

Exploring the effects of language on angry drivers' situation awareness, driving performance, and subjective perception

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Research shows that anger has a negative impact on cognition due to the rumination effect and in the context of driving, anger negatively impacts situation awareness, driving performance, and road safety. In-vehicle agents are capable of mitigating the effects of anger on driving behavior. Language is another important aspect that influences human behavior and information processing. This study aims to explore the effects of the language of in-vehicle agents on angry drivers' situation awareness, driving performance, and subjective perception. The results of this study are indicative of the importance of native language processing in the context of driving. Native language agent condition resulted in improved driving performance and heightened situation awareness. The study results and discussions have practical design implications and are expected to help foster future work in this domain.

CCS Concepts: • **Human-centered computing** → **Empirical studies in HCI**.

Additional Key Words and Phrases: angry driving, in-vehicle agents, native language processing, situation awareness, driving performance

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1 INTRODUCTION

Emotions have a substantial influence on the cognitive processes of humans, including perception, reasoning, and problem-solving [49]. Research has shown that the emotion of drivers plays a vital role in influencing driving performance and affects driving safety [19, 22, 41]. Drivers' emotions can negatively impact driving capabilities, such as attention, evaluation, and decision making [14] and need to be regulated to address safety issues on the road [18, 31]. Specifically, anger has a negative impact on cognition due to the rumination effect and in the context of driving negatively impacts situation awareness, driving performance, and road safety [16]. Thus, it is important to design systems that are capable of mitigating the effects that emotions can have on driving performance and road safety.

In-vehicle agents can be utilized to balance the emotional state of the driver. Studies show that the presence of in-vehicle agents and their social interaction with drivers have a beneficial effect on the trust levels of drivers [35]. Emotion detection and agent interventions can positively impact the drivers' safety and situation awareness [8, 52]. Until level 3 of automated vehicles, manual driving is required to varying extents depending on the context. The current study focuses on this stage and explores how in-vehicle agent interactions can be leveraged to facilitate safe driving.

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Besides emotions, language is another important aspect that influences human thoughts, behavior and decision making [2, 46, 53]. According to the theory of linguistic relativity, the structure of a language influences the way humans conceptualize the world [43, 50]. Research shows that native language processing can be more effective than secondary language processing [3, 7]. This provides exciting potential to be explored while designing in-vehicle agent interactions with the driver.

The objective of this study is to explore the impact of the language of in-vehicle agents on angry drivers' situation awareness, driving performance and subjective perception. This is a niche space that has not been explored previously and this study aims to make a significant contribution to research relating to emotions, language, and social interactions with in-vehicle agents. Additionally, the effects of the presence and absence of in-vehicle agents is also studied.

2 REVIEW OF LITERATURE

2.1 Effects of Anger on Driving

Emotion is an important factor that influences human actions and thoughts [1, 37]. Studies show that anger can narrow attentional scope relative to a neutral state and also narrows conceptual cognitive categorization [16]. Driving is a complex, cognitive-behavioral task and is an attention demanding task and anger while driving can affect the judgment of the driver and can diminish their decision making capabilities, thereby resulting in unsafe driving behaviors and road accidents [9, 10, 30, 51]. Research also indicates that anger in drivers potentially leads to deteriorated situation awareness [4, 24, 27, 42]. This raises the need to employ mechanisms to mitigate anger and the subsequent effects of anger on driving behavior.

2.2 Influence of In-vehicle Agents on Driving

Research has suggested that drivers' interaction with in-vehicle agents is capable of improving the drivers' emotional state and can lead to increased road safety [14, 27, 35, 52]. In-vehicle agents have the potential to enhance angry drivers' driving performance and can reduce their anger level [27, 52]. The effects of the embodiment of in-vehicle agents have been studied and the results indicate that an embodied in-vehicle agent was perceived as warmer and more competent than voice agents [35, 38, 47].

Research efforts have studied the effects that different characteristics of agents on driving performance and subjective perception. These characteristics include young or older voice agents wherein the young agent was preferred [32] and male or female voice agents wherein the female voice agent was preferred [11]. However, studies exploring the influence of in-vehicle agents' language on driving are lacking.

2.3 Influence of Language on Cognition

Language is an important factor that influences human behavior [53]. Research suggests that a variety of cognitive processes are affected by language [2, 5, 23]. The theory of linguistic relativity affirms that the structure of a language has an impact on the way humans perceive their surroundings [43]. Research also shows that language and the way information is framed impacts the decision-making process [33, 39, 40].

Native language processing can vary significantly from secondary language processing in various domains [3, 7]. Research has shown that native language processing can be more effective when compared to secondary language processing [6, 36].

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2.4 Language and Driving

The above studies are indicative of the negative effects of anger on cognition and driving. Research shows that in-vehicle agents are capable of regulating the emotions of the driver and can positively influence driving performance. On the other hand, research also shows that language is an important factor in the context of human processing and native language processing can be more effective.

While there have been efforts made to study the effects of multi-modal language-based warning systems for handovers of control in automated cars, the scope is limited to warning systems and does not extend to in-vehicle agent conversations [44]. The current study aims to contribute to this space by leveraging the combined strength of in-vehicle agents and language to explore the effects of in-vehicle agent's language on angry drivers' situation awareness, performance, and subjective perception.

3 METHODS

3.1 Experimental Design

The study followed a within-subject design. The independent variables comprised of the state of the in-vehicle agent (present or absent) and the language of the agent (native or secondary). Each participant experienced three conditions during the experiment: No agent, Native-language speaking agent, and English speaking agent. The native language was either Hindi or Chinese based on the participant. Anger was induced prior to the participants driving the scenario to study the effects of the different agents on angry drivers. The order in which the three scenarios were experienced was fully counterbalanced across participants. Situation awareness, driving performance, and subjective perception were the dependent variables of this study. Situation awareness was evaluated using the Situation Awareness Global Assessment Technique (SAGAT) [13]. For driving performance, the response time, minimum, maximum, and average speed were taken into consideration. Subjective questionnaires pertaining to agent characteristics and preference were used to evaluate subjective perception.

3.2 Equipment

The study was conducted in a motion-based driving simulator by Nervtech. The simulator consists of a car seat, a steering system and sport pedals. Visuals were displayed on a triple-screen configuration. The screens were configured to cover a 120° horizontal field of view and consisted of 3 equal curved 48-inch HD TVs. The in-vehicle agent used was Milo, a humanoid robot developed by Robokind.

3.3 Participants

A total of 24 participants were recruited for this study (18 male, 6 female; *mean* age = 23.37, *SD* = 2.63; *mean* years of driving = 4.54, *SD* = 2.92). Twelve participants were Chinese speaking and the other 12 were Hindi speaking. English was the second language for all the participants. The participants reported having a valid driver's license and had at least 1 year's driving experience to avoid any novice driver effects. All participants provided informed consent.

3.4 Procedure

The experiment lasted for approximately an hour. Prior to the study, the participants were asked to drive in the simulator for a short (3-5 minutes) duration to serve as a simulation sickness test run and to provide an opportunity for the participants to get accustomed to the driving simulator. Post this, a seven-point Likert scale questionnaire was used to

collect the participants' current (baseline) emotional states. Nine emotional states were reported as important and most relevant in the context of driving [28]. These nine emotions were included in the questionnaire: happy, angry, fearful, depressed, bored, confused, urgent, embarrassed, and relieved.

To induce anger, participants were given 12 minutes and asked to write about a past emotional experience associated with anger. The participants were instructed to recall the memory of the experience as clearly as possible and were asked to revisit the experience emotionally. Participants were shown two sample paragraphs related to anger-inducing incidents to assist them with their writing. Following this anger-induction process, the participants were asked to complete the emotional Likert scale once again to gauge their emotional state post the anger-induction process.

Then, the participants were made to drive the three different scenarios. Each scenario lasted for about 10 minutes. Prior to each scenario, the context was set to the participants and it was explained that they were heading to work and were running late for a meeting and had to reach within 10 minutes. The participants were intimidated by the experimenter at regular intervals of 3 minutes regarding how much time was left from the 10 minutes. This was done to induce a sense of urgency. The scenario was stopped after 10 minutes.

Under each condition, the participants faced five different events intended to induce negative arousal (anger or fear) in the driver. Adding more negative incidents on road is expected to maintain participants' angry state throughout the drive and provide the agent with intervention opportunities. Example scenarios and interventions are documented in Table 1. Figure 1 depicts screen captures of some events the participants faced.

Event	English Intervention	Hindi Intervention	Chinese Intervention	Emotion/Tone of Intervention
Jaywalker startling the participant	Wow! Where did that person come from?! Stay calm, you are doing fine	Arre yaar! Woh ladakee aae kahaan se?! Don't worry, kuchh nahin hua	Wai Nàgè rén shì cóng nǎi chūlái de? Bào chí zhènjìng, nǐ zuò dé hěn hǎo	Empathetic/Reassuring
Upcoming fog with reduced visibility	Seems like there is some unexpected fog ahead which might affect visibility	Lagata hai aage thoda unexpected fog rahega jise visibility kam ho sakti hai	Qiánmiàn hāoxiàng yǒu yíxiē yì xiāngbùdào de dà wú, kěnéng huì yǐngxiǎng néngjiǎndù	Informative/Concerned
Car swerving out of its lane and cutting the participant's vehicle	Watch out, the driver ahead of you is beginning to swerve.	Aapake saamane wali kaar mudne lagee hai	Xiǎoxīn, qiánmiàn de sījī túrán kāishǐ biàn dào	Cautioning

Table 1. Sample scenarios and interventions

For each scenario, the Situation Awareness Global Assessment Technique (SAGAT) was employed to measure the three situation awareness levels (perception, comprehension and projection) of the driver. To measure perception, the participants were asked the question "What elements of interest did you see on the screen?". To measure comprehension, the participants were asked the question "What do these elements of interest indicate with respect to the current situation?". To measure projection, the participants were asked the question "What do you think will happen next?".

After each scenario was completed, participants were asked to fill the emotional Likert survey and subjective questionnaires relating to the agent to record the participant's emotions, agent perception, agent compassion, and agent likeability. At the end, the participants were asked to record their overall agent preference (none, native, or English).

Given that emotions are a temporary psychological state, the anger induced at the beginning of the study would not persist after the experimental procedure is completed. However, to address the possibility that the self-induced emotional state does persist, the participants were debriefed about the overall meaning of the experiment at the end, to dampen any prolongation of the self-induced emotional state [26, 34].

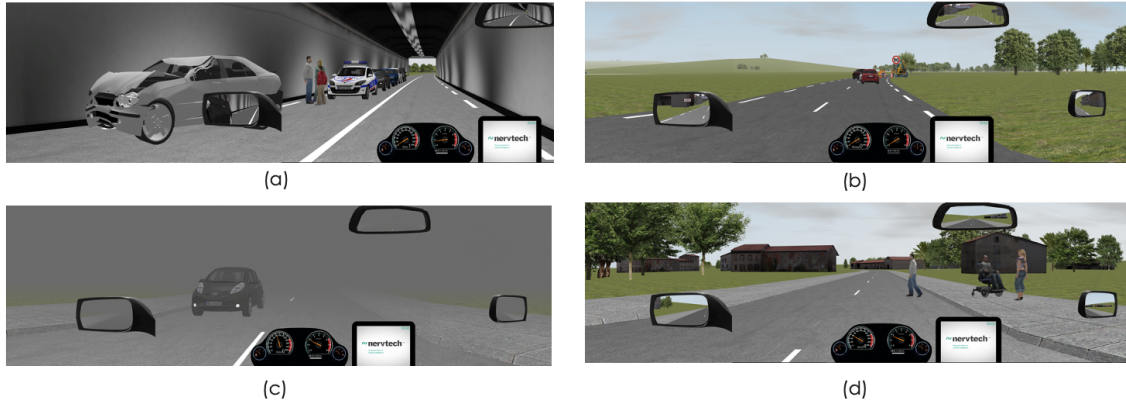


Fig. 1. Screen captures of some events from the driving scenario: (a) Accident with bystanders and police vehicles inside a tunnel, (b) Construction site with cars swerving in front of participant's vehicle while crossing the site, (c) Fog that reduces visibility with traffic, (d) Jaywalker

4 RESULTS

4.1 Emotion Induction

Participants recorded their emotional state at the beginning of the study, after emotion induction, and at the end of the study. The results are depicted in Figure 2. A Friedman test revealed a statistically significant difference among the three states: $\chi^2(2) = 19.65, p < 0.0001$. Wilcoxon's pair-wise comparison with a Bonferroni corrected alpha value of 0.0167 to minimize Type I error was used. The anger levels after induction ($mean = 3.2, SD = 2.02$) was significantly higher than before induction ($mean = 1.5, SD = 1.14$), $p = 0.0009$. The anger levels after the experiment ($mean = 1.9, SD = 1.28$) was significantly lower than after induction, $p = 0.0029$.

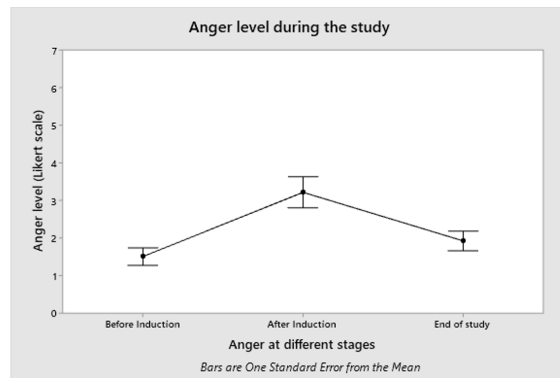


Fig. 2. Change in anger levels in participants throughout the study

4.2 Situation Awareness

Situation awareness results are depicted in Figure 3. An ANOVA revealed no statistical difference for Level 1 SA, $F(2,46) = 3.079$, $p > 0.05$. However, significant differences between the different agent conditions for Level 2 SA: $F(2,46) = 4.928$, $p = 0.0099$, Level 3 SA: $F(2,46) = 6.01$, $p = 0.0039$ and Mean SA $F(2,46) = 5.68$, $p = 0.0048$ was observed.

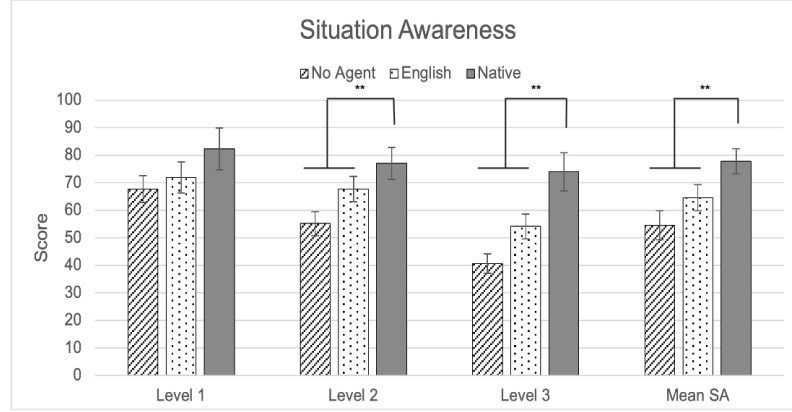


Fig. 3. Situation awareness results across different in-vehicle agent conditions. ** $p < 0.0167$. Error bars represent standard error of the mean

Post-hoc pairwise t-tests revealed that the situation awareness in the native agent condition was significantly higher than the English agent condition in the following cases: Level 2 ($p = 0.043$); Level 3 ($p = 0.013$) and Mean SA ($p = 0.014$). Additionally, the situation awareness in the native agent condition was significantly higher than the no-agent condition in the following conditions: Level 2 ($p = 0.013$); Level 3, ($p = 0.0097$); and Mean SA, ($p = 0.009$). Although there is a numerical trend amongst the different agent conditions, there is no statistical significance for Level 1 SA.

4.3 Driving Performance

4.3.1 Response Time. Response time was measured as the time from when an intervention started until either the steering wheel angle was changed by ± 2 degrees or the acceleration or brake pedal was engaged by 10% or more [17, 45]. The interventions were warning the participants regarding an upcoming incident (for instance, “Looks like there is some unexpected fog ahead which might affect visibility”). Given that the participants processed and reacted to this new information while it was being shared by the agent, the response time was calculated from when the intervention started. There was no significant difference between the mean length of the interventions in the different agent conditions ($p = 0.94$) to ensure that the length did not affect the response time of the participants (English interventions length: $mean = 5.42$, Chinese interventions length: $mean = 5.5$, Hindi interventions length: $mean = 5.57$).

Figure 4 shows the response time across the different agent conditions. An ANOVA revealed a statistically significant difference among the three different agent conditions, $F(2,46) = 49.57$, $p < 0.0001$. Post-hoc pairwise t-tests revealed that the response time in case of the native agent condition ($mean = 4.04$ s, $SD = 1.59$ s) was statistically lower than the no-agent condition ($mean = 9.24$ s, $SD = 2.39$ s) ($p < 0.0001$) and the English-speaking agent condition ($mean = 4.71$ s, $SD = 1.83$ s) ($p = 0.0079$). The response time in case of the English-speaking agent condition was found to be statistically lower than the no-agent condition, $p < 0.0001$.

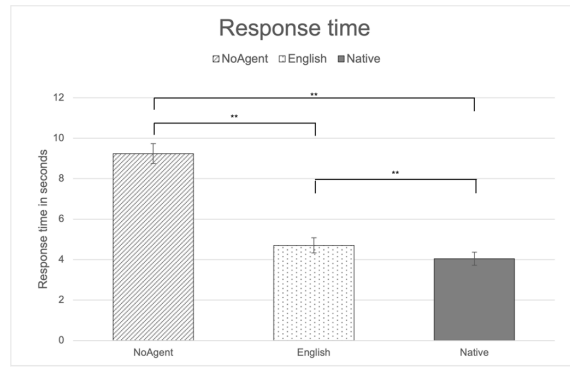


Fig. 4. Response time in seconds. $**p < 0.0167$. Error bars represent standard error of the mean

4.3.2 *Speed*. Figure 5 shows the minimum, maximum and average speed across the different agent conditions. An ANOVA revealed a statistically significant difference among the three different agent conditions for minimum speed ($F(2,46) = 10.75, p < 0.0001$), maximum speed ($F(2,46) = 35.507, p < 0.0001$), and average speed ($F(2,46) = 47.69, p < 0.0001$).

Post-hoc pairwise t-tests revealed that the minimum speed in the native agent condition was statistically lower than the English agent condition ($p = 0.007$). The minimum speed in the no agent condition was statistically lower than the English agent condition ($p = 0.0014$). The maximum speed in the native agent condition was statistically lower than the English agent condition ($p < 0.0001$) and the no agent condition ($p < 0.0001$). The average speed in the native agent condition was statistically lower than the English agent condition ($p < 0.0001$) and the no agent condition ($p = 0.0006$). The average speed in the no agent condition was statistically lower than the English agent condition ($p < 0.0001$).

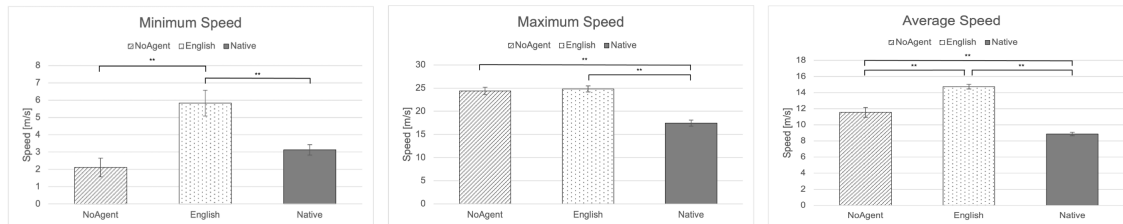


Fig. 5. Minimum speed in m/s . $**p < 0.0167$. Error bars represent standard error of the mean

4.4 Agent characteristics questionnaires

The questionnaire results showed that there were significant differences in the emotional, likeability, perceived intelligence, anthropomorphism, and animacy scales associated with the language of the in-vehicle agent. Figure 6 shows the overall mean rating scores for each of the above scales across the different agent conditions. The agent characteristics representing anthropomorphism and animacy only depict the comparison between the native agent and English agent conditions since including the no agent condition in these scales would not be meaningful.

Results from Friedman tests revealed statistically significant differences between agents in the warmth scale: emotional, $\chi^2(2) = 7.39, p = 0.0248$, compassionate, $\chi^2(2) = 11.60, p = 0.0030$, happy, $\chi^2(2) = 8.46, p = 0.0144$, sociable,

$\chi^2(2) = 11.87, p = 0.0026$; the likeability scale: kind, $\chi^2(2) = 9.35, p = 0.0092$, pleasant, $\chi^2(2) = 10.65, p = 0.0048$; and the perceived intelligence scale: intelligent, $\chi^2(2) = 7.92, p = 0.0190$. Wilcoxon's pair-wise comparison showed statistically significant differences between agents in the anthropomorphism scale, $\chi^2(2) = 60.0, p = 0.0176$; and the animacy scale, $\chi^2(2) = 54.5, p = 0.011$.

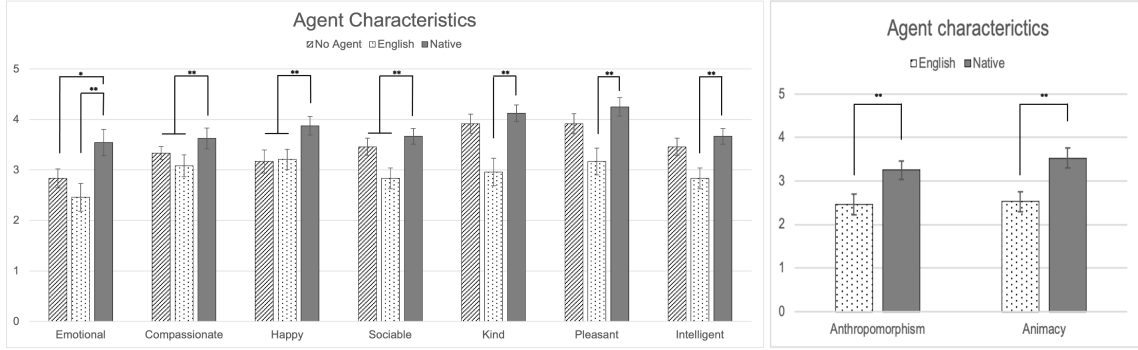


Fig. 6. Subjective evaluation results across different in-vehicle agent conditions. $**p < 0.0167$ and $*p < 0.05$. Error bars represent standard error of the mean

5 DISCUSSION

The primary goal of this study was to study the effect of an in-vehicle agent's language on angry drivers' situation awareness, driving performance, and subjective perception. Specifically, native (Hindi or Chinese) and secondary (English) languages were considered. The secondary goal of this study was to study how the presence and absence of in-vehicle agents influence the driver.

5.0.1 Situation Awareness. The situation awareness results indicate that the language of the in-vehicle agent does not have an impact on angry drivers with respect to Level 1 but influences higher levels of situation awareness. Angry drivers had a higher mean situation awareness when the agent spoke in their native language as opposed to English. With respect to the effects of the presence and absence of an agent, the results indicate that the absence of an agent lowers the situation awareness of the drivers considerably for higher levels (comprehension and projection).

5.0.2 Driving performance. The response time and speed results indicate that the driving performance is better in the native agent condition when compared to the English agent condition. Research shows that lower speeds are associated with safe driving [12] and the response time and speed trends are significantly lower in the native agent condition when compared to the English agent condition. The response time in the no agent condition is significantly higher than the other two conditions. The speed trends indicate that the driving performance in the native agent condition is better than the no agent condition. Based on the response time trends among the different conditions and the speed trends between the no agent and the native agent, we cautiously infer that the driving performance is better with the presence of an in-vehicle agent.

5.0.3 Subjective perception. The agent characteristics results indicate that the drivers prefer the native agent condition more than the other two agent conditions and have rated the native agent to be warmer, kinder, and more intelligent.

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The results also indicate that the participants equally prefer the English-speaking agent and the no agent condition as their first preference. As a result, it cannot be concluded affirmatively that the presence of an agent is more preferred than the absence of an agent. Based on the feedback received, drivers indicated the need to switch between the agent modes and preferring the no agent condition at certain times depending on their current emotional state, thereby not always preferring the presence of an agent.

5.1 Theoretical Implications

5.1.1 Language and Situation Awareness. According to the results, native language positively influenced higher levels of situation awareness that relate to interpretation and prediction and often require more cognitive processing than level 1 (perception). The response time results indicate that information processing is significantly faster in native language than the secondary language. One potential contributing factor could be that the native language is *automatized* based on life-long learning and as a result, requires less cognitive resources than the secondary language. As a result, more cognitive resources are available for interpretation and prediction, thereby leading to heightened situation awareness in the native language condition. The results are in agreement with previous research efforts that showed that information relayed in the native language is more effective than the foreign language in complex domains [3, 53].

5.1.2 Emotion Regulation and Situation Awareness. Emotion regulation is a specialized discipline of psychology and [20] details an emotion regulation process model that can be employed for emotion regulation. In this process model, one of the most widely accepted strategy is the attention deployment emotion regulation strategy which involves distracting an individual from an affective source to assist the driver to concentrate on the driving environment [21]. Research has shown this attention deployment strategy can be employed to heighten situation awareness [25].

The results of this study show that the native agent condition led to heightened situation awareness in angry drivers which could be attributed to the possibility that the in-vehicle agent intervention in the native language, was successfully able to distract the driver from their state of anger rumination, thereby enabling the driver to concentrate on the driving environment. The native language agent was able to mitigate the impact of anger on situation awareness.

5.1.3 Anger and Driving. Research has shown that anger can worsen driving performance by negatively impacting attention, focus, and perception [10, 14]. This study employed in-vehicle agents and designed interventions to regulate the emotions of angry drivers, and to curb subsequent effects of anger on driving behavior. The results indicate that the presence of an agent was also able to improve the response time of angry drivers. The absence of an agent was detrimental to driving performance and situation awareness. These results are in agreement with previous studies that have shown the effectiveness of in-vehicle agents on angry drivers [29].

5.2 Practical Implications

5.2.1 Guidelines for future research. A motion-based simulator was used as opposed to a static simulator to provide better physiological arousal for the drivers. The driving experience in this motion-based simulator was similar to actual driving and the procedure specified in this study can help future driving-based research. This study also validated the writing-based emotion induction process and the methodology detailed in this study can help foster future emotion-based research.

The scenario events and intervention designs also contribute to the larger driving related research community. A multi-faceted approach was employed in this study, where, post anger induction, the scenario events were designed to maintain the anger levels of the drivers to better study the influence of agents. The agent interventions were designed

based on language theories and were modelled to regulate the emotions of the drivers. The intention was to empathize with the driver's emotional state and to deter the effects of their emotional state from affecting their driving performance and situation awareness.

5.2.2 Design Guidelines. The results from the data analysis in conjunction with the feedback received have potential design implications that need to be considered while designing in-vehicle agent interfaces.

Native language support for in-vehicle agent interfaces can be beneficial to the drivers in regulating their emotional state and preventing their emotions from affecting their driving performance. This would also make the interfaces accessible to a wider range of audiences.

Notwithstanding the fact that an in-vehicle agent certainly can be beneficial to the driver, an option to disable the in-vehicle agent needs to be presented to the driver. The driver could choose to use this option based on their emotional state or other circumstances.

6 LIMITATIONS AND FUTURE WORK

Although the driving simulator was of moderately high fidelity, it is not the same as a real driving experience. This may have led to slightly different driving behaviors when compared to real life.

When considering the emotion induction methodology, although the results showed successful anger induction based on the self-reported emotional state, measuring physiological indicators of arousal or emotion would have increased the validity of this study. Measuring heart rate (ECG), the oxygen level in frontal lobe using fNIRS [15], and using facial emotion detection techniques [48] may help alleviate this issue.

The current study focused on two native languages (Hindi and Chinese) and English as the secondary language. Additional combinations of native and secondary languages can be explored to validate the results of this study.

7 CONCLUSION

The influence of the language of in-vehicle agents on angry drivers' situation awareness, performance, and subjective perception was studied by conducting a within subject experiment. The results of this study are indicative of the importance of native language in the context of driving and cognitive processing. The drivers' response time and higher levels of situation awareness were found to be better in the native agent condition when compared to the other conditions. Besides language, the effects of the presence and absence of in-vehicle agents were also studied. While the results indicated that the native agent condition was preferred over the no agent condition, there was no clear distinction between the English agent condition and the no agent condition. Driving performance was better in the native agent condition than the no agent condition. Additionally, drivers expressed the need to control the state of the in-vehicle agent, conditionally preferring the presence and absence of the agent.

The results and discussions from this study posit future directions for designing in-vehicle agent interfaces to effectively regulate the emotions of the drivers. Specifically, for drivers in an angry state, in-vehicle agent interventions can employ native language to better regulate the emotions of the driver to avert the possibility of the angry state developing into aggressive driving or road rage.

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