ESTUDOS EM DESIGN
DESIGN ARTICLES

Agentes de Voz de Gênero Ambíguo para Mitigação do Viés de Gênero em Interfaces de Voz no contexto de Direção Autônoma

Gender-Ambiguous Voice Agents for Mitigating Gender Bias in Voice User Interfaces in the Context of Autonomous Driving

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Resumo
Atualmente, as Interfaces de Usuário por Voz (VUIs) têm sido amplamente aplicadas em dispositivos inteligentes. No entanto, o design atual dos agentes de voz usados nesses sistemas resultou em um viés de gênero prejudicial durante essa interação humano-computador. Para reduzir esse viés, agentes de voz de gênero ambíguo foram considerados uma solução em potencial. Desta forma, este estudo exploratório visa investigar os efeitos do gênero do usuário e a aplicação de agentes de voz de gênero ambíguo em VUIs. Um experimento online (N=50) investigou a percepção de quatro fatores de usabilidade no contexto de múltiplos cenários de direção automatizada. Os usuários foram apresentados a dois tipos de agentes de voz de gênero ambíguo e dois tipos de redação para cada mensagem, a fim de avaliar cada cenário. Nossos resultados revelam que o uso de agentes de voz com gênero ambíguo em VUIs reduziu significativamente a diferença de pontuação entre os gêneros dos usuários e que o gênero do usuário não tem efeito significativo na percepção dos fatores de usabilidade.

Palavras-chave: Design de Experiência do Usuário, Design de Interfaces de Usuário, Interfaces de Usuário por Voz, Agentes de Voz, Voz de Gênero Ambíguo

Abstract
Lately, Voice User Interfaces (VUIs) have been widely applied in smart devices. However, the current design of the voice agents used by these systems have resulted in harmful gender bias during this human-computer interaction. To reduce this bias, gender ambiguous voice agents have been considered as a potential solution. This exploratory study aims to investigate the effects of user gender and the application of gender ambiguous voice agents in VUIs. An online experiment (N=50) investigates the perception of four usability factors in the context of multiple automated driving scenarios. Users are presented with two types of gender ambiguous voice agents and two types of wording for each message to evaluate each scenario. Our findings reveal that using gender ambiguous voice agents in VUIs significantly closes the gap in scores between user genders and that the user's gender has no significant effect on the perception of usability factors.

Keywords: *User Experience Design, User Interface Design, Voice User Interfaces, Voice Agents, Gender Ambiguous Voice*

Introduction

The widespread availability of Voice Assistants (VAs) in smartphones, smart speakers, and other digital devices (Bentley et al., 2018; Hoy, 2018; Lopatovska & Williams, 2018) has significantly increased the adoption of Voice User Interfaces (VUIs) as a primary mode of human-computer interaction. As these devices become more ubiquitous, VAs are now accessible to a vast and diverse user base, seamlessly integrating into daily life.

Considering VUIs' design, the addition of anthropomorphic characteristics to VAs, such as assigning a gender and name, has been shown to enhance usability and user acceptance of these systems (Forster et al., 2017). This is evident in popular VAs like Alexa, Siri, and Google Assistant, which are marketed as virtual personas with distinct names, voices, and traits that encourage users to attribute personalities to them. However, most leading VAs are default to female traits, such as a names and voices, reflecting a persistent gender bias in these interfaces (Kuzminykh et al., 2020; Sutton, 2020).

This bias has sparked growing interest in how voice characteristics and gender influence user interaction with VUIs. Since VAs are designed to be activated through commands and fulfill an assisting role, they often reinforce the stereotype of an assistant or servant—a role traditionally associated with women (Gustavsson, 2005). This design choice can inadvertently encourage negative behaviors, such as the replication of the commanding tone used on the activation of VUIs on the interaction with real women (Ard, 2021).

The voice characteristics of a VA, such as those derived from recordings of female speakers, can significantly impact user experiences. Tymburiba Elian et al. (2022a) revealed that female users tend to report a noticeably worse experience with VAs that use female voices compared to male users, highlighting the nuanced effects of gendered design in VUIs. The findings by Tymburiba Elian et al. (2022a) align with a technical report presented by UNESCO in 2019, which explores gender bias, sexism, and gender inequality in technology (UNESCO, 2019). The report highlights that the gendered design of VAs may reinforce harmful stereotypes about women, echoing concerns raised by studies on user experiences with female-voiced VAs. To address these issues, the report suggests that adopting gender-ambiguous voice agents could reduce perceptions and replications of gender bias and stereotypes.

A gender-ambiguous voice agent is defined as the voice agent whose voice characteristics do not conform to traditional gender norms or binary gender identification. This can be achieved either by using a voice agent recorded by a speaker who does not identify with the male/female gender binary or by employing post-processing techniques to modify the voice recordings of male or female speakers to create a more neutral or non-binary sound. Such an approach would also enhance inclusivity for individuals who do not conform to binary gender identities (Sutton, 2020). However, research on the impact of gender-ambiguous voice agents remain incipient, with only a few studies focusing on the design of the voice agents (Q, 2019; Sutton, 2020; Tolmeijer et al., 2021), presenting a gap that this study aims to address.

Considering these challenges, we propose an exploratory study to investigate the impact of two types of gender-ambiguous voice agents and participant gender on the perception of four key usability factors: Ease of Understanding, Pleasantness, Commandingness, and Urgency. The

study examines these factors within the context of four automated driving scenarios, where users are expected to respond to messages spoken by the Voice User Interface (VUI) of an autonomous vehicle. These scenarios differ in urgency, with higher levels requiring prompt action to avoid potential harm — such as in take-over requests during conditionally automated driving, where failure to act could lead to accidents.

To conduct this study, we designed an online experiment with 50 participants (N=50), who were asked to imagine the proposed automated driving scenarios and then complete a survey reflecting their perceptions of each usability factor after listening to VUI messages. Additionally, the study explores how the form in which the message is delivered — whether declarative or imperative — affects user perceptions. The results indicate that gender-ambiguous voice agents significantly reduced the perception gap between male and female users, suggesting that these agents can help mitigate harmful gender biases in human-computer interactions while enhancing the user experience for female users.

This paper represents one of the first studies to explore users' perceptions of VUIs using gender-ambiguous voice agents across multiple driving scenarios. The findings demonstrate that gender-neutral voice agents can bridge the perception gap between male and female users. This offers promising implications for the design of VUIs, presenting a potential solution to combat gender biases that often arise in human-computer interactions. By fostering more balanced and inclusive experiences, these voice agents could improve the overall user experience—especially for female users—and pave the way for more equitable interactions in the future of autonomous systems. The insights provided by this study are vital for advancing the field of human-computer interaction and lay the groundwork for further research and development of inclusive technologies.

Background

Automated Driving Scenarios

In automated driving scenarios, users shift from actively controlling a vehicle to a monitoring role (Beattie et al., 2015). The degree of supervision and intervention required depends on the system's level of automation. The Society of Automotive Engineers (2021) defines vehicle autonomy on a scale from level 0, where no automation exists, to level 5, where the vehicle operates autonomously without any user intervention. Our study focuses on autonomous vehicles operating at level 3, or conditional automation. At this level, the system can handle tactical and operational functions but may require the user to intervene when necessary (Naujoks et al., 2017; Du et al., 2020; SAE, 2018).

A key intervention in a conditional automated driving context is the Take-Over Request (TOR). A TOR occurs when the automated system reaches its safety boundaries and prompts the user to take control of the vehicle by getting "motor-ready”: redirecting their gaze to the road and placing their hands on the steering wheel and feet on the pedals to perform any necessary maneuvers (Zeeb et al., 2015, 2016). Since TORs are communicated through the vehicle’s interface, various studies have examined the use of pure abstract sounds versus speech-based messages in this scenario (Beattie et al., 2015; Politis et al., 2015; Naujoks et al., 2016; Forster et

al., 2017). Research has shown that speech-based messages tend to result in higher perceptions of usability compared to abstract sound cues. This finding reflects a growing trend: the presence of a virtual assistant, which interacts with users via a VUI, is increasingly seen as a key factor in automobile purchasing decisions (Kisella, 2020).

Gender Ambiguous Voice Agents

Currently, there is a lack of text-to-speech tools that feature voice agents with gender-ambiguous characteristics. However, previous studies have explored potential solutions to address this gap. For example, the Q (2019) project created gender-ambiguous voice agents by using recordings from individuals who do not identify strictly as male or female. They then applied a complex sound manipulation process, adjusting pitch, formants, and harmonics, to generate and screen their voice agents via a survey (Nørgaard, 2019; Tolmeijer et al., 2021).

In another approach, Tolmeijer et al. (2021) utilized a speech synthesizer based on the Wavenet algorithm, which is trained on data recorded by male or female speakers. The generated speech was subsequently post-processed by shifting the pitch of each agent by a certain number of semitones toward the opposite gender. These voice agents were also evaluated through a survey.

Building on these methodologies, Tymburiba Elian et al. (2022b, 2023) further investigated these approaches by comparing natural recordings from speakers who identify across six different positions on the gender spectrum with three Wavenet-based voice agents. The voice agents were then post-processed to morph them into gender-ambiguous versions by adjusting their pitch. Tymburiba et al. (2023) also conduct a survey to screen which of these natural and artificial voice agents were perceived as most the most gender ambiguous by the users.

Methodology

In this exploratory study, we aim to tackle the following research questions: **RQ1:** How does the participant gender affect the perception of usability when using gender ambiguous voice agents in VUIs? **RQ2:** How does the type of agent (natural or artificial) affect the perception of usability? **RQ3:** How do the semantics in scenarios that require participant action with different levels of urgency affect the perception of usability? **RQ4:** What combination of agent type and semantics would be more suitable for increasing the perception of usability in scenarios with different levels of urgency?

Table 1: Messages used in each scenario.

Situation	Message text	
	Declarative	Imperative
System Startup	*"The system is starting."*	*"Please wait, the system is starting."*
Sign in	*"Welcome! Signing in is required to continue."*	*"Welcome! Sign in to continue."*
Seatbelt	*"Attention: Seatbelts are not fastened."*	*"Attention: fasten your seatbelts."*
Take-over	*"Warning: Take-over is required."*	*"Warning: Take-over the controls."*

Source: Authors.

Usability Factors

This paper explores four key usability factors in VUIs within a driving context: Ease of Understanding, Pleasantness, Commandingness, and Urgency. *Ease of Understanding* refers to the capacity to easily retrieve and process information, facilitating comprehension of the system's intentions (Naujoks et al., 2016). In this study, it not only encompasses the understanding of the speech-based message's textual meaning but also the perception of how the voice itself affects this understanding. The second factor, *Pleasantness*, is crucial in a driving context as it influences user satisfaction. A low level of Pleasantness can cause the message to be ignored or disrupt the user's focus, which may compromise the awareness needed to complete the task triggered by the warning message (Burt et al., 1995; Garcia-Chico & Corker, 2007; Eichelberger & McCartt, 2014). The third factor, *Commandingness*, reflects the user's tendency to accept the alert and take the suggested action (Bazilinskyy & de Winter, 2017). Finally, *Urgency* is a central factor when designing sound warnings. Different levels of perceived urgency can help users assess hazard levels and react properly and promptly. Also, the perceived urgency has a direct effect on the degree of priority the user assigns to completing the task (Baldwin, 2011; Guillaume, 2011)

Proposed Scenarios

The proposed automated driving scenarios are inspired by previous studies (Tymburiba Elian et al., 2022a). Four scenarios are investigated, each one with a different level of designed urgency. From the lowest to the highest level of designed urgency, they are defined as: "System Startup" - an alert related to starting up the vehicle's system; "Sign in" - related to action of signing into the system; "Seatbelt" - an alert for the users to fasten the seatbelts; "Take Over" - an alert related to necessity of retaking the controls of the vehicle.

Each scenario is expressed by a speech-based message that is given to the user by the VUI using the gender ambiguous voice agent. For each scenario, the message is presented in two forms: one declarative, which usually expresses statements (Collins Dictionary, 2024a); and one imperative, which usually expresses commands (Collins Dictionary, 2024b). Therefore, a total of eight messages are used throughout the online experiment. To manipulate the level of designed urgency, scenarios with higher urgency such as the "Seatbelt" and "Takeover" present the words "Attention" and "Warning" to their messages. These words are closely associated with higher levels of urgency (Wogalter et al., 2002; Hellier et al., 2002). The messages used for each scenario are presented in Table 1 according to its semantics.

Gender Ambiguous Voice Agents

In this paper, two voice agents from Tymburiba Elian et al. (2023) are chosen for comparison. These two voice agents are chosen because they were found to be the most ambiguous in Tymburiba Elian et al. (2023). In their study, Tymburiba Elian et al. (2023) presented various voice agents in a survey to assess users' gender perceptions. Participants were asked to assign a gender to each voice, with the options "male," "female," and "other," based on the methodology

outlined by Sutton (2020). The agents were ranked according to the number of mixed gender assignments, with particular attention given to the frequency of the "other" category and the opposite-gender assignment of the original speaker. This approach aligns with previous studies on gender-ambiguous voice agents (Nørgaard, 2019; Tolmeijer et al., 2021).

One of the selected voice agents was created using natural recordings from a non-binary speaker, referred to as the "natural" agent. The other was generated using a Wavenet speech synthesizer, trained on data from a male speaker, and is referred to as the "artificial" agent. The Parallel Wavenet algorithm, a state-of-the-art model for high-fidelity, fast speech synthesis (Oord et al., 2018), was used to generate the artificial agent. It's important to note that both the non-binary speaker's recordings and the Wavenet-generated voice were post-processed using pitch-shifting to enhance their gender ambiguity, in line with the methodology from Tymburiba Elian et al. (2023), as further outlined in the Discussion section of this study. Additionally, all messages were spoken with a neutral tone, and their amplitude peaks were normalized to -6dBFS. Table 2 presents the parameters representing the characteristics of the gender-ambiguous voice agents used in this study

Table 2: Parameters of the gender ambiguous voice agents used in the experiments.

Voice Agent	Original Gender	Original Mean Pitch	Pitch shift (semitones half-steps)	Morphed Mean Pitch	Type of Recording
Natural	Non-Binary	176Hz	-3	146Hz	Natural
Artificial	Male	153Hz	2	185Hz	Google en-US-Wavenet-B TTS

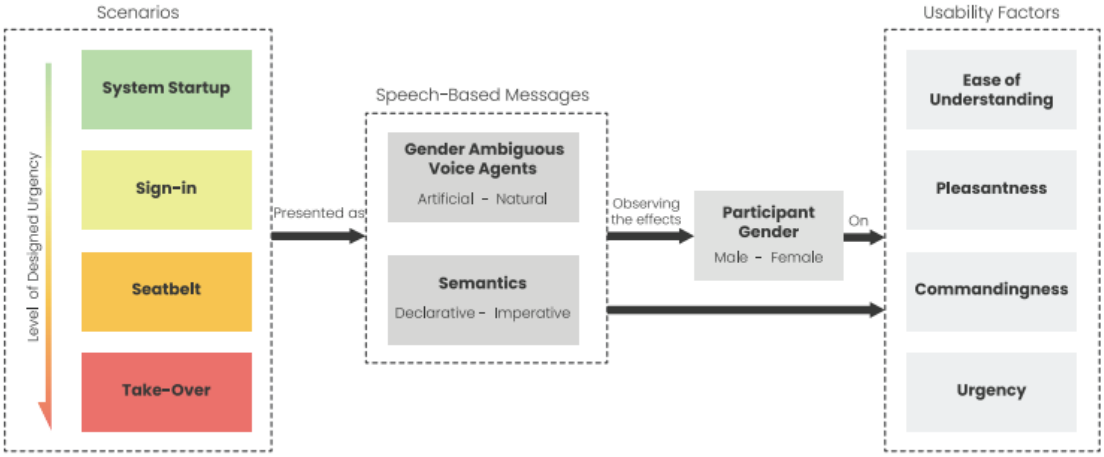
Source: Authors.

Survey and Participants

The experiment was conducted through an online survey that presented the messages for each scenario given by both natural and artificial gender ambiguous voice agents. In total, sixteen speech-based messages were spoken to participants until the completion of the survey. After listening to each message, participants were asked to answer questions about their perceptions on the four usability factors (Ease of Understanding, Pleasantness, Commandingness, and Urgency) through 5-point Likert scales according to their agreement to the statements: "I could easily understand this message"; "This message was pleasant."; "This message was commanding" and "This message was urgent"; where the scale ranged from 0 (totally disagree) to 4(totally agree).

English proficiency was required to all participants given that messages were provided in English. A diagram with the structure of the online experiment is shown in Fig. 1. A total of 50 participants were recruited, where 28 were Male and 22 Female, with the mean age of 29 years old, ranging from 18 to40 years old. It is important to highlight that, even though the participants were proficient in English, all were non-native speakers and from the same nationality (Brazilians). A further discussion regarding the fact that the participants were non-native speakers, and the participants' cultural background, is presented in the Discussion section.

Figure 1: Diagram of the experimental setting.



Source: Authors.

Results

Considering that the experimental design contains within and between subjects variables, a Mixed ANOVA (Murrar & Brauer, 2018), to analyze the effects and interactions is conducted. All the analyses mentioned in this section are performed with a confidence interval level of 95%. For post-hoc analysis, Bonferroni adjustment is used for pairwise comparisons (Chen et al., 2017). For the analyses of variance in which there is a violation of sphericity, the necessary corrections for each test are applied (Field, 2013). The variables and their classes (levels) are defined as follows: Scenarios (System Startup, Sign-in, Seatbelt and Take-over); Usability (Ease of Understanding, Pleasantness, Commandingness and Urgency); the Agent Type (Natural and Artificial); the Semantics (Declarative and Imperative). For the within-subjects tests, significant results for main effects and interactions are shown in Table 3.

Table 3: Results for within-subjects effects tests.

Variables	Mixed ANOVA	*p* value
Scenarios	F(3, 144) = 88.358	$p<0.001$
Usability[1]	F(2.203, 105.721) = 84.833	$p<0.001$
Agent Type	F(1, 48) = 31.751	$p<0.001$
Semantics	F(1, 48) = 54.300	$p<0.001$
Scenarios x Usability[1]	F(4.730, 227.036) = 43.482	$p<0.001$
Usability x Agent Type[1]	F(1.920, 23.405) = 10.100	$p<0.001$
Usability x Semantics[2]	F(2.554, 122.606)= 20.380	$p<0.001$
Agent Type x Semantics	F(1, 48) = 9.957	$p=0.003$
Scenarios x Usability x Agents[2]	F(8.298, 398.323) = 2.583	$p=0.008$
Scenarios x Usability x Semantics[1]	F(6.158, 295.600) = 2.815	$p=0.010$
Scenarios x Agent Type x Semantics	F(3, 144) = 3.337	$p=0.021$
Usability x Agent Type x Semantics	F(3, 144) = 3.068	$p=0.030$
Scenarios x Usability x Agents x Semantics[1]	F(6.183, 296.761) = 5.047	$p<0.001$

[1] Greenhouse-Geisser correction applied for violation of sphericity.
[2] Huynh-Feldt correction applied for violation of sphericity.

Source: Authors.

Main Effects

For between-subjects tests, the only variable analyzed is Participant Gender (male or female). Even though in the survey a third option for gender ("other") was given, no participants have assigned themselves to this gender option. The results for the between-subjects effects test revealed no main effect of the Participant Gender ($F(1,48) = 0.530$, $p = 0.470$). When observing pairwise comparisons for this variable, no significance was found, but it was noticed that male participants have a slightly higher score when compared to female participants (mean difference = 0.083, $p = 0.470$).

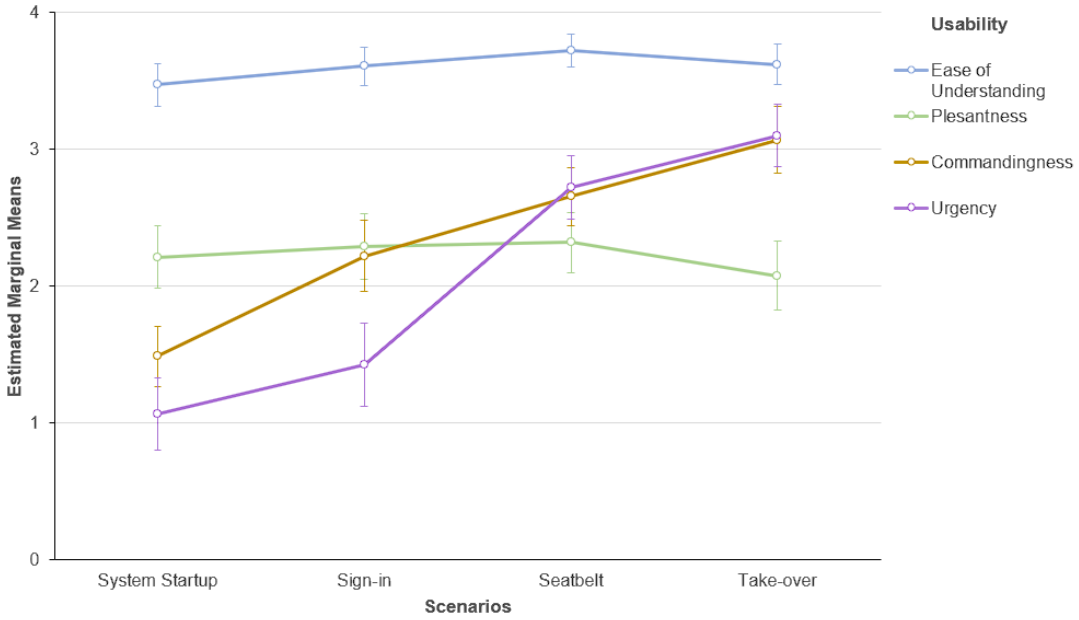
For within-subjects tests, it was found a main effect for Scenarios ($p<0.001$). In post-hoc analyses, pairwise comparisons revealed that all the scenarios have significant differences when compared to each other (all cases presented $p<0.001$). These results confirm that the designed scenarios are perceived differently from each other. When observing the mean scores for each scenario, it is possible to observe an increase of the mean score across the scenarios, according to its level of designed urgency. Mean scores for the four proposed scenarios were: System Startup (mean score = 2.057), Sign-in (mean score = 2.386), (mean score = 2.854), Take-over (mean score = 2.966). A main effect for the Usability ($p<0.001$) variable was also found. Pairwise comparisons revealed significant positive differences of the Ease of Understanding when compared to all the other factors (for all cases, $p<0.001$), demonstrating that its perception is not affected by the other usability factors, different from what was found for Pleasantness, that seem to be affected by the perception of Commandingness and Urgency.

The main effect found for the Agent Type ($p<0.001$) variable revealed a significant difference in the pairwise comparison between Natural and Artificial voice agents (mean difference = 0.440, $p<0.001$). These results indicate that the Artificial agent is perceived as more effective within the explored context of this study. Finally, a main effect ($p<0.001$) is also found for the Semantics variable. Post-hoc analyses revealed a significant difference between the Imperative and Declarative wording (mean difference = 0.290, $p<0.001$). This difference suggests that Imperative wording has led to higher scores when compared to Declarative wording for the messages designed for the scenarios proposed in this study.

Interactions

When analyzing interactions between the observed variables, we first found a significant interaction for Scenarios x Usability ($p<0.001$). For this interaction, pairwise comparisons revealed that the Scenarios significantly affect how the usability factors are perceived. It is possible to observe that the increase in the perception of Urgency negatively impacts the perception of Pleasantness. It is also shown that for the scenarios Seatbelt and Take-over, that have higher levels of designed urgency, higher scores for both Commandingness and Urgency are observed. These results indicate that the usage of the words “attention” and “warning” when designing the messages spoken to the user is effective to increase the perception of these factors. The scores for this interaction are presented in Figure 2.

Figure 2: Interaction for Scenarios x Usability.

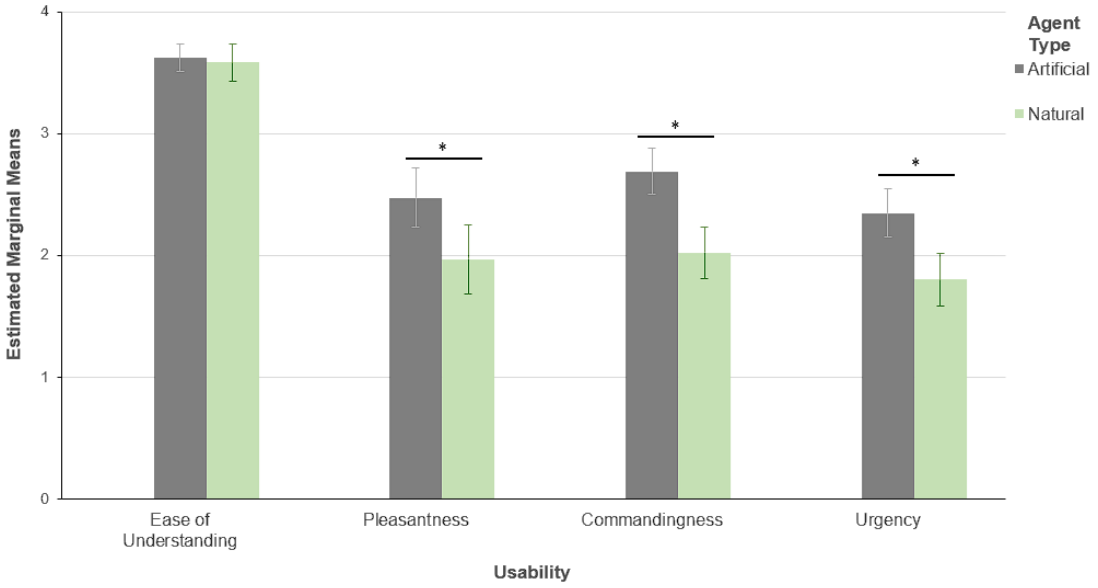


Source: Authors.

The significant interaction for Usability x Agent Type ($p<0.001$) shows that the Artificial voice agent had a significant difference when compared to the Natural voice agent for all the usability

factors except for the Ease of Understanding (for Ease of Understanding, p = 0.637, for Pleasantness, p = 0.002, for Commandingness and Urgency, p<0.001). These results are shown in Fig. 3. The mean difference between both voice agents for Ease of Understanding is considerably low (mean difference = 0.039). This can be interpreted as that the type of agent does not have a significant impact in terms of comprehensibility by the user. Since there are more factors that may have contributed to this result, such as the complexity of the messages designed for each scenario and the characteristics of the participants, this result is further explored in the Discussion section.

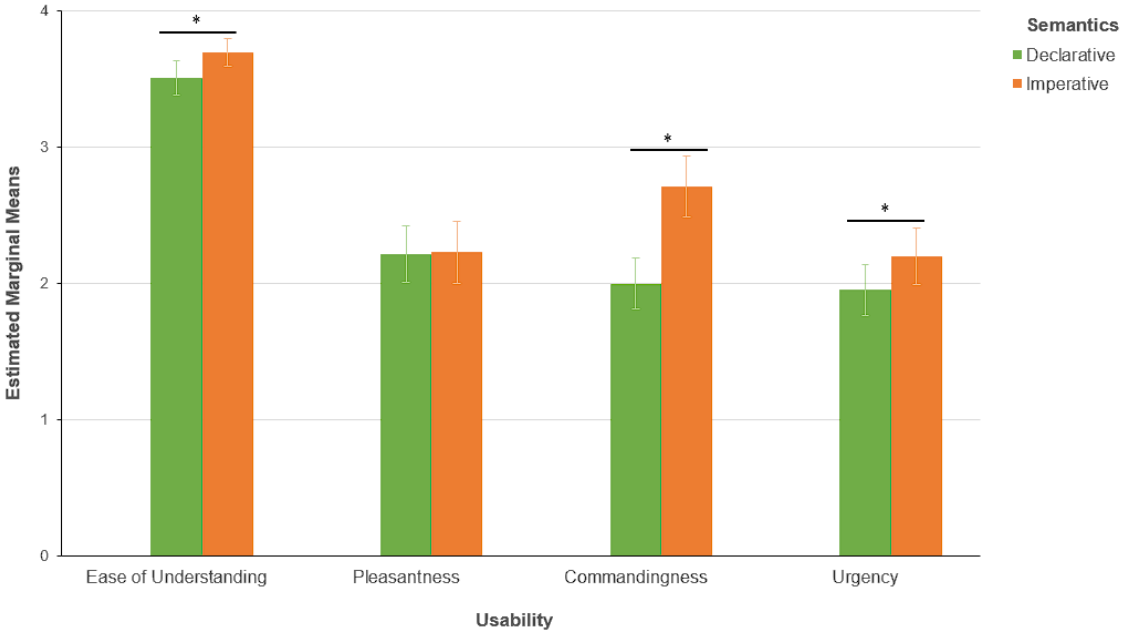
Figure 3: Interaction for Usability x Agent Type.



Source: Authors.

For the significant interaction of Usability x Semantics (p<0.001), the Imperative wording had higher mean scores for all the usability factors when compared to Declarative wording. The post-hoc analysis revealed that Semantics significantly affects the perception of all usability factors except for Pleasantness (mean difference = 0.014, p = 0.801). In Fig. 4, it is possible to see that the differences between the two levels of Semantics have a greater impact on Commandingness and Urgency. This result suggests that, even though there is an impact of the Semantics on the perception of usability factors, the type of wording should be chosen according to the characteristics of each scenario. For scenarios where a higher level of Commandingness and Urgency is not necessary, Declarative wording may be more adequate. The right choice of wording adjusts the user's awareness according to the demand of the scenario and avoids startling or stressing the user in unnecessary situations.

Figure 4: Interaction for Usability x Semantics.



Source: Authors.

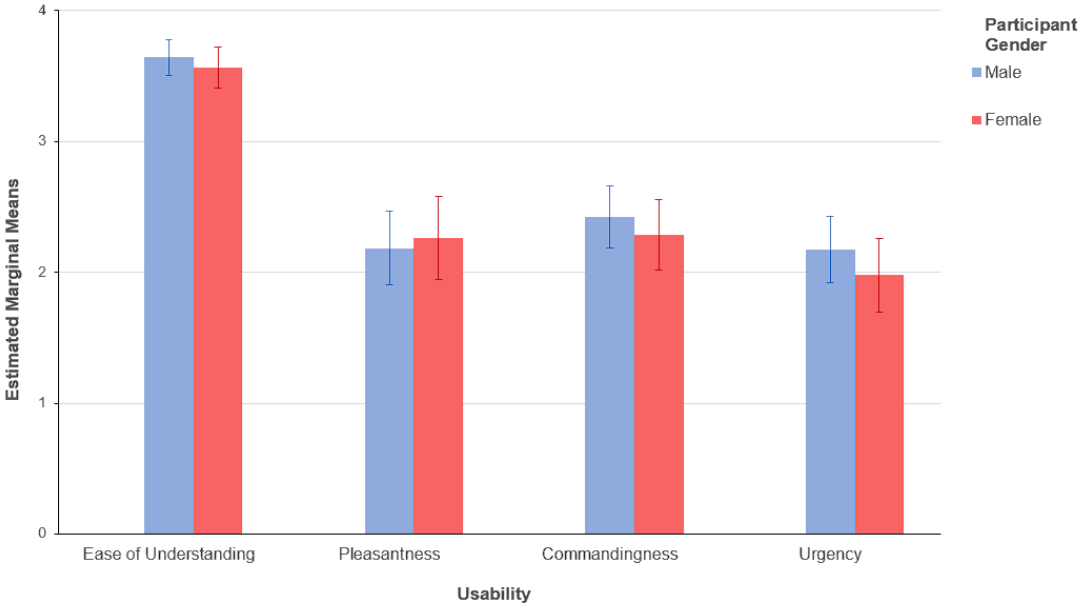
For the significant interaction Agent Type x Semantics ($p = 0.003$), the post-hoc analysis shows a significant difference between the voice agents for both types of wording (for all cases, $p<0.001$). The Artificial voice agent had higher scores compared to the Natural voice agent. It is also observed that the difference in the perception of the agents is lower in the case of Declarative wording. This result suggests that the type of wording, i.e. how a message is designed, has an effect on the perception of voice agents.

For two-way interactions we focus on the report of the interaction between Usability x Participant Gender. Even though this interaction had a not a statistically significant result ($p = 0.577$), neither a significant difference was found in the pairwise comparisons in the post-hoc analysis, it is relevant to observe the graph presented in Fig. 5. The graph shows that female participants had a similar score for Ease of Understanding, a higher score for Pleasantness, and a lower score for Commandingness and Urgency when compared to male participants. The result obtained in this analysis contradicts the results obtained in previous studies (Tymburiba Elian et al., 2022a) that used voice agents based on male and female speakers. The results obtained in the perception of the usability factors in Fig. 5 might be a direct influence of applying gender ambiguous voice agents in VUIs. This result is discussed in depth in the following section.

For the significant three-way interactions, firstly, we describe the one between Scenarios x Usability x Agent Type ($p = 0.008$). Its post-hoc analyses revealed that there is a significant difference between the Artificial and Natural voice agents for the usability factors Pleasantness, Commandingness and Urgency in all scenarios. Although it shows an effect of the Artificial voice agent in the Usability, it is relevant to highlight that the Ease of Understanding not being significant reinforces that the Agent Type does not deteriorate the comprehension of the presented messages. This interaction also shows that, for the situations with lowest and highest level of designed urgency (System Startup and Take-over), the Natural voice agents had higher scores for

Ease of Understanding than the Artificial one. This result complements the interpretation found in the interaction between Usability x Agent Type.

Figure 5: Interaction for Usability x Participant Gender.



Source: Authors.

Pairwise comparisons for the post-hoc analysis of the significant interaction between Scenarios x Usability x Semantics ($p = 0.010$) show that the scenarios with usability most impacted by Semantics were the System Startup and Sign-in. The only usability factor not significantly affected in this analysis is the Ease of Understanding. For all the scenarios and usability factors, Imperative wording had higher scores. It is also relevant to highlight that the only factor that had significant differences in scores for Semantics in all scenarios is Commandingness. This result suggests that this usability factor might be one most influenced by the type of wording in the automated driving context explored in this study.

For the significant interaction between Scenarios x Agent Type x Semantics ($p = 0.021$), the post-hoc analysis showed that Imperative wording when spoken by the Artificial voice agent had higher scores for all scenarios when compared to other combinations of Semantics and Agent Type. When observing the scores with Declarative wording, complements the analysis performed for the two-way interaction between Agent Type x Semantics. Messages with Declarative wording have reduced the difference between both types of agents for all the explored scenarios, having, then, a lower impact in the perception of Agent Type.

Finally, the only four-way interaction found significant was between Scenarios x Usability x Agent Type x Semantics ($p<0.001$). Its post-hoc analysis revealed that the combinations of the Agent Type and Semantics explored have a greater impact on Commandingness and Urgency. Both usability factors presented significant differences for all the combinations in all scenarios. This result complements the ones found on the other interactions previously presented, observing that in a multiple scenario context the differences among them, in this case, the level of designed

urgency, affected the usability factors that are more related to this manipulation.

Discussion

As an important first discussion, we observed that the presented results support the validation of the experiment design. For the Agent Type and Semantics variable the results confirmed our expectations that there would be a difference in the perception between Artificial and Natural agents and between Declarative and Imperative wording. For the Scenarios, the main effects allowed us to confirm that each scenario was perceived according to the designed level of urgency. Thus, each message being perceived as unique, according to the expected, supports the study methodology and design.

In our **RQ1**, we aimed to investigate how the participant gender affects the perception of usability when using gender ambiguous voice agents in VUIs. The results revealed that participant gender had no main effect in the perception of the voice agents presented. No significant interaction was found between Usability x Participant Gender. Previous studies that analyzed Usability x Participant Gender with male and female voice agents (Tymburiba Elian et al., 2022a), on the other hand, found this interaction to be significant and affecting the perception of usability factors. Here, then, we conjecture that when using gender ambiguous voice agents in this given context, we reduce the bias of the gender of the participant on the perception of usability factors.

For RQ1, these results suggest that the participant gender does not significantly affect the perception of usability when using gender ambiguous voice agents. Also, the presentation of gender ambiguous voice agents reduces the difference in perception of usability factors between male and female participants. Since there is no significant effect of the participant gender in the perception of usability when using gender ambiguous voice agents in VUIs, there is an indication that the observed lack of impact of the participant gender helps in closing the gap between genders in the perception of usability in this context. This finding gives a fresh perspective to the usage of gender ambiguous voice agents when compared to male and female voice agents. The development of gender ambiguous voice agents not only may help to promote inclusiveness (Sutton, 2020), but it also may help to mitigate harmful gender effects and bias in VUIs, as highlighted by UNESCO (2019).

For **RQ2**, we further discuss how the type of agent affects the perception of usability. The results reveal that the Agent Type has a significant effect on the perception of the usability factors explored. For the interaction between these variables, it is observed that the artificial voice agent used in the experiments led to higher perception of all usability factors. In terms of comprehensibility, through the perception of the Ease of Understanding, it was noticed that the difference between the natural and artificial voice agents is considerably lower when compared to the difference in the perception of other usability factors. This indicates that both agents are considered comprehensible, which is expected due to the familiarity of the participants with the messages and the scenarios explored.

The main difference between the types of agents lies in the perception of Pleasantness, Commandingness and Urgency. The artificial agent has a higher perception of all usability factors,

including Commandingness and Urgency. This result might seem unjustified, but the application of signal processing algorithms such as pitch-shifting directly affects Pleasantness for both, natural and artificial, agents and may lead to the perception of negative effects of problematic auditory warnings design, such as annoyance and thought-disruptive alerts (Garcia-Chico & Corker, 2007; Eichelberger & McCartt, 2014). These results lead the authors to discuss further the design methodology when creating gender ambiguous voice agents.

The gender ambiguous voice agents used in this work are created based on two different methodologies. One is created based on the recordings of a speaker that is not ascribed to a gender in the binary frame. The other is created based on a state-of-the-art speech synthesizer. To increase their perception as gender ambiguous, their pitch is shifted to a frequency region that intercepts the male (60-180 Hz) and female (160-300 Hz) pitch ranges (Andreeva et al., 2017). Here, we argue that this methodology negatively affects the observed Pleasantness by participants, and additional methodologies should be explored. Next, we present three methodologies to be further explored to design gender ambiguous voice agents. Firstly, data-driven state-of-the-art speech synthesizers are trained based on a robust speech dataset recorded by a speaker in a professional studio. Therefore, a dataset specifically designed to the development of gender ambiguous voice agents is a possible methodology to alleviate this problem.

The second methodology can explore the training of data-driven algorithms such as Wavenet using mixed datasets. For example, mixing existing datasets recorded by male and female speakers with different pitch ranges. Recent research work (Latorre et al., 2019) has shown that training speech synthesizers with mixed gender datasets improve performance and could be a possible solution to create new voices for targeted applications. The last methodology involves substituting the pitch-shifting algorithm by more robust speaker adaptation techniques (Wu et al., 2015; Huang et al., 2020). In this case, for instance, speech generated by speech synthesizers could be adapted by a few data recorded by a speaker selected as highly pleasant and being perceived as gender ambiguous following a methodology similar to Tymburiba Elian et al. (2023). We argue that the development of a gender ambiguous voice agent using one of the aforementioned methodologies will be crucial to their adoption in commercial applications in which Pleasantness is a critical factor.

In **RQ3**, we study how the semantics in scenarios that require participant action with different levels of urgency affect the perception of usability. The results indicate that different semantics is an important factor in the perception of the usability factors. It has a greater impact in the perception of Commandingness and Urgency while achieving similar scores for Ease of Understanding and Pleasantness. Overall, messages that used imperative wording had led to higher scores. In agreement with Tymburiba Elian et al. (2022a), it is possible to suggest that the choice of wording when designing VUIs with gender ambiguous voice agents may be done in a similar way to the one when using binary voice agents. The type of semantics should be applied according to which usability factor should be enhanced for a target scenario. We suggest that messages with declarative wording might be more effective to scenarios with a lower level of designed urgency, while messages with imperative wording might be more effective to scenarios with a higher level of designed urgency.

Since the perceived urgency in the scenarios is manipulated by the wording used, we anticipated a difference based on the semantics of the terms. In our study, the two scenarios with higher levels of urgency, Seatbelt and Take-Over, included the words “attention” and “warning.” The results aligned with previous literature (Wogalter& Silver, 1995; Hellier et al., 2002), showing that scenarios with the word “warning” were perceived as more urgent than those with “attention.” However, cultural factors, such as participants' nationality, can influence these perceptions, particularly for non-native speakers. For example, in Tymburiba Elian et al. (2022a), the study involved Brazilian participants, whose native language is Portuguese, and they reported a higher perception of urgency for the scenario with the word “attention” compared to the scenario with the word “warning.”. This result may be influenced by a cultural variable: in Portuguese, the word “atenção” is the direct translation of “attention” and sounds similar to its English counterpart, while the word for “warning” has no close equivalent in Portuguese. However, in the scenarios we explored, no effect related to this cultural variable was observed.

In **RQ4**, we explore which Agent Type and Semantics are most suitable for enhancing the perception of usability factors in scenarios with varying levels of designed urgency. To answer this question, we performed three-way and four-way interactions analyses between all variables. The results show that, across all scenarios, the usability factors most influenced by the combination of Agent Type and Semantics are Commandingness and Urgency. Specifically, we found that when using declarative wording, the gap in perception between the natural and artificial voice agents was reduced. Based on these findings, we suggest that when designing VUIs with gender-ambiguous voice agents, the agent type and wording should be tailored to the urgency level of the scenario.

For scenarios with low urgency or those that do not require immediate action from the user, messages with declarative wording are more appropriate. Additionally, we propose that when the voice agent meets the necessary thresholds for Ease of Understanding and Pleasantness, using a natural voice agent recorded by someone who identifies outside the binary gender frame would be a significant step toward inclusiveness. For scenarios with higher urgency, however, messages with imperative wording were found to be more effective. In such cases, the voice agent should be perceived as more commanding and urgent. Our study showed that the artificial voice agent elicited higher levels of Commandingness and Urgency in these scenarios. In addition, for scenarios where not taking any action directly impacts user safety, further research is needed to investigate reaction times and accuracy in completing the required tasks brought by the warning messages.

To finalize this chapter, the authors would like to further discuss the participants’ demographic information. The requirement for participating in the online experiment was proficiency in the English language. Related to the fact that the participants were non-native speakers, the results obtained by our study for the usability factors revealed that Ease of Understanding had the highest mean score among all the observed factors (mean score = 3.605). Considering that the Ease of Understanding represents the ability of the participants to understand and retrieve information from the message delivered the result for its perceived mean score was close to the maximum on the five-point Likert scale applied (ranging from 0 to 4). This finding suggests that the fact that participants were non-native speakers did not affect this usability factor. This aligns with the

"interlanguage speech intelligibility benefit" (Bent & Bradlow, 2003), which found that non-native listeners can comprehend speech as well as native speakers when the speakers have a relatively high level of proficiency and share the same native language background.

Nevertheless, it is important to note that all participants in our study (N=50) were non-native speakers of the same nationality. The authors consider this fact as a limitation of our study in which the replication of these findings to a statistically more diverse set of participants is to be investigated as future work. In this case, participants should be from different nationalities, to identify the impact of cultural variables, and a mix of native and non-native speakers. To empirically verify the effectiveness of the proposed design and the completion of target tasks in multiple automotive driving scenarios, we would also like to extend the application of gender ambiguous voice agents to experiments in a real vehicle VUI.

Conclusion

This study aimed to explore the effects of gender-ambiguous voice agents and user gender on the perception of usability factors in various automated driving scenarios. Specifically, we examined how gender-ambiguous voice agents were perceived in relation to four usability factors across four driving-related scenarios. The scenarios differed in terms of urgency, which was manipulated through the wording of the messages. We investigated whether factors such as the type of voice agent (natural or artificial), the semantics of the message (declarative or imperative), and user gender affected the perception of these voice agents. Participants (N=50) took part in an online experiment, where they evaluated sixteen messages representing automated driving scenarios, each with different levels of urgency, using five-point Likert scales to assess Ease of Understanding, Pleasantness, Commandingness, and Urgency.

Our findings show that gender-ambiguous voice agents significantly narrowed the perception gap between male and female users, compared to studies that used binary voice agents. Additionally, we found no significant effect of user gender on the perception of gender-ambiguous voice agents. This result is one of the main contributions of our study, highlighting the potential for gender-ambiguous voice agents to promote inclusivity. Building on this finding, we encourage future research aiming the design of new methods that aim reduce gender disparity in the usage and perception of technology. Furthermore, our results emphasized the importance of matching the type of voice agent and the semantics of the message to the urgency level of the scenario. Specifically, the natural agent with declarative wording was found to be more effective in lower-urgency scenarios, while the artificial agent was more effective in higher-urgency scenarios, where a prompt user response is critical.

To the best of our knowledge, this study is the first to systematically demonstrate how gender-ambiguous voice agents influence the perception of usability in VUIs applied to an Automated Driving context. However, we acknowledge two key limitations that warrant further exploration and call upon researchers to explore it. First, since our participants were non-native speakers of the same nationality, it is important to verify these findings with users from diverse cultural and linguistic backgrounds. Second, the two types of voice agents used in this study were created

through pitch-shifting post-processing, which may have impacted the perception of pleasantness. Therefore, we suggest a closer collaboration between researchers from the design and speech synthesis fields to further develop gender-ambiguous voice agents.

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