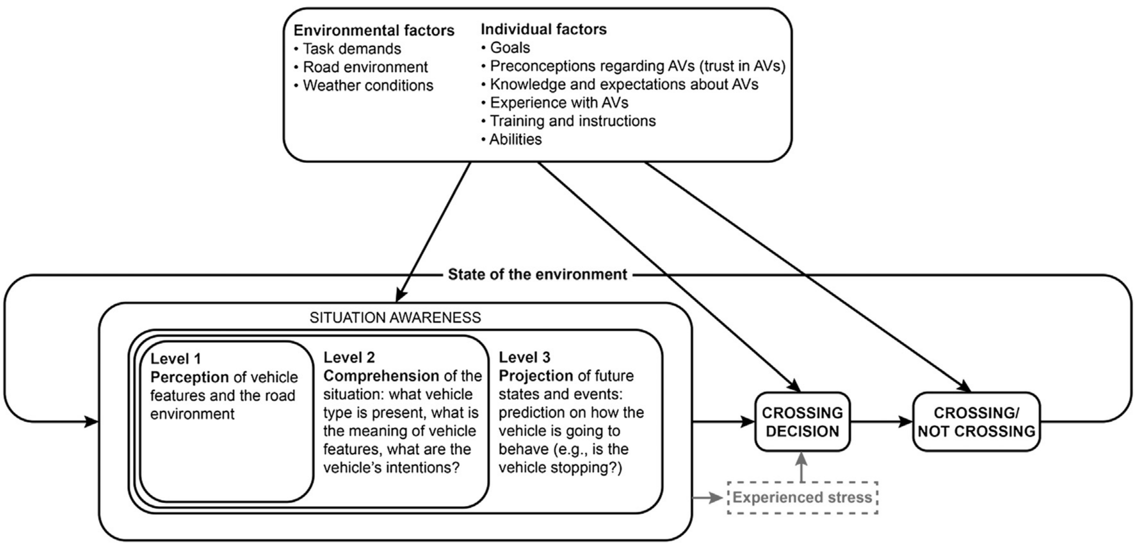

Fig. 1. Model of situation awareness in dynamic decision making, describing the interaction between a pedestrian and an AV (adapted from Endsley, 1995).