Child Pedestrians' Perception of External Car Display: Effects of Communication Style and Visualization Type on Trust and Perceived Safety

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Abstract

Background The use of External Car Displays (ECDs) in Autonomous Vehicles (AVs) has been verified as an effective means of communication to replace driver cues. However, there is still limited information available on child pedestrians' experiences with ECDs as particularly vulnerable road users and the design characteristics of ECDs that impact the user experience have not been thoroughly analyzed. This study examines the design characteristics of ECDs, including communication style and visualization type, and their effect on child pedestrian trust and perceived safety.

Methods To investigate the influence of ECD design concepts on child pedestrians' trust and perceived safety, we designed a within-subject study with 2 (communication styles: advisory and informative) × 3 (visualization types: text, sign and symbol) experiments. Six design concepts were presented in videos and randomly shown to the participants, who were elementary school students with a range of ages from 10 to 12 years old. We collected information about pedestrian trust and perceived safety from the answers to questions that used a 4-point Likert scale.

Results The results showed that the perceptions of child pedestrians with regards to the affirmations and uncertainty of information components in ECDs have a substantial impact on their level of trust and perceived safety towards AVs. Therefore, it is recommended to address these affirmations and uncertainties in the design of a trustworthy and safe ECD.

Conclusions This work contributes to a deeper understanding of AV-pedestrian communication from the perspective of child pedestrians and has implications for ECD design practices. Although the visualization type in this study can offer a new perspective for designing ECD concepts in future studies, we suggest that more design concepts be verified, with a specific focus on the sign and symbol category.

Keywords AV-Pedestrian Communication, External Human Machine Interface (eHMI), External Car Display (ECD), Child Pedestrian

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1. Introduction

Simple traffic cues can confuse child pedestrians in interpreting their meaning. Cars' lights indicating their intention to turn left or right can be easily understood by adults but may not be clear to children. Children also find it challenging to estimate the speed and gap distance of a distant car, making them vulnerable road users who are at higher risk than other commonly known vulnerable road users such as pedestrians, cyclists, and motorcyclists (Holländer, Colley, Rukzio & Butz, 2021; WHO, 20 June 2022). As a result, child pedestrians rely heavily on adult guidance and drivers' cues such as eye contact and hand gestures when making decisions to cross the road (Deb, Carruth, Fuad, Stanley & Frey, 2020; Gitelman, Levi, Carmel, Korchatov & Hakkert, 2019; Koekemoer, Van Gesselleen, Van Niekerk, Govender & Van As, 2017; Morrongiello & Barton, 2009; Rosenbloom, Ben-Eliyahu & Nemrodov, 2008; Schwebel et al., 2018).

However, with the advent of autonomous vehicles (AVs) in which drivers become passengers, pedestrians will no longer be able to rely on driver cues. This could be particularly deadly for children. Researchers have identified the potential for external human-machine interfaces (eHMIs) to replace driver cues and provide more information to pedestrians in FAVs (Dey et al., 2020a; Holländer et al., 2019a; Rouchitsas & Alm, 2019). They have developed various designs for vehicle sound (Mahadevan, Somanath & Sharlin, 2018), car lights (Ackermans, Dey, Ruijten, Cuijpers & Pfleging, 2020; De Clercq, Dietrich, Núñez Velasco, De Winter & Happee, 2019; Dey, Habibovic, Pfleging, Martens & Terken, 2020; Dey, Martens, Wang, Ros & Terken, 2018; Li, Dikmen, Hussein, Wang & Burns, 2018), displays (Chang, Toda, Igarashi, Miyata & Kobayashi, 2018; Chang, Toda, Sakamoto & Igarashi, 2017; De Clercq et al., 2019; Deb, Strawderman, & Carruth 2018; Holländer et al., 2019a; Stadler, Cornet, Novaes Theoto & Frenkler, 2019), smartphone haptics (Mahadevan et al., 2018), and road projections (Chang et al., 2018; Fridman et al., 2017), and found that these can increase the acceptability and usability of AVs, and enhance pedestrians' confidence, trust, and perceived safety when making crossing decisions (Chang et al., 2017; De Clercq et al., 2019; Deb et al., 2018; Holländer et al., 2019a; Rouchitsas & Alm, 2019; Stadler et al., 2019). Despite these new findings, previous studies have mostly focused on adult pedestrians, and research on child pedestrians is still lacking.

The aim of this study was to examine child pedestrians' characteristics in interpreting external car display (ECD) designs, a type of eHMI on AVs, with a focus on their trust and perceived safety. We categorized ECD design concepts into two communication styles (advisory and informative) and three visualization types (text, sign, and symbol), and we investigated child pedestrians' trust, perceived safety, and preferences. This was done using a combination of quantitative analysis through questionnaires and qualitative data analysis through in-depth interviews, providing a more comprehensive understanding.

The contributions of this study are as follows: First, our findings contribute to a better understanding of the impact of communication styles and their visualization types on pedestrians' perceptions and crossing decisions, and provide a new perspective for designing

ECD concepts for future studies. Second, the insights into child pedestrians' perceptions of ECDs can inform researchers and practitioners in developing more effective ECD design concepts for AV-pedestrian communication. Given the scarcity of research on child pedestrians' perceptions and interactions with AVs, understanding their needs and concerns can provide valuable information for developing guidelines and recommendations for ECD design concepts in AVs.

2. Related Works

2. 1. External Human–Machine Interfaces of Fully Autonomous Vehicles

In the context of AVs, eHMIs are projected to play a crucial role in not only substituting traditional driver cues, but also in enhancing pedestrian safety when making crossing decisions. Mahadevan et al. (2018) mixed visual, auditory, and physical cues in their eHMI prototypes, incorporating a speaker and smartphone haptic (Mahadevan et al., 2018). The speaker, mounted on the vehicle, played the voice of "stopping" or "starting," while the smartphone held by participants vibrated to signal that it was safe to cross.

On the other hand, visual cues are the most frequently used eHMIs, ranging from car lights to road projections (Fridman et al., 2017). Among the various visual types of eHMIs, ECDs have received significant attention and have been verified to be effective in prior studies (Rouchitsas & Alm, 2019). ECDs are typically located at the front of the vehicle, such as the front grill or window, and aim to provide information about the vehicle to pedestrians. The information conveyed through ECDs varies, ranging from symbolic graphic images (e.g., a hand and walking pedestrian) to specific textual messages (see Figure 1).

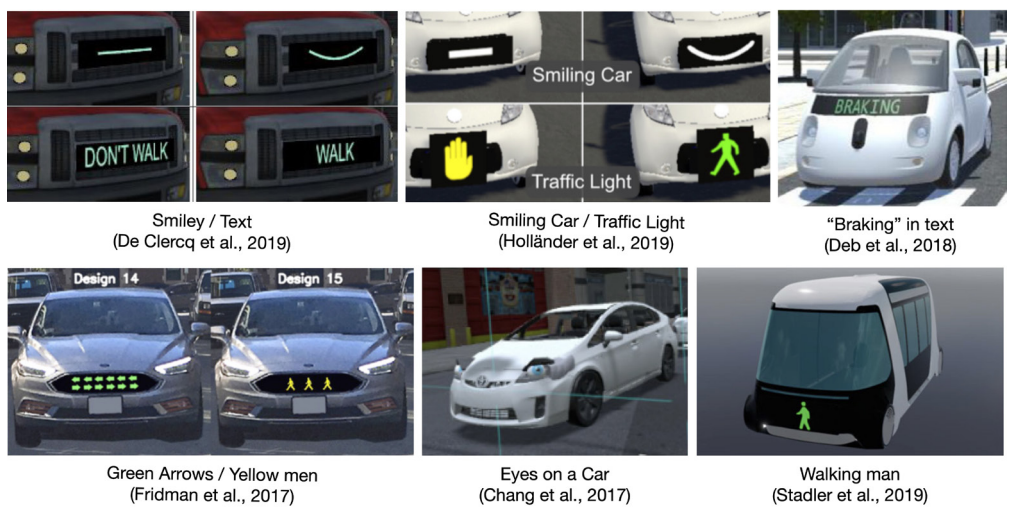

Figure 1 ECD design concepts from prior works

Similar to traditional traffic signals, ECDs that provide visual instructions to pedestrians have the potential to reduce uncertainty and enhance trust and perceived safety. Results

from prior studies have indicated that compared to conditions without ECDs, the use of ECDs leads to a more positive effect on trust and perceived safety (Deb et al., 2018; Holländer et al., 2019a; Löcken, Golling & Riener, 2019). However, further research is necessary to examine the design components of ECDs in order to enhance their effectiveness.

One aspect of ECD design that requires further investigation is the visualization type. If the different forms of representation such as text, signs, or symbols in ECD are confusing, they may reduce pedestrians' perceived safety and increase the time taken to make crossing decisions (Deb et al., 2020; Deb et al., 2018). Additionally, the appropriate communication style to be used in ECDs is also a subject of debate. There are many prior studies that have utilized advisory messages (e.g., "walk"), but it has been suggested that informative messages (e.g., "braking") may be more appropriate for enhancing safety and avoiding excessive assumptions or misleading pedestrians (Bazilinskyy et al., 2019; Cefkin et al., 2019; Habibovic et al., 2018; Liu et al., 2020; Rasouli & Tsotsos, 2019; Schaefer et al., 2016; She et al., 2021).

Although previous studies have validated the overall effectiveness of ECD designs, they have generally overlooked the specific design components that comprise these systems. In light of these considerations, it is essential to investigate the impact of the various components of ECD design, including visualization type and communication style, on pedestrian trust and perceived safety.

2. 2. Characteristics of Child Pedestrians in Crossing Decision

Child pedestrians, classified as "especially vulnerable road users," have received less attention in comparison to adult pedestrians despite having distinct characteristics (Holländer et al., 2021). Children are typically accompanied by adults and may rely on their guidance while crossing the road (Schwebel et al., 2018).

However, research has shown that relying solely on adult supervision can lead to unsafe behaviors because children trust the accompanying adults rather than learning to monitor the traffic situation themselves (Gitelman et al., 2019; Koekemoer et al., 2017; Rosenbloom et al., 2008). Based on the child pedestrians' characteristics, a study by Deb et al. (2020) found that children were more reliant on eHMI cues compared to adults and were less likely to consider other environmental factors, such as the direction and speed of the vehicle (Deb et al., 2020).

While eHMIs, such as ECDs, can provide visual instructions to reduce uncertainty and improve trust and perceived safety, they also have the potential to induce overtrust in AVs (Holländer et al., 2019b; Lee & See, 2004). Pedestrians tend to trust ECD information even when it is incorrect, which can decrease safety on the road by encouraging misuse of AVs (Holländer et al., 2019b). Child pedestrians, who are more dependent on ECDs, are at a higher risk of danger due to this induced overtrust. Moreover, children's generational characteristics, such as background knowledge and educational level, can result in unpredictable risks. A study by Charisi et al. (2017) found that while most visual intention signals were decoded correctly by children, some were interpreted ambiguously (Charisi et

al., 2017). This highlights the need for eHMI designs to consider the characteristics of child pedestrians.

3. Categorization of ECD Design Concepts

Before studying child pedestrians' characteristics in crossing decisions, we investigated ECD design concepts presented in prior studies. Some studies have classified the design concepts for ECDs according to their components, yet their focus is either too specific or too broad to be used in our study (Bazilinskyy et al., 2019; Löcken et al., 2019; Otherson et al., 2018). Otherson et al. (2018) who focused specifically on visualization style divided their design concepts into two types (i.e., lighting elements and symbols) and two dynamics (i.e., static and dynamic) (Otherson et al., 2018).

On the other hand, Löcken et al. (2019) who covered broad design components classified 28 design concepts presented in prior works using two axes—communication categories (i.e., visual, combinations of acoustic and visual, simulation of human behavior, and smart infrastructure) and complexity ranges (i.e., a simple cue, detailed cues, multiple modes of communication, and mimicking human behavior). Despite these efforts to examine various ECD design concepts, a more investigation into the components offered by ECD designs is necessary to gain a better understanding of the specific characteristics of ECDs that influence the perception and behavior of pedestrians (Bazilinskyy et al., 2019; Rouchitsas & Alm, 2019; She et al., 2021).

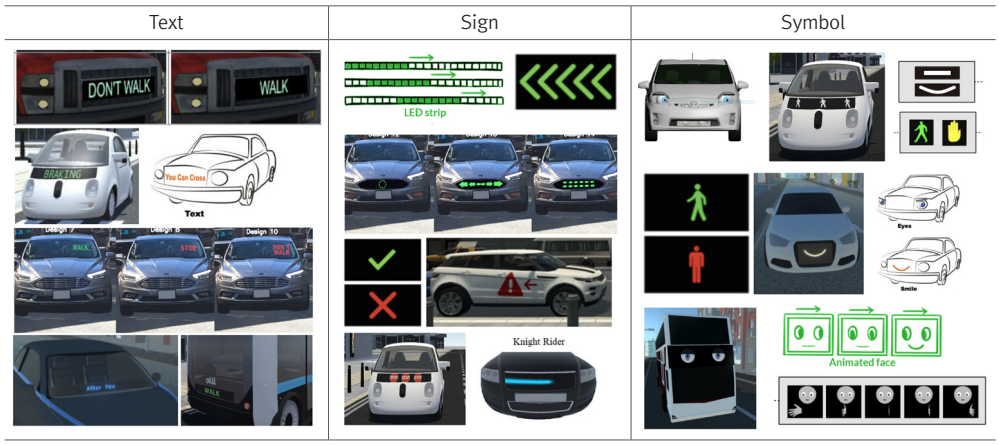

Figure 2 Outcome of categorization of ECD design concepts presented in prior studies

In this study, the design concepts of ECDs were categorized into two components: visualization type and communication style. With regards to visualization type, various ECD design concepts have been presented, and they can be grouped into three categories: texts (e.g., "Walk" or "Don't walk"), signs (e.g., arrows), and symbols (e.g., walking man and anthropomorphic smile) (see Figure 2) (Ackermans et al., 2020; Chang et al., 2018; Chang et al., 2017; Deb et al., 2018; Fridman et al., 2017; Holländer et al., 2019a; Mahadevan et al.,

2018; Stadler et al., 2019). Communication style categorization includes “advisory” which refers to messages that suggest appropriate actions to pedestrians and “informative” which delivers the status of vehicles (Li et al., 2018; Rasouli & Tsotsos, 2019; She et al., 2021). For instance, when transmitting the message “yielding,” De Clercq et al. (2019) utilized a textual message with an advisory style (e.g., “walk”), whereas Deb et al. (2018) used an informative style (e.g., “braking”).

4. Methods

Based on the literature review, we designed an experiment to test the following two research questions:

RQ 1: How do different communication styles (advisory and informative) in ECD design concepts influence/affect child pedestrians’ trust and perceived safety?

RQ 2: How do different visualization types (text, sign, and symbol) in ECD design concepts influence/affect child pedestrians’ trust and perceived safety?

4. 1. Study Design

To investigate the influence of ECD design concepts on child pedestrians’ trust and perceived safety, we designed a within-subject study with 2 (communication styles: advisory and informative) × 3 (visualization types: text, sign and symbol) experiments. Six design concepts were presented in videos and randomly shown to the participants. In the videos, there was a black car with a display presenting design concepts in the first lane of the road, and the car approached the crosswalk (see Figure 3). Physical prototypes or virtual reality (VR) were also considered but excluded in the end due to safety issues for the children participants (Kiefer, Pincus, Richardson, & Myer, 2017; Rouchitsas & Alm, 2019; Salanger, Lewis, Vallier, McDermott & Dergan, 2020).

Figure 3 Captured images of advisory–text concept stimuli simulated with 3D videos (left: the first scene of an approaching car; right: the second scene of a stopped car).

Design concepts for our experiments were created from two axes: communication style and visualization type. The communication style in our study was categorized into advisory and informative, as outlined by Rasouli and Tsotsos(2019), with an emphasis on elucidating “how

to communicate the message" from the pedestrian perspective. Concerning visualization, three distinct types(text, sign and symbol) were selected to examine information based on Langer's (1942) definition, where a sign serves as a "proxy for their objects," and a symbol represents "vehicles for the conception of objects." While acknowledging that signs and symbols may not be entirely mutually exclusive, our exploration was to delve deeper into these distinctions; specifically, sign "announce" their object, event, or situation, whereas symbols "lead him to conceive" their objects or meaning (Langer, 1942).

All the design concepts were created in a blue-green color with a black background for legibility and consistency (Faas, Stange & Baumann, 2021). We used the text type stimuli translated in Korean, reflecting the cultural context. The images of the six design concepts are shown in Figure 4.

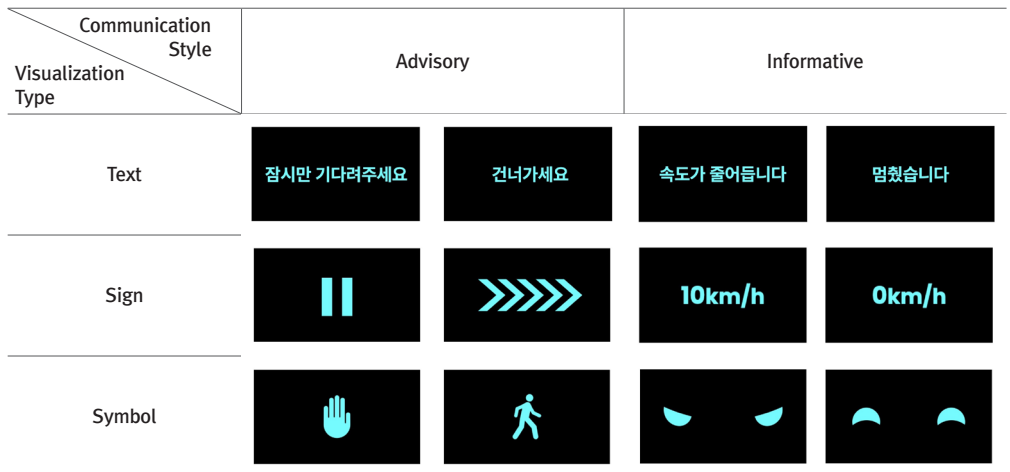

Figure 4 Six design concepts for the ECDs used in the experiment

4. 2. Measures

We collected information about pedestrian trust and perceived safety from the answers to questions that used a 4-point Likert scale. To measure trust, our operational definition of trust was "the predictability of the AV's behavior that makes child pedestrians confident when making crossing decisions," reflecting the future-oriented aspect of trust (Muir, 1987). The operational definition of perceived safety was "the feeling of being able to cross the road without danger that child pedestrians experienced at the moment of making a crossing decision," focusing on the user's perception during the interaction (Bartneck, Kulić, Croft, & Zoghbi, 2009). Based on the operational definitions, we adapted the questions from existing studies and modified them to the context of child pedestrian–AV interactions. Self-reported trust questions were adapted from a study about pedestrian trust in AVs (Jayaraman et al., 2019).

4. 3. Procedures

The sample size was calculated using G*power software. The recommended total sample size was 28 to achieve a statistical power of 95% for the 1 groups and 6 measurements with an anticipated effect size of 0.25 and a probability level of 0.05 (Faul et al., 2007; Faul et

al., 2009). A total of 38 children(25 boys, 13 girls) were recruited through posts in online communities. The participants were elementary school students with a range of ages from 10 to 12 years old (M=10.73, SD = 1.12) who could read Korean messages used in the study, and their and parental consents were obtained prior to study. All participants received a $20 reward after completing the 40-minute experiment.

All the procedures of this study were conducted online. The participants entered the online Zoom meeting room on the scheduled date and time, and each session lasted about 40 minutes. Their parents or tutors were asked to stay freely with the participants but not to intervene during the session. At the beginning of the experiment, we explained the purpose and procedure of the study and asked for permission for the video recording. No participants refused to participate or be recorded.
This study had three parts and the summary of the procedure is shown in Figure 5. This procedure was reviewed and approved by the Institutional Review Board(IRB) of Yonesi University.

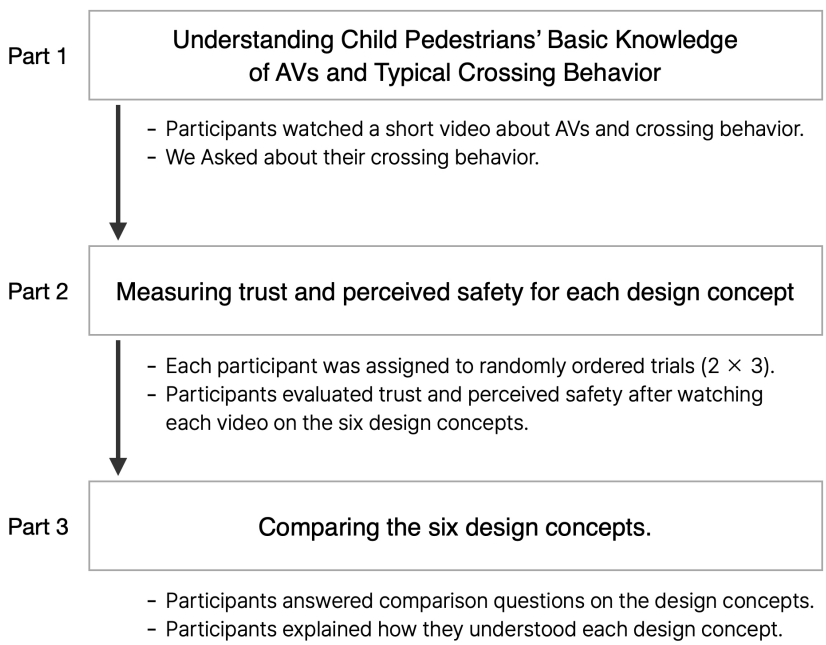

Figure 5 Summary of the procedure

4. 4. Data Analysis

The quantitative data were analyzed using IBM SPSS Statistics version 26.0. Of the 38 participants in the experiment, data for 37 were analyzed, and the answers of one who could not concentrate on the experiment were excluded. In the first step, we tested the distribution of our data using the Kolmogorov-Smirnov test, which supported the assumption of normality for both trust ($p = .06$) and perceived safety ($p = .08$). To test the main effects of communication style and visualization type, 2 (communication style: advisory vs. informative) × 3 (visualization types: text vs. sign vs. symbol) repeated-measures analyses of variances (ANOVAs) were employed (Table 1 and 2). The interview data were qualitatively analyzed using thematic analysis (Braun & Clarke, 2006) based on our interests in trust and

perceived safety. By using open coding procedures, we discovered clusters of similar topics and organized them inductively according to thematic relationships. By reiterating this process until there were no further disagreements, we finalized two main themes with three and four sub-themes each. The themes are shown in Table 3.

Table 1 Descriptive statistics

Dependent Variables	M	SD
Trust	2.14	0.31
Perceived Safety	3.00	0.49

Table 2 Summary of results in analyses of variance

Independent Variables	Dependent Variables	Multiple Comparison	*df* 1	*df* 2	*F*	*P*	η^2
Communication Style	Trust	No significant difference	1	35	3.53	.07	.09
	Perceived Safety	Advisory 〉 Informative	1	35	9.97	**.00**	.22
Visualization Type	Trust	Text 〉 Symbol	2	70	4.22	**.02**	.11
	Perceived Safety	Text 〉 Sign	2	70	5.56	**.01**	.14
		Text 〉 Symbol					
Communication Style* Visualization Type	Trust	No significant difference	2	70	2.56	.09	.11
	Perceived Safety	No significant difference	2	70	0.12	.89	.00

*Notes: Bold results are significant at $\alpha = 0.05$.

Table 3 The themes identified in relation to trust and perceived safety

Main Theme	Sub–Theme	Definition
Affirmation	About communication	Beliefs in the message communicated by the ECD
	About predictability	Beliefs in their prediction based on the ECD
	About technology	Beliefs in the automation system of the car free from humans' mistakes.
Uncertainty	About subsequent cues	Concerns about unexpected design cues that will be shown on the car after a 'slowing down' message.
	About the interpretation	Concerns about themselves or others' misinterpretation of the design, contrary to the actual intent of the car.
	About the vehicle behavior	Concerns about sudden behavioral change of the car after a 'stopped' message due to system error or other reasons.
	About the environment	Concerns about the unexpected behavior of the car on other lanes, people, or surroundings.

5. Results

In this section, we present our findings from the analysis of the quantitative and qualitative data. We follow this with a detailed description of the results of the analysis of the quantitative and qualitative data.

5. 1. Influence of Communication Style on Trust and Perceived Safety

The main effect of communication style on trust was not significant ($F[1, 35] = 3.53$, $p = .07$, $\eta 2 = .09$); however, it showed a significant effect on perceived safety ($F[1, 35] = 9.97$, $p = .00$, $\eta 2 = .22$). Advisory communication induced greater perceived safety ($M = 3.19$, $SD = .10$) than informative communication ($M = 2.80$, $SD = .11$).

The reasons for the results could be explained by two related themes extracted from the interviews. The first theme is "affirmation about communication." The participants tended to feel safe when the advisory style was shown on the ECD because they were more familiar with following instructions than making decisions themselves.

"I think this is the most dangerous. It just said 'stopped' rather than giving a direction like a traffic light." (P9, informative–text)
"The car said, 'You can cross,' so I will just follow the direction." (P17, advisory–text)

The second theme is "affirmation about technology." The greater feeling of safety from the advisory communication was based on the belief in the automation system of the car; thus, the participants believed in the instructions provided by the car.

"(How dangerous did you think?) Honestly, I never thought it was dangerous because this is the judgment based on the automation system." (P14, advisory–symbol)
"I will cross right away after the arrow is presented on the car. That's because if the car recognizes me, it will stop, wouldn't it?" (P13, advisory–sign)

5. 2. Influence of Visualization Type on Trust and Perceived Safety

The main effect of visualization type on trust was significant ($F[2, 70] = 4.22$, $p = .02$, $\eta 2 = .11$). Further analyses using multiple comparisons ($\alpha = 0.05$) revealed that there was no significant difference between text ($M = 2.25$, $SD = .08$) and sign ($M = 2.18$, $SD = .08$) or between sign and symbol ($M = 1.97$, $SD = .07$). However, the score for text was significantly higher than for symbol (95% confidence interval [CI] [0.04, 0.52], $p < .05$).

Moreover, the main effect of the visualization type was significant for perceived safety ($F[2, 70] = 5.56$, $p = .01$, $\eta 2 = .14$). Analysis with multiple comparisons ($\alpha = 0.05$) showed that there was no significant difference between signs ($M = 2.93$, $SD = .09$) and symbols ($M = 2.86$, $SD = .11$); however, text ($M = 3.18$, $SD = .10$) induced significantly higher perceived safety than signs and symbols. Additionally, the interaction effects between communication style and visualization type were not significant.

The reasons for the results could be explained by two related themes extracted from the interviews. The first theme was "uncertainty about the subsequent cues." Regardless of the communication style (informative or advisory), the participants easily understood what the next message was when the text was shown on the screen, but for the sign and symbol types, they tended not to expect what would be shown next.

"It is more accurate to show text than images because I knew it would say 'go' or 'cross' when the 'please wait' was shown on the car." (P20, advisory–text)
"I'm going to wait for a second before crossing because the image could change suddenly." (P22, advisory–sign)

The second theme is "uncertainty about the interpretation." The participants tended to be worried about the sign and symbol type due to the possibility of misinterpretation by both themselves and others.

"I thought it could be dangerous because people might interpret it differently." (P7, informative–eyes)

"When the younger children only glance briefly at it, they don't know what it means." (P34, informative–sign)

"This is a little bit dangerous. People could bump into the car if they don't understand the meaning." (P2, advisory–symbol)

5. 3. Comparisons of Six Design Concepts

In this section, we demonstrate the frequency analysis for comparison questions of trust, perceived safety, and preference for all six design concepts. The results were consistent with the preceding outcomes but provided somewhat different insights since we allowed multiple responses. A summary of the frequency analysis results of the comparison questions is shown in Figure 6.

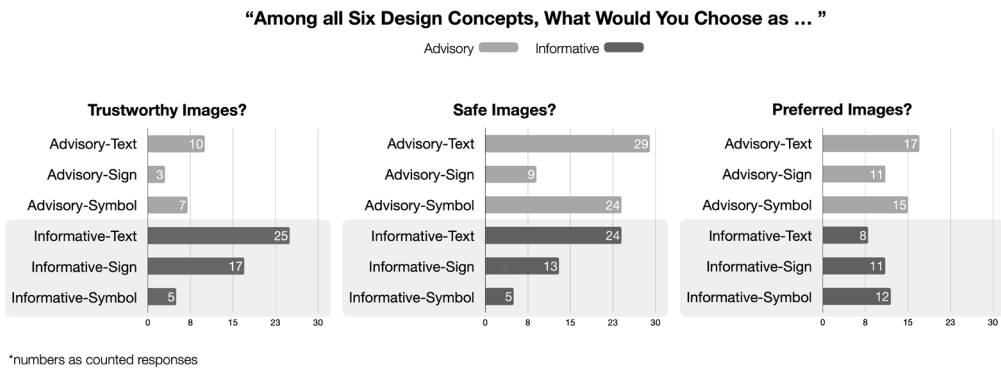

Figure 6 Frequency analysis results of the comparison questions

5. 3. 1. Comparison of Trust

Regarding the multitude of responses dealing with the trustworthiness of the design concepts, 25 participants (37.3%) selected informative–text, 17 selected informative–sign (25.4%), 10 selected advisory–text (14.9%), 7 selected advisory–symbol (10.4%), 5 selected informative–symbol (7.5%), and 3 selected advisory–sign (4.5%) to be the most trustworthy. The quantitative results did not show significant differences in the preceding sections; however, the comparison questions that allowed multiple responses showed that the informative communication was often considered trustworthy (Figure 6, left). One of the related themes that can explain this is the "affirmation of predictability." The participants tended to trust their crossing decisions, which they made by predicting the car's behavior.

"I'll choose the second one because this word means it is completely 'stopped' literally." (P20, informative–text)

"It shows [the car is] gradually slowing down in numbers, so I can be certain it will stop." (P36, informative–sign)

The other related theme is "uncertainty about the environment." Some participants were concerned about sudden changes in their surroundings, such as other moving cars in the next lane, although advisory communication may still appear in the focus car. In this case, they could trust informative messages that were more trustworthy because they displayed the current status of each vehicle.

> "I'm worried about the truck in the next lane. I don't know whether the truck will keep moving even though the car said 'cross now.'" (P31, advisory–text)
> "How can I believe the message (cross now)? There is a truck in the next lane." (P4, advisory–text)

5. 3. 2. Comparison of Perceived Safety

Regarding responses to the safety afforded by the design concepts, 29 participants (27.9%) chose advisory–text, 24 chose advisory–symbol (23.1%), 24 chose informative–text (23.1%), 13 chose informative–sign (12.5%), 9 chose advisory–sign (8.7%), and 5 chose informative–symbol (4.8%) as the safest models (Figure 6, middle). The advisory communication style and text message were most often chosen as best at ensuring safety, which is consistent with the results in the preceding section, indicating that the participants felt safe when complying with the instructions, knowing the following cues, and having confidence when interpreting the ECD design. This is related to the themes "affirmation about the instruction," "uncertainty about the subsequent cues," and "uncertainty about the interpretation."

> "I'll select the sixth one because the symbols are just the same as the traffic light. I can just follow the signals." (P26, advisory–symbol)
> "I do know what will come up after the first text, 'please wait,' so I think it is safe." (P12, advisory–text)

Furthermore, the advisory–symbol was also chosen the most as the design that provided a feeling of safety, unlike the quantitative results in the preceding section that revealed symbols were not considered safe. We interpreted this to be the result of consistency in the participants' mental models and familiarity with images in traffic lights.

> "It makes me feel safe because I'm familiar with these images." (P35, advisory–symbol)
> "I've especially seen the sixth one a lot. It is the traffic light." (P10, advisory–symbol)

5. 3. 3. Comparison of Preferences

Regarding the preferred design concepts, 17 participants chose advisory–text (23.0%), 15 chose advisory–symbol (20.3%), 12 chose informative–symbol (16.2%), 11 chose informative–sign (14.9%), 11 chose advisory–sign (14.9%), and 8 chose informative–text (10.8%) (Figure 6, right). There was no significant difference in terms of distribution. However, there were some notable differences in pattern, unlike the preceding results for trust and perceived safety (Figure 6, left and middle), which showed a higher preference for the informative–symbol type compared to informative–sign and informative–text (Figure 6, right). This can be explained by the participants' emotional responses to the design concept for ECDs as follows:

"It's fun. It feels like a human." (P17, informative–symbol)
"The annoyed face and smiling face are so cute" (P35, informative–symbol).

Overall, the participants' understanding of the design concepts was consistent with our intentions, but some interpreted specific design concepts slightly differently than expected. For example, the "km/h" sign used in the informative–sign concept was read as the distance between the car and crossroad since some participants were yet to learn what "km/h" means. Nevertheless, it was interesting that the children perceived the decreasing numbers to mean that the car was slowing down. The "pause" design used in the advisory–arrow concept was interpreted to mean the car was in play mode, as some participants correlated the two-stick image with YouTube video-playing functionalities. There was a response that the "hand" sign in the advisory–symbol model was the car saying "hello" to pedestrians.

6. Discussion

The present study revealed that the perceptions of child pedestrians with regards to the affirmations and uncertainty of information components in ECDs have a substantial impact on their level of trust and perceived safety towards AVs. Our findings highlight the importance of considering the themes of affirmation and uncertainty during the design process of ECDs for child pedestrians. This approach could enhance trust in AVs while preventing an excessive level of trust.

6. 1. Addressing Pedestrians' Affirmation about ECD Design Concepts

The affirmations about the ECD design concepts were explained using three themes: communication, predictability, and technology (see Table 3). The child pedestrians who were accustomed to following adults' advice largely trusted and felt safe when the ECD communicated direct advice. These perceptions were based on initial trust in the technology of automation systems in AVs. However, when the participants were required to make crossing decisions on their own, they found informative messages that communicated the vehicle's current actions to be trustworthy, as it was easy to predict the vehicle's behavior. These findings align with previous research, which showed that child pedestrians rely heavily on adult or ECD instructions (Deb et al., 2020). Therefore, designers of ECDs should be mindful of these affirmations to avoid overtrust. Earlier studies have suggested that AVs should use informative messages instead of advisory ones to prevent overtrust, as AVs cannot guarantee that other road users would not put pedestrians at risk (Rasouli & Tsotsos, 2019; Schaefer et al., 2016). However, there are advantages to using the advisory communication style in terms of trust and perceived safety, as demonstrated by the results of the current study (Carmona, Guindel, Garcia, & de la Escalera, 2021).

Therefore, to address the issue of overtrust, we recommend to use both advisory and informative communication styles, each for a different purpose. Colley et al. (2021) proposed a concept using parked AVs on the roadside to search for the surroundings and give warning

messages to pedestrians to increase pedestrian safety (Colley et al., 2021). However, they found that this message sometimes puts pedestrians at risk when misinterpreted as advice due to overtrust. We may consider informative communication when delivering surrounding situations, whereas advisory communication may be used when advising crossing behavior. For example, when an AV communicates the advice "cross now" on an ECD, it could also show the information "I will stop and other lanes are empty" on the edge of the ECD to remind us that there are uncertainties about other vehicles' behaviors and the environment. However, this may lead to the display of more information than has been proposed earlier, which may consequently increase pedestrians' cognitive loads (Colley et al., 2021; Holländer et al., 2019a; Mahadevan et al., 2018). Therefore, future studies should explore how to visually display more detailed information without increasing cognitive load. Some potential solutions from prior research include using other types of visual cues or modalities (e.g., lights, sound, and smartphone haptics), and mixed location on a vehicle (e.g., bumper and windshield) (Dey et al., 2020c; Dey et al., 2021; Löcken et al., 2019; Mahadevan et al., 2018).

6. 2. Addressing Pedestrians' Uncertainty about ECD Design Concepts

The uncertainties about the ECD design concepts were explained using four themes: subsequent cues, interpretation, vehicle behavior, and environment. As discussed in the preceding section, the uncertainties related to vehicle behavior and environment can be leveraged to regulate affirmations and prevent overtrust. However, to enhance trust and improve the perceived safety of AVs, it is crucial to address the uncertainties related to subsequent cues and interpretation as well (see Table 3).

For instance, some participants expressed concerns about the lack of clarity surrounding the subsequent cues that would follow the "slowing down" message displayed on the ECD. Additionally, they expressed uncertainty about the accuracy of their interpretation of the various design concepts presented in the ECD, particularly in regards to signs and symbols. While the use of text-based messages may alleviate these concerns, signs and symbols have more advantages of being universally accessible to people who are illiterate or who do not understand a particular language, as noted by the participants.

Based on the findings of the study, two strategies are proposed to address the uncertainties expressed by child pedestrians in relation to signs and symbols in ECD. Firstly, it is suggested that the design concepts of the ECD should align with child pedestrians' mental models, especially when utilizing symbols or signs. The participants in this study expressed concerns regarding signs and symbols, however, they favored the advisory-symbol concept in terms of safety as they were already familiar with the symbols, such as "walking pedestrian" and "upraised hand," commonly found in traffic lights (Holländer et al., 2019a). Secondly, it is proposed that the design concepts of the ECD should take into account aesthetic and emotional aspects. The study found that the informative-eyes concept, which incorporated eye expressions, was preferred when participants reported high emotional satisfaction, as opposed to low levels of trust and perceived safety.

Although previous research has investigated anthropomorphic designs similar to eye expressions in ECDs, the aesthetic aspects that elicit emotional satisfaction have been rarely

considered (Chang et al., 2017; Mahadevan et al., 2018). This highlights the need for future research to explore novel design concepts that take into account users' preferences and emotional satisfaction, which can indirectly mitigate negative emotions such as worry or distrust arising from uncertainty.

6. 3. Limitations and Future Work

Our study has several limitations that require further exploration in future research. Firstly, while our research focused on child pedestrians, a comparative study between children and adults is necessary to better understand child pedestrian behavior (Deb et al., 2020). Our findings indicate that child pedestrian characteristics and familiarity with instructions can impact trust and perceived safety of ECD design concepts. Future research should investigate differences between children and adults in terms of their responsiveness to information design components. Secondly, it would also be useful to thoroughly measure the initial knowledge of and trust in Avs; for example, scales suggested by a previous study (Deb et al., 2017) can be used to determine the effect of child pedestrians' initial knowledge of AVs on the results. Raats et al. (2020) pointed out that trust in AVs is established on initial trust prior to interaction, referring to Hoff and Bashir (2015), yet our study only measured children's crossing behavior and their general understanding of AVs (Hoff & Bashir, 2015; Raats, Fors, & Pink, 2020). Lastly, the six design concepts presented in this study are limited examples that require further exploratioin. Although the visualization type in this study can offer a new perspective for designing ECD concepts in future studies, we suggest that more design concepts be verified, with a specific focus on the sign and symbol category.

7. Conclusion

In this study, we explored the effect of the design of ECDs' communication style and visualization type on child pedestrians' trust and perceived safety. The findings indicate that child pedestrians exhibit both affirmations and uncertainties in relation to ECDs, necessitating a dual approach to increasing trust while avoiding overtrust. To address the affirmations, we propose the implementation of advisory communication in conjunction with context-based informative messages. To address the uncertainties, it is recommended to preserve child pedestrians' existing mental models and to incorporate design elements that evoke positive emotions in the ECD design concepts.

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