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ARTICLE

Similarity May Be Safer: The Effect of Similarity Between Speech-Based Takeover Request Style and Driver Personality

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Abstract

In Level 3 automated driving, it is critical that drivers can rapidly and effectively shift from non-driving-related tasks back to the driving task. While previous research has examined the modality, timing, and vocal characteristics of takeover requests (TORs), little is known about how the style of speech-based TORs interacts with drivers' personality traits. This study conducted a driving simulator experiment with 49 participants using a 2 × 2 within-subjects design. Drawing on the dominant-submissive dimension of personality, we examined the similarity of personality tendencies between speech-based TORs and drivers under takeover scenarios of varying urgency (low: road construction; high: traffic accident). The findings reveal that personality similarity had a significant impact on both response time and takeover performance. When the speech-based TORs aligned with the driver's personality tendencies, participants demonstrated shorter attention-redirection times and more stable takeover quality. And high urgency scenarios elicited faster takeover responses but at the cost of reduced stability. Importantly, similar speech-based TORs were shown to mitigate this deterioration in takeover stability. Future applications may consider integrating personality-matching speech-based TORs into automated driving systems . This study provides insights for designing human-machine interfaces for automated driving, contributing to improved takeover safety.

Keywords: conditionally automated driving, speech-based takeover requests, personality, takeover scenarios, similarity–attraction effect

1. Introduction

Automated driving systems (ADSs) are designed to reduce traffic accidents, improve mobility, and relieve drivers of routine tasks (Ma and Zhang 2021). However, due to current technological constraints, many ADSs are still at SAE Level 3 automation. Under Level 3 conditional automation, the ADS performs dynamic driving tasks but may issue takeover request (TOR) when nearing its operational limits. In this mode, drivers are not required to monitor the road continuously but must remain alert and ready to regain control at any moment. At the same time, drivers are allowed to engage in non-driving-related tasks (NDRTs) during automated driving, further increasing their reliance on TORs (SAE International 2021, *UN regulation no. 157 - automated lane keeping systems (ALKS) | UNECE* 2020). Therefore, TOR design must facilitate rapid attention redirection and ensure stable takeover execution.

TORs have garnered increasing attention in research among the various modalities (Ma et al. 2023, Ou, Huang, and Fang 2021, Wang et al. 2022). Comparative studies involving auditory, visual, and tactile TORs indicate that auditory requests are more effective than visual requests. This may be because auditory requests prompt drivers to respond more quickly, thereby reducing collision risks, enhancing vehicle handling stability, and improving safety perception (Zhu et al. 2025, Zhang et al. 2025). However, not all auditory interactions are without risk. Some studies suggest that when drivers are engaged in cognitively demanding auditory tasks during automated driving, their takeover performance can be compromised (Hwang, Choi, and Kim 2024). This highlights that while the benefits of speech-based TORs are widely emphasized, their potential cognitive costs must also be carefully considered.

The advancements in text-to-speech (TTS) technology have driven the widespread use of various speech styles in in-vehicle interfaces such as navigation systems and driving agents, aiming to simultaneously enhance user experience and driving performance (Kadam 2023, Yoo et al. 2022, Jestin et al. 2022). In recent years, speech-based TORs have gained prominence in autonomous driving systems to guide drivers in regaining vehicle control (Wang, Zhang, and Zhou 2022, Ma and Zhang 2021). Existing research primarily focuses on the acoustic properties and content design of speech-based TORs (Pavone and Desveaud 2025, Chai et al. 2024). For instance, Pavone and Desveaud (2025) investigated preferences for synthetic voice gender, while other studies explored the effects of informational framing, personalized processing, and the integration of verbal and nonverbal cues on takeover performance. Chai et al. (2024) compared the impacts of linguistic and non-linguistic TORs on both performance metrics and subjective evaluations. Stier et al. (2020) found that in-vehicle voice systems could adjust their output based on user's personality traits, with drivers of different personality types exhibiting distinct vocal patterns during driving. These findings suggest that matching voice style to driver personalities may safer takeovers. However, the applicability of this principle to ADSs has yet to be fully validated. Therefore, the current study aims to further investigate this relationship.

Recent research has shown that, compared to sudden events during manual driving, TORs tend to induce stronger anxiety, which is closely linked to reduced takeover performance and is influenced by the scenario type and environmental conditions (Yi et al. 2025). Additionally, the use of specific speech styles may cause some drivers to feel annoyed or experience reduced operational accuracy (Wong et al. 2019), potentially due to the influence of personality similarity. Researches on manual driving have demonstrated that speech that aligns with the driver's personality can enhance driving performance, while dissimilar speech may have adverse effects (Stier et al. 2020, Jonsson and Nils Dahlbäck 2013). However, the question of whether speech styles should match the driver's personality during automated driving takeovers has not been sufficiently explored. Previous research on personality has largely relied on the Big Five Personality Traits (BFPT) framework (Nordhoff and Lehtonen 2025), but this framework is relatively broad and does not fully address the power dynamics involved in automated driving takeovers. Thus, this study focuses on the "dominant–submissive" personality dimension to explore the impact of similarity between speech style and driver personality on takeover performance.

In summary, this study aims to systematically investigate how the similarity of personality tendencies between speech-based TORs and drivers, measured on the "dominant–submissive" dimension, affects both takeover performance and subjective experience in scenarios with varying urgency levels. The results are expected to provide empirical evidence to optimize the design of takeover human-machine interface (HMI) in ADSs and offer theoretical insights for enhancing takeover safety.

1.1 Styles of Speech-Based TORs

Research on speech style in the driving domain can generally be categorized into two main areas. One area focuses on specific personality traits, positing that speech reflecting certain characteristics can improve driving performance and user experience (Jestin et al. 2022, Wong et al. 2019, Large et al. 2019). For example, Yoo et al. (2022) found that dominant speech enhanced situational awareness during manual driving, while submissive speech fostered greater trust and reduced subjective workload during automated driving. Further evidence suggests that drivers' own personality traits have a significant impact on takeover performance. For instance, Huang, Yang, and Nakano (2024) employed the Big Five personality traits in a simulated driving experiment, which found that extraversion and openness primarily affected takeover time, while neuroticism and agreeableness influenced longitudinal and lateral control, respectively. These findings highlight the importance of considering driver personality factors when investigating takeover behavior. Another area of research focuses on the similarity between speech style and personality traits. Jonsson and Nils Dahlbäck (2013) demonstrated that during manual driving, speech that is similar to the driver's personality encourages greater compliance with instructions and enhances driving performance, whereas dissimilar speech impairs the driving experience. This is consistent with the "similarity–attraction" effect, which posits that individuals are more likely to accept and be influenced by traits that resemble their own (Jiang and Xu 2024, Ruijten 2020). Similar effects have also been observed when speech aligns with a driver's emotional state (Nass et al. 2005). Thus, compared to fixed stylized speech, those aligned with the driver's personality may improve driving performance. However, personality similarity can also cause distractions. While it may enhance enjoyment, it may simultaneously reduce situational awareness, thereby increasing risk (Jonsson and Nils Dahlbäck 2013, Large and Burnett 2013). Consequently, the impact of personality similarity on driving performance remains inconsistent and warrants further investigation.

Furthermore, due to significant differences in attention distribution between manual and automated driving, the benefits of personalized speech matching in manual driving may not necessarily apply to automated driving. During manual driving, the driving task is the primary focus, and any NDRT is generally regarded as a distraction (Abbasi et al. 2024). In contrast, during automated driving, drivers' attention is often occupied by NDRTs. Upon receiving a takeover request, they must quickly refocus on the driving task and restore sufficient situational awareness. Existing research has primarily examined speech anthropomorphism (Wang et al. 2021) and message content (Wang, Zhang, and Zhou 2022, Ma and Zhang 2021). While anthropomorphic speech (incorporating prosody, emotional expression, or personalized tones) can inspire trust, they may also lead drivers to overestimate the system's capabilities, fostering excessive reliance on automation that ultimately compromises takeover performance (Wang et al. 2022, Zhao et al. 2024). As Cambre and Kulkarni (2019) points out, using a stylized anthropomorphic speech as speech-based TOR without consideration of context is irresponsible, as it may increase rather than decrease takeover risk. This raises an important unresolved question: in takeover situations, does the "similarity–attraction" effect help drivers redistribute their attention more effectively and achieve better takeover performance?

Scholars have further emphasized that, although personality can be assessed across various dimensions, social psychology widely considers the "agency-communion" framework (i.e., the dominant-submissive dimension) as a central construct for explaining interpersonal interactions and compliance behavior (Wiggins, Trapnell, and Phillips 1988, Abele and Wojciszke 2007). Highly dominant individuals tend to be decisive and controlling, while those with high communion are typically submissive and affiliative (Patel and Cougle 2023). Given that takeover requests inherently demand drivers to swiftly regain control (Borowsky, Zangi, and Oron-Gilad 2022), this study operationalizes speech style along the "dominant-submissive" dimension and further explores whether similarities with the personality tendencies of the driver influence takeover performance.

1.2 The Urgency of Takeover Scenarios

To examine the generalizability of the effects of personality similarity on takeover performance, it is necessary to account for how this similarity interacts with different takeover scenarios. A takeover scenario refers to an event that causes the ADS to disengage (Wu et al. 2022), and the urgency of the scenario is considered one of the most critical factors influencing takeover performance (Lee et al. 2023). Various frameworks have been proposed to classify urgency. For example, the international standard ISO/TR 21959-1:2020 categorizes urgency into short-term, medium-term, and long-term levels according to the temporal range of system limitations (Table 1). Gold et al. (2018) proposed a multidimensional framework including urgency, system predictability, severity, and the driver's response context (Table 2).

Table 1. Definition of urgency

Rank	Definition ISO/TR 21959-1:2020	Urgency
Short-term	Short-term system constraints (e.g., sensor range limitations) require the driver to immediately take over dynamic tasks	Low
Medium-term	Medium-term system constraints (e.g., approaching road construction that the system can't handle) require drivers to take over for a certain period of time	Medium
Long-term	Long-term system constraints can be communicated in advance (e.g., planned transitions for highway pilots as they reach exits) to allow for adequate preparation	High

Previous studies have reached inconsistent conclusions regarding the impact of takeover scenario urgency on takeover performance. For example, Petermeijer, Doubek, and Winter (2017) simulated six different takeover scenarios and found no significant differences in the drivers' response times, possibly due to insufficient control over the takeover time budget. The takeover time budget refers to the interval between the issuance of the TOR and the

Table 2. Takeover scenario classification

Factor	Low urgency	Medium urgency	High urgency
Urgency	High time budget	Medium time budget	Low time budget
System predictability	System limit low near-term detection	Predictable, but occurs depending on situation	Known from back-end, MAP, V2V communications
Criticality	Low security risk	Increased security risk	High security risk
Driver response	Low complexity (e.g., stabilization)	Medium complexity (e.g., steering)	High complexity (e.g., lane change)

point of collision or system failure if the driver fails to respond (Wu et al. 2022). A widely accepted finding is that shorter takeover time budgets are linked to reduced takeover stability (Wu et al. 2022, Gold et al. 2013, Si et al. 2025). In contrast, Radlmayr, Fischer, and Bengler (2019) held the time budget constant across different scenarios of varying urgency (low: road construction vs. high: traffic accident) and found that higher urgency scenarios led to shorter takeover times and more abrupt longitudinal and lateral maneuvers. However, Wu et al. (2022) found that urgency had no significant effect on lateral control stability. These discrepancies may stem from the differing specific actions required across scenarios, making direct comparisons challenging. Therefore, under conditions of consistent time budget, the impact of scenario urgency on takeover performance remains an open question worthy of further investigation.

1.3 Research Objectives and Questions

Based on the "dominant-submissive" personality dimension, this study aims to explore how the similarity between the personality tendencies of the drivers and styles of speech-based TORs, as well as the urgency of the takeover scenario, impacts takeover performance. In the experiment, we used a driving simulator to design two takeover scenarios with different urgency levels: a low urgency scenario (road construction, high predictability, low risk) and a high urgency scenario (traffic accident, low predictability, high risk). To control for potential confounding variables, the takeover time budget was kept consistent across all conditions. When the TOR was issued, participants were required to respond to a similar or dissimilar speech-based TOR, regain control of the vehicle, and complete a lane change. Reaction times, takeover quality, and eye-movement behavior were recorded using the driving simulator and a wearable eye tracker.

In summary, this study aims to answer the following questions:

Q1. In Level 3 automated driving, does a speech-based TOR style that is similar to the driver's dominant-submissive tendencies improve takeover performance and subjective evaluation?

Q2. With the same takeover time budget, do scenarios of different urgency levels lead to differences in takeover performance?

Q3. Does the effect of speech-based TORs on takeover performance vary between scenarios with different urgency levels?

2. Methods

2.1 Participants

Participants were recruited through convenience sampling in Hangzhou, China. A priori power analysis was performed using G*Power (version 3.1.9.7) for a 2 × 2 within-subjects ANOVA (α = 0.05, power = 0.80, r = 0.50, ε = 1). The analysis indicated that a minimum sample size of 24 participants was needed to detect a medium effect size (f = 0.25, approximately $\eta_p^2 \approx 0.059$). An online questionnaire was used to screen 72 potential participants according to the following criteria: (a) possession of a valid driver's license with at least one year of driving experience; (b) normal or corrected-to-normal vision and normal hearing; (c) no history of motion sickness; (d) no prior experience with L3 automated driving simulation experiments. A total of 49 participants (24 male, 25 female) met the inclusion criteria and completed the experiment. Their ages ranged from 20 to 25 years (M = 23.29, SD = 1.51), with driving experience ranging from 1 to 7 years (M = 3.53, SD = 1.75). All procedures were approved by the Ethics Committee of Zhejiang University of Technology, and each participant received 30 RMB as compensation.

2.2 Apparatus

The experiment was conducted using a desktop driving simulator (Fig. 1) equipped with a 1920 × 1080 resolution monitor and a Logitech G29 steering wheel and pedal set (Logitech Inc., US). The simulation environment was created using UC-win/Road Version 15.1.4 (FORUM8 Co., Ltd., JP), a setup validated in previous HMI studies on automated driving (Yoo et al. 2022,Wang, Zhang, and Zhou 2022,Tan and Hao 2023,Jin et al. 2021). Eye-tracking data were recorded using Tobii Glasses 3.0, a wearable eye tracker with a 100 Hz sampling rate. To ensure participants focused on NDRTs, they were given a smartphone to play the single-player puzzle game "2048". The objective of the game is to slide and merge numbered tiles to form the number 2048. This game has been validated in prior studies (Richie et al. 2018,Sanghavi et al. 2021) and can effectively prevent the drivers from prematurely shifting attention away from the road. It also aligns with Dogan et al. (2019) recommendations for NDRTs, helping to avoid discomfort or boredom stemming from cognitive overload or underload. Speech-based TORs were delivered through speakers on both sides of the monitor. Before the experiment, the volume was calibrated to ensure clarity, with an average sound pressure level of approximately 70 dB.

2.3 Experimental Design

This experiment employed a 2 × 2 within-subjects design. Independent variables included the similarity between speech style and personality traits of the driver(similar/dissimilar), and the urgency level of the takeover scenario (high/low). Participants were divided into a dominant personality group (n=24) and a submissive personality group (n=25) based on personality test scores. All participants completed the experiment under four conditions. A Latin square design balanced the combination of takeover scenario presentation order and voice TOR style.

Figure 1. Left: Driving simulator and related experimental equipment; Right: Participants performing NDRTs during the automated driving tests.

2.3.1 Speech Style and Personality Similarity

To assess personality tendencies, all participants completed the Chinese version of the IAS-R scale, which measures the PA (assured-dominant) and HI (unassured-submissive) dimensions (Wiggins, Trapnell, and Phillips 1988, Li 2010). This version has been widely applied in Chinese samples and has demonstrated good reliability and validity. Participants rated self-descriptive adjectives on an 8-point Likert scale (1 = very inaccurate, 8 = very accurate). A dominant-submissive (DS) score was then calculated as $DS = PA - HI$. $DS > 0$ indicated a dominant tendency, while $DS < 0$ indicated a submissive tendency.

According to personality psychology, dominant-submissive traits can be effectively conveyed through speech characteristics, with the pitch being the most prominent acoustic feature and a reliable indicator for measuring interpersonal dominance (Aung and Puts 2020, Yoo et al. 2022). Variations in intonation, tone, and expression convey distinct personality attributes. Following the findings of Moon (2002), dominant individuals tend to use more commanding and decisive language, whereas submissive individuals are more likely to employ suggestive or interrogative expressions. Based on this, this study created two standardized TTS TOR styles: dominant and submissive (Table 3), rather than customizing speech parameters individually for each participant. Participants were classified as dominant or submissive based on their IAS-R scores. When the TOR style matched a participant's personality tendency, it was coded as "similar"; otherwise, it was coded as "dissimilar". This design ensured experimental control while enabling within-subjects comparisons across similarity conditions.

2.3.2 Urgency of Takeover Scenarios

Two levels of urgency were defined for the takeover scenarios (Fig. 2) to evaluate the driver's performance under different urgency conditions. Drawing on prior research (Lee et al. 2023, Gold et al. 2018, Radlmayr, Fischer, and Bengler 2019), urgency was operationalized along two dimensions: urgency and predictability (Table 4). The low urgency scenario was designed as a "road construction" event, representing a predictable static obstacle where drivers can anticipate risks without requiring immediate reaction. The high urgency scenario was modeled as a "traffic accident" at an intersection with lateral traffic flow, representing a sudden and dynamic conflict with relatively low predictability. To minimize interference

Table 3. Speech-based TOR

Personality tendencies	Fundamental frequency	Urgency of scenarios	Speech content
Dominant	82.3 Hz	Low (road construction)	Road construction ahead, please take over the vehicle immediately
		High (traffic accidents)	Vehicle collision ahead, take over and avoid immediately
Submissive	168.3 Hz	Low (road construction)	Road construction ahead, it is recommended that you take over the vehicle
		High (traffic accidents)	Vehicle collision ahead, you need to take over and avoid

from extraneous factors and establish clear differences in urgency, no surrounding traffic was included in the low urgency scenario (Wang, Zhang, and Zhou 2022, Yoon, Kim, and Ji 2019). These two scenarios represent the typical extremes of the urgency–predictability continuum (Gold et al. 2016,Radlmayr et al. 2014). To ensure that differences stem solely from variations in scenario urgency, external variables such as road conditions and traffic flow were strictly controlled in both scenarios.

To eliminate the potential effects of takeover time budget, the time budget was fixed at 7 seconds in both scenarios. 7 s is considered sufficient time for takeover and this interval time has been adopted by other studies (Huang and Pitts 2022, Sanghavi et al. 2021). Moreover, to isolate the role of scenario urgency, the takeover task was kept identical across conditions: after the TOR was issued, the drivers were required to perform a lane change to avoid an obstacle.

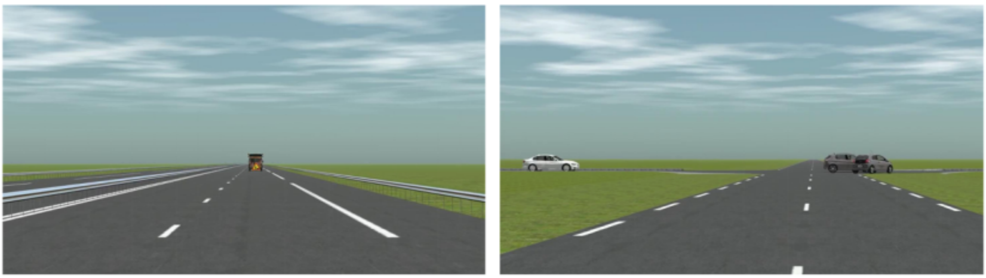

Figure 2. Left: low urgency scenario of the experiment in the use of the driving simulator; Right: high urgency scenario of the experiment in the use of the driving simulator

2.4 Measures

2.4.1 Reaction Time

Eye-tracking data and simulator logs were used to measure the drivers' fixation response time and takeover time. Fixation response time was defined as the interval between the issuance of the TOR and the drivers' first gaze on the road (Wu et al. 2022, Gold et al. 2013, Gruden et al. 2022). This measure captures the redirection of attention from NDRTs to the takeover task, marking the onset of the takeover process. Since situational awareness begins once the driver fixates on the road, attention redirection time is considered a critical indicator of

Table 4. Takeover Scenario Contextual Evaluation

Number	Scenario Classification	Constructive dimension	
		Urgency	**Predictability**
1	Narrowing of the road (known from the rear end)	1	3
2	Vehicles driving through the intersection (due to traffic on the adjacent lanes)	3	2
3	Hazardous areas/obstacles ahead (detected by onboard sensors)	3	1

1 = Low, 2 = Medium, 3 = High

takeover performance (Wu et al. 2022). Takeover time was defined as the interval between the TOR and the initiation of takeover actions. Specifically, it begins with either a 2° change in steering wheel angle or a 10% depression of the brake pedal, whichever came first (Du et al. 2020, Gold et al. 2013).

2.4.2 Takeover Quality

The driving simulator evaluates takeover quality across two dimensions: longitudinal control and lateral control. Longitudinal control was assessed using minimum Time-to-Collision (TTC) and maximum longitudinal acceleration, representing the urgency and stability of the takeover process, respectively. TTC was defined as the time required for two objects to collide while maintaining their current speeds and trajectories (Du et al. 2020). When a collision occurred, the minimum TTC was recorded as 0. Lateral control was assessed using maximum lateral acceleration, maximum lateral deviation (Agrawal and Peeta 2021), and the standard deviation of lane position (Wang, Zhang, and Zhou 2022). These indices reflect lateral stability during takeover maneuvers as well as lane-keeping quality after the lane change.

2.4.3 Eye Movement Data

To avoid interrupting the takeover process—as would occur with traditional situational awareness measures (e.g., SAGAT, SART) (Zhou, Yang, and Winter 2021)—we used eye movement metrics as indicators of the drivers' situational awareness. Eye-tracking measures are widely adopted for this purpose (Zhang et al. 2020), as they are non-invasive and do not interfere with driving behavior. The drivers' total fixation duration and average scan path length were recorded using the wearable Tobii Glasses 3.0 eye tracker. Total fixation duration represents the cumulative time spent acquiring information through gaze, while average scan path length indicates the dispersion of visual search strategies (Zhou, Yang, and Winter 2021, Liang et al. 2021). The measurement window was set to 7 seconds following the issuance of the TOR (Table 5).

2.4.4 Subjective Attitudes

The drivers' perceptions of speech-based TORs under different scenarios were evaluated in terms of usefulness and satisfaction, drawing on prior studies (Huang and Pitts 2022). The UMUX-LITE scale was applied using its two standard items to minimize response burden while maintaining reliability (Borsci et al. 2015): (1) Usefulness: "I find this speech-based

Table 5. Objective measurement measures and descriptions

Measures	Metrics	Unit	Description
Reaction time	Attention redirection time	s	The time between the issuance of the TOR and the driver's first gaze on the road
	Takeover time	s	The time between TOR issuance and driver takeover operation
Quality of takeover	Minimum TTC	s	Minimum TTC relative to obstacles during manual driving after TOR
	Maximum longitudinal acceleration	m/s^2	Maximum longitudinal acceleration during manual driving after TOR
	Maximum lateral acceleration	m/s^2	Maximum lateral acceleration during manual driving after TOR
	Maximum lateral deviation	m	Maximum deviation from the centerline of the target lane during manual driving after TOR
	Standard deviation of lane position	m	Standard deviation of lateral position from the center of the lane during manual driving
Eye-movement data	Total fixation duration	s	Total duration of all gazes on the monitor
	Average scan path length	px	Average of all scan lengths within the time window

TOR helpful for my takeover." (2) Satisfaction: "I am satisfied with this speech-based TOR." Each item was rated on a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree).

2.5 Materials

2.5.1 Speech-Based TOR

Artificially synthesized voices were generated using the iFlytek online TTS platform (iFlytek TTS), output in MP3 format at 24 kHz and 16-bit. The speech rate was set to the system default (normal), corresponding to approximately 240 Chinese words per minute (Bazilinskyy and Winter 2017). Extreme speech rates were avoided, as excessively fast speech impairs comprehension, while overly slow speech is perceived as unpleasant. To minimize gender-related biases, only male voice type was used (Richie et al. 2018). Each TOR included information about the cause of the event to facilitate the understanding of the driving environment (Wang, Zhang, and Zhou 2022). Four TORs were developed by combining scenario urgency (low: road construction; high: traffic accident) with voice style (dominant/submissive) (Table 3). All recordings were standardized to a duration of 2.9 s using Adobe Audition CC 2020 (Adobe Systems Inc., US). Fundamental frequency (F0) served as the primary acoustic manipulation, as prior research identifies F0 as a robust indicator of perceived dominance, with lower F0 associated with stronger dominance evaluations (Puts et al. 2007, Chappuis and Grandjean 2022). Following Wolff and Puts (2010), the average F0 was set in Praat at 82.3 Hz for the dominant voice and 168.3 Hz for the submissive voice. Apart from differences in F0 and wording, other acoustic parameters (speech rate, duration, loudness, peak amplitude) were held constant.

To validate the manipulation, we followed the speech personality evaluation procedure outlined by Zuckerman, Levitt, and Lubin (1961) and employed the "dominant-submissive" dimension of the peer rating scale. An online survey with 60 participants assessed the two TOR styles on a 7-point scale. Results showed that the dominant speech received significantly higher dominance ratings than the submissive speech ($M = 5.06$, $SD = 0.94$ vs. $M = 3.22$, $SD = 1.08$), with high reliability (Cronbach's $\alpha > 0.70$). A repeated-measures ANOVA confirmed a significant main effect ($F(1, 59) = 178.98$, $p < 0.001$), indicating that the voices were effectively differentiated along the "dominant-submissive" dimension.

2.5.2 Experimental Scenarios

The driving environment consisted of a bidirectional four-lane highway and a two-lane road with an intersection (Fig. 3). The route was 10 km in total length, comprising both straight and curved segments, with a posted speed limit of 60 km/h. Each session lasted approximately 10 minutes and contained two takeover points, located at 3 km and 8 km along the route. The low urgency scenario was a road construction scenario in the right lane; the high urgency scenario was a traffic accident at the intersection ahead, and a vehicle driving fast in the lateral lane. In order to minimize the interference of other vehicles and to create a difference in the urgency level of the scenarios, there was no traffic flow in the low-urgency scenario. When the vehicle approached a takeover point—approximately 117 m in advance (calculated as 60 km/h × 7 s)—the system issued a speech-based TOR, giving the driver 7 seconds to regain control.

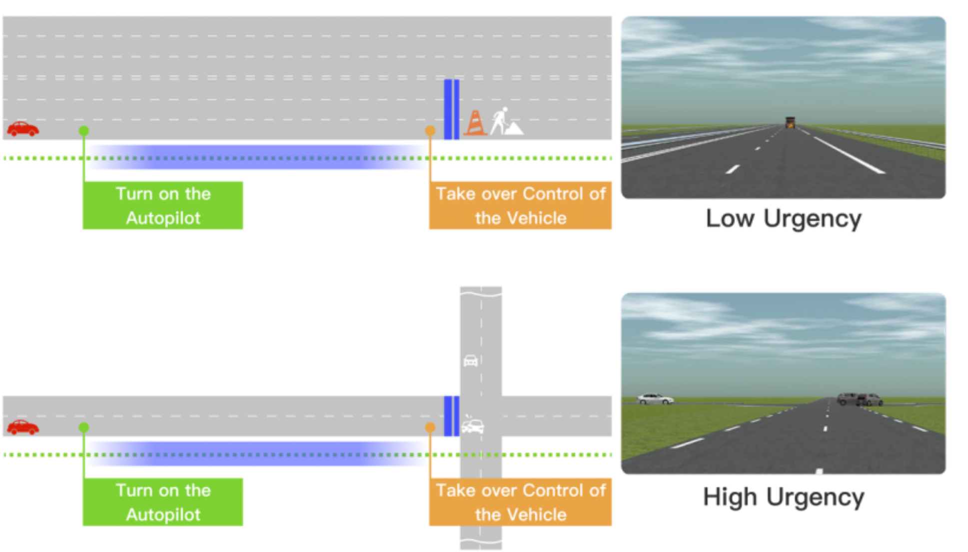

Figure 3. Top: low urgency road construction scenario; bottom: high urgency traffic accident scenario

2.6 Experimental Procedure

Before the formal experiment, participants provided written informed consent and received standardized instructions. Then they completed a 10-minute practice session to become familiar with the simulator, including activating and deactivating the ADS, switching between manual and automated modes, and performing takeover operations. During practice, participants heard only the standard prompt "Take over" and were not informed that different TOR styles and takeover scenarios would be introduced during the formal sessions.

In the formal experiment, participants wore a calibrated eye tracker before beginning the tasks. Each participant completed two driving sessions, each containing two takeover events. The order of takeover scenarios and speech-based TOR styles was counterbalanced using a Latin square design to control for sequence effects.

At the start of each session, the vehicle traveled approximately 200 m before the system prompted the driver to activate ADS via a steering wheel button. The vehicle then maintained its position in the rightmost lane. While ADS was active, participants focused on the NDRT (2048 game) and had no expectation of an upcoming takeover. When the vehicle reached a takeover point, the system delivered a speech-based TOR (identical style for both TORs within a session). Participants were required to put down their smartphones, regain control, and complete a lane change to avoid an obstacle. After the lane change, the vehicle returned to its lane and re-engaged ADS. Following each takeover, participants completed a subjective questionnaire before resuming the NDRT until the next TOR occurred. At the end of the experiment, a brief retrospective interview was conducted to gather participants' impressions of different TOR styles and takeover scenarios. The entire experiment lasted about 30 min, and participants were free to withdraw at any time if they experienced discomfort.

2.7 Data Analysis

Eye-tracking data were processed using the Ergolab platform (Kingfar International Inc., Beijing, China). All statistical analyses were conducted in SPSS 26. A 2 × 2 mixed design was applied, with personality similarity (similar vs. dissimilar) and scenario urgency (high vs. low) as the independent variables. Two-way repeated-measures ANOVA were used to examine the effects, and Bonferroni corrections were applied for multiple comparisons.

3. Results

A total of 196 takeover events were recorded, and all participants successfully regained control of the vehicle within the designated takeover time. Two collisions occurred, both in the low urgency scenario and involving female participants—one with a personality-similar speech TOR and the other with a dissimilar TOR. For these cases, the minimum TTC was recorded as 0. Due to missing or corrupted eye-tracking data from six participants, eye-movement analyses were conducted on data from the remaining 43 participants.

3.1 Reaction Time

Table 6 shows the ANOVA results. A significant main effect of similarity was observed for attention redirection time ($F(1, 42) = 8.733$, $p = .005$, $\eta_p^2 = .172$). Under the similar-voice condition, attention redirection time was significantly shorter than under the dissimilar-voice condition ($M = 1.47$ s vs. $M = 1.62$ s). Neither the main effect of urgency ($F(1, 42) = 1.157$, $p = .288$, $\eta_p^2 = .027$) nor the interaction effect ($F(1, 42) = 0.707$, $p = .405$, $\eta_p^2 = .017$) was significant (Fig. 4). These findings indicate that personality-similar speech TORs facilitate quicker attention redirection, regardless of scenario urgency.

For takeover time, the main effect of urgency was significant ($F(1, 48) = 5.726$, $p = .021$, $\eta_p^2 = .107$). In high-urgency scenarios, takeover time ($M = 3.02$ s) was significantly shorter than in low-urgency scenarios (M = 3.17 s). Neither the main effect of similarity ($F(1, 48)$ = 0.064, p = .801, η_p^2 = .001) nor the interaction effect ($F(1, 48)$ = 0.705, p = .405, η_p^2 = .014) was significant. This suggests that high-urgency scenarios drive faster takeovers, whereas the similarity between speech style and the driver personality does not influence takeover time.

Table 6. ANOVA results for response time

Variables	Factor	F	p	η_p^2
Attention redirection time	Similarity	8.733	.005	.172
	Urgency	1.157	.288	.027
	Interaction effect	.707	.405	.017
Takeover time	Similarity	5.726	.021	.107
	Urgency	.064	.801	.001
	Interaction effect	.705	.405	.014

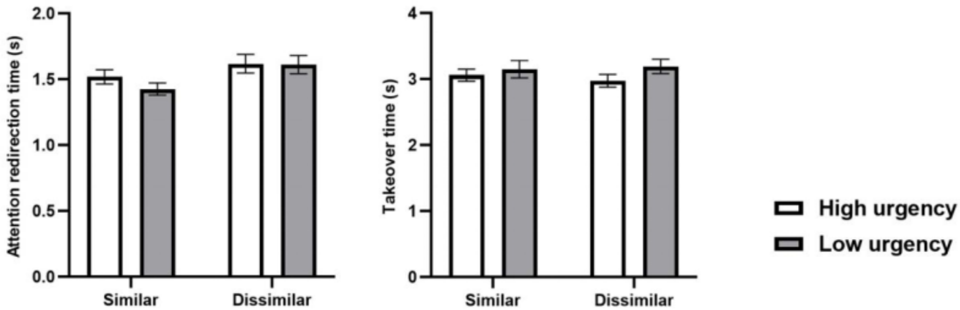

Figure 4. Mean values and standard errors of attention redirection time, takeover time for two personality-similarity relationships, and two takeover scenario urgency levels. Note: Error bars represent standard errors.

3.2 Takeover Quality

3.2.1 Longitudinal Control

Table 7 shows the ANOVA results. For minimum TTC, there was a significant main effect of urgency ($F(1, 48)$ = 5.725, p = .021, η_p^2 = .107). In high-urgency scenarios, the minimum TTC (M = 2.37 s) was significantly higher than in low-urgency scenarios (M = 2.20 s), indicating that high-urgency scenarios were associated with lower longitudinal safety margins. Neither the main effect of similarity ($F(1, 48)$ = 0.137, p = .712, η_p^2 = .003) nor the interaction effect ($F(1, 48)$ = 1.390, p = .244, η_p^2 = .028) was significant (Fig. 5).

For maximum longitudinal acceleration, no significant effects were found for similarity ($F(1, 48)$ = 1.119, p = .295, η_p^2 = .023), urgency ($F(1, 48)$ = 0.718, p = .401, η_p^2 = .015), or their interaction ($F(1, 48)$ = 1.065, p = .307, η_p^2 = .022).

3.2.2 Lateral Control

As shown in Fig. 6, there was a significant main effect of similarity on maximum lateral acceleration ($F(1, 48)$ = 5.904, p = .019, η_p^2 = .110). The maximum lateral acceleration

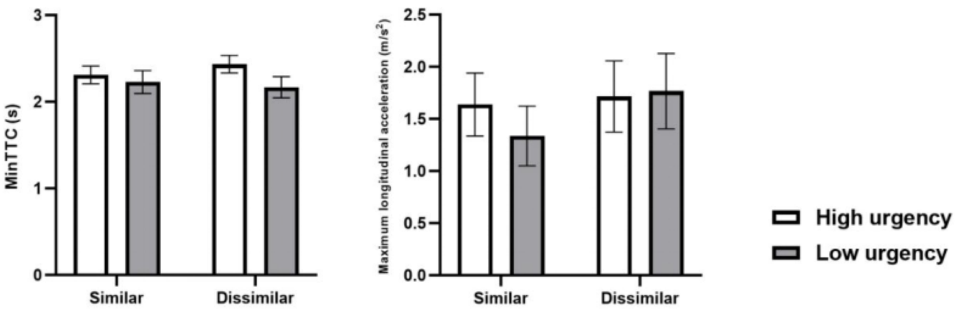

Figure 5. Mean values and standard errors of minimum TTC and maximum longitudinal acceleration for two personality–similarity relationships and two degrees of urgency of takeover scenarios. Note: Error bars represent standard errors.

in the similar condition (M = 2.67 m/s^2) was significantly lower than in the dissimilar condition (M = 2.90 m/s^2), indicating that speech-based TORs aligned with the driver's personality tendency result in greater lateral stability. Neither the main effect of urgency ($F(1, 48) = 0.149$, $p = .701$, $\eta_p^2 = .003$) nor the interaction effect ($F(1, 48) = 0.154$, $p = .697$, $\eta_p^2 = .003$) was significant.

For maximum lateral deviation, there was a significant interaction effect between similarity and urgency ($F(1, 48) = 4.766$, $p = .034$, $\eta_p^2 = .090$). Bonferroni-adjusted comparisons indicated that, in high-urgency scenarios, the maximum lateral deviation was significantly smaller in the similar condition (M = 0.71 m) than in the dissimilar condition (M = 0.97 m, $p = .002$), indicating improved lane-change accuracy with personality-similar speech TORs. However, in low-urgency scenarios, this effect was not significant ($p = .765$). In addition, both similarity ($F(1, 48) = 6.442$, $p = .014$, $\eta_p^2 = .118$) and urgency ($F(1, 48) = 7.404$, $p = .009$, $\eta_p^2 = .134$) showed significant main effects.

For the standard deviation of lane position, significant main effects were found for both similarity ($F(1, 48) = 6.124$, $p = .017$, $\eta_p^2 = .113$) and urgency ($F(1, 48) = 12.407$, $p = .001$, $\eta_p^2 = .205$). Lane position variability was lower under the similar condition (M = 1.80 m) than under the dissimilar condition (M = 1.89 m). By contrast, lane position variability was higher in high-urgency scenarios (M = 1.90 m) compared to low-urgency scenarios (M = 1.79 m). This suggests that when the speech TOR style is similar to the driver's personality tendencies, the driver is better able to maintain lane consistency after the lane change, although overall performance was worse in the high-urgency scenario. The interaction effect was not significant ($F(1, 48) = 0.170$, $p = .682$, $\eta_p^2 = .004$).

3.3 Eye Movement Data

Table 8 shows the ANOVA results. For total fixation duration, the total fixation time in high-urgency scenarios (M = 4.10 s) was slightly longer than in low-urgency scenarios (M = 3.96 s), but the difference was not significant ($F(1, 42) = 2.999$, $p = .091$, $\eta_p^2 = .067$). Neither the main effect of similarity ($F(1, 42) = 0.236$, $p = .630$, $\eta_p^2 = .006$) nor the interaction effect ($F(1, 42) = 0.029$, $p = .865$, $\eta_p^2 = .001$) was significant (Fig. 7).

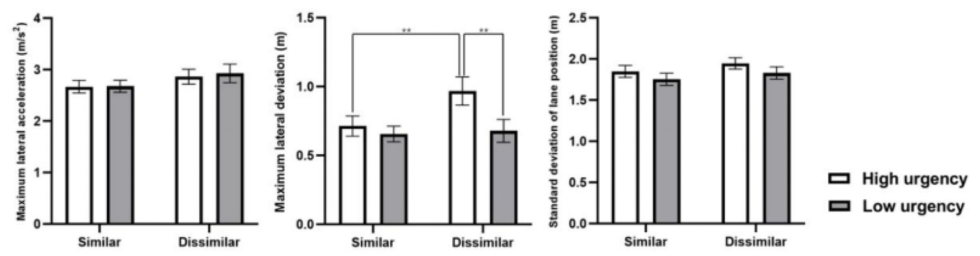

Figure 6. Mean values and standard errors of maximum lateral acceleration, maximum lateral deviation, and standard deviation of lane position for two personality-similarity relationships and two takeover scenario urgency levels. Note: Error bars represent standard errors, * p < 0.05, ** p < 0.001.

Table 7. ANOVA results for takeover quality

Variables	Factor	F	p	η_p^2
longitudinal control				
Minimum TTC	Similarity	.137	.712	.003
	Urgency	5.725	.021	.107
	Interaction effect	1.390	.244	.028
Maximum longitudinal acceleration	Similarity	1.119	.295	.023
	Urgency	.718	.401	.015
	Interaction effect	1.065	.307	.022
Lateral control				
Maximum lateral acceleration	Similarity	5.904	.019	.110
	Urgency	.149	.701	.003
	Interaction effect	.154	.697	.003
Maximum lateral deviation	Similarity	6.442	.014	.118
	Urgency	7.404	.009	.134
	Interaction effect	4.766	.034	.090
Standard deviation of lane position	Similarity	6.124	.017	.113
	Urgency	12.407	.001	.205
	Interaction effect	.170	.682	.004

For average scan path length, there was a significant main effect of similarity ($F(1, 42)$ = 4.348, p = .043, η_p^2 = .094). The average scan path length in the similar condition (M = 79.66 px) was significantly shorter than in the dissimilar condition (M = 90.00 px). This indicates that when the speech TOR style aligns with the driver's personality tendencies, the driver's scanning strategy is more focused. Neither the main effect of urgency ($F(1, 42)$ = 0.679, p = .415, η_p^2 = .016) nor the interaction effect ($F(1, 42)$ = 0.245, p = .623, η_p^2 = .006) was significant.

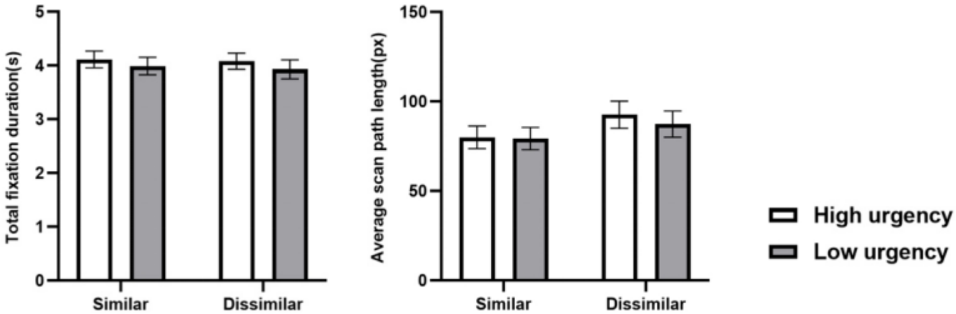

Figure 7. Mean values and standard errors of total fixation duration, average scan length for two personality-similarity relationships, and two takeover scenario urgency levels. Note: Error bars represent standard errors.

Table 8. ANOVA results for eye movement data

Variables	Factor	F	p	η_p^2
Total fixation duration	Similarity	.236	.630	.006
	Urgency	2.999	.091	.067
	Interaction effect	.029	.865	.001
Average scan path length	Similarity	4.348	.043	.094
	Urgency	.679	.415	.016
	Interaction effect	.245	.623	.006

3.4 Subjective Attitudes

Table 9 shows the ANOVA results. For usefulness, the main effect of the similarity was significant ($F(1, 48)$ = 8.977, p = .004, η_p^2 = .158). The usefulness rating for the similar speech TOR style (M = 5.54) was higher than that for the dissimilar speech TOR style (M = 5.04), indicating that the drivers found a speech TOR similar to their dominant-submissive personality tendencies more helpful for the takeover task. Neither the main effect of urgency on usefulness ($F(1, 48)$ = 0.112, p = .739, η_p^2 = .002) nor the interaction effect ($F(1, 48)$ = 0.930, p = .340, η_p^2 = .019) was significant (Fig. 8).

A similar pattern for satisfaction was observed, with a significant main effect of the similarity ($F(1, 48)$ = 11.549, p = .001, η_p^2 = .194). The satisfaction rating for the similar speech TOR style (M = 5.07) was higher than for the dissimilar speech TOR style (M = 4.50).

Neither the main effect of urgency on satisfaction ($F(1, 48) = 0.044$, $p = .836$, $\eta_p^2 = .001$) nor the interaction effect ($F(1, 48) = 0.599$, $p = .443$, $\eta_p^2 = .012$) was significant.

Table 9. ANOVA results for subjective attitudes

Variable	**Factor**	F	p	η_p^2
Usefulness	Similarity	8.997	.004	.158
	Urgency	.112	.739	.002
	Interaction effect	.930	.340	.019
Satisfaction	Similarity	11.549	.001	.194
	Urgency	.044	.836	.001
	Interaction effect	.599	.443	.012

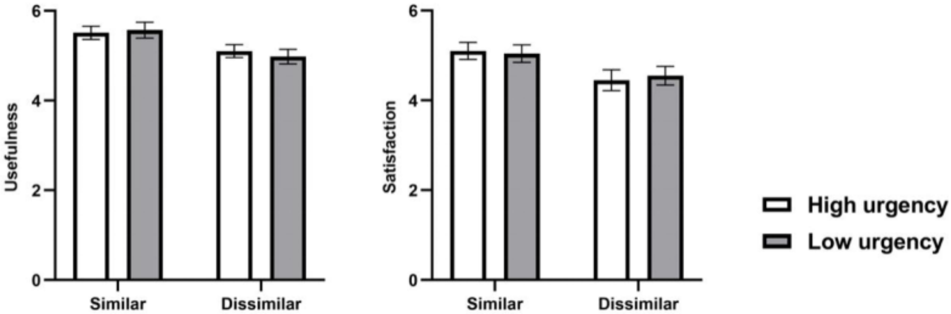

Figure 8. Mean values and standard errors of usefulness and satisfaction for the two personality-similarity relationships and the degree of urgency of the two takeover scenarios. Note: Error bars represent standard errors.

3.5 Interview Results

The interview results showed that most participants preferred speech TOR styles that matched their dominant-submissive tendencies, and none reported that this preference was influenced by scenario urgency. Dominant participants found the dominant speech TOR clear and direct, while submissive participants felt the submissive speech-based TOR was too mild and lacked authority, leading to distraction that could increase the reaction time. Conversely, submissive participants preferred the submissive speech TOR, finding it polite and more friendly, while dominant participants felt the dominant speech-based TOR was too intense and oppressive, potentially triggering negative memories and diverting attention from the takeover task. Reasons for disliking personality-dissimilar TOR styles, along with their frequencies, are summarized in Table 10.

4. Discussion

4.1 The Effect of Similarity and Scenario Urgency on Reaction Time

In this experiment, a significant effect of similarity on attention redirection time was observed: speech-based TORs that matched the driver's personality significantly reduced attention redirection time (similar: $M = 1.47$ s vs. dissimilar: $M = 1.62$ s). This result can be explained

Table 10. Reasons and frequency of participants' dislike of TOR voices with dissimilar personalities

Speech TOR	Reason	Frequency	Details
Dominant	Too forceful/serious	7	"The dominant voice is too strong and intimidating."
	Oppressed, ordered	5	"Feeling ordered around makes me more nervous."
	Brings back bad memories	2	"It feels like a driving instructor is watching me drive on the side and feels uncomfortable."
	Too rigid	3	"No emotion, too raw, too rigid."
Submissive	Unable to get attention	6	"The submissive type's voice is too weak to get my attention."
	Don't want to take over	3	"It makes me think about what I would do if I didn't take it over."
	Bored	3	"It's a little annoying to talk too much."
	Distraction	4	"It would make me want to ask it back and cause me to not be able to focus very quickly."

by the "similarity–attraction" theory, which suggests that individuals prefer interacting with others or technologies similar to themselves (Seifert, Friedrich, and Schleidgen 2022) and expect consistency in interactions. When inconsistency arises, individuals must adjust their perceptions, which increases cognitive load and slows attention redirection (Fiske and Taylor 2013). The interview results further support this explanation: drivers found speech TORs inconsistent with their personality tendencies to be distracting. Dominant drivers perceived submissive TORs as "not direct enough" and "easily annoyed", while submissive drivers found dominant TORs "stressful" and "likely to trigger negative associations ", such as "like a driving school instructor", which diverted attention from the task. Additionally, Ruijten (2020) found that systems with personality-similar outputs are more persuasive. In this study, drivers immersed in the 2048 game were more easily persuaded by personality-similar speech TORs to shift attention back to the road. Subjective evaluations also revealed a similar trend, suggesting that a single speech style may reduce acceptance for some drivers.

For the takeover time, the results indicate that the scenario urgency played a primary role. In high urgency scenarios (traffic accident), takeover time was significantly shorter than in low urgency scenarios (road construction) (M = 3.02 s vs. M = 3.17 s), suggesting that high urgency scenarios prompt faster responses. This finding aligns with Wu et al. (2022), who indicated that perceived urgency can drive quicker takeovers, even with the same takeover time budget. This contrasts with Petermeijer, Doubek, and Winter (2017), who found no significant differences in takeover time across six scenarios. We believe this discrepancy may stem from differences in the takeover time budgets (7 seconds in this study vs. 10 seconds in their study). Huang and Pitts (2022) argued that a time buffer might cause drivers to delay responding to gather more information and assess the best course of action, whereas a shorter time budget may have enhanced the urgency effect on driver responses. While this study provides empirical evidence of the effect of scenario urgency on takeover with a 7-second time budget, further studies are needed to verify whether this effect persists under shorter time budgets.

It is important to note that while similarity in speech TORs accelerated attention redirection, it did not shorten the takeover time. A plausible explanation is that the similarity effect primarily facilitates the attentional resource reallocation, making it easier for the driver to focus on road information. However, the execution of the takeover still relies on the efficiency of visual information processing (Metz et al. 2025). This phenomenon highlights the separation between attention redirection and actual takeover behavior: although personality-similar speech facilitates faster attention redirection, transitioning from attention redirection to the actual takeover actions involves further cognitive stages such as situation assessment, risk judgment, and decision-making. Similar "cognitive processing bottleneck" has been identified in multi-task cognitive load research, where early attention allocation optimization does not guarantee better overall performance due to subsequent stages of information integration and decision-making (Wang et al. 2025, Zhang, Yu, and Tan 2025). Additionally, the moderate time budget in this study placed limited pressure on drivers (Li and Xuan 2023), meaning they would not initiate the takeover until they had sufficient situational awareness. Consequently, the similarity effect did not manifest in takeover time. This is supported by the interview results, with some participants stating that "After seeing the obstacle, I felt there was enough distance, so I didn't need to take over immediately". Future research could further investigate how speech similarity affects takeover speed under shorter time budgets.

4.2 The Effect of Similarity and Scenario Urgency on Takeover Quality

The results for longitudinal control revealed that scenario urgency significantly influenced the minimum TTC. In high urgency scenarios, the minimum TTC value was larger (M = 2.37 s vs. M = 2.20 s), suggesting that drivers tended to initiate lane changes earlier. This finding contrasts with the conclusions of Radlmayr, Fischer, and Bengler (2019), possibly due to differences in experimental design: they defined high urgency scenarios as requiring a lane change, while low urgency scenarios required lane keeping, whereas in this study, lane changes were uniformly controlled. Since the minimum TTC is calculated before the lane change is executed, high urgency scenarios led to earlier lane changes, resulting in a larger minimum TTC. Following the experiment, participants reported that the "traffic accident" scenario felt more unpredictable and dangerous, prompting them to take evasive action sooner, despite the fact that all scenarios in this study were static. However, for the lane-change task, minimum TTC may not be the most reliable indicator of safety (Guo, Xie, and Keyvan-Ekbatani 2023). A larger minimum TTC does not necessarily indicate better longitudinal safety, as early lane changes could increase lateral instability. Therefore, evaluating takeover safety should consider both longitudinal and lateral control metrics.

For lateral control, similar speech TORs significantly reduced maximum lateral acceleration, maximum lateral deviation, and the standard deviation of lane position, suggesting that personality-matching speech improved lateral stability. This result is consistent with Jonsson and Nils Dahlbäck (2013), who found in manual driving that personality-matching navigation voices enhanced driving performance. Our study suggests that the similarity–attraction effect also applies to automated driving takeovers, where personality-similar speech-based TORs lead to faster attention redirection, providing drivers with more time to process environmental information, and improving situational awareness without adding cognitive load, thus enhancing lateral stability during takeovers.

Interestingly, a significant interaction effect was found between similarity and urgency on maximum lateral deviation, with this effect being significant only in high urgency scenarios. In these situations, the maximum lateral deviation was significantly smaller in the similar speech condition ($M = 0.71\ m$) compared to the dissimilar speech condition ($M = 0.97m, p = 0.002$). A possible explanation is that high urgency scenarios demand more cognitive resources (Wu et al. 2022, Dogan et al. 2019), and dissimilar speech imposes additional cognitive load (Montoya and Horton 2012), leading to distractions and reduced situational awareness. By contrast, in low urgency scenarios, where cognitive load is lower, the differences between similar and dissimilar speech had less impact on lateral control, and the interaction effect was not significant. Nass et al. (2005) found that voice-emotion matching in vehicles alleviates drivers' stress during takeovers, reducing cognitive load and improving road safety. When the speech style aligns with the driver's personality, it facilitates quicker attention redirection and restores higher situational awareness, leading to more stable takeovers. This may be because personality matching reduces semantic decoding costs (Jiang, Zheng, and Lu 2020), freeing up cognitive resources for core tasks.

Eye-tracking data further confirmed this conclusion. Total fixation duration was longer in high urgency scenarios (M = 4.10 s vs. 3.96 s), suggesting that drivers in high urgency scenarios needed more time to fixate and gather sufficient road information to complete the takeover. This indicates the higher cognitive load in high urgency scenarios, consistent with Wu et al. (2022). In contrast, under the similar speech condition, the average scan path length was shorter (M = 79.66 px vs. 90.00 px). Previous studies have shown that shorter scan path lengths are associated with higher search efficiency and better situational awareness (Zhou, Yang, and Winter 2021, Zhang et al. 2020, Du, Zhi, and He 2022). Conversely, longer scan paths indicate more scattered gaze strategies and poorer visual information organization, reflecting lower situational awareness.

To better visualize the effect of similarity and scenario urgency on takeover quality, we used a trajectory approximation to plot the approximate obstacle avoidance trajectories under four conditions (Fig. 9). The specific method was as follows: the minimum and maximum lateral positions of the actual obstacle avoidance trajectory were taken, and the 10% and 90% feature points between the two extreme points were selected as the start and end points of the obstacle avoidance process. These points were then connected by a straight line and intersected with lines that passed through the extreme points and were parallel to the lane lines, forming the vehicle's approximate obstacle avoidance trajectory (Wu et al. 2022).

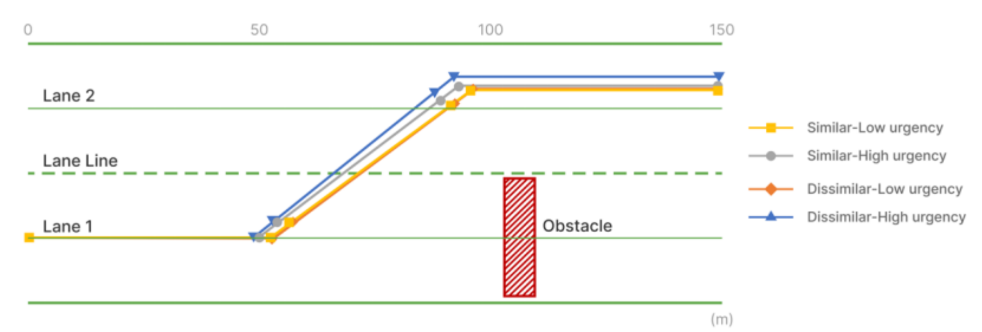

Figure 9. Approximate obstacle avoidance trajectory

As shown, in the low urgency scenario, the two avoidance trajectories were relatively close, with the endpoint closer to the lane centerline, indicating better lateral control. In contrast, in the high urgency scenario, the starting point of the avoidance trajectory was further forward, with a steeper slope and a greater distance from the obstacle. This suggests that drivers were more likely to initiate an early lane change to avoid the obstacle, resulting in poorer lateral stability. However, in the personality-similar speech TOR condition, the trajectory had a shallower slope, and the endpoint was closer to the lane centerline, further indicating that personality-similar speech can improve takeover stability in high urgency scenarios by facilitating faster attention redirection (M = 1.47 s vs. 1.62 s) and enhancing situational awareness.

This study controlled for NDRTs, takeover time budget, and the takeover task, exploring the effects of similarity in the "dominant–submissive" personality dimension and the urgency of takeover scenarios on takeover performance. Based on the analysis results, we answered the research questions as follows:

1. Speech TOR styles similar to the driver's personality tendencies helped improve takeover performance, specifically by shortening attention redirection time, enhancing lateral control stability, and fostering more positive subjective evaluations;
2. In scenarios with the same 7-second takeover time budget, high urgency scenarios prompted faster takeovers, but resulted in poorer takeover quality;
3. Some results suggested that the impact of similarity of speech TOR styles on takeover quality was more pronounced in high urgency scenarios, whereas it was not significant in low urgency scenarios.

5. Conclusion

This study addressed the unclear role of similarity in takeovers and explored how scenario urgency influences takeover performance under identical time budgets. Within the "dominance–submission" personality framework, this study examined the similarity between TOR styles and drivers' personality tendencies, as well as the impact of situational urgency on takeover performance. Research findings indicate that in high urgency scenarios, even when takeover response times accelerate, takeover quality still declines. Conversely, speech-based takeover patterns aligned with the drivers' personality tendencies enable drivers to shift attention more rapidly to takeover tasks and restore higher situational awareness. In such situations, drivers achieved a more stable and safer takeover, resulting in better usefulness and satisfaction ratings.

This study contributes to understanding similarity in speech TORs, filling a gap in research on automated driving speech-based TORs and providing new empirical data on the impact of scenario urgency on takeover performance under the same time budget. Furthermore, the findings offer insights into the design of automated driving systems and takeover HMIs design. In high urgency scenarios, it is recommended to appropriately increase the takeover time budget to provide drivers with more time for cognitive processing and decision-making. Additionally, when designing speech TORs, using speech styles similar to the driver's personality may help drivers quickly redirect their attention, regain sufficient situational awareness, and enhance takeover safety.

However, this study has limitations: the experimental sample was limited to young drivers (ages 20-25), which may restrict the generalizability of the results to older drivers. Older drivers may perform worse in takeovers due to reduced situational awareness (Ding et al. 2024,Agrawal and Peeta 2021), so further verification of the effectiveness of similarity-based speech TORs in different age groups is needed. Additionally, since the experiment was conducted using a driving simulator with relatively simple scenarios, future research should validate these results in real vehicles and more complex situations. Finally, a head-mounted eye-tracking device was used to assess situational awareness in this study. Future studies should consider using noninvasive devices to collect physiological indicators of drivers, such as heart rate variability or galvanic skin response, to provide a comprehensive assessment of driver situational awareness.

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Competing Interests

None

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