Intelligent Agents in Cars: Investigating the Effects of Anthropomorphism and Physicality of Agents in Driving Contexts

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Abstract. An increasing number of intelligent agents are developed for driving contexts. Anthropomorphism is a commonly used strategy to embody intelligent agents. This research investigates two specific ways of anthropomorphizing agents: the anthropomorphism level (low vs high) and physicality (virtual vs physical). We conducted a 2×2 between-subjects ($N = 115$) experiment through Wizard-of-Oz methodology. Participants' subjective evaluations were collected. Results revealed the interaction effects of anthropomorphism level and physicality on drivers' trust, perceived control, and attitude. Specifically, for high-level anthropomorphized agents, a physical agent significantly lower drivers' trust, perceived control, and attitude in comparison to a virtual one. No significant differences between physical and virtual agents were found for low-level anthropomorphized agents.

Keywords: Agent · Anthropomorphism · Physicality · Driving

1 Introduction

Driven by innovative technologies, an increasing number of intelligent agents are developed for daily lives, such as Google Assistant and Amazon Alex. Intelligent agents refer to the autonomous entities that can perceive and communicate with the surroundings. To some extent, intelligent agents can even have intentions and achieve their goals [1]. Intelligent agents have also been integrated into driving contexts. Automotive manufacturers often integrate an agent with in-vehicle information systems (IVIS) to communicate with drivers, such as Yui developed by Toyota and Pia developed by Audi. The intelligent agents become assistants for drivers. Through communicating with intelligent agents, drivers can learn traffic conditions, navigation information, weather conditions, and other communication messages, such as email and voice messages.

Anthropomorphism is a commonly used strategy to embody intelligent agents. Anthropomorphism refers to people's tendency to attribute human characteristics to objects or systems [2]. Designers can purposely integrate cues related to humans while

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designing objects or systems. These cues can trigger users to interact objects or systems in a way as interacting with a real person [3]. As a result, people favor anthropomorphized brands [4]. In driving contexts, previous studies revealed benefits of integrating anthropomorphized agents into IVIS, including improving drivers' motivation of driving safely [5] and enhancing drivers' trust [6]. However, prior research also found that users experience fewer enjoyments while interacting with anthropomorphized systems because their sense of autonomy is threatened [7]. Therefore, current results suggest that the influences of anthropomorphized agents are contextual dependent. The influences could depend on how intelligent agents are anthropomorphized.

This research aims to investigate two specific ways of anthropomorphizing agents: the anthropomorphism level (low vs high) and physicality (virtual vs physical). In current practice, automobile manufacturers used these ways to embody agents. For example, a physical embodied and low-level anthropomorphized agent, NOMI, is integrated in-car NIO. In contrast, a high level of anthropomorphized agent XiaoP is virtually presented in a car developed by XiaoPeng Motors. Results of this research can thus guide integrating intelligent agents in cars.

2 Related Works

Intelligent agents can vary in anthropomorphism levels, ranging from a low to a high level of anthropomorphism. Prior research found that the increasing anthropomorphism level can improve users' trust in a system [8]. However, a high level of anthropomorphism can be detrimental for users when control is crucial for them. Specifically, in game playing contexts, autonomy and control are essential for users' enjoyment. Anthropomorphism is demonstrated to reduce users' sense of autonomy, which hinder users' enjoyment [7]. Following this, as autonomy and control are essential factors for users' driving experience, drivers' attitudes can be largely discounted if they feel less control over a car. For example, prior research reported drivers' difficulty accepting virtual agents with a high-level anthropomorphism [9].

Physicality is another factor that influences users' responses to agents. Agents can be embodied virtually or physically [10]. A virtual agent can be represented on a screen, while a physical agent is presented to users in the same physical space. Previous studies demonstrated that in comparison to virtual agents, users reported enhanced attitudes and trusts towards physical agents [11, 12] because physical agents were found to improve users' feeling of social presence [13].

Thus far, current studies have investigated the effects of anthropomorphism level and physicality independently, but limited research attentions have been paid on examining the interaction effects of anthropomorphism level and physicality. This research aims to fill in this gap.

3 Method

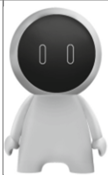
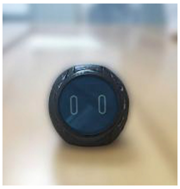
3.1 Design and Participants

A 2 × 2 between-subjects experiment was designed, with agents' anthropomorphism level (low vs high) and physicality (virtual vs physical) as independent subjects. Participants were randomly assigned to one of the four conditions. 115 participants were collected (62.93% male, mean age = 22.88). All the participants had qualified driving licenses and normal or corrected visual acuity.

3.2 Stimuli Creation

To manipulate the anthropomorphism level, we intended to create two versions of anthropomorphic agents: an agent with a low level of anthropomorphism and a high level of anthropomorphism. In the current research, multiple strategies exist to manipulate the anthropomorphism level, such as agents with different realism level [14], agents with 2D vs 3D [15], agents with anatomical anthropomorphism [16], and agents with presence or absence of human form [17, 18]. We decided to create differentiated anthropomorphic agents through anatomical way [16]. As a result, two anthropomorphism agents were created: one agent with head and another agent with full body. Next, these two versions of agents were embodied in a virtual and physical way (see Table 1).

Table 1. Stimuli: four agents differentiated by physicality and anthropomorphism level.

Low anthropomorphism in virtual	High anthropomorphism in virtual	Low anthropomorphism in physical	High anthropomorphism in physical
			

The intelligent agents were presented to drivers together with a voice interaction system. Drivers can interact with the system directly by talking. The agents responded to drivers through voice and facial expressions. According to drivers' behavior, the agents exhibit different facial expressions: waiting, listening, loading, and talking. At the same time, IVIS also provided real-time information relating to vehicle status.

This experiment adopted a Wizard-of-Oz setup [19]. While participants interacted with the system, the agent responded to them by voice and different facial expressions. Participants thought the system automatically interacted with them, but the experimenter actually controlled the system and responded to participants simultaneously.

3.3 Apparatus

The experiment was conducted using a medium-fidelity simulator, including a steering wheel, pedals, seats, monitor, and vehicle mock-up. The simulator uses UC-win/Road to provide a 135-degree field of view of the driving environment with three 27-inch monitors. In addition, an iPad was used to present the interaction system (see Fig. 1).

Fig. 1. Driving simulator with interaction system.

The designed driving route in UC-win/Road was the typical roads in China. Participants drove in the right lane of the road. The driving route was around 4 km long, and it consisted of a variety of scenarios such as stop-sign intersections (with/without crossing traffic), signalized intersections, car-following, and pedestrian crossing to resemble a real driving experience as much as possible.

3.4 Procedure

Upon arrival, we firstly welcomed participants and explained the aim and procedure of the experiment. Next, the driving simulator and voice interaction system were introduced to them. They were also explained how to use the driving simulator and how to interact with the system by voice. They were given time for a trail on the simulator and an opportunity to talk to the agent. After participants confirmed that they acquired how to drive and interact with the car, the main session started.

In the main session, all participants drove the car in simulator along the set course. They were asked to drive steadily as they usually did in a real-life setting. During driving, participants were also required to perform several tasks by interacting with the agent by voice. Specifically, they were asked to search for music, re-navigate, and send a message to a friend. The whole driving task was around 10 min. After completing the driving task, participants were asked to fill out a questionnaire for their subjective evaluation of the driving experience and their response to the interaction system.

3.5 Measures

We used subjective questionnaires to measure participants' attitudes towards the agents and their driving experience. In the questionnaire, we measured participants attitudes of the system through self-reported 7-point scales (anchored between "describes very poorly and "describes very well") featuring six adjectives (positive, good, attractive, pleasant, likeable, and high-quality) (α = 0.919) (adapted from [20]). Trust was measured by three 7-point Likert scales by rating the following statements "the system that I just used was credible/accurate trustworthy from 1 (strongly disagree) to 7 (strongly agree) (α = 0.937) [21]". Perceived control was measured by asking participants to indicate to what extent they agreed with the following two items: "when I use the interaction system, I feel that use procedure is completely up to me" and "when I use the interaction system, I feel more control over the driving process" on 7-point Likert scale from 1 (strongly disagree) to 7 (strongly disagree) ($r = .731$, $p < 0.01$) (adapted from [22]). Moreover, to measure participants' driving performance, the driving data was recorded by the software associated with the simulator.

4 Results

A two-way ANOVA was conducted to test the interaction effect between anthropomorphism level and physicality. The result reveals significant interaction effect between anthropomorphism level and physicality on drivers' trust of the interaction system ($F(1,112) = 4.97$, $p < .05$), perceived control ($F(1,112) = 6.20$, $p < .05$), and attitude ($F(1,112) = 4.43$, $p < .05$) (see Fig. 2).

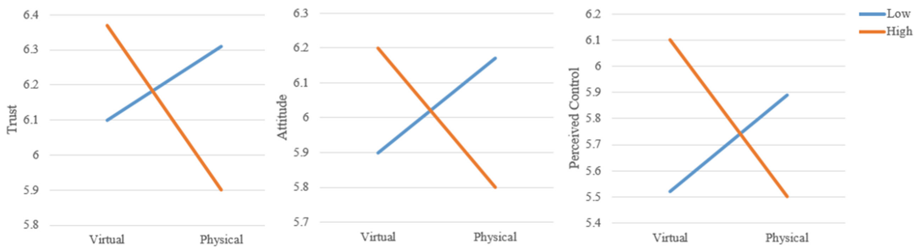


Fig. 2. Results for drivers' trust, attitude, and perceived control related questionnaires.

More specifically, when agents with a high level of anthropomorphism, participants who interacted with virtual agents reported significantly higher ratings than the ones who interacted with physical agents in terms of trust ($F(1, 58) = 5.77$, $p < .05$; $M_{virtual} = 6.38$ vs $M_{physical} = 6.90$), perceived control ($F(1, 58) = 6.85$, $p < .05$; $M_{virtual} = 6.13$ vs $M_{physical} = 5.50$), and attitudes ($F(1, 58) = 4.24$, $p < .05$; $M_{virtual} = 6.22$ vs $M_{physical} = 5.81$). But when interacting with low-level anthropomorphized agents, participants did not show significant differences between the virtual and physical condition in terms of trust, perceived control, and attitude (see Fig. 2).

5 General Discussion

This research reveals the interaction effects between anthropomorphism level and physicality of intelligent agents on drivers' trust, attitude and perceived control. For the low-level anthropomorphized agents, physicality does not significantly influence users' trust, perceived control and attitudes. In contrast, for the high-level anthropomorphized agents, virtual agent lead to significantly better trust, attitudes, and perceived control. These results suggest that for high-level anthropomorphized agents, physical agents can be detrimental because it reduces drivers' perceived control, which further lower their trust and attitudes. There are several opportunities to strengthen this research. This research only analyzed the subjective ratings. In addition to the subjective ratings, the objective driving performance is also essential to know. Future research can analyze the lane deviation data, which can help us learn the objective driving performance.

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