Examining pedestrians' trust in automated vehicles based on attributes of trust: A qualitative study

1. Introduction

The automotive industry is rapidly evolving towards developing and commercializing automated vehicles (AVs). Such vehicles are expected to bring significant changes to the transportation sector by reducing or removing human involvement in driving, and giving the public the best benefits possible, such as improving road safety and mobility, along with mitigating the environmental impact caused by road traffic (Mahdinia et al., 2021; Schieben et al., 2019). According to the Society of Automotive Engineering (SAE), six levels of driving automation, from Level 0 (no automation) to Level 5 (full automation), have been classified based on the degree to which the driving automation system could replace the human operation of vehicles in various traffic scenarios (SAE-International, 2016). AVs at SAE Level 3 and higher should be capable of monitoring the driving environment and managing the driving task with reduced, or even without, human intervention during a journey (SAE-International, 2016).

There is a consensus among researchers that AVs with different levels of autonomy will be introduced into the market during the coming years and decades, first on highways and later in other more complex environments, such as towns and cities (e.g., Kyriakidis et al., 2019; Sun et al., 2020; Tabone et al., 2021). Mercedes-Benz, for example, in December 2021, gained regulatory approval in Germany for its Level 3 conditionally automated driving system called DRIVE PILOT (Mercedes-Benz, 2021). Users of this driving system are permitted to operate in conditional automated mode at speeds of up to 60 km/h on designated motorway sections in Germany where heavy or congested traffic exists (Mercedes-Benz, 2021). This marks a level of maturity reached by AV technology, but significant challenges remain for integrating AVs into the existing urban transport networks. Apart from the technological barriers, there are also challenges with the societal impact of this technology, particularly from the aspect of trust in, and trustworthiness of, AVs (Sun et al., 2020).

Trust is a critical psychological variable to consider both before and in the early stages of the adoption of AVs, especially in urban areas, where many members of society have not yet adapted themselves to repeated or habitual interactions with AVs (Choi and Ji, 2015; Ghazizadeh et al., 2012). Among these, pedestrians constitute one of the most vulnerable groups of road users, and they are considered key stakeholders within the AV ecosystem (Pulugurtha et al., 2010; Verma et al., 2019). For this reason, recently, increased attention has been devoted to understanding pedestrian-AV trust (e.g., Faas et al., 2020; Holländer et al., 2019; Jayaraman et al., 2019). Some studies have indicated that trust is a key determinant of pedestrian receptivity and acceptance of AVs in real urban traffic (Deb et al., 2017b; Zhou et al., 2022). However, poorly calibrated trust (i.e., overtrust and distrust) may emerge as a common issue before and during interactions, possibly causing severe or fatal consequences (Holländer et al., 2019; Reig et al., 2018). To facilitate safe interaction with AVs, there is a clear need for researchers to address how to effectively measure and then calibrate pedestrians' trust to appropriate levels (Faas et al., 2021; Jayaraman et al., 2019).

Given the multidimensional and context-dependent nature of trust, this general concept has to be broken down into several lower-level components (also known as the attributes of trust) that allow measurement in particular contexts of use or interaction (Miller and Perkins, 2010; Sheridan, 2019). However, studies that exclusively explore the attributes of trust involved in the pedestrian-AV context are scarce. For instance, trust is often discussed and treated as a broad concept (e.g., Holländer et al., 2019; Kaleefathullah et al., 2022), or being measured multidimensionally using questionnaires from the automation domain[1], such as the trust scale constructed by Jian et al. (2000) (e.g., Faas et al., 2021). It is noteworthy that these approaches may fail to capture as fully as possible the aspects peculiar to pedestrians' trust toward AVs, thus leading to an improper interpretation of trust in this context (Körber, 2019). On the other hand, Sheridan (2019) proposed a number of attributes that are applicable to trust in automation in general, and grouped these into two categories: objective and subjective attributes. In addition to the conventional focus on objective attributes of trust/trustworthiness (e.g., the trustworthiness of the automation such as *reliability*, and *dependability*), Sheridan (2019) highlighted the need to consider the sociological aspect of "automation morality" (e.g., *authority/subversion*, and *care/harm*) as subjective criteria with which to assess trust in intelligent automation. However, a critical unknown is whether these attributes of trust could be applied to the pedestrian-AV context.

To address these gaps in the research, the main objectives of this study are twofold: first, to examine pedestrians' trust in AVs, based on the attributes of trust and trustworthiness; and second, to identify and interpret the attributes involved. Immersive virtual reality (VR) was used in this study to simulate pedestrian-AV interaction. We employed scenario-based

[1] Most existing questionnaires in the automation domain examine trust from the standpoint of users. However, the development of users' trust in AVs may be different from that of pedestrians, who do not directly use, but need to interact with, that system to ensure safety and effectiveness.

interviews and a hybrid approach of inductive and deductive thematic analysis to gauge both the objective and subjective attributes constituting pedestrians' trust in AVs. The results provided empirical grounding for trust theories and quantitative assessment of trust, especially in the pedestrian-AV context.

2. Literature Review

2.1 Intelligent automation and AVs

Intelligent automation refers to systems that incorporate sophisticated heuristics and algorithms, empowered by artificial intelligence (AI) and allied technologies, to enable "any or all of sensing, analysis, memory, decision for action, and implementation of that action" (Sheridan, 2019, p.2). This is quite different from traditional automation, which is designed for a limited number of pre-programmed tasks and requires supervision during operation (de Visser et al., 2018). AVs are a typical example of the application of intelligent automation in transport (Hengstler et al., 2016; Sheridan, 2019). They rely heavily on AI and related technologies to interpret the surrounding environment (such as traffic signals and other road users), to make driving-related decisions, as well as to implement actions independently in the automated driving mode (Loke, 2019; Nascimento et al., 2020). Many have envisaged a transition in human interaction with AVs, from the simple interaction or use of automated aids as tools, to the establishment of human relationships with these systems (e.g., de Visser et al., 2018; Lokshina et al., 2022). In addition to the requirements for system performance, AVs are also expected to exhibit morally acceptable behaviors (such as obeying traffic regulations) to garner an appropriate level of trust from pedestrians (Thornton et al., 2016). AVs are expected to become increasingly intelligent and human-like, and therefore, it is important to consider both objective and subjective attributes when examining pedestrian-AV trust.

2.2 Pedestrian-AV trust and trust calibration

A widely recognized definition of trust in AVs was developed by Lee and See (2004), who identified trust as "the attitude that an agent will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability" (p.54). In view of the pedestrian-AV context, pedestrians play the role of the trustor, and AVs play the part of the trustee (Zhou et al., 2022). Since trust is a dynamic construct that develops and changes over time, the process in which pedestrians adjust their trust levels to correspond to the trustworthiness of AVs is referred to as trust calibration (Khastgir et al., 2017; Lee and See, 2004). During the process of calibrating trust in AVs, pedestrians are likely to contextualize and individualize the risks and benefits of AVs based on their perceptions regarding the capabilities and limitations of such systems (Hoff and Bashir, 2015; Wagner and Robinette, 2021). An appropriately calibrated level of trust is viewed as the optimal result of the trust calibration process, which will reflect pedestrians' accurate understanding of the actual performance of AVs, and the imperfections inherent in intelligent automation (Kraus, 2020; Zhou et al., 2022). There are two types of poorly calibrated trust, namely overtrust and distrust (Lee and See, 2004). Overtrust (i.e., trust exceeding system capabilities) tends to occur when pedestrians underestimate the chance that AVs will malfunction, or the severity of the consequences related to system errors or failures (Ackermann et al., 2018; Wagner and Robinette, 2021). Pedestrians who exhibit overtrust may rely on AVs beyond the intended scope of the system, such as believing that AVs will always stop for them (Deb et al., 2017b; Domeyer et al., 2020). In contrast, distrust (i.e., trust falling short of system capabilities) can appear when pedestrians misjudge the capabilities of AVs and fail to rely upon them appropriately (Mirchi et al., 2015; Zhou et al., 2022). This lack of trust among pedestrians would hinder the adoption of AVs, making it difficult to take full advantage of this new technology (Sun et al., 2020; Wintersberger et al., 2019).

2.3 Attributes of trust

Trust as a general concept needs to be deconstructed into specific attributes to fit the pedestrian-AV context (Miller and Perkins, 2010). Sheridan (2019) defined some objective and subjective attributes of trust/trustworthiness. Objective attributes are considered "conceivably measurable by *objective* means" (Sheridan, 2019, p.3), whereas subjective attributes are highly dependent on the *subjective* judgements of individuals (Sheridan, 2019).

Most of the previous literature has concentrated on the objectively measurable attributes of automation trustworthiness (e.g., *reliability*, *dependability*, and *predictability*), and human trust in automation (e.g., *familiarity* and *dependence*). For instance, Sheridan (1989) discussed the nature and significance of trust in command and control systems, suggesting the following seven attributes: *reliability*, *robustness*, *familiarity*, *understandability*, *explication of intention*, *usefulness*, and *dependence*. Later, Muir and Moray (1996) proposed six related properties of trust, namely *reliability*, *dependability*, *predictability*, *competence*, *faith*, and *responsibility*. Many researchers have adopted these attributes as lower-level measurable specifics through which to examine trust in different automated systems from the user perspective (e.g., Lee et al., 2021; Tenhundfeld et al., 2019). These attributes are conceivably measurable through objective methods (Sheridan, 2019). For example, information regarding human-automation performance obtained from simulations can be used to investigate how far people might use or interact with the system in the way that was originally intended by the designer of the automation, as well as to evaluate how proper such behaviors were in correspondence with the actual capabilities of the system, such as in terms of *reliability*, *dependability*, and *predictability* (Large et al., 2018).

However, subjective attributes analogous to the properties of human morality have previously been neglected in the literature. As AI and related technologies allow for more complex and human-like capabilities in automated systems, Sheridan (2019) highlighted the important role that subjective attributes would play in the affective aspect of trust in automation. People are likely to apply identical social rules to technology as they do to humans when making their judgements on its trustworthiness (Lokshina et al., 2022). In this sense, Sheridan (2019) applied a set of human morality attributes defined by Haidt (2012) as the subjective criteria of trust in intelligent automation. That consisted of six main components: *care/harm*, *liberty/oppression*, *fairness/cheating*, *loyalty/betrayal*, *authority/subversion*, and *sanctity/degradation*. These are seen as continuous scales and are required to be assessed by subjective scaling (Sheridan, 2019). Since the notion of "subjective attributes" is relatively new in the field of trust in automation, very few studies have considered this aspect, and no empirical evidence has yet been found. A recent study by Choi et al. (2020), for instance, provided a literature-based discussion of the role of subjective attributes in trust development between AI technologies and radiologists for improving collaborative work in clinical settings.

Inspired by these insights, this study attempts to move beyond the theoretical discussions on subjective attributes of trust/trustworthiness, and provide empirical grounding for the attributes constituting pedestrians' trust in AVs.

2.4 Factors affecting pedestrians' trust in AVs

The theoretical model of pedestrian-AV trust by Zhou et al. (2022) was used as the basis for this study, which comprised three layers of variability related to pedestrians' trust in AVs (dispositional trust, situational trust, and learned trust). This model was developed following a systematic review of the literature on trust in automation and AVs, and the interaction between pedestrians and vehicles. As shown in Figure 1, the dispositional layer of trust represents the overall long-term tendency of a pedestrian to trust AVs, independent of context or a specific system (Hoff and Bashir, 2015). It is a relatively stable characteristic over time, cultivated under the influence of biological and environmental factors, such as gender, age, and culture (Hoff and Bashir, 2015; Merritt and Ilgen, 2008). Regarding the situational layer of trust, there are two main sources of variability: external and internal. External variability relates to the effect of the external environment (e.g., traffic signals and the behaviors of other pedestrians) on trust, while internal variability is associated with the internal, context-based traits of the pedestrian (e.g., emotional state and attentional capacity) (Zhou et al., 2022). The development of trust varies significantly across different situations (Hoff and Bashir, 2015). Lastly, learned trust reflects pedestrians' attitudes toward AVs drawn from their past experiences or direct interactions (Hoff and Bashir, 2015). This may be further categorized into initial or dynamic learned trust. Initial learned trust represents people's trust in AVs before any actual interaction with AVs (Zhou et al., 2022), while by contrast, dynamic learned trust represents the level of people's trust in AVs during their interactions with AVs.

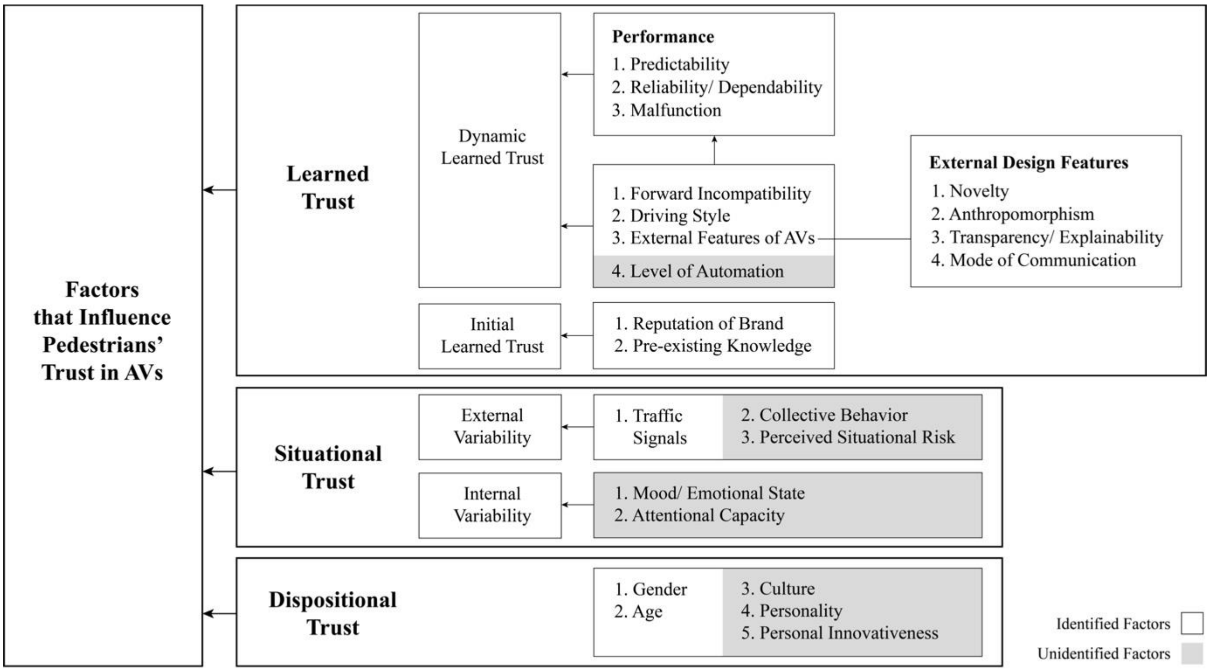

Fig. 1 The conceptual model of pedestrian-AV trust (adapted from Zhou et al., 2022).

The existing literature has shown that exploring people's perceptions and ideas about trust in a specific *other* (e.g., a person or a system) is an effective approach to gaining an understanding of the attributes of trust involved in that particular context (e.g., Hillen et al., 2012; Sheridan, 2019). For example, through semi-structured interviews, Hillen et al. (2012) examined cancer patients' trust in oncologists by assessing qualitatively their determination and intention to trust their oncologists. Based on this rationale, we adopted scenario-based interviews to explore the attributes of trust in the pedestrian-AV context by understanding how and why different factors would influence pedestrians' trust in AVs in a qualitative manner.

3. Methods

Due to the exploratory nature of this research, a qualitative approach was considered suitable and able to generate the kind of comprehensive information which is necessary to identify and interpret the attributes of trust involved (Banister et al., 2011; Wilson and Sharples, 2015). The qualitative method is also useful for examining empirically rare but theoretically important cases, such as gaining an understanding of the subjective attributes that have rarely been studied in the literature (Hochstetler and Laituri, 2014). Typically, the qualitative examination of trust relies on interview data as a critical component of theory development (Buckley et al., 2018; Hillen et al., 2012). Interviews would provide a foundation of detail to help us better understand the psychological underpinnings of pedestrians' trust in AVs.

Numerous researchers have also suggested the use of scenario building as an effective tool with which to make an in-depth exploration of people's views on a new product or system (e.g., Aylward et al., 2021; Nardi, 1992). The 'scenario' in our case can be understood as a set of natural, constructed, or imagined contexts designed for pedestrian-AV interaction (Suri and Marsh, 2000). Scenario-based methods serve as a useful means of integrating various interplaying factors to depict "some set of real ongoing activities with an imaginative futuristic look at how technology could support those activities better" (Nardi, 1992, p.13). The use of multiple scenarios could help researchers to focus on different aspects of problems to be investigated (Nardi, 1992). Furthermore, recent studies have shown the role of scenarios in eliciting rich narratives from participants about the qualitative aspects of their interactions or experience with a system (e.g., Aylward et al., 2021; Jaidin, 2018; Kip et al., 2019). Mediums that could be used to develop scenarios vary from traditional techniques (e.g., annotated sketches and written stories) to advanced technologies (e.g., augmented and virtual reality) (Aylward et al., 2021; Suri and Marsh, 2000). To resemble closely the actual interaction between pedestrians and AVs, we used immersive VR for building scenarios (Bhagavathula et al., 2018; Deb et al., 2017a). The subjects were then interviewed about their attitudes and opinions about AVs after their interactions with the same in virtual environments. We also used a hybrid form of inductive and deductive thematic analysis to extract the attributes of trust from their responses.

The study was approved by the University Research Ethics Committee.

3.1 Participants

A total of 36 individuals (18 males, and 18 females) took part in this study. A small sample was considered sufficient for semi-structured interviews to capture in-depth information about the research question (Hilgarter and Granig, 2020; Qu and Dumay, 2011). The participants were recruited through snowball sampling. None of the participants experienced any symptoms of simulation sickness, and none were withdrawn from the study. Furthermore, participants were recruited to ensure diversity of gender, age, educational level, and occupation for the purpose of obtaining the broadest possible insights. The sample was stratified to have equal numbers by gender and in four age groups: 18-24, 25-34, 35-44, and 45 years or above. They were all from China, ranging from 21 to 61 years (M=35.50 years, SD=11.82 years) and with different backgrounds, including students, educators, businesspeople, employees, freelancers, as well as retirees. As presented in Table 1, most of the participants (75%) had received higher education (i.e., undergraduate and above), and a half (50%) had previous experience with an autopilot system (e.g., Tesla Model 3, Volvo S90, Mercedes-Benz C200, and Xpeng P7). Additionally, some (44.4%) had previously used VR devices (e.g., Oculus Quest, HTC Vive, and HP Reverb G2). The majority (61.1%) spent more than 30 minutes per day walking on city streets.

Table 1
Demographic information of the sample

	Frequency	**Percentage (%)**
No. of participants	36	100
Age group (in years)		
18-24	9	25
25-34	9	25
35-44	9	25
> 45	9	25
Gender		
Male	18	50
Female	18	50
Educational background		
Junior school and below	4	11.11
High school	5	13.89
Undergraduates	2	5.56
Graduates	16	44.44
Postgraduates	9	25
Previous experience with autopilot systems		
Some experience	18	50
No experience	18	50
Previous experience with VR devices		
Some experience	16	44.44
No experience	20	55.56
Time spent per day walking on streets (in minutes)		
0-15	4	11.11
15-30	10	27.78
30-45	5	13.89
45-60	7	19.44
> 60	10	27.78

3.2 Apparatus

The study was conducted in a laboratory setting. Virtual traffic scenarios were built and implemented in Unity 2020.3.4f1c1, and were experienced with an Oculus Quest 2 headset. The three-dimensional (3D) model of the Waymo self-driving car was purchased from the Turbosquid website (www.turbosquid.com), and later modified in Unity to suit the research purposes of the study.

3.3 Virtual scenarios

Virtual scenarios were used in this study for two purposes: first, to provide participants with a realistic experience with AVs (Aylward et al., 2021); and second, to elicit more detailed and richer narratives from participants (Jaidin, 2018; Williams et al., 2005).

We extracted factors that could potentially affect trust, and then integrated these into different scenarios to investigate how they might affect trust during pedestrian-AV interactions. As presented in Table 2, a total of 14 factors having the potential to influence situational and learned trust in AVs were identified and extracted from the theoretical model of Zhou et al. (2022). Given the exploratory nature of the study, and to ensure our participants were not overburdened, only a handful of all possible combinations of these factors were integrated into the virtual scenarios, and the choices of these combinations were partly based on the existing literature (see Column 3, Table 2). For instance, among the eHMI design concepts proposed in the literature for improving the transparency of AVs, the text-based and anthropomorphic-based eHMIs were found to have been discussed widely in previous works (e.g., Deb et al., 2018; Löcken et al., 2019), and thus were chosen as representative examples for this study. It was determined that this would allow participants to have a better and more concrete understanding of how eHMIs can be used to communicate an AV's intent to pedestrians, and thereby prompt discussion in the interviews accordingly.

Some factors were ultimately excluded from the VR scenarios (but were still worthwhile topics for discussion in the interviews) for the following three reasons: (a) some factors represent the internal characteristics of pedestrians themselves, such as mood/emotional state and attentional capacity, which could vary across individuals (Hoff and Bashir, 2015); (b) some affect the initial learned trust of pedestrians, such as brand reputation and pre-existing knowledge of AVs (Lee and Kolodge, 2020; Zhou et al., 2022); and (c) some are difficult to co-integrate in a scenario. For example, one notable difference between different levels of driving automation is the extent to which AVs could replace human drivers in different situations[2] (SAE-International, 2016). However, it was difficult to show such differences in VR scenarios owing to time and budget constraints.

Table 2
Factors that were included in or excluded from the scenarios

No.	Factors	Included in the scenarios	If excluded, reasons for exclusion
01	Traffic signals	Signalized crosswalks (Jayaraman et al., 2019).	/
02	Collective behavior	Presence of surrounding pedestrians (Zileli et al., 2019).	/
03	Perceived situational risk	Two-lane and four-lane streets; non-mixed and mixed traffic settings (Rasouli and Tsotsos, 2020).	/
04	Mood/Emotional state	/	Being an internal characteristic of pedestrians.
05	Attentional capacity	/	Being an internal characteristic of pedestrians.
06	Reputation of brand	/	There are so many AV brands, and the inclusion of these could induce biased results given that their reputations differ significantly.
07	Pre-existing knowledge	/	It is very difficult to incorporate differences in participants' pre-existing knowledge of AVs.
08	Forward incompatibility	Without the presence of a person in the driver's seat (Van Loon and Martens, 2015).	/
09	Driving style	Aggressive, standard, and defensive styles of driving (Jayaraman et al., 2019).	/
10	The novelty of external AV appearance	Sensors outside the vehicle (Dey et al., 2019).	/
11	Anthropomorphism	A smiling face on the eHMI (Deb et al., 2018).	/
12	Transparency	A smiling face on the eHMI; the text 'safe to cross' on the eHMI; a female voice saying 'safe to cross' (Deb et al., 2020).	/
13	Mode of communication	Visual and auditory modes of communication (Dey et al., 2020).	/
14	Level of automation	/	It is difficult to show the difference between the various levels of automation in VR scenarios.

In all scenarios, the AV was designed to decelerate and stop at a four-way intersection in an urban area with a speed limit of 50 km/h, to allow a pedestrian to cross in front (see Figure 2). Four-way intersections in many urban areas of China have a crosswalk on each side (Zhang

[2] In Level 3 and certain types of Level 4 vehicles, people are still required to resume manual control following a take-over request. In contrast, Level 5 vehicles can perform dynamic driving tasks independently without human intervention during an entire journey.

and Zhang, 2019). We created a series of encounters with AVs at crosswalks to study how and whether these factors would affect pedestrians' trust. According to Lee and See (2004), trust exists and is important in a situation of uncertainty and vulnerability. This indicated that scenarios should contain a certain level of uncertainty and vulnerability (Hoff and Bashir, 2015; Lee and See, 2004). The justification for these scenarios in terms of being able to generate uncertainty or vulnerability is discussed in detail below. First, new technologies are naturally associated with certain level of uncertainty for people who are new to such technologies (Jayaraman et al., 2019; Jensen, 1992). Some people may even question whether the AV system is truly reliable (Fallon, 2018), or may be confused about how AVs would react to them (Zandi et al., 2020). In a VR experiment, Deb et al. (2020) provided evidence that many pedestrians began crossing the road before the AV had stopped, and then rushed across the crosswalks. Such behavior was interpreted as pedestrians having a lack of trust in AVs, even in locations where crosswalks were marked (Deb et al., 2020). Second, given the specific traffic culture in China, drivers in conventional vehicles do not always give way to pedestrians at unsignalized crosswalks where pedestrians are given the right-of-way by law (Muley et al., 2019; Zhuang and Wu, 2014). In a previous study investigating drivers' yielding behavior at uncontrolled midblock crosswalks in five urban sites in Beijing, China, Zhuang and Wu (2014) reported that only 3.5-12.9% of drivers yielded to pedestrians, while 38.8-63.5% did not even slow down. A level of uncertainty was, therefore, assumed to be present at unsignalized crosswalks. Here, such encounters were also studied to ascertain whether the presence of traffic signals could help alleviate uncertainty and reinforce the trust of pedestrians toward AVs (Jayaraman et al., 2019). Finally, owing to the inherent vulnerability of pedestrians in traffic, there could be a common perception of risk on the road (Noonan et al., 2022). On this basis, these scenarios were considered suitable for a qualitative examination of trust between pedestrians and AVs.

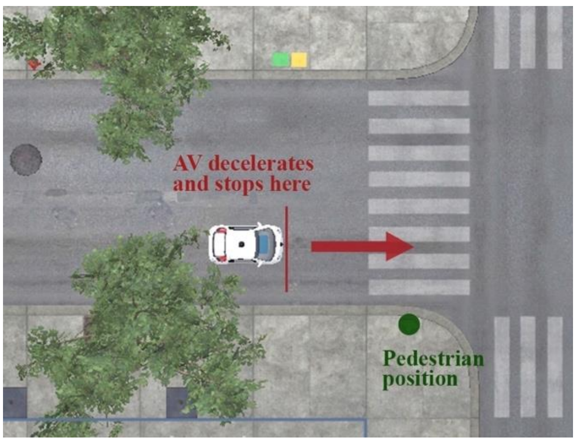

Fig. 2 Intersection with two-way, two-lane streets. The red arrow indicates the moving direction of the AV, which is consistent with traffic rules in China. The green circle indicates the original position of the pedestrian at the beginning of the trial.

Figure 3 illustrates five carefully chosen scenarios showing different interesting aspects of pedestrian-AV interactions. Only the Waymo car was assumed to be automated in this study, while the other vehicles shown in Scenario 05 were conventional. We applied a transparent and tinted window effect to the AV(s) and conventional vehicles, respectively, to distinguish them by external appearance. Hence, the pedestrian could recognize the AV and see that there was no driver inside. Each scenario consisted of several key factors to be investigated (see Column 2, Table 3). Based on our literature review and real-life information, we specified the important parameters of certain 3D objects (such as vehicles and pedestrians) for each scenario (see Column 3, Table 3). For instance, there were three different driving styles in our scenarios: aggressive, standard, and defensive. Sun et al. (2020) suggested a desired initial speed of 50 km/h for the AV with an aggressive or standard style, and 40 km/h for a defensive style, based on their interview results with local traffic police officers in China. Some researchers have recommended using 10-15 ft/sec^2 for the deceleration rate in daily driving situations (e.g., Lee et al., 2018; Wortman and Fox, 1994). The deceleration rate for the AV with an aggressive, standard or defensive style was thus set to 20, 15, and 10 ft/sec^2, respectively. In addition, Tolea et al. (2010) found that men and women walked at an average speed of 1.14 and 1.05 m/s, respectively. These data were then applied to our virtual scenarios to produce an experience that was as similar as possible to the real world.

Scenario 01

Scenario 02

Scenario 03

Scenario 04

Scenario 05

Fig. 3 Visualization of the five virtual scenarios in Unity. The camera icon represents the pedestrians' position and point of view at the beginning of the trial.

Table 3
The design of the scenarios

No.	Factors to be investigated	Descriptions of scenarios
01	• *Forward incompatibility* (Without the presence of a person in the driver's seat) • *The novelty of external AV appearance* (Sensors outside the vehicle)	- The AV approached the pedestrian at a four-way unsignalized intersection with a two-way, two-lane road. - The AV exhibited standard driving behavior. It moved at 50 km/h (13.89 m/s) at the beginning of the trial and began to decelerate at an average rate of 15 ft/sec^2 (4.57 m/s^2). The deceleration time was 3.04s. - The AV stopped 3m before the crosswalk and waited for 10s to allow the pedestrian to cross.
02	• *Anthropomorphism* (A smiling face on the front eHMI) • *Driving style* (Defensive) • *Transparency* (A smiling face on the front eHMI) • *Mode of communication* (The visual mode)	- The AV approached the pedestrian at a four-way unsignalized intersection with a two-way, two-lane road. - The AV moved at 40 km/h (11.11 m/s) at the beginning of the trial and began to decelerate at an average rate of 10 ft/sec^2 (3.05 m/s^2). The deceleration time was 3.64s. - A smiling face appeared on the front eHMI at approximately 1.5m away from the stop position of the AV. - The AV stopped 4.5m before the crosswalks and waited for 12s to allow the pedestrian to cross. - The smiling face disappeared 2s before the AV began to move.
03	• *Collective behavior* (Presence of other pedestrians) • *Driving style* (Aggressive) • *Transparency* (An auditory cue saying 'safe to cross' in Chinese)	- The AV approached the pedestrian at a four-way unsignalized intersection with a two-way, two-lane road. - The AV moved at 50 km/h (13.89 m/s) at the beginning of the trial and began to decelerate at an average rate of 20 ft/sec^2 (6.10 m/s^2). The deceleration time was 2.28s. - The AV stopped 1.5m before the crosswalks and waited for 8s to allow the pedestrian to cross.

	• *Mode of communication* (The auditory mode)	- A female voice began to speak a 6-s-long message (‘safe to cross’ in Chinese) at the time when the AV stopped. - Two other pedestrians began to cross the road when the AV stopped. The average walking speed of the male and female pedestrian was set to 1.14m/s and 1.05m/s, respectively.
04	• *Traffic signal* (Signalized crosswalks) • *Transparency* (The text ‘safe to cross’ on the eHMI) • *Mode of communication* (The visual mode)	- The AV approached the pedestrian at a four-way signalized intersection with a two-way, two-lane road. - The AV exhibited standard driving behavior. It moved at 50 km/h (13.89 m/s) at the beginning of the trial and began to decelerate at an average rate of 15 ft/sec^2 (4.57 m/s^2). The deceleration time was 3.04s. - The text ‘safe to cross’ (in Chinese) appeared on the front eHMI at approximately 1.5m away from the stop position of the AV. - The AV stopped 3m before the crosswalks and followed traffic signals to allow the pedestrian to cross (waiting for approximately 15 s). - The text ‘safe to cross’ disappeared 2s before the AV began to move.
05	• *Perceived situational risk* (Four-lane road; mixed traffic setting)	- Two AVs approached the pedestrian at a four-way signalized intersection with a two-way, four-lane road. - The AVs exhibited standard driving behavior. They moved at 50 km/h (13.89 m/s) at the beginning of the trial and began to decelerate at an average rate of 15 ft/sec^2 (4.57 m/s^2). The deceleration time was 3.04s. - Other conventional vehicles moved at 40-50 km/h (11.11-13.89 m/s) and decelerated at an average rate of 10-15 ft/sec^2 (3.05-4.57 m/s^2). - Two AVs stopped 3m before the crosswalks and followed traffic signals to allow the pedestrian to cross (waiting for approximately 15 s).

3.4 Procedures

Prior to the commencement of the study, participants were provided with an information sheet that outlined the purpose of the research. Written informed consent was obtained from each participant. They were then instructed to don the VR headset (Oculus Quest 2) and become familiar with the virtual environment (i.e., the Oculus Home menu environment). We adjusted the lens spacing for each individual to ensure the best image clarity. At the beginning of each trial, we informed participants that the vehicles with no driver inside were automated, and the vehicles with tinted windows were conventional. However, they were not specifically instructed or trained to learn the meaning of the eHMIs. Then, all of the participants began with the first scenario, following which they engaged in a succession of the other four VR scenarios outlined above. During each session, we explicitly asked each participant to pay considerable attention to the external features of the AV(s) and the surrounding environment. Participants were allowed to behave as naturally as possible so that they could decide by themselves whether and when to cross in front of the AV(s). By asking “how” and “why” questions about the effect of various elements (e.g., contextual or design features such as a smiling face) on their trust in AVs (see Appendix A), we were able to gain a basic understanding of how participants formed and explained trust when drawing upon their direct experience. Previous studies have suggested that researchers should take into account the alignment of trust, and separate the concepts of overtrust, trust, and distrust in the analysis, rather than simply examining and discussing 'trust' in a general sense (Lee and See, 2004; Zhou et al., 2022). Hence, participants were asked to state in words how their trust was affected by including the following words or synonyms: "trust", "distrust", "overtrust" or "not being affected". Lastly, a scenario-based interview was conducted to gain deep insights into how participants perceived the whole set of factors listed in Table 2. For each factor, participants were asked to discuss freely the aspects that might affect their trust (e.g., diminishing trust, facilitating trust, causing distrust, and causing overtrust) based on the VR session, their personal life experience and prior knowledge. For instance, we first explained to participants the key differences between different levels of driving automation, and then asked them to discuss separately the aspects related to this factor that could lead to different levels of trust. This method would give us a more comprehensive picture of participants' explanations of trust beyond the insights obtained from the virtual scenarios. Meanwhile, images of the five scenarios were made available to the participants during the interview to help them recall the details. The study lasted approximately 40 minutes for each participant.

3.5 Data analysis

The interviews were audio-recorded and transcribed verbatim by the first author, and all data were de-identified to protect the privacy of participants. The transcripts of the interviews were analyzed using a hybrid inductive and deductive thematic analysis. The thematic analysis offers practical and effective procedures for identifying, analyzing, and reporting themes (or patterns) within qualitative data (Attride-Stirling, 2001; Braun and Clarke, 2006). Researchers have postulated that themes within data can be identified in an inductive or deductive way, or a mix of both, depending on the purpose of the study (e.g., Braun and Clarke, 2006; Fereday and Muir-Cochrane, 2006; Roberts et al., 2019). While an inductive approach seeks to derive themes from the facts or raw data (Roberts et al., 2019), a deductive approach is theoretically or analytically driven, in which the coding scheme often emerges from the conceptual framework (Proudfoot, 2022). A combined approach of inductive and deductive analysis can achieve greater rigor in the analysis of textual data (Fereday and Muir-Cochrane, 2006). Hence, we applied a mixed inductive/deductive approach to the investigation of the attributes relevant to trust in pedestrian-AV relationships. In this study, NVivo 12 software (QSR International

Pty Ltd) was used for coding and analysis to add rigor to the qualitative research process (Parnell et al., 2018; Welsh, 2002).

3.5.1 Inductive and deductive thematic coding

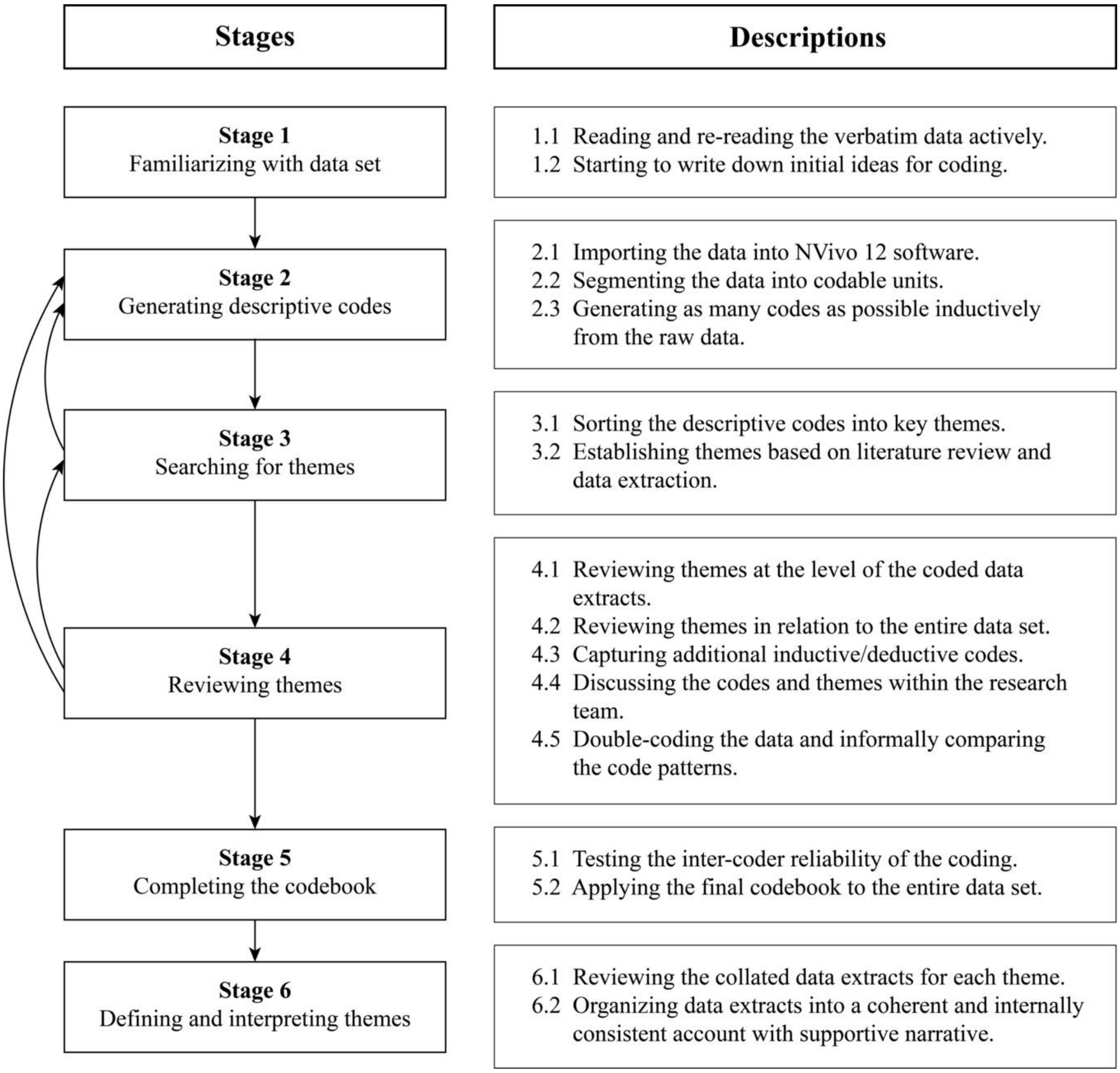

Fig. 4 Stages of the hybrid inductive and deductive thematic analysis

Data were coded following the guidelines for thematic analysis, such as those given by Braun and Clarke (2006) and Roberts et al. (2019). As illustrated in Figure 4, themes were developed and refined through an iterative process of inductive and deductive coding. The term "code" refers to "the most basic segment, or element, of the raw data or information that can be assessed in a meaningful way regarding the phenomenon" (Boyatzis, 1998, p.63). The term "theme" is defined here as "something important about the data in relation to the research question, and represents some level of *patterned* response or meaning within the data set" (Braun and Clarke, 2006, p.82). To ensure the accuracy and consistency of coding, we also produced a codebook with a list of detailed definitions and descriptions of each theme (see Table 4). As some researchers have stated, both clarity of the process and practice of the method used to develop thematic codes is essential (e.g., Braun and Clarke, 2006; Parnell et al., 2018). Hence, a step-by-step explanation of our method is provided in the following section.

Table 4
A thematic codebook of inductive and deductive codes

No.	Code label (Theme)	Definition	Descriptions coded under each theme
01	*Authority/subversion*	The extent to which AVs comply with traffic laws and regulations (Thornton et al., 2016).	Code text to this theme when participants discussed AVs' adherence to traffic regulations as a criterion for trust. This could be the respect for authority to achieve locally acceptable driving behaviors, particularly where traffic signals are deployed. - Viewing/Not viewing AVs as law-abiding. - Indicating that AVs should violate traffic rules when doing so would be safer than complying.
02	*Care/harm*	The extent to which AVs care for life and avoid harm to pedestrians (Thornton et al., 2016).	Code this when discussing whether or not AVs were perceived to care about pedestrians and their safety. This could relate to driving behaviors that may cause varying degrees of harm to pedestrians. - Believing/Not believing that AVs consider the safety of pedestrians. - Viewing AVs as dangerous to human safety.
03	*Competence* (also known as *robustness*)	The degree to which AVs can perform variations of the task effectively (Sheridan, 2019).	This should be coded when participants formed their level of trust in AVs based on how competent they perceived AVs to be in driving, detecting surrounding objects, or reacting appropriately to pedestrians. - Recognizing/Not recognizing the ability of AVs to perform specific tasks.
04	*Familiarity*	The degree to which AVs are familiar and friendly to pedestrians (Sheridan, 1989).	Code this when participants mentioned that their trust could be biased by how familiar they were with AVs. This could be the sense of familiarity and/or friendliness evoked by the external characteristics of AVs or fostered by pre-existing knowledge. - Feeling/Not feeling friendly. - Feeling/Not feeling familiar.
05	*Liberty/oppression*	The degree to which AVs are flexible in providing a variety of communication options to pedestrians (Dey et al., 2020).	Code this when participants expressed their attitudes toward the use of different modalities or carriers in pedestrian-AV communication. - Favoring/Not favoring mixed modes of communication. - Having/Not having their preferred communication means.

06	*Predictability* (also known as *understandability*)	The extent to which AVs behave in a manner consistent with the expectations of pedestrians (Hoff and Bashir, 2015).	Code this when views were expressed that their trust was influenced by how predictable and understandable AVs are. This could relate to a series of implicit or explicit cues conveyed by AVs. - Being/Not being able to predict the behavior of AVs. - Understanding/Not understanding the intent of AVs. - Believing/Not believing that AVs act consistently, and their behavior can be forecasted.
07	*Sanctity/degradation*	The degree to which AVs communicate with pedestrians clearly and straightforwardly (Sheridan, 2019).	Code text to this theme when participants considered the clarity/ambiguity and straightforwardness in communication as influential to their trust building with AVs. - Perceiving/Not perceiving information as unambiguous. - Perceiving/Not perceiving communication as clear and straightforward.
08	*Statistical reliability and dependability*	The extent to which AVs have rare and infrequent automation breakdowns or error messages (Large et al., 2019).	This should be coded when participants discussed how the occurrence and frequency of automation breakdowns or errors affected their trust in AVs. This could relate to a malfunction of one or more components of AVs. - Believing/Not believing that AVs are free of errors or breakdowns. - Assuming that a malfunction will rarely, sometimes, or often occur.

We first familiarized ourselves with the depth and breadth of the content before data coding and analysis (Stage 1, Fig. 4), for instance, by repeatedly reading the verbatim data in an active way and starting to record initial ideas for possible emerging codes and themes. Efforts were then made to generate initial codes and themes as part of the preliminary codebook development (Stages 2-3, Fig. 4). At this stage, the transcribed data were imported into NVivo 12 software to facilitate systematic coding in both an inductive and deductive manner. Many researchers have commented that while the deductive approach provides a sound theoretical framework for coding, the inductive process is valuable for the initial construction of codes that emerge directly from the data themselves, which enables vital insights to surface without being constrained by predetermined ideas or theories (e.g., Fereday and Muir-Cochrane, 2006; Proudfoot, 2022; Roberts et al., 2019). Based on this rationale, the first author performed an initial reading of a relatively small subset of texts, and segmented the data into codable units. Codes were then inductively derived from the raw data (marked in NVivo as child nodes) to capture as fully as possible the thoughts and attitudes of pedestrians toward AVs. Table 5 shows examples of data extracts with codes applied.[3] Here, the authors coded the data related to trust levels using the following words: “diminishing trust”, “facilitating trust”, “causing distrust” and “causing overtrust”. Diminishing trust means that trust is impaired to some extent, but does not reach the level of distrust. This is also the case for the term “facilitating trust”. Next, following the literature review and data extraction, the themes were established (marked in NVivo as parent nodes), and checked for their compatibility with the raw information. These contributed to the first draft of the preliminary codebook.

Table 5
Examples of data extracts with codes applied (translated into English).

Data extract	Coded for
When I see the smiling face on the front of the AV, I would trust it more… For me, it is no longer a cold machine, but rather [a system] with a warm and friendly look. (Participant 05)	Feeling friendly (facilitating trust, anthropomorphism).
… when the AV drives fast and stops too close to the pedestrian, this would be a sign of potential danger to me, and I would trust it less. (Participant 08)	Viewing AVs as dangerous to human safety (diminishing trust, aggressive driving style).

By applying the drafted codebook to a larger data set, we continued to review and refine the candidate themes in two levels through iterations (Stage 4, Fig. 4). First, the themes were assessed by the first and second authors at the level of the coded data extracts. This involved examining whether the candidate themes could “adequately capture the contours of the coded data” (Braun and Clarke, 2006, p.91), as well as whether the existing codes could fit well into established themes. For instance, during this phase a few codes failing to fit well to form a coherent pattern were discarded from the preliminary codebook. At level two, we reviewed the candidate themes again to ensure that they ‘work’ in relation to the entire data set. The raw data were re-read, following the literature review, to capture any additional inductive/deductive codes that were omitted in earlier coding stages. These steps were crucial in making the themes to accurately reflect the overall narrative of the data set (Braun and Clarke, 2006; Byrne, 2022). Given the iterative nature of the thematic analysis, the descriptive codes and themes identified in the preliminary codebook were discussed repeatedly within the research team until consensus was reached about the essence of each theme. Furthermore, we recruited an external researcher to recode a small subset of the data (e.g., one interview transcript) at this stage. Such an informal comparison of code patterns enabled us to clarify immediately any obvious misinterpretations of the themes, and to refine the coding framework before the formal inter-

[3] The verbatim text quotes and codes shown in this paper were translated into English using forward and backward translation by the first author and a qualified linguistic translator.

coder reliability (ICR) test. The above procedures (Stages 2-4, Fig. 4) were repeated until thematic saturation was achieved, with no new codes or themes emerging. The final version of the codebook is shown in Table 4.

The final codebook was tested for ICR by two independent coders (see Section 3.5.2 for more details). After its reliability was established, the first author applied the final codebook to the entire data set (Stage 5, Fig. 4). In the last phase of thematic analysis, we systematically reviewed the collated data extracts for each theme, and then organized these into a coherent and internally consistent account with supportive narrative (Stage 6, Fig. 4).

3.5.2 ICR test

We recruited a researcher external to the research team to recode a subset of the data to validate the inter-coder reliability of our codebook (Boyatzis, 1998; Parnell et al., 2018). According to O'Connor and Joffe (2020), 10-25% of data units are typically considered suitable for the assessment of coding reliability. Therefore, we randomly selected 11.1% of the participants' transcripts (i.e., four transcripts) and recruited an external researcher with a human-computer interaction (HCI) background to test the ICR. In this study, the first author was Coder 1, and the external researcher was Coder 2. First, Coder 1 segmented the subset of data included in the ICR test into data units and coded them in NVivo 12 following the codebook paradigm. Once completed, the coded file was saved. Next, Coder 1 duplicated the file and removed the applied codes from the verbatim data. A 'clean' version of the NVivo file was passed to Coder 2, which showed only the data units being segmented, but without the relevant codes. Coder 2 was then asked to independently code these data units by using the codebook as a coding framework in NVivo 12. After this, we directly compared the finished coding by using a coding comparison query in the NVivo software. Cohen's Kappa coefficient of 0.82 was obtained, indicating an excellent agreement between the two coders and a high level of ICR (Burla et al., 2008).

4. Results

Using the collected interview data, we examined pedestrians' trust in AVs based on attributes of trust. Eight themes emerged from the responses through a hybrid of inductive and deductive thematic analysis. In line with previous trust theories (e.g., Muir and Moray, 1996; Sheridan, 2019), four of the themes were objective attributes, whereas the remaining four were subjective attributes. Figure 5 shows the key factors associated with the attributes of trust identified in the pedestrian-AV context.[4]

Attributes / **Factors affecting trust**	*Traffic signals*	*Collective behavior*	*Perceived situational risk*	*Reputation of brand*	*Pre-existing knowledge*	*Driving style*	*Novelty of external appearance*	*Anthropomorphism*	*Transparency*	*Mode of communication*
Statistical reliability and dependability				26	12					
Competence			23		19					
Predictability									26	
Familiarity							1	15		
Authority/subversion	25									
Liberty/oppression										21
Care/harm		14				34				
Sanctity/degradation									8	

Fig. 5 Key factors associated with the attributes of trust identified in the pedestrian-AV context. The numerical value in each cell represents the number of participants who mentioned the corresponding theme(s).

4.1 Objective attributes

The first three objective attributes identified (i.e., *statistical reliability and dependability*, *competence*, and *predictability*) are related to the trustworthiness properties of the automation, while *familiarity* is the trust attribute of the pedestrian (Sheridan, 2019).

4.1.1 Statistical reliability and dependability

The participants' responses indicated that *statistical reliability and dependability* relate to their concerns about the occurrence of potential breakdowns and errors in an AV system. *Statistical reliability* often refers to the consistency of measurement by the system (Drasgow et al., 2007), whereas *dependability* refers to the frequency of automation breakdowns or error messages (Large et al., 2019). A reliable and dependable system is usually associated with infrequent and/or a lack of automation errors (Merritt and Ilgen, 2008). This attribute was mentioned by many participants when asked about their views on brand reputation and pre-existing knowledge. It was found that the majority of those interviewed (n=26, 72.2%) tended

[4] Some factors, such as mood/emotional state and attentional capacity, are not listed in Figure 5. As revealed in participant responses, these factors were not closely related to one specific trust/trustworthiness attribute, but rather affect the general trust of pedestrians toward AVs.

to judge the statistical reliability and dependability of an AV system based on their brand perceptions of the original equipment manufacturers (OEMs). The AVs with highly reputable or favorable brand perceptions would generally be considered more reliable and dependable than less-established brands, thus attaining a higher level of trust. As explained by one participant, "I think the manufacturers of highly reputable brands would only launch high-quality and reliable AVs to avoid damaging their reputation."

Several participants (n=12, 33.3%) also discussed the impact of pre-existing knowledge on this aspect of trust. The findings revealed that negative news coverage of related incidents or accidents could lead to a lack of trust or distrust in AVs. One participant expressed the concern that "if I have recently heard about any accidents related to automated driving or similar technologies, I would be more suspicious about the reliability of the AV system."

4.1.2 Competence

According to the study participants, *competence* (also known as *robustness*) was critical for examining their perceptions of the ability of AVs to perform a variety of tasks in different road and traffic environments (Miller and Perkins, 2010). Numerous participants mentioned this attribute when discussing the effects of perceived situational risk and pre-existing knowledge on trust in AVs.

Many responses (n=23, 63.9%) acknowledged that the increased situational risk, such as those attributed to complex road and traffic situations, or adverse weather conditions, could trigger lower trust and even distrust in the competence of AVs to guarantee safe interaction in such settings. As some commented, traffic complexities would make it much more difficult to "detect and predict the behaviors and trajectories of pedestrians" and react appropriately to any possible uncertainties encountered.

Some participants (n=19, 52.8%) highlighted the role of prior knowledge about AVs or related technologies, either obtained from the media or learned from their experience, in assisting the judgement of this aspect of automation trustworthiness. Two of the interviewees mentioned that they would rely on information from media sources, along with their test drive results[5] (if available), to assess critically the competence of AVs. If the actual competence of the system was not the same as claimed in the manufacturers' advertisements, they were likely

[5] The information from test drive may include but is not limited to such as whether the AV could "detect pedestrians well under various circumstances" and whether it could "notify the driver promptly to prevent any possible pedestrian-involved collisions".

to exhibit a lower level of trust in the AV and be more cautious as a pedestrian when crossing in front of such vehicles.

4.1.3 Predictability

Another critical objective attribute to be considered is *predictability*, which examines the matching of an AV's behaviors with the expectations of the pedestrian in a given setting (Zhou et al., 2022). Participant responses showed that this attribute was associated mainly with the transparency of AVs. On the one hand, more than half of the interviewees (n=20, 55.6%) suggested that when the AV system was predictable, such as being able to convey its intention through the information presented on the eHMI, they could better align their expectations with the system outcomes and place more trust in the same. One participant explained, "when I see the text 'safe to cross', I can at least know that the AV is now stopping and giving the right-of-way to me." Moreover, it is noteworthy that the information communicated to pedestrians may require a sophisticated design to garner appropriate trust, by following the cognitive process of how pedestrians would predict the behavior of AVs. For instance, the time at which the text 'safe to cross' began to disappear from the eHMI placed our interviewees (n=3, 8.3%) in a dilemma, "I am not sure if it means that the AV will start moving immediately or a few seconds later".

On the other hand, some participants (n=6, 16.7%) self-reported that they would exhibit overtrust in such explicit information on the eHMI. When the text "safe to cross" was present on the front of the vehicle, some believed that "the AV will certainly stop" and "allow pedestrians to cross safely". However, it should be noted that the AV may, in rare cases, display false (or at least risky) information on the eHMI, such as that induced by a malfunction of one or more components of the system (Schieben et al., 2019). Therefore, the issue of overtrust associated with the predictability of an AV system deserves further investigation.

4.1.4 Familiarity

Familiarity assesses the extent to which an AV is familiar and friendly to pedestrians (Sheridan, 1989). The participants' opinions regarding the anthropomorphism and novelty of the external appearance of AVs signified the importance of familiarity in developing human trust in AVs. It was evident from our participants (n=15, 41.7%) that the anthropomorphic features (e.g., a smiling face) could generate a sense of friendliness and familiarity to enhance their trust in AVs. One individual remarked that "when I see a smiling face displayed on the AV, I feel that it is no longer a cold machine, but rather it is creating warm and friendly feelings."

Furthermore, concerning the novelty of the external appearance of AVs, one participant provided an interesting insight indicating that trust could be negatively impacted when the outward appearance of such vehicles looked too ‘creative’ or unfamiliar to pedestrians. As commented by that interviewee, “it is likely that I will lose trust in AVs, and I am not sure how to interact with such vehicles if they look too novel to me.” Consequently, to facilitate the appropriateness of trust among pedestrians, a fine balance should be maintained between imaginative or creative forms and those with which the general public is familiar.

4.2 Subjective attributes

Our findings, reported in Figure 5, revealed the following four subjective attributes in pedestrian-AV trust: *authority/subversion*, *liberty/oppression*, *care/harm*, as well as *sanctity/degradation*. Here, the first term of each pair is considered morally acceptable for intelligent automation, whereas the second term is seen as undesirable. Pedestrians’ subjective judgements on these aspects of “automation morality” constitute the affective component of their trust toward AVs (Sheridan, 2019).

4.2.1 Authority/subversion

Authority/subversion is an attribute of trust that examines the extent to which an AV will comply with traffic laws and driving regulations during a journey. Many participants (n=25, 69.4%) stressed the role of *authority/subversion* in cultivating their trust when an AV is driven normally in urban environments with traffic signs and signals. Most tended to view the AV as law-abiding, representing a fundamental facet of the future AV setting (Millard-Ball, 2018). Some (n=17, 47.2%) expressed greater trust and willingness to walk in front of the AV at signalized crosswalks. Another interviewee explained, “I would assume that AVs are all programmed to adhere strictly to the rules of the road. They ought to stop at a red light to allow pedestrians to cross, and start moving once the light turns green.” The other five participants similarly explained that the presence of traffic signals or signs could determine authoritatively the right-of-way for all road users, thus securing the levels of pedestrians’ trust necessary for smooth and effective interaction. However, concerns about overtrust in AVs cannot be ruled out. For instance, a small number of those interviewed (n=5, 13.9%) believed that AVs will, under all circumstances, perform in accordance with the traffic lights or signs. Pedestrians might thus underestimate the likelihood of a malfunction of the AV in certain instances, particularly in traffic situations that are considered relatively simple for AVs to handle (such as at signalized intersections).

Three participants brought up another interesting point concerning the misbehavior of other road users. One participant commented, “there may be a case whereby, if a person rushes out into the street, to avoid a potential accident the AV will have to drive into the wrong lane, thereby breaking one of the rules of the road.” Therefore, to earn the trust of pedestrians, AVs should be allowed to violate traffic rules or laws in rare cases, such as when doing so would be safer than obeying the same.

4.2.2 Liberty/oppression

Participant responses regarding the modes of pedestrian-AV communication indicated the necessity of considering *liberty/oppression* in the process of building pedestrian-AV trust. This attribute is concerned primarily with people’s subjective judgements on the flexibility of an AV system in its communication strategies with pedestrians. Our findings indicated that a large number of the participants (n=21, 58.3%) had their preferred means of communication (e.g., visual, auditory, haptic, or some combination of any or all of these modalities) and expressed their views about the strengths and limitations of using each communication mode. According to some interviewees (n=14, 38.9%), different options concerning the information modalities (e.g., visual or auditory) and carriers (e.g., through eHMIs, augmented reality (AR), or smart infrastructures), should be provided if possible and necessary, which could better suit pedestrians’ preferences and needs, while also enhancing their trust in AVs. One individual stated, “in comparison to a single communication mode, I prefer AVs with a combined presentation of visual and auditory cues, and I would trust it more.” This view was echoed by another respondent, who suggested that “if the auditory cues from the environment could supplement the visual information on the eHMI, I would understand the AV’s intent more straightforwardly.”

However, to facilitate calibrated levels of trust in different traffic situations, the availability of multiple communication options can pose some challenges as to how information should be arranged and conveyed through different modalities and carriers. Some responses (n=5, 13.9%) provided evidence that overtrust may arise when pedestrians receive identical instructions (e.g., about being “safe to cross”) from different modes of communication. For example, one participant said, “if the vehicle, road infrastructure, and even my wearables all tell me that it is safe to cross the road, I would fully trust the AV. They look like a well-integrated system. It seems almost impossible that all of them could make errors simultaneously.” Consequently, this fact deserves attention, and more research efforts are required to prevent misaligned trust without compromising the flexibility of communication with pedestrians.

4.2.3 Care/harm

Care/harm assesses the degree to which an AV will care about pedestrians and their safety. This attribute was identified by most of those interviewed as essential in shaping their trust in AVs, when focusing on the influences of the AV driving styles, and the presence of surrounding pedestrians on trust. When asked about their opinions on driving style, almost all participants (n=34, 94.4%) were unanimous that an aggressive AV style would certainly impair trust and even lead to distrust. Many explained their concerns about aggressive driving in terms of its potential detrimental or harmful consequences, and the fear that "even if it makes an emergency stop, pedestrians are still likely to be hit or killed." In contrast, the defensive style of driving seemed to guarantee higher levels of trust toward AVs. Participants tended to regard a defensive AV as less likely to cause physical harm and felt safer crossing in front of such a vehicle. As one stated, "a lower speed may allow for more reaction time to prevent accidents, so a defensive driving style is desirable to me."

Some participants (n=14, 38.9%) also believed that the subjective attribute of *care/harm* was important in the context of when other pedestrians nearby began to cross the road. Many participants felt a greater sense of safety when crossing as part of a group rather than alone. They perceived that an AV was more likely to yield the right-of-way to groups of pedestrians (i.e., more than two people), especially at unsignalized crosswalks. As commented by one interviewee, "when many pedestrians are waiting or starting to cross, I think it is quite unlikely that AVs would continue moving and put the lives of pedestrians in danger." This implies the need for moral and ethical considerations in designing an AV system, to ensure that pedestrians are cared for and supported by intelligent automation.

4.2.4 Sanctity/degradation

The findings drew our attention to *sanctity/degradation*, which examines the extent to which pedestrians perceive the communication of an AV system as clear and straightforward (Sheridan, 2019). According to some participants (n=8, 22.2%), when the AV's intent was delivered using gaudy information, there may exist a degree of uncertainty and distrust. An example provided by those interviewed was the presence of a smiling face on the front eHMI. One participant pointed out that, "since the smiling face is just a symbolic cue, I am not sure whether it means to allow me to cross or not." Another interviewee also showed concern that "children may see the smiling face as playful and thus interact with the AV in a risky manner in traffic." It stands to reason that for trust calibration, ambiguous and poorly communicated information should be avoided in pedestrian-AV interaction.

5. Discussion

5.1 Eight trust/trustworthiness attributes

The themes uncovered in this study show that pedestrian-AV trust is a complicated and multidimensional construct. It reflects pedestrians' attitudes toward the trustworthiness of AVs mainly in terms of the system performance and automation morality. The eight attributes (of which four are objective and four are subjective) identified in the analysis can be reasonably used as lower-level components to examine pedestrians' trust in AVs. A comparison of the results to the early literature on trust in automation, including the theories of Muir and Moray (1996) and Sheridan (2019), indicates that the attributes constituting the trust of pedestrians are different and should be distinguished from those of users (or operators). For instance, *loyalty/betrayal* is one of the attributes applicable to trust in automation from user perspectives (Sheridan, 2019), but according to our interview data, this attribute is considered inappropriate in the context of pedestrian-AV trust. It can be argued that AVs are more likely to be designed to be loyal to the passengers inside vehicles (e.g., responding and conforming to their demands) rather than pedestrians for transportation purposes (Seymour, 2018). This also demonstrates the need to define a general concept of "trust" through its deconstruction into several lower-level measurable specifics to fit in the pedestrian-AV context.

Furthermore, the results of our study, coupled with the existing literature in this area, shed light on the interpretation of each attribute of trust in pedestrian-AV interactions (see Table 6). The current work goes beyond the theoretical framework of Sheridan (2019) by providing empirical evidence to support the fact that both objective and subjective attributes are important in determining trust between pedestrians and AVs. While objective attributes are concerned mainly with the objectively measurable trustworthiness of an AV system, subjective attributes that underpin the affective dimensions of pedestrians' trust in AVs are analogous to properties of human morality.

Table 6
Interpretations of trust/trustworthiness attributes in the pedestrian-AV context.

No.	Attributes of trust	Interpretations in a pedestrian-AV context
1	Objective *statistical reliability and dependability*	The degree to which an AV system is associated with the infrequency and lack of automation breakdowns or error messages (Large et al., 2019; Merritt and Ilgen, 2008). A statistically reliable and dependable system is

		essential for securing the level of pedestrians' trust required for safe interaction with AVs.
2	Objective *competence*	The degree to which the AV will be able to perform the variations of driving tasks in different situations (Miller and Perkins, 2010). Generally, high competence of an AV system is desired, but the tendency towards overtrust in these more competent systems should be noted.
3	Objective *predictability*	The extent to which the behavior of an AV can create predictable outcomes and match the expectations of pedestrians in a given setting (Hoff and Bashir, 2015). The information presented should consider the cognitive process of how pedestrians often predict an AV's behaviors to avoid the occurrence of miscalibrated trust (Habibovic et al., 2018; Wagner and Robinette, 2021).
4	Objective *familiarity*	The extent to which the AV is familiar and friendly to pedestrians. A sense of familiarity and friendliness is desirable to be achieved between pedestrians and AVs to improve the appropriateness of trust (Large et al., 2019). Additionally, there is a need to maintain a good balance between the imaginative forms of AVs and those with which people are familiar (Zunino et al., 2019).
5	Subjective *authority/subversion*	The degree to which the AV will perform as required by traffic rules and driving regulations on the road (Thornton et al., 2016). Only in rare cases should AVs be allowed to violate traffic rules and laws, such as when doing so would be safer than obeying the same (Brown et al., 2018; Pappas et al., 2022).
6	Subjective *liberty/oppression*	The degree to which the AV is flexible and able to offer different options with regard to information modalities (e.g., visual, auditory, or haptic) and carriers (e.g., via eHMIs, AR, or smart road infrastructures) desired by a variety of pedestrians (Dey et al., 2020). The AV system shall, insofar as possible, be resilient when pedestrians have misaligned levels of trust (if estimable), providing the information necessary for recalibrating their trust properly through different modalities and carriers (Sheridan, 2019).
7	Subjective *care/harm*	The extent to which the AV will care about pedestrians and their safety is based on its detection and analysis of pedestrians' behaviors, and an understanding and prediction of crossing intentions. Insofar as possible, it will consider the group size of pedestrians and adjust its driving characteristics (e.g., speed, yielding distance) properly when approaching pedestrians for producing little or no perceived harm (Jian et al., 2000; Thornton et al., 2016).
8	Subjective *sanctity/degradation*	The degree to which the information shown in the AV system is simple, clear, and straightforward. Poorly communicated and ambiguous information should be avoided (Hoff and Bashir, 2015). It is also worth considering the necessity for politeness in pedestrian-AV communication (Lee and Lee, 2022).

The four objective attributes identified in the analysis are commonly studied in the area of trust in automation (Miller and Perkins, 2010; Sheridan, 2019). However, unlike users who may accumulate substantial experience after a long period of driving together with an AV, in most cases pedestrians are required to interact only with the external features of AVs. It can be difficult for them to assess and align their trust with the automation trustworthiness of AVs in terms of *statistical reliability and dependability* and *competence*, based merely on their interaction experience with AVs. Rather, our findings suggest that pedestrians' judgement on these aspects relies heavily on their brand perceptions of the OEMs, and on pre-existing knowledge about AVs or similar technologies. In line with the study of Forster et al. (2018), we found that pedestrians were more inclined to view a favorable or highly reputed OEM brand as reliable. Furthermore, the kind and amount of knowledge pedestrians possess about AVs (e.g., the performance and process of an AV system) could impact significantly their trust in AVs, which is consistent with the studies of Hengstler et al. (2016) and Khastgir et al. (2018). As AVs become increasingly intelligent and complex, it should be acknowledged that many pedestrians can be poorly equipped with the knowledge (e.g., either from the media or from their past experience) necessary to reach an appropriate level of trust in AVs, particularly in the early stages of AV adoption (Reig et al., 2018). For these so-called technology novices, they tend to have an incomplete picture of what AVs are, and how they would operate and behave in traffic (Kraus, 2020), which can hinder the alignment of their trust to the actual level of the *statistical reliability and dependability*, and *competence* of an AV system. Alternatively, many pedestrians seek to use automated cues (such as the explicit information on the eHMI) as a heuristic replacement for information seeking and processing. This finding reinforces the importance of the *predictability* of the system in facilitating pedestrians' trust toward AVs (Clamann et al., 2017; Faas et al., 2020). Nevertheless, it should be noted that under such circumstances, pedestrians can be susceptible to automation bias, which is the tendency to place blind or excessive trust in automated cues without recognizing the limitations of AVs (Chiou et al., 2019; Waldron et al., 2007). This phenomenon has been observed in many other studies (e.g., Holländer et al., 2019; Kaleefathullah et al., 2022). One possible solution to this problem is to convey to pedestrians the AV's uncertainty about the traffic environment (e.g., using color or text) to prevent overtrust, especially when the AV encounters situations beyond its understanding or capability (Kunze et al., 2018; Wagner and Robinette, 2021). Lastly, the findings from our interviews show the emerging importance of *familiarity* in constituting the trust of pedestrians. In addition to revealing how a sense of friendliness and familiarity, generated by anthropomorphism, contributes greatly to their trust in AVs (Large et al., 2019), our study also stresses the need to maintain a good balance between the creative forms of AVs and those with which people are familiar in the design of AVs (Zunino et al., 2019).

The results also underscore the role of subjective attributes in trust development; this has hitherto been underexplored in the field of intelligent automation. Previous studies have suggested the use of moral norms to explain the driving behaviors of human drivers (Chorlton et al., 2012; Shukri et al., 2022). In this sense, attributes of human morality are considered applicable as subjective trust criteria (i.e., "automation morality") to judge and regulate the behavior of AVs as revealed in the interview data. For instance, Holman and Popusoi (2018) contended that moral norms are expected to play an important role in affecting drivers' decisions to violate or obey traffic rules. In line with this statement, *authority/subversion* is defined as a criterion of "automation morality" to assess the extent to which the behaviour of AVs will follow traffic rules and driving regulations. Several researchers have reported that AVs are expected by the public to be law-abiding (e.g., Diepold et al., 2017; Lengyel et al., 2020), so *authority/subversion* is an essential attribute of pedestrians' trust, especially in traffic environments where road signs and traffic signals are present (Jayaraman et al., 2019). Furthermore, it is interesting to note that participants frequently mentioned the theme of "*care/harm*" in discussing their views on the driving styles of AVs. Holman and Popusoi (2018) showed that the different driving styles (e.g., defensive or aggressive style) adopted habitually may be attributed to their possession of different moral norms. Our participants' responses indicated that, similar to human drivers, AVs could be judged according to how well they would care in moral terms about pedestrians and their safety when performing driving tasks (Thornton et al., 2016). AVs are also perceived by the participants as less likely to cause harm to them when being affected by the presence and behavior of other pedestrians nearby. Empirical evidence has demonstrated that such perceptions are directly linked to their trust-building process (Jian et al., 2000).

The participants articulated several subjective attributes with respect to the communication between pedestrians and AVs. The flexibility of an AV system in its communication strategies with pedestrians is first examined. We propose to use *liberty/oppression* to define this aspect of "automation morality". Our findings suggest that the availability of different options concerning the information modalities and carriers is merited for future AVs to better accommodate the preferences and needs of pedestrians, thereby enhancing their trust in AVs (Dey et al., 2020). However, Tabone et al. (2021) highlighted the challenges and barriers that may obstruct the successful implementation of new technologies (such as AR) in pedestrian-AV communication, including those of privacy, technological feasibility, and inclusiveness. These issues should be carefully considered along with the risk of overtrust and overreliance on the information provided among pedestrians. Moreover, *sanctity/degradation* is identified as an important attribute of trust, which examines the extent to which the information delivered to pedestrians is simple, clean, and straightforward. These findings are in line with Zhou et al. (2022), stating that the optimum type and amount of information need to be communicated clearly to pedestrians to ensure their trust is calibrated appropriately. Lee and Lee (2022) also pointed out that adopting linguistic politeness in communication can facilitate trust between users and AVs, so its value in the pedestrian-AV context deserves further consideration.

5.2 Implications and future research directions

Synthesizing the results of this study with previous work indicates that pedestrian-AV trust is comprised of both objective and subjective dimensions (Sheridan, 2019). These findings have important theoretical implications for AV manufacturers, researchers, and designers, in promoting appropriate levels of trust among pedestrians. They should not only set specifications for technical performance, but also need to integrate societal expectations of "automation morality" into the design process, such as when designing eHMIs and algorithms for motion planning (Thornton et al., 2016). However, many challenges remain in mapping moral values (e.g., *authority/subversion* and *care/harm*) to engineering specifications. For instance, AV designers will have to consider that driving in a defensive style can easily cause traffic congestion and increase travel time (Rahman et al., 2019; Tabone et al., 2021). More research efforts are needed to solve possible conflicts between stakeholders when incorporating moral considerations into the design of AVs.

The findings also provide implications for the assessment of pedestrians' trust in AVs. The deconstruction of pedestrians' trust into eight attributes allows for a more appropriate definition of trust in the pedestrian-AV context, and helps to distinguish it from that of users (or operators). Furthermore, by providing a detailed interpretation of each attribute based on interview data, our findings would serve as a basis for further research that aims to develop a questionnaire to quantitatively examine and measure the trust of pedestrians in AVs. Such a scale is essential and is seen as a prerequisite for the development and implementation of trust-targeted interventions for pedestrians (Hillen et al., 2012).

There are several areas in which future research efforts can be concentrated. First, when considering the rapid development of technology and design solutions used in pedestrian-AV interaction, future work is encouraged to critically apply those trust/trustworthiness attributes, or to explore new dimensions to explain pedestrians' trust in AVs in a coherent way under novel circumstances. For instance, pedestrians' perceptions of anthropomorphic features, such as the eye concept and the hand gesture concept, may be different from that of the smiling face concept and, therefore, deserve further investigation (Zileli et al., 2019).

Second, researchers in future studies may need to distinguish between initial and dynamic trust when attempting to assess quantitatively pedestrians' trust in AVs, based on the attributes of trust involved (Choi and Ji, 2015; Merritt and Ilgen, 2008). Initial trust represents the level of trust before any actual interaction, while dynamic trust depends on a series of direct experiences and interactions (Kopp et al., 2022). Several researchers have indicated that, given the dynamic and evolving nature of trust, it has to be measured at multiple points in time to capture a detailed understanding of the role of different attributes in constituting initial and dynamic trust, respectively (e.g., Lee and Kolodge, 2020; Merritt and Ilgen, 2008).

6. Conclusion and limitations

Trust is an important construct that mediates the relationship between pedestrians and AVs. In this study, we used immersive VR and scenario-based interviews to examine the trust of pedestrians toward AVs based on attributes of trust. A hybrid approach of inductive and deductive thematic analysis was employed to extract and interpret the attributes of trust/trustworthiness involved. The eight attributes, including *statistical reliability and dependability*, *competence*, *predictability*, *familiarity*, *authority/subversion*, *liberty/oppression*, *care/harm*, and *sanctity/degradation* were identified as lower-level components of pedestrians' trust in AVs. The major contributions of this paper are twofold. Firstly, it offers empirical grounding for trust theories, with a fuller review of both objective and subjective attributes. Specifically, this study reveals that subjective qualities such as "*automation morality*", "*care/harm*" and "*authority/subversion*" deserve significant attention for engineering goals. To the best of our knowledge, this is the first empirical study that demonstrates the importance of subjective attributes in examining human-AV trust. Secondly, detailed insights have been obtained into the relationship between each attribute and its relevant factors. This would allow researchers and designers to have a better understanding of how each attribute may arise, and how misaligned levels of trust in AVs may occur.

There are several limitations of this study that warrant discussion. Firstly, this qualitative study focuses more on exploratory insights. For the generalizability of the findings related to the attributes of trust in the pedestrian-AV context, data from larger and more diverse samples of pedestrians are required and should be examined using different methods (e.g., quantitative approaches). Second, the current sample is rather homogeneous in terms of cultural background (all Chinese pedestrians). Given the global nature of the automotive market, understanding diverse cultural perspectives of trust in AVs among pedestrians would be important for the culturally attuned design of AVs (Large et al., 2017). Although we have carefully translated the texts (such as the verbatim text quotes and codes) from Chinese to English, there are inevitably subtle differences in the word choices and the construction of phrases. Some of the intended meanings in the original verbatim data may not be accurately reflected in the translated work. Third, owing to time and budget constraints, other factors, such as different levels of driving automation, were not implemented in the VR scenarios. Lastly, when multiple factors were included in one scenario, we did not investigate qualitatively the interacting effects of different factors on the trust of pedestrians toward AVs. Such factors are required to be manipulated carefully when the interacting effects are studied.

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Appendix A

Topic list for the interview during the VR session

Scenario	Factors	Elements included	Key questions (related to specific contextual or design elements)
Scenario 01	Forward incompatibility	No driver inside the AV	• Do you think that seeing there is no person present in the driver's seat will affect your trust in the AV(s)? How and why does this affect trust?
	The novelty of external AV appearance	Sensors outside the AV	• Do you think the external appearance of the AV looks novel or not? • Do you think that the sensors outside the AV will affect your trust in the AV(s)? How and why does this affect trust?
Scenario 02	Anthropomorphism	A smiling face on the front eHMI	• Do you think that a smiling face shown on the front eHMI will affect your trust in the AV(s)? How and why does this affect trust?
	Transparency		
	Mode of communication		
	Driving style	Defensive style of driving	• Do you think that a defensive style of driving (e.g., lower speed and deceleration rate; yielding far away from pedestrians) will affect your trust in the AV(s)? How and why does this affect trust?
Scenario 03	Collective behavior	Presence of other pedestrians	• Do you think that the presence and behavior of other pedestrians nearby will affect your trust in the AV(s)? How and why does this affect trust?
	Driving style	Aggressive style of driving	• Do you think that an aggressive style of driving (e.g., higher speed and deceleration rate; yielding too close to pedestrians) will affect your trust in the AV(s)? How and why does this affect trust?
	Transparency		

	Mode of communication	A female voice saying ‘safe to cross’	• Do you think that a female voice saying ‘safe to cross’ will affect your trust in the AV(s)? How and why does this affect trust?
Scenario 04	Traffic signal	Signalized crosswalks	• Do you think that the presence of traffic signals will affect your trust in the AV(s)? How and why does this affect trust?
	Transparency Mode of communication	The text ‘safe to cross’ displayed on the front eHMI	• Do you think that the text ‘safe to cross’ on the front eHMI will affect your trust in the AV(s)? How and why does this affect trust?
Scenario 05	Perceived situational risk	Four-lane streets; mixed traffic setting	• Do you think that four-lane streets and mixed traffic settings will affect your trust in the AV(s)? How and why do these elements affect trust?

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