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Assessing the influence of show, don’t tell principle on external human-machine interfaces across cultures

Master’s thesis in Mobility Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY

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Cover: Snippet of the actual test illustrating a Blinking Red LED strip eHMI.

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Abstract

Together with the shift towards green renewable energy sources, the automotive industry is currently witnessing a rapid advancement in the context of *autonomous vehicle technology.* In this setting, the way in which the autonomous vehicle interacts with the vulnerable road users will be indispensable both in terms of safety and acceptance. Therefore, understanding the societal perceptions and cultural influences on the *external human-machine interfaces (eHMIs)* has become significant. This research investigates the intersection of social constructivism and the *show, don't tell* principle within the context of eHMIs for autonomous vehicles. Grounded in the hypothesis of social constructivism and technological insights from the *show, don't tell* principle, the study aims to analyse the alignment between the current theoretical frameworks and the practical design solutions. Specifically, it explores how cultural factors impact the acceptance and effectiveness of eHMIs among pedestrians. In order to achieve autonomous driving with minimal or zero human intervention, seamless integration of these vehicles into complex urban traffic is required. This research suggests that the development of culturally sensitive design solutions may facilitate the harmonious co-existence of autonomous vehicles and vulnerable road users in urban landscapes.

Keywords: Autonomous vehicles, external human-machine interfaces, culturally sensitive, dynamic human-machine interfaces, vehicle-pedestrian interaction, urban traffic, vulnerable road users.

Preface

This study is an attempt to assess the influence of external human-machine interface designs across different cultures. The report presents the outcome of my master's thesis project carried out at the Department of Mechanics and Maritime Sciences at Chalmers University of Technology during the spring of 2024.

Acknowledgements

I offer my sincere gratitude to Ola Benderius for supervising the work and providing invaluable guidance throughout the project, including report writing. I appreciate him spending his precious time regularly to ensure the swift continuation of the thesis. Additionally, I am grateful to all the test volunteers who made it possible to conduct the tests in a safe and secured manner without hampering the real-traffic. Last but not the least, I would like to thank all the survey participants for their unbiased and insightful responses.

Shouvanik Saha, Gothenburg, June 2024

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Introduction

The exponential increase in the technology readiness levels of autonomous vehicles (AVs) makes it quintessential to take into account the values which various automated and autonomous driving functions would add to the perception of its external surroundings. As we are moving towards a future with zero human intervention, an effective and smooth integration of these vehicles into complex urban environments has become cardinal. By capitalising on the hypothesis of social constructivism [2], in the context of external human-machine interfaces (eHMIs), this research focuses on investigating how the current theoretical frameworks and practical design solutions align with the *show, don't tell* principle [7][8]. The main idea of this study is to explore and analyse whether cultural factors of pedestrians influence the acceptance and effectiveness of such eHMIs. As the market potential in autonomous vehicles is emerging, it is constitutional to take into account the interaction between the occupants and the vehicle's internal and external systems as an important aspect of user satisfaction and safety [4]. In the context of designing suitable eHMIs for autonomous cars, there is an inadequacy in the available design frameworks, hindering the seamless development of design concepts [1]. Current eHMIs often lack the artistry required for a harmonious interaction with pedestrians and other road users, particularly in a culturally diverse setting. Also, the demonstrated concepts of eHMIs tend to initiate a direct contact with pedestrians, which is not viable for complex road conditions—indicating that a shift towards dynamic and culturally sensitive eHMIs are required with good contextual awareness [9][10]. With increasing automation levels, the complexity of vehicles increases proportionally. Most people do not have the ability and the motivation to fully understand all the functions of these advanced systems. Consequently, they might struggle to trust such technology. Trust is an important aspect for the drivers to accept highly automated vehicles [10]. This chapter reviews existing all eHMI design concepts used for AV-pedestrian communication, highlighting both their strengths and limitations. While most of these designs—using text, symbols, and other visual cues—enhance vehicle-pedestrian interactions, they often rely on explicit communication, which may not be effective in all cultural settings. This research instead focuses on a different approach, rooted in the *show, don't tell* principle, aiming to reduce explicit signals in favor of more intuitive, culturally sensitive visual cues. By understanding existing methods, this study sets the stage for exploring this new design direction.

1.1 eHMIs for AV-pedestrian interaction

Effective vehicle-pedestrian interactions are crucial for the acceptance and safety of AVs. Traditional nonverbal cues, such as gestures and eye contact, are essential for safe interactions but are absent in AVs. eHMIs have been proposed to fill this communication gap, providing clear and understandable signals to pedestrians [31]. Studies show that eHMIs, especially those using text, significantly improve crossing efficiency compared to graphic-based systems, as textual information is easier to understand [17][34].

Building on the latest developments and insights in the areas of *human-machine* interfaces and AVs, interactive information should be presented in phases: trigger *indicating intent*, contact *guiding pedestrians*, and end *confirming status*. Early and clear communication is recommended to give pedestrians sufficient time to respond, enhancing their trust in AVs [15][30]. The usefulness of eHMIs also depends on cultural and contextual factors, necessitating designs that consider regional differences and pedestrian familiarity [23][24].

According to Lagström and Lundgren, when encountering a fully autonomous vehicle, pedestrians may perceive a decrease in safety mainly because of the fact that these vehicles does not occupy a considerable part in the human culture yet. The research suggests that eHMIs could potentially offer better vehicle-to-pedestrian communication specifically in complex traffic crossings [43].

eHMIs serve as secondary information sources for pedestrians, influencing their crossing decisions. Eye contact between pedestrians and AVs, facilitated by eHMIs, significantly increased perceived safety and reduced decision-making time. Interfaces displaying AV intentions improved perceived safety and comfort, highlighting the importance of eHMIs in negotiation situations [29].

Research indicates that unsafe vehicle-pedestrian interactions often result from either drivers failing to yield or pedestrians making risky crossing decisions. To address these problems, AVs are expected to adopt a conservative strategy, yielding to pedestrians when their crossing intent is detected [22][32]. This strategy necessitates effective communication of AV intentions, which can be facilitated through eHMIs. Studies have shown that pedestrians are more likely to cross when encountering AVs equipped with eHMIs, suggesting increased interaction efficiency [15][34].

1.2 Comparison of eHMI designs

Different methods, including images, videos, and virtual reality have been used to study eHMI effects. Four categories of information are suggested for eHMI design are vehicle status, AV intention, AV environmental perception, and AV cooperation capabilities. Studies show that *status & intent* eHMIs enhance user experience, with egocentric messages being clearer to pedestrians. Textual and symbolic eHMIs are user-friendly, especially for those unfamiliar with traffic rules, due to their low learning cost [42][38].

However, implicit communication remains dominant. Pedestrians often rely on vehicle motion patterns rather than eHMI displays. Cultural differences and demographic factors influence eHMI preferences, suggesting the need for tailored designs considering specific regional symbols and expressions [39].

Experimental designs, such as adding *eyes* on AVs to mimic eye contact, have been found to improve pedestrian decision-making speed and safety [15]. However, some studies indicate that eHMIs might only increase perceived risk without significantly altering crossing behavior [28]. This implies that pedestrians might still rely on traditional gap acceptance strategies, such as judging vehicle speed and distance, rather than solely on eHMI signals [16].

To achieve seamless integration of AVs into traffic, Nissan enlisted anthropologist Gitti Jordan and a team of social scientists to define what *socially acceptable* driving entails. This interdisciplinary approach emphasized the social nature of road use, where human interaction is crucial for navigating traffic. Ethnographically informed research played a crucial role in this context, providing insights grounded in social science, before adapting these findings to engineering needs [39]. Road interactions are inherently social, involving the interpretation of cultural signs and signals to interact with others. Many road rules depend on human judgment, which AVs struggle to replicate. This highlights the contrast between social science and AI research, as human behavior is contingent and non-algorithmic. Understanding pedestrian behavior requires considering its social context, which is essential for developing effective eHMIs [40][38]. AVs must engage in real–time negotiations based on the behaviors of other road users, adapting to be good *social partners*. Nissan's concept of an interactive light strip aims to replace *hand–waving* and *eye–gazing* with visual signals, though current technology limits this to displaying intentions rather than real-time interactions. This *intention indicator* concept emphasizes the importance of considering social dynamics in AV design [42].

1.3 Challenges in eHMI design for AVs

A significant problem in the design and implementation of eHMIs for AVs is the lack of detailed descriptions of interface functionalities in specific situations, which complicates the understanding of the underlying concepts of many eHMIs. Moreover, the lack of a shared understanding of how these communication interfaces function has made it challenging to develop a consistent approach for addressing their various uses. Another critical challenge is the need for AVs to communicate effectively with other road users (ORUs), including vulnerable road users (VRUs) such as pedestrians and cyclists, to achieve the *vision zero* goal of zero traffic fatalities proposed by the European Commission [37].

1.4 Cultural constructs in eHMI designs

According to some expert and focus-group interviews conducted by Chan Lee and others in 2021 [45], it was hence confirmed that there is a cultural impact in developing an *internal* HMI (iHMI) for autonomous vehicles. In the context of iHMIs, passengers while sitting inside a fully autonomous vehicle (FAV) are bound to get engaged in various activities such as sleeping, eating, monitoring vehicle status, making phone calls, watching movies or using social media. And due to this, it was found that people coming from different cultural backgrounds hold varying perception towards the advantages and the disadvantages associated with FAVs. But when it comes to eHMIs, the level of intricacy multiplies—they are not only required to convey the vehicles' intention to the road users, but also to capture and understand their behavioral intentions. This widens the perspective of implementing an eHMI developed based upon *show, don't tell* (SDT) principle—which means, in order to reduce the complexities involved, the primary focus should be on how to deliver and project the intention of an FAV to the road users.

Integrating cultural constructs into design education enhances cross-cultural awareness and prepares students for global collaboration. Culture, learned rather than inherent, influences attitudes and behaviors towards external stimuli, making cross-cultural learning vital in design [35][12][20]. Empirical evidence supports the benefits of intercultural experiences, such as design study tours, in fostering cultural intelligence and creative outcomes [20][30].

These educational practices help students appreciate cultural diversity and apply cultural insights to practical design challenges. For example, participation in intercultural projects enables students to transfer abstract cultural concepts into tangible design solutions, promoting innovative thinking and a deeper understanding of different cultural contexts [36].

1.5 Importance of eHMIs in pedestrian safety

In a study conducted by Guo and others, it was found that 68.5% of participants felt safer crossing streets with eHMIs that included *green*, *text*, *symbols*, or *dynamic* features. eHMIs positively affect vehicle-to-everything communication, with textual eHMIs being particularly clear to pedestrians [47]. In mixed traffic environments, explicit communication is necessary to compensate for the lack of implicit cues, especially in ambiguous scenarios like parking [41]. In a study involving several volunteers conducted by Habibovic, participants reported feeling significantly less safe when encountering an AV without an external interface. This suggests that user-centric eHMIs could enhance the overall user experience and provide pedestrians with an improved sense of safety [46].

1.6 Public acceptance of AVs

Despite the potential benefits of AVs, public acceptance remains low, posing a significant barrier to widespread adoption. Surveys indicate that safety concerns and a lack of trust are major factors hindering acceptance [11][26][33]. Trust in AVs is influenced by their perceived performance, process, and purpose, with safety measures being crucial for building trust [5][19].

Trust is an integral aspect towards the acceptance of highly automated vehicles. The complexities in such vehicular systems increases exponentially with an increase in the level of automation. However, many individuals lack both the capacity and readiness to encompass these complex systems, leading to potential trust issues with such vehicles when they are out on the roads. And, because of this, in his paper, Parasuraman came to a conclusion that HMIs (both internal and external) should be intuitive so that it clearly conveys what it intends to do [6]. A culturally-sensitive eHMI could help to build trust, thereby increasing its acceptance among the users.

For AVs to gain public trust and achieve market penetration, it is essential to enhance their perceived safety and reliability. Clear and effective communication using eHMIs can greatly enhance the interaction between autonomous vehicles and pedestrians. Addressing these trust issues is key to overcoming legislative barriers and achieving large-scale adoption of AVs [21][25][27].

Pedestrian understanding of AV intentions can vary based on the design and familiarity with the eHMI messages [23][24]. While assistance information from AVs aids safer crossing decisions, the overall impact on decision-making remains modest, suggesting pedestrians' reliance on legacy behaviors [18]. This underscores the need for further exploration into the optimal design and implementation of eHMIs to enhance pedestrian safety [32] [29].

1.7 Aim

The primary objective of this thesis is to explore application of *show, don't tell* principle in the design philosophy of eHMIs in AVs, specifically for complex urban environments. The ultimate goal of this research is to investigate the impacts of integrating dynamic response and humane awareness in a comprehensive manner, so that it can contribute to build a shared and common societal understanding of vehicle behavior in the era of fully autonomous vehicles. These are the research questions:

- How is the research community currently harnessing the *show, don't tell* principle and social constructivism theory in the development of eHMIs for AVs explicitly addressing complex traffic conditions in urban intersections?

- How do cultural differences in pedestrians influence the acceptance and effectiveness of eHMIs in AVs which are designed based on the *show, don't tell* principle?

1.8 Limitations

Before reflecting upon the limitations, the common short–comings of these kind of literature–based survey analysis is usually the limited availability of data or responses. Cultural sensitivity often leads to stereotyping and generalizations, specially in a complex and diverse environment such as a city intersection point. Despite of good results and successful outcome, individual preferences and perceptions might hamper user acceptance and effectiveness of external HMIs [5].

This study has certain limitations primarily related to the distribution and reach of the survey. The questionnaire was shared exclusively through social media groups, leading to a sample that was largely limited to those with internet access and active engagement on such platforms. This method inherently restricted participation to a specific segment of the global population, possibly skewing the demographics towards younger, tech–savvy individuals. As a result, the data collected may not be fully representative of broader, more diverse populations, particularly those from regions with limited internet access or differing social media usage patterns. Consequently, the findings should be interpreted with caution, as they may not accurately reflect the perspectives of a wider demographic spectrum. Further studies with more inclusive and varied distribution methods would be necessary to validate the results on a global scale.

2
Theory

This chapter delves into two pivotal theoretical frameworks: the *show, don't tell* (SDT) principle and social constructivism theory, both of which play crucial roles in the design of external human-machine interfaces (eHMIs) for autonomous vehicles (AVs). The SDT principle advocates for the use of visual and non-verbal cues to convey AV intentions, enhancing clarity and trust among road users. This approach avoids explicit verbal communication, aligning with social constructivism to foster a shared understanding of AV behaviors across diverse cultural contexts.

2.1 The *show, don't tell* principle

The SDT principle in AV development emphasizes the importance of implicitly communicating the AV's intentions without directly addressing specific road users. The principle suggests that instead of using direct verbal commands, vehicles should rely on visual cues and behaviors that pedestrians can interpret naturally—much like how humans intuitively understand the actions of animals or other humans without explicit instructions [14][13]. A study by Rasouli and Tsotsos in 2019 reviewed various eHMI concepts and found that visual signals, such as light patterns and displays, effectively convey AV intentions without verbal explanations, aligning with the *show, don't tell* approach [29]. These visual cues help pedestrians and other road users anticipate the AV's actions, thereby improving safety and reducing uncertainty.

The implementation of the SDT principle as a design concept for eHMIs would mean that the vehicle will always clearly demonstrate its planned actions, but without any further motivation [2]. The focus should be on designing eHMIs that are universally understandable without being overly directive, enhancing pedestrians' trust and confidence. For instance, when a pedestrian and a cyclist are approaching a crossing simultaneously, the FAV should clearly indicate its intention to halt and wait without any explicit reason for the action. This deliberate exclusion is also justified by the theory of social constructivism [44] which aims to avoid any kind potential misunderstandings between the pedestrian and the cyclist. By refraining from providing detailed justifications, the design concept prioritizes a culturally shared understanding of the vehicle's overall behavior, thereby omitting explicit interaction with the road users. Therefore, if implemented, this design ideology will not require any previous understanding or knowledge of various isolated scenarios which could hamper overall perception towards FAVs [2].

2.2 Theory of social constructivism

Social constructivism theory posits that knowledge and meaning are constructed through social interactions and cultural contexts. In the realm of AVs, this theory suggests that effective communication between AVs and humans must consider the social and cultural norms that govern road use behaviors. Research by Merat in 2018 highlights the importance of designing AV interfaces that reflect social norms and expectations [41]. Their study on pedestrian–AV interactions demonstrated that culturally informed eHMI designs significantly impact pedestrian trust and crossing decisions, underscoring the relevance of social constructivism in AV design.

As of now, there are no clear conventions for designing an eHMI, and most importantly none of the existing design prototypes has taken into account the cultural aspect while developing the HMI. But, based on the theory of social constructivism [44], the motivation for this coherence is to find an accepted design, which over time will act as a culturally shared understanding of vehicle behavior and intention. The design platform for this work is based on this theoretical framework, which suggests an overall design with few contradictions and with good possibilities for global standardization.

Ethnographic studies provide valuable insights into the social dynamics of road use, informing the design of AVs that can seamlessly integrate into human environments. For example, the work of Walker [42] involved video analysis of pedestrian–vehicle interactions, revealing the nuanced ways in which people negotiate crossings and interpret vehicle behavior. These findings support the development of eHMIs that mimic human-like communication methods, such as subtle movements and eye contact, to signal AV intentions effectively.

3

Methods

This methodology section describes several key steps that is taken to carefully evaluate if there are any cultural impact of different eHMIs for AVs on the pedestrians. According to existing research and industrial developments, potential HMI design concepts based on the SDT principle are chosen for further investigation. A test scenario is prepared where a test car is virtually fitted with the each of the chosen HMI types. The test vehicle is made to steer towards a pedestrian crossing in a realistic urban traffic. The test event is recorded, post-processed and is presented in the form of an online survey in order to receive responses from people of different cultural backgrounds. Statistical methods are adopted to analyse the survey responses with an intention to find any cultural effect on chosen HMI design concepts.

3.1 Preparation and conduct of the test scenario

A test vehicle is made to navigate towards a pedestrian crossing with a volunteer crossing the street at the exact same time. Three cameras were set up:

- The first one at the sight of the test scene to capture the interaction between the car and the pedestrian—giving an overall perspective of the test event.

- The second one on the head of the volunteer crossing the road to capture the state of the eHMI of the test vehicle approaching from the front.

- The last one on the dashboard of the test vehicle capturing the intention and motive of the pedestrian who is about the cross.

The test vehicle is manually driven at a controlled speed of around 30 kmph, making sure that it did not cause any hindrance to the already existing traffic on road. The recorded video is post-processed by simulating four different kinds of eHMI based on the SDT principle:

1. **Blinking green and red LED strip**: the external HMI starts throbbing in green and red as soon as the sensors detected that a pedestrian is crossing the street as seen in figure 3.1(a) and (b).

2. **Blinking red LED strip**: the eHMI starts blinking in red in the presence of a pedestrian as seen in figure 3.1(c) and (d).

3. **LED strip of varying width**: based upon the distance between the car and the pedestrian, the width of the LED strip varies. The width of the strip increases as the gap between the car and the pedestrian decreases as seen in figure 3.1(e) and (f).

4. **Blinking blue and white circular LED plate**: this eHMI is a circular LED plate which starts blinking in blue and white upon pedestrian detection as seen in figure 3.1(g) and (h).

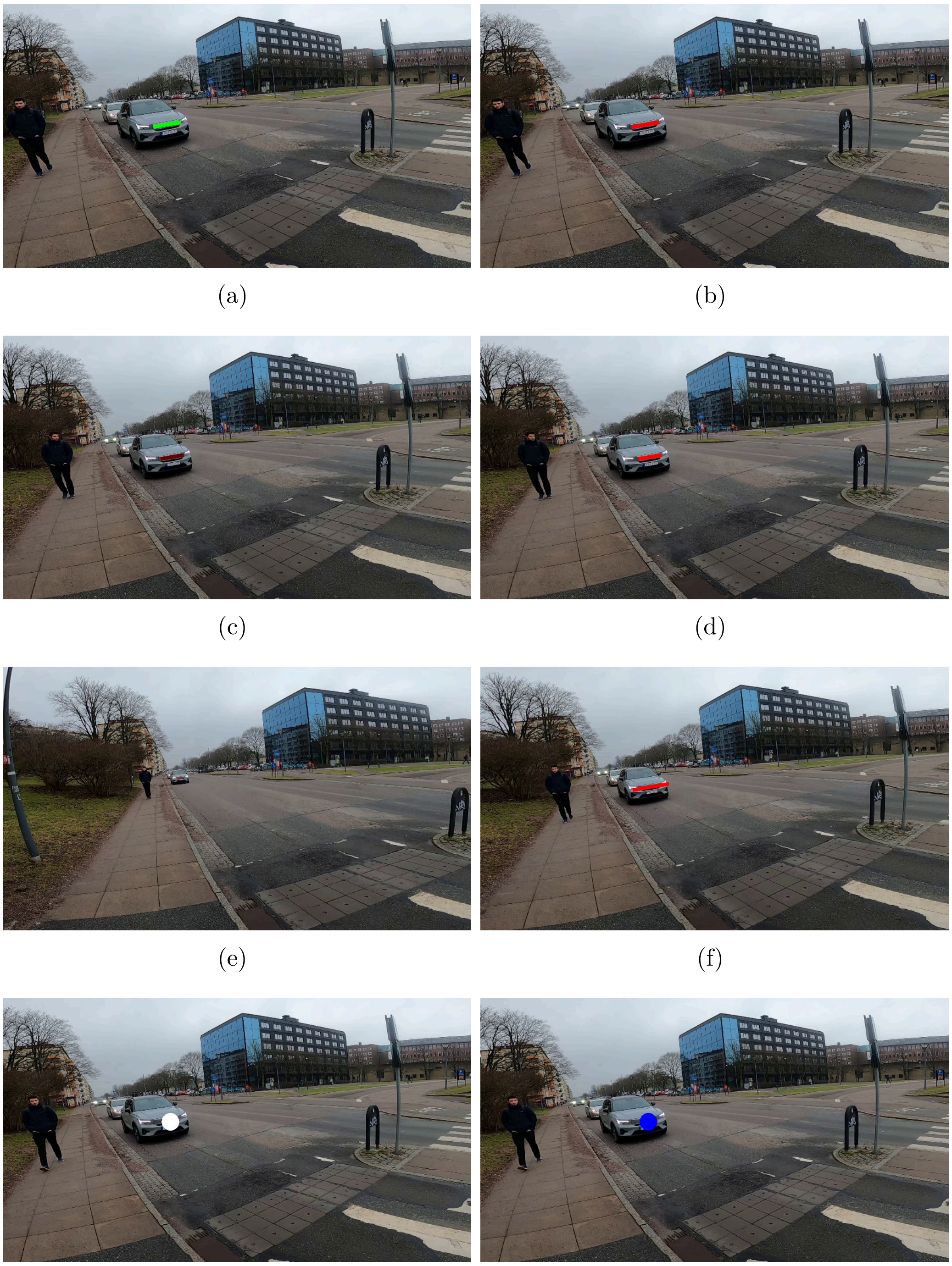
3.2 Selection of survey metric

In assessing the cultural impacts of eHMIs developed based upon the SDT principle for autonomous vehicles, several metrics can provide valuable insights into how these interfaces are perceived and understood across diverse cultural backgrounds. While an exhaustive assessment might include various metrics such as *(i) perceived understanding of road signs and symbols, (ii) cultural sensitivity, (iii) degree of familiarity with autonomous vehicles, (iv) trust in eHMI communication, (v) emotional responses, (vi) perceived biases related to certain communities, (vii) preferences for specific features or colors, (viii) demographic variations, (ix) usability across cultures,* real-life constraints often demands on adopting a rudimental approach.

To accommodate all these constraints, a set of fundamental questions is devised and incorporated in the online survey. Participants are asked to provide information about their age, gender and current country of residence—the condition here is that the participant should be living in that country for at least three years. Additionally, when observing the videos of each type of eHMIs while attempting to cross a street, they are prompted to rate their stress and confidence levels in between 1 (minimum) and 10 (maximum) along with a mandatory motivation for each of the perceived ratings. While this approach may not capture the intricate aspects of cultural perception and preferences comprehensively, it serves as a reasonable method to gather essential data points within the constraints of the survey design.

3.3 Survey conduct

With the chosen metrics in place, an online user-perception study is conducted among people coming from diverse cultural backgrounds. In correlation to the simulated scenarios involving the four types of eHMIs, participants are asked to provide stress and confidence ratings. They are also asked about the reason for giving such ratings, thereby offering valuable insights into the effectiveness of the eHMIs.



(a) (b) (c) (d) (e) (f) (g) (h)

Figure 3.1: (a) and (b): Green and red blinking, (c) and (d): red blinking, (e) and (f): varying width, (g) and (h): circular blinking.

3.4 Analysis

The analysis stage is divided into two parts:

- **Quantitative analysis**: The collected data is referred to as the base of quantitative analysis. To find any significant differences in stress and confidence ratings across various eHMI variants and cultural backgrounds, statistical methods such as t-tests and F-tests are deployed.

- **Qualitative data collection**: In addition to quantitative analysis, qualitative data is also collected to deep dive into the motivations behind the stress and confidence ratings provided by the survey respondents. This allowed the participants to articulate their thoughts and perceptions regarding the eHMIs.

4

Results

4.1 User study overview

The user study comprised 54 participants from various regions worldwide. The responses primarily came from individuals residing in Sweden and India, providing a rich demographic insight into the cultural impacts on the evaluation of eHMI variants. Additional responses were received from the rest of Europe, Australia, Turkey, Iran, the US, Kenya, and Argentina. But for better representation, the top three distribution of responses are illustrated in figure (4.1), and the others are placed under *others*.

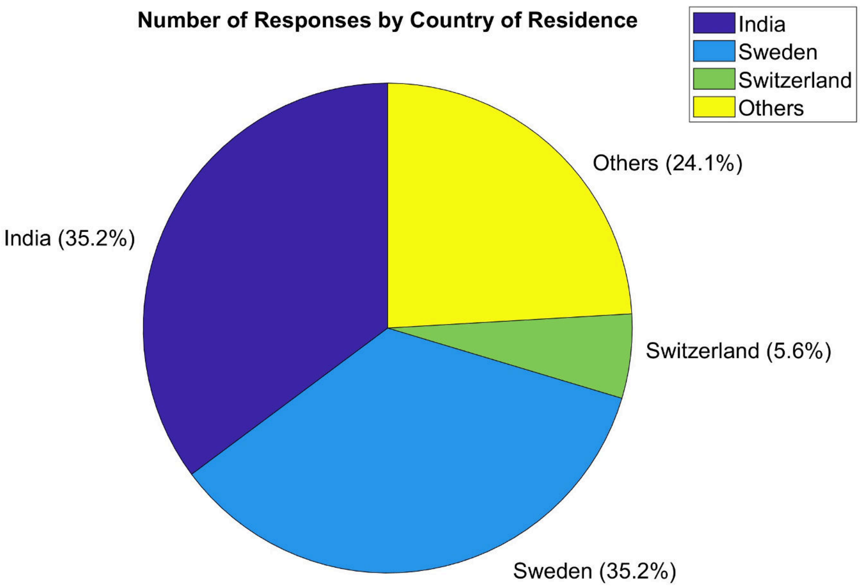


Figure 4.1: Demographic distribution of responses.

4.2 Demographic distribution

Most of the responses were from Swedish and Indian participants. To gain a better understanding of the demographic distribution, a pie chart was plotted to show the percentage shares of the responses from different regions as seen in figure (4.1).

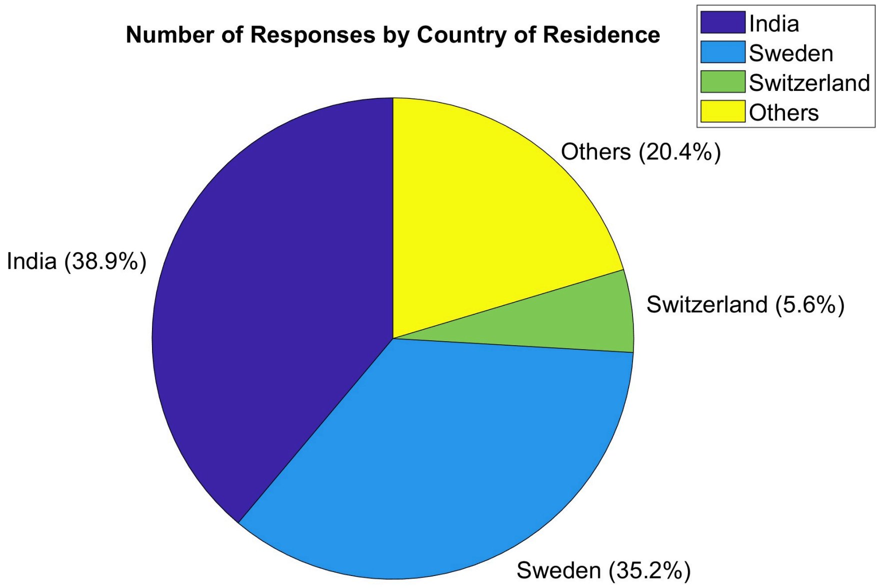


Figure 4.2: Demographic distribution after adjustment.

4.3 Adjusting for residence duration

From the survey data, if a participant had lived in a particular country for less than three years, their responses were attributed to their previous country of residence. This adjustment ensures that the cultural background is accurately represented in the analysis. Post-adjustment, there were 19 Swedish responses and 21 Indian responses. This updated distribution is depicted in the new pie chart in figure (4.2).

4.4 Cultural backgrounds in consideration

The primary objective of this study is to assess and verify whether there is a cultural impact on the stress and confidence ratings for the different external eHMI variants. Cultural impact refers to the variations in ratings based on cultural biases or perceptions of road signs and symbols. For a more focused analysis, the comparison between stress and confidence ratings is based upon the predominant responses from Swedish and Indian participants, providing insights that may reflect European and South-Asian cultural influences, respectively. This approach helps to identify any cultural differences in the perception of eHMI variants.

4.5 Statistical methods adopted

To analyze the data, statistical methods such as t-tests and Analysis of variance (ANOVA) are employed. These methods are essential to determine if there are statistically significant differences between the groups. In this study, cultural background is represented by the current country of residence, divided into Swedish and Indian categories.

4.5.1 Independent samples t-test

The t-test, specifically the independent samples t-test (Welch's t-test for unequal variances), is used to compare the mean stress and confidence ratings between the two cultural groups. The significance level (alpha value) was set at 0.05.

4.5.1.1 Analysis of HMI variants

As mentioned in the Methodology section, this study analyzed four different types of eHMIs developed based on the SDT principle. For each HMI variant, two t-tests were conducted (one for stress ratings and one for confidence ratings), resulting in a total of eight t-tests. This analysis aimed to uncover any cultural influences on the perception of different HMI types.

Null and Alternative Hypotheses

For each t-tests, the following hypotheses were formulated:

- **Null hypothesis (H0):** There is no significant difference in the mean ratings of stress and confidence between Swedish and Indian participants.

- **Alternative hypothesis (H1):** There is a significant difference in the mean ratings of stress and confidence between Swedish and Indian participants.

Statistical results

HMI 1: Blinking green and red LED strip

For the *blinking green* and *red LED strip eHMI*, the p value associated with the t-test for stress and confidence levels is 0.64895 and 0.71417 respectively, which is greater than the typical significance level of 0.05. This fails to reject the null hypothesis, suggesting that there is no significant difference in stress and confidence levels between Swedish and Indian people.

- **Stress ratings:**
  - p value: 0.64895
  - t-statistic: -0.45885
  - Degrees of freedom: 37.9975
  - 95 % Confidence interval: [-1.9396, 1.2228]

- **Confidence ratings:**
  - p value: 0.71417
  - t-statistic: -0.36904
  - Degrees of freedom: 37.6039
  - 95 % Confidence interval: [-2.0975, 1.4508]

In figure 4.3, it is seen that the frequency or the probability of the stress and confidence ratings are similar to some extent for both Indian and Swedish responses. This indicates that people from both the backgrounds were equally stressed or confident upon seeing the AV with this eHMI setting.

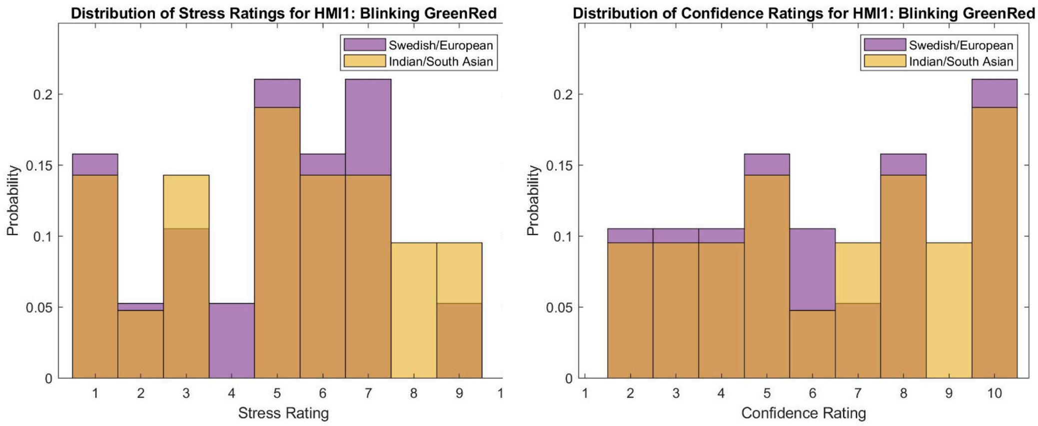


Figure 4.3: Distribution of stress and confidence ratings for eHMI 1.

HMI 2: Blinking red LED strip

For this eHMI variant, the p value for the stress levels is 0.049143, which is just below the set level. This signifies that there could be a significant difference in the ratings based upon the country of residence. The p value for the confidence levels is just above the significance level, which fails to reject the null hypothesis statistically.

- **Stress ratings:**
  - p value: 0.049143
  - t-statistic: -2.033
  - Degrees of Freedom: 37.6975
  - 95 % Confidence Interval: [-3.3468, -0.0066]

- **Confidence ratings:**
  - p value: 0.05764
  - t-statistic: 0.56347
  - Degrees of freedom: 37.5857
  - 95 % Confidence interval: [-1.3068, 2.3143]

Figure 4.4 indicates that for the stress rating, there are two different clusters. Indians gave more high stress ratings as compared to the Swedish people. For confidence rating, the responses between both the groups did not deviate much.

HMI 3: Varying width red LED strip

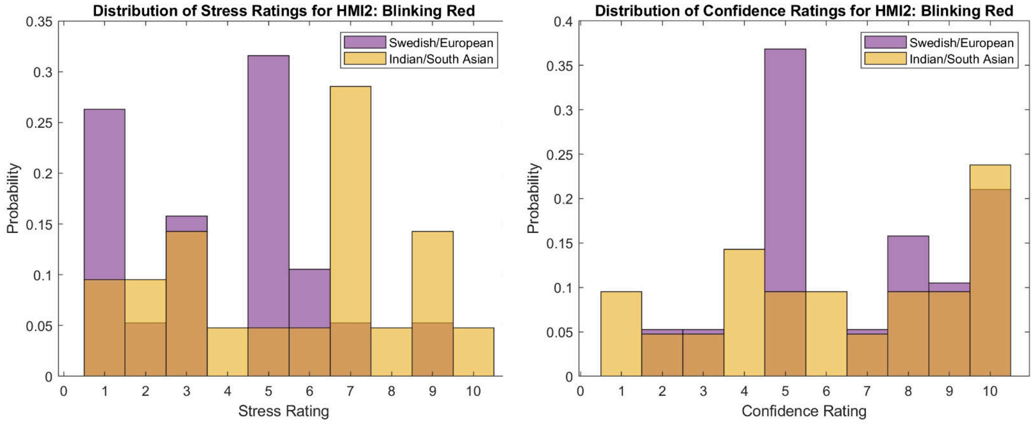


Figure 4.4: Distribution of stress and confidence ratings for eHMI 2.

For both stress and confidence levels, the p value is way below 0.05. This indicates evidence against the null hypothesis, suggesting that there is a significant difference in stress and confidence levels between Indian and Swedish people. The t-statistic for stress is -3.1142 indicates the magnitude of the difference between the means of two groups. The negative sign here suggests that the means stress level for Swedish people is lower than that for Indian people. The positive t-statistic of 2.6357 for confidence levels suggests that the mean confidence level for Swedish people is higher than that for Indian people.

- **Stress ratings:**
  - p value: 0.0035117
  - t-statistic: -3.1142
  - Degrees of freedom: 37.764
  - 95 % Confidence interval: [-3.4369, -0.72854]

- **Confidence ratings:**
  - p value: 0.01211
  - t-statistic: 2.6357
  - Degrees of freedom: 37.7852
  - 95 % Confidence interval: [0.47464, 3.6206]

The distribution plots in figure 4.5 suggests that there is a difference of opinion related to stress and confidence ratings between the Indian and Swedih people. For eHMI3, the indication is, the Swedish people were more confident and less stressed than the Indian people.

HMI 4: Circular blinking LED plate

For this eHMI variant, the p values are way above the significance level.

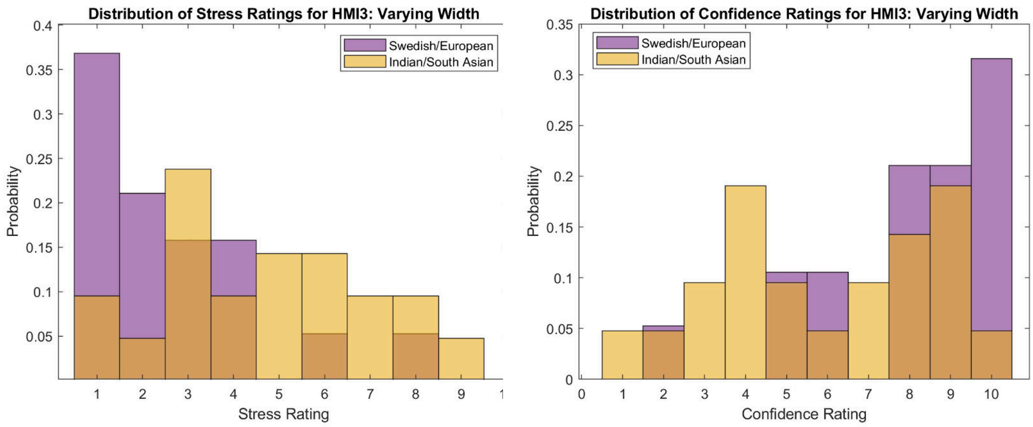


Figure 4.5: Distribution of stress and confidence ratings for eHMI 3.

- **Stress ratings:**
  - p value: 0.74024
  - t-statistic: 0.33396
  - Degrees of freedom: 37.9934
  - 95 % Confidence interval: [-1.4843, 2.0707]

- **Confidence ratings:**
  - p value: 0.84699
  - t-statistic: 0.1943
  - Degrees of freedom: 37.5845
  - 95 % Confidence interval: [-1.6295, 1.9753]

Figure 4.6 indicates that in general, the stress ratings were high for both Indian and Swedish responses. For confidence ratings, the mean ratings for both of the responses lies mainly in the centre of the rating scale.

4.5.1.2 Within-culture analysis

An additional analysis is conducted to compare stress and confidence ratings between two HMI variants within each cultural group. For example, independent two-sample t-tests were performed between stress and confidence ratings for eHMI 2 and eHMI 3 from Indian responses. This analysis aimed to detect any variations in ratings within a particular culture. All six combination pairs of eHMI variants are used to perform 12 t-tests (six for stress ratings and six for confidence ratings).

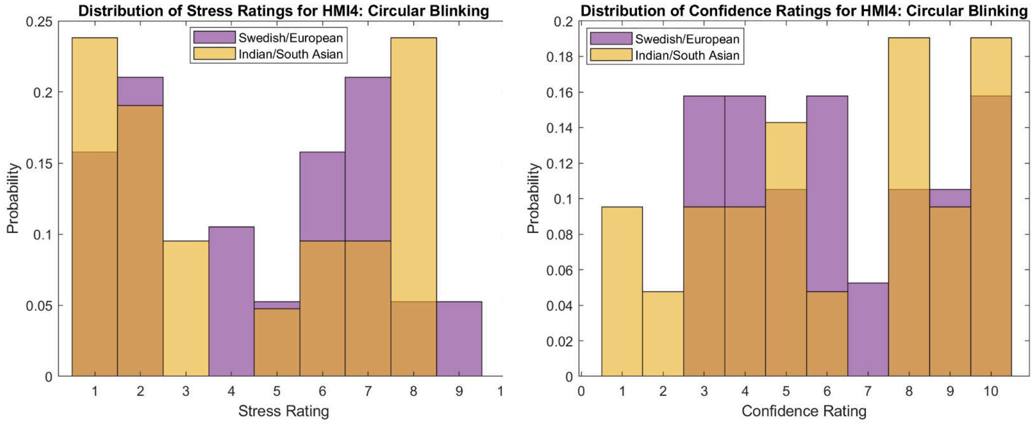


Figure 4.6: Distribution of stress and confidence ratings for eHMI 4.

Within-culture t-test hypotheses

- **Null hypothesis (H0):** There is no difference in stress (or confidence) ratings between the two HMI variants for each cultural background.
- **Alternative hypothesis (H1):** There is a significant difference in stress (or confidence) ratings between the two HMI variants for each cultural background.

Statistical results

Within Indian responses, none of the eHMI variant combinations have shown significant differences in the stress and confidence stress ratings as seen in table 4.1. This indicates that for Indian people, they did not find any one eHMI variant more effective than the others.

Whereas, for Swedish responses, there are some statistically significant data for two different eHMI combination pairs, i.e., eHMI 1&3 and 3&4, as seen in the table 4.2. This indicates that Swedish people found a certain eHMI variant more effective than others.

Table 4.1: t-test results of various eHMI combinations within Indian responses.

	p value		t-stat		95% CI	
	Stress	Confidence	Stress	Confidence	Stress	Confidence
eHMI 2&3	0.29095	0.83793	1.0702	-0.20587	[-0.7616, 2.4750]	[-2.0604, 1.6794]
eHMI 1&3	0.61713	0.95666	0.50385	-0.05469	[-1.1471, 1.9090]	[-1.8073, 1.7121]
eHMI 2&4	0.15559	0.88242	1.4474	0.14885	[-0.5096, 3.0811]	[-1.7968, 2.0826]
eHMI 1&4	0.34556	0.75445	0.95451	0.31492	[-0.9045, 2.5236]	[-1.5479, 2.1194]
eHMI 1&2	0.57434	0.87598	-0.56632	0.15707	[-2.1756, 1.2232]	[-1.6953, 1.9810]
eHMI 3&4	0.5990	0.71989	0.53005	0.36114	[-1.2056, 2.0627]	[-1.5321, 2.1988]

Table 4.2: t-test results of various eHMI combinations within Swedish responses.

	p value		t-stat		95% CI	
	Stress	Confidence	Stress	Confidence	Stress	Confidence
eHMI 2&3	0.078345	0.12682	1.8119	-1.5629	[-0.1507, 2.677]	[-2.7813, 0.36027]
eHMI 1&3	0.0046178	0.026026	3.0208	-2.3216	[0.69186, 3.5187]	[-3.5499, -0.23957]
eHMI 2&4	0.40595	0.5665	-0.8409	0.57854	[-2.3344, 0.96598]	[-1.1868, 2.1342]
eHMI 1&4	0.84719	0.80761	0.1941	-0.24531	[-1.4919, 1.8077]	[-1.9511, 1.53]
eHMI 1&2	0.2775	0.43149	1.1026	-0.79559	[-0.70677, 2.391]	[-2.4284, 1.06]
eHMI 3&4	0.013703	0.035867	-2.5919	2.1801	[-3.4711, -0.42362]	[0.11745, 3.251]

4.5.2 2-way ANOVA test

The third type of statistical analysis conducted is a two-way ANOVA for stress ratings of two different eHMI variants from the two cultural backgrounds. The purpose of this analysis is to assess the main effects of eHMI type and cultural background on stress ratings, as well as to examine any interaction effect between these two factors. This approach provides insights into how the relationship between eHMI type and stress ratings might vary across different cultural backgrounds. Similar test is conducted by taking into account the confidence ratings as well.

ANOVA hypotheses

1. **eHMI type (Factor 1):** This factor examines the differences in stress ratings between the two types of eHMIs.
   - **Null hypothesis (H0):** There is no significant difference in stress ratings between the two types of eHMIs.
   - **Alternative hypothesis (H1):** There is a significant difference in stress ratings between the two types of eHMIs.

2. **Country of residence (Factor 2):** This factor examines the differences in stress ratings between individuals from different cultural backgrounds.
   - **Null hypothesis (H0):** There is no significant difference in stress ratings between individuals from different cultural backgrounds.
   - **Alternative hypothesis (H1):** There is a significant difference in stress ratings between individuals from different cultural backgrounds.

3. **Interaction between eHMI type and cultural background:** This examines whether the effect of one factor (eHMI type) depends on the level of the other factor which is the country of residence or cultural background in this case.
   - **Null hypothesis (H0):** There is no interaction effect between eHMI type and cultural background on stress ratings.
   - **Alternative hypothesis (H1):** There is an interaction effect between eHMI type and cultural background on stress ratings.

Statistical results

F-test between eHMI 2 and 3

For *HMI type* factor, the F-statistic is calculated as 3.91, and the associated p value (Prob>F) is 0.0516 as seen in table 4.3. The p value (0.0516) is slightly above 0.05, suggesting that the effect of *HMI type* on stress ratings is marginally non-significant.

For *country of residence* factor, the F-statistic is calculated as 12.1236, and the associated p value (Prob>F) is 0.0008. Since the p value is less than the significance level, the null hypothesis for the *cultural background* factor is rejected. This suggests that there is a significant difference in stress ratings between the two cultural backgrounds.

For the interaction between the *HMI type* and *country of residence*, the F-statistic is calculated as 0.14, and the associated p value (Prob>F) is 0.7059. Since the p value is greater than the significance level, the null hypothesis for the interaction effect cannot be rejected. This suggests that there is no significant interaction effect between *HMI type* and *cultural background* on stress ratings.

Table 4.3: F-test results of eHMI 2 and 3.

Analysis of variance					
Source	Sum sq.	DOF	Mean sq.	F	Prob>F
HMI type (Factor 1)	22.422	1	22.4222	3.91	0.0516
Country of residence (Factor 2)	70.489	1	70.4887	12.3	0.0008
Interaction	0.822	1	0.8222	0.14	0.7059
Error	435.639	76	5.7321		
Total	529	729			

Figure 4.7 shows the mean stress and confidence ratings of eHMI 2&3 by comparing the two cultural backgrounds. For both of the cultural groups, eHMI 3 was more effective as its mean stress rating was lower than that of eHMI 2. Similarly, the mean confidence rating was higher for eHMI 3 across all cultures. The error bar represents the average variability within each groups.

F-test between eHMI 1 and 3

For *HMI type* factor, the F-statistic is calculated as 5.77, and the associated p value (Prob>F) is 0.0188 as seen in table 4.4. Since the p value is less than the significance level, the null hypothesis for the *HMI type* factor is rejected. This suggests that there is a significant difference in stress ratings between eHMI 1 and 3.

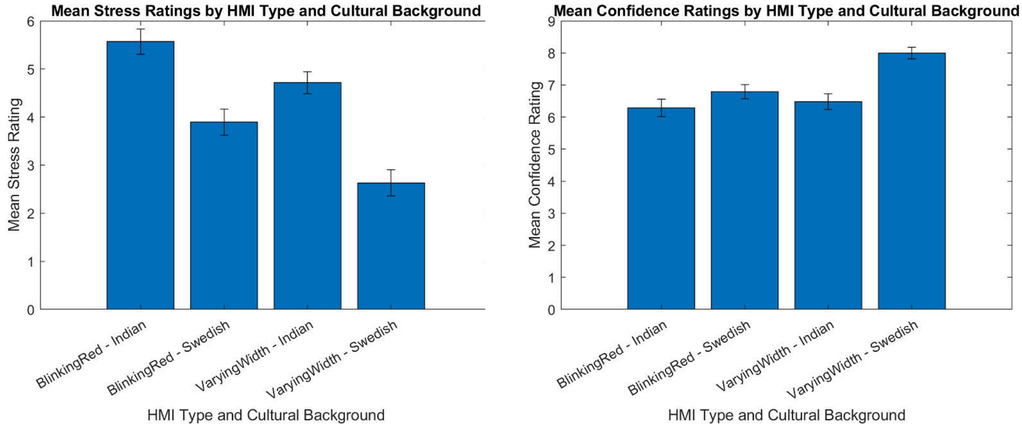


Figure 4.7: Distribution of mean stress and confidence ratings between eHMI 2 and 3.

For *country of residence* factor, the F-statistic is calculated as 5.56, and the associated p value (Prob>F) is 0.0209. Since the p value is less than the significance level, the null hypothesis for the *country of residence* factor is rejected. This suggests that there is a significant difference in stress ratings between the two cultural backgrounds.

For the interaction between the *HMI type* and *country of residence*, the F-statistic is calculated as 2.77, and the associated p value (Prob>F) is 0.0999. This p value suggests that the interaction between eHMIs 1&3 and the *country of residence* has a notable effect on stress ratings, but it does not reach conventional levels of statistical significance, hence the null hypothesis for the interaction effect cannot be rejected.

Table 4.4: F-test results of eHMI 1 and 3.

Analysis of variance					
Source	Sum sq.	DOF	Mean sq.	F	Prob>F
HMI type (Factor 1)	30.829	1	30.8291	5.77	0.0188
Country of residence (Factor 2)	29.72	1	29.7204	5.56	0.0209
Interaction	14.829	1	14.8291	2.77	0.0999
Error	435.639	76	5.3447		
Total	479.550	79			

From the distribution plot in figure 4.8, it is evident that for eHMI 3 the mean stress rating for Swedish responses is considerably lower than the rest. On the other hand, for Indian responses, there is very less notable differences in the mean stress and confidence ratings for both of the eHMI variants.

F-test between eHMI 1 and 2

For *HMI type* factor, the F-statistic is calculated as 0.1, and the associated p value (Prob>F) is 0.75 as seen in table 4.5. Since the p value is not less than the signifi-

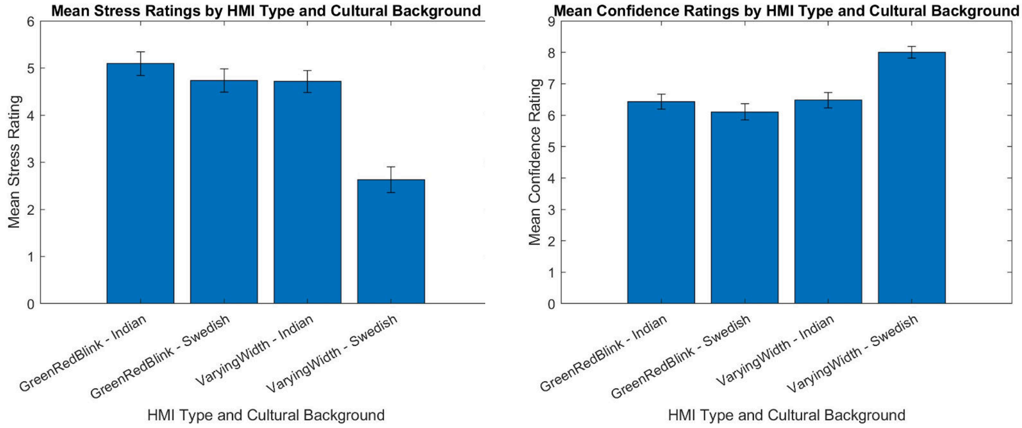


Figure 4.8: Distribution of mean stress and confidence ratings between eHMI 1 and 3.

cance level, the null hypothesis for the *HMI type* factor is not rejected. This suggests that there is no significant difference in stress ratings between eHMI 1 and 2.

For *country of residence* factor, the F-statistic is calculated as 3.16, and the associated p-value (Prob>F) is 0.0794. The null hypothesis cannot be rejected here as the p-value is not less than the significance level.

For the interaction between the *HMI type* and *country of residence*, the F-statistic is calculated as 1.33, and the associated p value (Prob>F) is 0.253. This p value suggests that there is no interaction between eHMIs 1&2 and the *country of residence* factor on the stress ratings, hence the null hypothesis for the interaction effect cannot be rejected.

Table 4.5: F-test results of eHMI 1 and 2.

Analysis of variance					
Source	Sum sq.	DOF	Mean sq.	F	Prob>F
HMI type (Factor 1)	0.668	1	0.6678	0.1	0.75
Country of residence (Factor 2)	20.656	1	20.6561	3.16	0.0794
Interaction	8.668	1	8.6678	1.33	0.253
Error	496.426	76	6.5319		
Total	526.2	79			

In figure 4.9, it is evident that there is not much difference in the mean stress and confidence rating among Swedish and Indian people between the two eHMI variants.

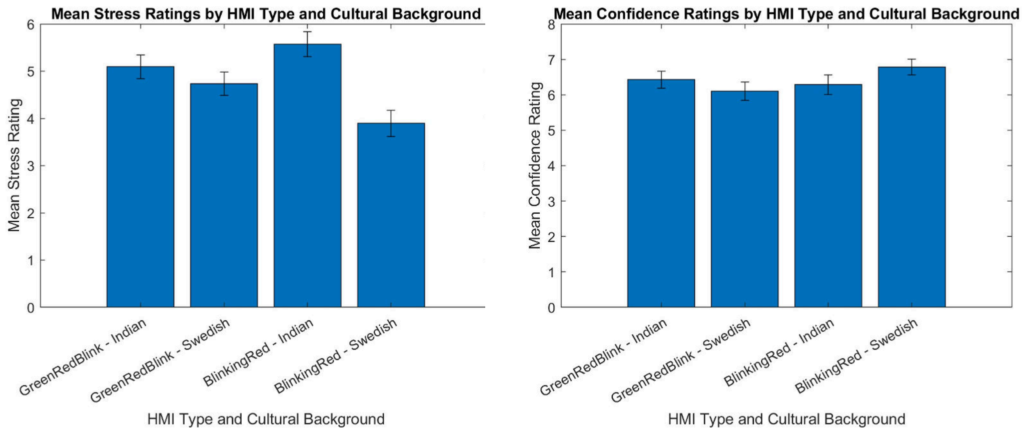


Figure 4.9: Distribution of mean stress and confidence ratings between eHMI 1 and 2.

F-test between eHMI 2 and 4

For *HMI type* factor, the F-statistic is calculated as 0.25, and the associated p value (Prob>F) is 0.6214 as seen in table 4.6. Since the p value is not less than the significance level, the null hypothesis for the *HMI type* factor is not rejected. This suggests that there is no significant difference in stress ratings between eHMI 2 and 4.

For *country of residence* factor, the F-statistic is calculated as 1.3, and the associated p value (Prob>F) is 0.2577. The null hypothesis cannot be rejected here as the p value is not less than the significance level.

For the interaction between the *HMI type* and *country of residence*, the F-statistic is calculated as 2.64, and the associated p value (Prob>F) is 0.1086. This p value suggests that there is no interaction between eHMIs 2&4 and the country of residence on the stress ratings, hence the null hypothesis for the interaction effect cannot be rejected.

Table 4.6: F-test results of eHMI 2 and 4.

Analysis of variance					
Source	Sum sq.	DOF	Mean sq.	F	Prob>F
HMI type(Factor 1)	1.805	1	1.8045	0.25	0.6214
Country of residence (Factor 2)	9.546	1	9.5459	1.3	0.2577
Interaction	19.355	1	19.3545	2.64	0.1086
Error	557.85	76	7.3401		
Total	589.2	79			

In figure 4.10, it is evident that the mean stress rating for eHMI 2 calculated from Indian responses is considerably higher than the rest. Point to note here is that the mean stress for eHMI 4 is similar in both the cultural groups. The mean confidence levels are also in equilibrium with less variations across the two cultures with respect to eHMI 2&4.

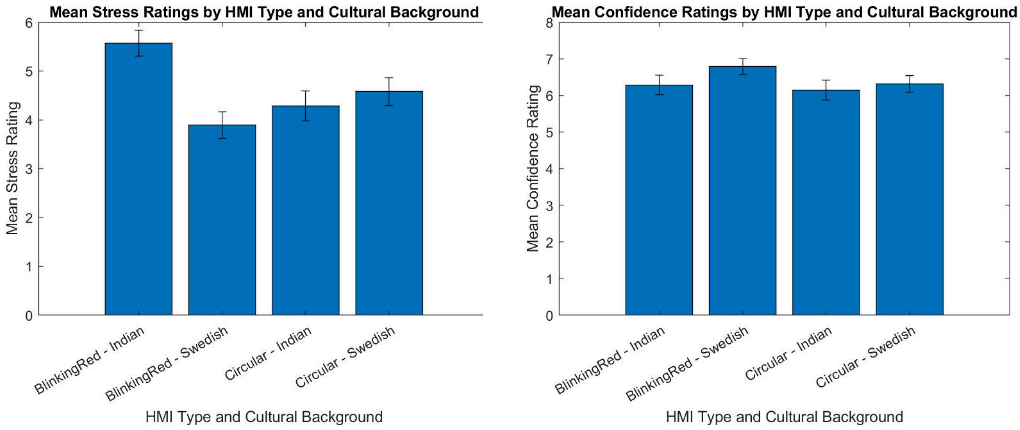


Figure 4.10: Distribution of mean stress and confidence ratings between eHMI 2 and 4.

F-test between eHMI 1 and 4

From table (4.7), Since the p value (0.4151) is not less than the significance level, the null hypothesis for the *HMI type* factor is not rejected. This suggests that there is no significant difference in stress ratings between eHMI 1 and 4.

The null hypothesis for *country of residence* factor cannot be rejected here as the p value (0.9561) is not less than the significance level.

For the interaction between the *HMI type* and *country of residence*, the F-statistic is calculated as 0.3, and the associated p value (Prob>F) is 0.5826. This p value suggests that there is no interaction between eHMIs 1&4 and the *cultural backgrounds* on the stress ratings, hence the null hypothesis for the interaction effect cannot be rejected.

Table 4.7: F-test results of eHMI 1 and 4.

Analysis of variance					
Source	Sum sq.	DOF	Mean sq.	F	Prob>F
HMI type (Factor 1)	4.668	1	4.66779	0.67	0.4151
Country of residence (Factor 2)	0.021	1	0.02118	0	0.9561
Interaction	2.118	1	2.11779	0.3	0.5826
Error	528.411	76	6.95278		
Total	525.55	79			

Figure (4.11) depicts that there is not much of a difference in the mean stress and confidence ratings between the two cultural groups. Though, the graph clearly implies that the Indian people were less stressed with eHMI 4, wehereas, the Swedish people were equally stressed with both of the eHMIs when they encountered them in the survey video.

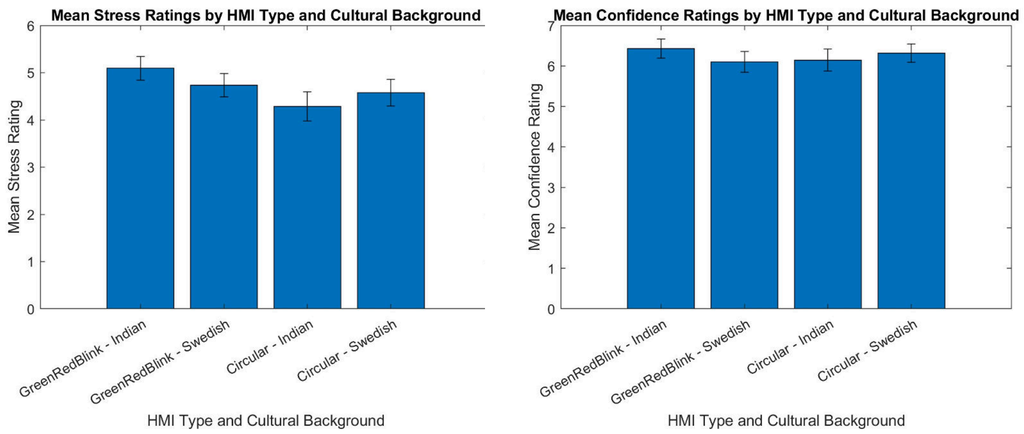


Figure 4.11: Distribution of mean stress and confidence ratings between eHMI 1 and 4.

F-test between eHMI 3 and 4

For both *HMI type* and *country of residence* factors, the respective null hypotheses cannot be rejected as their p values are not less than the significance level as seen in table (4.8).

But for the interaction between the *HMI type* and *country of residence*, the F-statistic is calculated as 4.58, and the associated p value (Prob>F) is 0.0356. This p-value suggests that there is an interaction between eHMIs 3&4 and the country of residence on the stress ratings, hence the null hypothesis for the interaction effect can be rejected.

Table 4.8: F-test results of eHMI 3 and 4.

Analysis of variance					
Source	Sum sq.	DOF	Mean sq.	F	Prob>F
HMI type (Factor 1)	11.505	1	11.5049	1.87	0.1755
Country of residence (Factor 2)	15.971	1	15.9711	2.6	0.1113
Interaction	28.155	1	28.1549	4.58	0.0356
Error	467.624	76	6.1529		
Total	521.55	79			

The distribution graph in figure (4.12), depicts that there was significantly low stress level and high confidence level among the Swedish people while encountering the AV with eHMI variant 3 as compared to eHMI variant 4. For Indian people the level of stress and confidence were similar for both of the eHMI variants, when they encountered them.

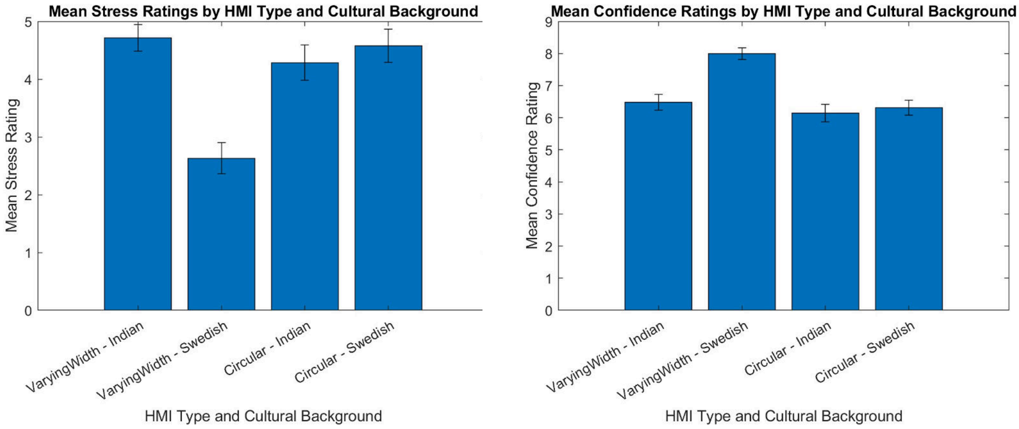


Figure 4.12: Distribution of mean stress and confidence ratings between eHMI 1 and 4.

5
Discussion

This chapter consolidates the insights gathered from both the extensive literature review and the conducted survey, addressing the research questions of this study. The first part explores how the research community is currently applying the *show, don't tell* (SDT) principle alongside social constructivism theory in the development of *external human-machine interfaces* (eHMIs) for *autonomous vehicles* (AVs), particularly in managing complex traffic situations at urban intersections. This section emphasizes the theoretical frameworks that guide current design practices and how these approaches aim to enhance vehicle–pedestrian interactions. The second part explores the cultural impact on the acceptance and effectiveness of eHMIs. The analysis focuses on survey data that reveals how cultural differences among pedestrians can influence their interaction with AVs, especially those employing implicit communication methods as suggested by the *show, don't tell* approach. By examining these cultural variations, the discussion highlights the need for designing eHMIs that are sensitive to regional contexts, ultimately contributing to safer and more intuitive AV integration in diverse urban environments. The chapter concludes by synthesizing these theoretical and empirical findings, offering a foundation for the conclusions and identifying areas for future research advancements.

5.1 Contribution

In this section, I will outline the contributions I aim to make with this thesis towards evaluating the cultural correlation of eHMIs on pedestrians. The primary objective is to address the research questions presented at the beginning of this thesis. I will provide detailed explanations of the inferences drawn from the results to answer these research questions, thereby attempting to enhance the existing knowledge in the field.

1. *How is the research community currently harnessing the show, don't tell principle and social constructivism theory in the development of eHMIs for AVs explicitly addressing complex traffic conditions in urban intersections?*

   Based on the extensive literature survey and referred study experiments, it is evident that for the successful integration of AVs in complex urban intersections, the development of effective eHMIs is quintessential. Here, *complex* refers to roads and streets used by vulnerable road users such as pedestrians and cyclists. These eHMIs are crucial for facilitating clear communication

between AVs and VRUs to ensure safety and efficiency.
Several eHMI design concepts that attempted two-way communication with pedestrians have been tried, but many resulted in confusion. When AVs had to interpret and respond to pedestrian gestures and behaviors, the communication became complicated and ambiguous. This complexity often hampered trust and acceptance among pedestrians, who were left uncertain about whether it was safe to cross. The ambiguity in these interactions highlighted the need for a more straightforward approach.
The eHMI designs developed based on the SDT principle leaves the interpretation to the road users, which aligns with how humans naturally understand intentions in traffic. For instance, an AV might use a front-mounted LED strip, indicating its movement intentions without direct verbal or written instructions.
Combining the principle with social constructivism theory provides a more effective strategy for eHMI design. Social constructivism emphasizes the importance of cultural and social contexts in understanding human behavior. By focusing on showing the vehicle's intent through minimalistic yet clear signals, eHMIs can leverage the natural social dynamics of road use. For example, the LED strip indicating proximity to objects can be easily interpreted by pedestrians based on common road-use behaviors and norms. This approach reduces ambiguity, enhances trust, and improves safety by aligning with pedestrians' expectations and experiences.
In summary, the research community is actively leveraging the *show, don't tell* principle and social constructivism theory to develop eHMIs for AVs that can effectively address the complexities of urban intersections. By focusing on implicit communication and culturally informed designs, these efforts aim to create AVs that seamlessly integrate into the social fabric of road use, reducing uncertainties and improving safety for all road users. Ethnographic studies and real-world implementations continue to provide valuable insights, guiding the development of interfaces that are both socially acceptable and effective in real-world scenarios.

2. *How do cultural differences in pedestrians influence the acceptance and effectiveness of eHMIs in AVs which are designed based on the show, don't tell principle?*

   Based on the quantitative analysis, there are valuable insights to answer this research question. Firstly, the analysis is divided into two main cultural groups—Swedish and Indian. Apart from being the majority of the responses captured country-wise, these two countries are also polar opposites when it comes to cultural preferences, knowledge about vehicle and traffic safety, etc. The challenge or the task here is to find any kind of indication or proof, whether a specific eHMI type would also have an effect on pedestrians' perception of AVs based on the cultural differences between the two groups under consideration, while crossing a road. From the independent samples t-test conducted in chapter (4) and section (4.5), it is evident that for a certain type of eHMI, there is a significant difference in the mean ratings of stress and confidence between the Swedish and Indian participants. This would mean, since the level of familiarity towards a particular technology widely varies across cultures, it is important to take into account how the user interprets of what is shown and intended.

For the first eHMI variant, the ratings given by the both of the groups matches to certain extent as seen in the figure (4.3). This particular variant flashed blinking green and red lights while approaching a pedestrian crossing. Based upon the motivations given by the participants, the qualitative analysis suggests that most of the Swedish people understood what is going on or what the car intends to do, and their mean stress rating was 4.74 out of 10 and their mean confidence rating was 6.10 out of 10. Few of them told that their stress level would remain the same both for AVs and human-driven vehicles. There were only two justifications which stated that it could not understand what the car is doing and that they are highly stressed. There is not much of difference in the mean ratings from the Indian participants as compared to the Swedish participants. The average rating for stress and confidence given by the Indians was 5.09 and 6.42 respectively. Coming to the qualitative justifications given by the Indian participants, there were a fair mix of comments stating being stressed and not being stressed while crossing. In general, for this variant, people from both backgrounds understood that something is going to happen and that they should stop and be somewhat careful while crossing. Mostly importantly, according to some justifications, the flashing of the green light gave a feeling of safety in both of the cultural groups.

The second eHMI variant is a red blinking LED strip, where average the stress is 3.89 and the mean confidence is 6.78 for the Swedish responses. For the Indian responses, it is 5.57 and 6.28 respectively. According to the figure (4.4), it is indicative that the Indian people were more stressed than the Swedish people while encountering this particular eHMI variant, and hence the null hypothesis rejected for this t-test. Whereas for the confidence ratings, there were not much variations between the two group. According to qualitative analysis, the motivations provided by the Swedish participants were mostly converging, with some stating that *"Red signal makes me feel that the autonomous vehicle detects me"*. In general, the Swedish people were clear of the car's intention that it would stop and would let them pass, hence they were less stressed. Coming to Indian responses, most of them mentioned a sense of ambiguity and uncertainty in their justifications.

Moving on to the third variant, the varying width LED strip proves to be the most statistically significant among the lot. The mean stress and confidence rating is 2.63 and 8 respectively for the Swedish responses. For Indians, the average stress was 4.7 and average confidence was 5.95. As discussed in chapter (4) and section (4.5), based on the statistical data, there is a significant difference in the mean ratings between Swedish and Indian participants for this particular eHMI. From a qualitative point of view, there are also difference in perceptions between the Swedish and the Indian people. Swedish justifications mostly stated the fact that the AV's intent was clearly understandable and that they would be more confident to cross as compared to the previous two variants. Most of the interpretations by the Swedish people were clinical and caught the AV's behavior on point, for example, *"Seems like the car is clearly indicating approaching some sort of obstacle with increasing signage levels showing it can accurately tell how close the obstacle is. This would indicate to me that I have been seen and it is safe to cross"*, *"These types of signal makes me more sure that the autonomous vehicle detects me"*, etc. For the Indian responses, the justifications mostly involved keywords such as *skeptical*, *worried*, *intense*, etc. Few of them also mentioned that they did not understand the AVs intention fully and someone wrote that *"Multiple encounters will develop confidence..."*. The last variant was sort of same for both the cultural groups. The mean stress and confidence ratings for the Swedish group is 4.57 and 6.31 respectively, and for Indian group it is 4.28 and 6.14 respectively. The fact that the Swedish group was slightly more stressed can be justified by the fact that the blue and white flashing of the light was perceived as an signal from a Police Vehicle by them. This was not the case for the Indian group as the color cues for police vehicle signal is different in India. They were more stressed when the color cues included red, as in the case of the other variants.

Analysis of different combinations of eHMI variants within each cultural groups was not fruitful (no significant difference), when it comes to Indian responses—which means their stress and confidence levels did not vary based upon the type of eHMI they are encountering. On the contrary, for the Swedish group, for certain combinations of eHMIs such as 1&3 and 3&4, the stress levels varied significantly. For eHMI combination 1&3, the Swedish people felt that eHMI 3 was less stressful than that of eHMI 1—this is justified by a positive t-stat value in the table (4.2). In the t-test involving variants 3&4, the t-stat value for the Swedish group is -2.59, where the negative value suggests that eHMI 3 has lower stress ratings than that of eHMI 4.

The purpose of conducting a two-way ANOVA in this context is to assess the main effects of eHMI type and cultural background on stress ratings, as well as to examine whether there is an interaction effect between these two factors. This allows to understand the individual and combined influences of eHMI type and cultural background on stress perception. Out of all the F-tests conducted, the findings for the F-test between eHMI 1 and 3 suggest that both the type of eHMIs and cultural background has an influence on perceived stress. Additionally, there appears to be a slight interaction effect between the two *eHMI types and cultural background*, indicating that the impact of eHMI types on stress ratings may vary depending on an individual's cultural background, and vice versa.

5.2 Conclusion

The literature review highlights that integrating the *show, don't tell* principle, alongside social constructivism theory, into the design of eHMIs for autonomous vehicles has the potential to enhance their cultural adaptability and effectiveness. While the *show, don't tell* principle does not solely focus on non-verbal cues, it outlines the importance of implicit, context-aware communication that does not rely on explicit commands. This approach encourages AVs to utilize intuitive signals, such as visual behaviors, to communicate intent. Such design strategies could enable AVs to interact more naturally with road users, especially in diverse urban settings, fostering an environment where AV behaviors are easily understood across different cultural contexts. By prioritizing subtle, non-direct communication, AVs may contribute to safer and more fluid interactions with pedestrians and other vulnerable road users in complex urban intersections.

Furthermore, the analysis of survey data and statistical assessments emphasizes that different eHMI designs induce varying levels of stress and confidence among users from different cultural contexts. Though conducted for a small data set, this variability suggests that future eHMI designs might incorporate cultural nuances to optimize user experience and acceptance. The findings indicate that culturally-informed eHMI designs can play a crucial role in the successful integration of AVs into real-time traffic conditions, reducing ambiguity and enhancing trust among road users. Therefore, a culturally adaptive approach to eHMI design is essential for the widespread acceptance and safe operation of AVs in diverse urban settings.

Although the results are promising and highlight significant differences, they serve merely as an indication. To gain full confidence in these findings, larger data sets are needed. Additionally, it's important to note that the color cues used in the four types of eHMIs are not legally compliant according to the current taxonomy of interface designs. These cues were specifically utilized in this survey analysis to assess any cultural impact they might have on observers.

5.3 Future work

These could some possible extensions to this work:

- **Focus groups involving 'specific' cross–cultural user studies:** It would be beneficial to conduct the same study in a country-side setting with larger data sets to understand how cultural diversity influences user preferences and acceptance towards Human–Machine Interfaces in autonomous vehicles.
- **Testing and evaluating real–world ccenarios:** Another extension could be to develop a culturally adaptive external interface prototype with legally compliant design cues and assess the user experience in a real–world setting or environment.

Bibliography

[1] Zheng, Y., & Ren, X. (2022). Developing a Multimodal HMI Design Framework for Automotive Wellness in Autonomous Vehicles. *Multimodal Technol. Interact.*, 6(9), 84. https://doi.org/10.3390/mti6090084.

[2] Benderius, O., Berger, C., & Malmsten Lundgren, V. (2018). The Best Rated Human–Machine Interface Design for Autonomous Vehicles in the 2016 Grand Cooperative Driving Challenge. *IEEE Transactions on Intelligent Transportation Systems*, 19(4), 1-6.

[3] Waymo. (2020). Waymo Safety Report: On the Road to Fully Self-Driving. Retrieved from `https://waymo.com/safety/`.

[4] Cheng, B., & Siu, K. W. (2019). The Impact of Autonomous Vehicles on Urban Transportation. *Transportation Research Part D: Transport and Environment*, 71, 1-14. https://doi.org/10.1016/j.trd.2019.01.010.

[5] Lee, J. D., & See, K. A. (2004). Trust in Automation: Designing for Appropriate Reliance. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 46(1), 50-80. https://doi.org/10.1518/hfes.46.1.50_30392.

[6] Parasuraman, R., & Riley, V. (1997). Humans and Automation: Use, Misuse, Disuse, Abuse. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 39(2), 230-253. https://doi.org/10.1518/001872097778543886.

[7] Dey, A. K. (2001). Understanding and Using Context. *Personal and Ubiquitous Computing*.

[8] McFarland, D. (2019). The Future of Automotive User Interfaces. *Interacting with Computers*.

[9] Wobbrock, J. O. (2016). Research Contributions in Human-Computer Interaction. *ACM Transactions on Computer-Human Interaction*.

[10] Hudson, S. E. (2018). The Impact of Human Behavior on Algorithms. *IEEE Pervasive Computing*.

[11] Abraham, H., et al. (2017). Public perceptions of automated driving technologies: An international comparison. *Journal of Intelligent Transportation Systems*, 21(2), 84-97.

[12] Ashton, K., & Deng, Y. (2010). Cultural constructs in design education. *Design Studies*, 31(3), 261-278.

[13] Wilbrink, M., Cieler, S., Weiß, S. L., Beggiato, M., Joisten, P., Feierle, A., & Oehl, M. (2023). Principles for External Human–Machine Interfaces. *Information*, 14(8), 463. https://doi.org/10.3390/info14080463.

[14] Carmona, J., Guindel, C., Garcia, F., & de la Escalera, A. (2021). eHMI: Review and Guidelines for Deployment on Autonomous Vehicles. *Sensors*, 21(9), 2912. https://doi.org/10.3390/s21092912.

[15] Chang, F., et al. (2017). Eyes on a car: an interface to assist pedestrian-AV interaction. *Proceedings of the ACM CHI Conference on Human Factors in Computing Systems*, 299-310.

[16] Clamann, M., et al. (2017). Pedestrian behaviors at unsignalized crossings: implications for AVs. *Journal of Intelligent Transportation Systems*, 21(4), 324-336.

[17] de Clercq, K., et al. (2019). External human-machine interfaces on automated vehicles: effects on pedestrian crossing behavior. *Safety Science*, 114, 106-120.

[18] Fuest, T., et al. (2018). How do pedestrians evaluate automated vehicles?. *Transportation Research Part F: Traffic Psychology and Behaviour*, 59, 460-473.

[19] Hoff, K. A., & Bashir, M. (2015). Trust in automation: integrating empirical evidence on factors that influence trust. *Human Factors*, 57(3), 407-434.

[20] Hoyos, C., et al. (2015). Benefits of intercultural learning in design education. *Design Journal*, 18(4), 569-585.

[21] IEEE. (2014). The future of autonomous vehicles: market and technology trends. *IEEE Transactions on Intelligent Vehicles*, 1(1), 1-12.

[22] Kaparias, I., et al. (2015). Pedestrian gap acceptance behavior at signalized crossings. *Transportation Research Part F: Traffic Psychology and Behaviour*, 33, 110-123.

[23] Lee, S., et al. (2019). Impact of eHMI designs on pedestrian behavior. *Human Factors*, 61(4), 637-652.

[24] Lee, S., et al. (2019). Learning effects on pedestrian understanding of AV intentions. *Transportation Research Part F: Traffic Psychology and Behaviour*, 65, 35-49.

[25] Liu, P., et al. (2018). Barriers to market penetration of AVs. *IEEE Transactions on Intelligent Vehicles*, 3(4), 387-398.

[26] Menon, N., et al. (2016). Consumer acceptance of automated vehicles. *Journal of Safety Research*, 56, 71-77.

[27] Noy, I. Y., et al. (2018). Public trust and acceptance of AVs. *Human Factors*, 60(1), 34-45.

[28] Nuñez Velasco, J. P., et al. (2019). Perceived risk and crossing intentions with AVs. *Accident Analysis & Prevention*, 131, 185-194.

[29] Rasouli, A., & Tsotsos, J. K. (2019). Pedestrian-vehicle interactions in AV environments. *Journal of Intelligent Transportation Systems*, 23(2), 108-120.

[30] Scharoun, L., et al. (2016). Cross-cultural experiences in design education. *Design and Culture*, 8(3), 273-290.

[31] Schieben, A., et al. (2019).eHMI concepts for AV-pedestrian interaction. *Transportation Research Part F: Traffic Psychology and Behaviour*, 62, 452-468.

[32] Schneemann , F., & Heinemann, P. (2016). Automated driving and pedestrian safety. *Procedia Manufacturing*, 3, 104-111.

[33] Schoettle, B., & Sivak, M. (2014). A survey of public opinion about autonomous and self-driving vehicles in the U.S., the U.K., and Australia. *Transportation Research Institute*, 1(1), 1-17.

[34] Song, Y., et al. (2018). The impact of eHMIs on pedestrian crossing behavior. *Transportation Research Part F: Traffic Psychology and Behaviour*, 59, 78-91.

[35] Tomico, O., et al. (2009). Cultural constructs in design and their impact on consumer behavior. *Journal of Consumer Culture*, 9(2), 247-269.

[36] Wood, A., & St. Peters, H. (2014). Cultural intelligence in design education: benefits and implications. *Journal of Design Education*, 4.

[37] Dey, D., Habibovic, A., Wintersberger, P., Pfleging, B., Riener, A., Martens, M. H., & Bengler, K. (2020). Taming the eHMI jungle: A classification taxonomy to guide, compare, and assess the design principles of automated vehicles' external human-machine interfaces. *Transportation Research Part F: Traffic Psychology and Behaviour*, 72, 316-339.

[38] Goodwin, C., & Heritage, J. (2021). Ethnomethodology and Conversation Analysis. *Annual Review of Sociology*, 47, 145-165.

[39] Jordan, G. (2020). Socially Acceptable Autonomous Driving: Nissan's Approach. In *Automotive UX: Insights from the Field*.

[40] Lynch, M. (1993). *Scientific Practice and Ordinary Action: Ethnomethodology and Social Studies of Science*. Cambridge University Press.

[41] Merat, N., Madigan, R., & Nordhoff, S. (2018). Human Factors, User Requirements, and User Acceptance of Ride-Sharing in Automated Vehicles. *Human Factors in Transportation*, 57, 142-158.

[42] Walker, F., Holstein, T., Baumann, M., & Hargutt, V. (2019). Human-like Handovers: Effect of Vehicle-Pedestrian Interaction on Pedestrian Trust in Automated Vehicles. In *Proceedings of the 12th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*.

[43] Lagström, T., & Lundgren, V. M. (2015). AVIP—Autonomous Vehicles Interaction with Pedestrians. (Master's thesis). Chalmers University of Technology, Gothenburg, Sweden, Dept. Product Prod. Develop.

[44] Kukla, A. (2000). *Social Constructivism and the Philosophy of Science*. Routledge, London, U.K.

[45] Lee, S. C., Nadri, C., Sanghavi, H., & Jeon, M. (2021). Eliciting User Needs and Design Requirements for User Experience in Fully Automated Vehicles. *International Journal of Human-Computer Interaction*. doi: 10.1080/10447318.2021.1937875.

[46] Habibovic, A., Campbell, J., Lundgren, V. M., Andersson, J., Klingegård, M., Malmsten Lundgren, M., Larsson, J., Granström, T. S., & Fagerlönn, J. (2018). Communicating Intent of Automated Vehicles to Pedestrians: The Development and Testing of Light Signals. *Transportation Research Part F: Traffic Psychology and Behaviour*, 58, 681-691.

[47] Guo, J., Yuan, Q., Yu, J., Chen, X., Yu, W., Cheng, Q., Wang, W., Luo, W., & Jiang, X. (2022). External Human–Machine Interfaces for Autonomous Vehicles from Pedestrians' Perspective: A Survey Study. *Sensors*, 22(9), 3339. https://doi.org/10.3390/s22093339.

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