Multimodal Feedback for Effective Takeover in Automated Vehicles for Hearing Impairment

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Most vehicles on the road today range from SAE Level 1 to 3 automated vehicles, where Level 3 automated vehicles can handle most of the driving tasks on the road. However, there are still moments when drivers need to prepare to take over the vehicle, such as when an object suddenly appears in the middle of the road. To respond to these critical events in time, multimodal displays have been introduced in instructional and informational formats. However, the effects of multimodal displays during takeovers for people with hearing impairments have yet to be studied. To address this, we investigated how signal type (single-modal vs. multimodal), informational type (instructional vs. informational), and hearing impairment (hearing-impaired and non-hearing-impaired drivers) can impact drivers' takeover performance. These study findings can be used when implementing multimodal displays in automated vehicles for drivers with hearing impairments.

CCS CONCEPTS • Human-centered computing • Accessibility • Empirical studies in accessibility

Additional Keywords and Phrases: automated vehicles; multimodal displays; hearing impairment

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1 INTRODUCTION

Current automated vehicles, such as SAE Level 3, still require human takeover when the automated system cannot handle certain situations, such as an unforeseen obstacle on the road. These situations require adequate situation awareness within a limited time frame (e.g., [1]). The goal of the takeover is to regain vehicle control effectively [2]. It usually involves two stages: (1) the signal response phase and (2) the post-takeover phase. However, unlike people with normal hearing, those with hearing impairments may face challenges such as a impaired ability to perceive auditory warning signals (e.g., emergency vehicle sirens) which limit situation awareness [3] while performing takeover tasks. This demographic represents approximately 5% of the global population, or 466 million people worldwide [4].

Previous studies indicate that multimodal-display setups with visual-auditory-tactile (VAT) modalities could enhance driver takeover performance (e.g. faster response times) compared to single-modal displays such as a single auditory display [5]. However, people with hearing impairments may find the auditory cues hard to identify. Previous studies also show that people with hearing impairments tend to increase reliance on visual cues to compensate for auditory limitations [6]. To mitigate the risks and navigate roads safely, innovative solutions presented through tactile and visual cues may offer effective options [7]. In addition, the meaning behind each display (beyond the warning purpose) enhances driver performance, particularly in instructional and informative formats. Instructional displays guide the driver on what to do, such as showing arrows indicating recommended maneuver directions [8]. Conversely, informative displays warn the driver about potential danger, such as presenting icons to depict surrounding vehicles [9]. However, the differences between the two information types have not been compared for hearing impaired drivers.

However, further research is needed to better understand the effectiveness of display types (single visual or tactile displays vs. multimodal displays) that do not have an auditory component, as well as the information type (informative vs. instructional), on hearing-impaired drivers' takeover performance. Therefore, the goal of this study was to investigate the impacts of hearing impairments and multimodal displays across various information types on takeover performance.

2 METHOD

The study employed a 3 (information type: instructional, informative, baseline) × 3 (signal type: tactile (T), visual (V), and multimodal (VT)) × 2 (individual differences: normal-hearing and hearing-impaired) full factorial design. A total of 40 participants were involved in this study, divided into two groups (20 for normal hearing and 20 for hearing-impaired) who were driving on a three-lane highway using a medium-fidelity driving simulator while playing a matching game. To simulate hearing impairments, noise-canceling headphones playing white noise in the background were used (Figure 1).

During the experiment, participants were asked to take over the vehicle and decide which lane to move into due to an approaching car on one side. The following three scenarios were randomly presented to the participants. In the instructional scenario, a green arrow (e.g. pointing left or right) was present, with corresponding tactile signals vibrating vertically on the seat back (Figure 2). Informative signals depicted a red car approaching from behind a black car. Additionally, the corresponding tactile signals showed the approaching vehicle's side (Figure 3). Baseline signals displayed a red circle visually and had tactile signals vibrating in the middle row of the seat back. This signal did not present specific information, prompting drivers to rely on their mirrors (Figure 4). Visual, tactile, and multimodal (combined visual and tactile) cues were employed for each information type twice in a random order.

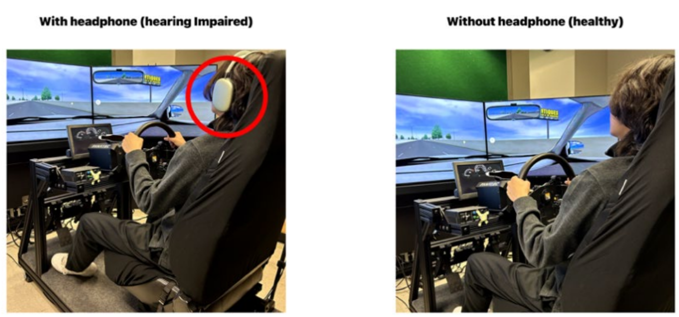

Figure 1: Experiment setup

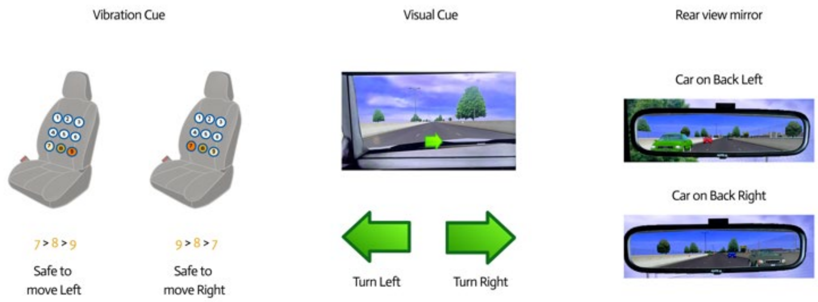

Figure 2: Instructional signal example

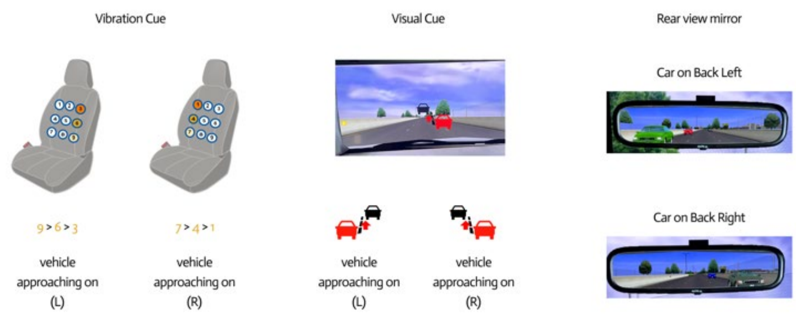

Figure 3: Informative signal example

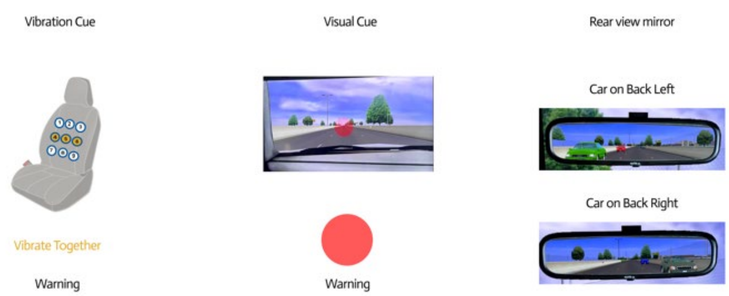

Figure 4: Baseline signal example

3 RESULT

Two dependent measures were used to evaluate takeover performance in this study, namely takeover and response times. Response time measured the time between the onset of the takeover request and the time when participants deactivated the automation (by pressing the brake pedal in this study), and takeover time measured the time from the first conscious action taken by the participant after the takeover request was presented.

Results showed that signal type had significant effects on both takeover and response times. The multimodal display (VT) showed faster takeover and response times compared to single visual and single tactile displays. Also, information type was found to have a significant effect on response times. The baseline had the fastest response, followed by informative and instructional. No significant effects of individual differences (normal-hearing and hearing-impaired) were found on takeover and response times.

4 CONCLUSION

Overall, this study aims to evaluate the takeover performance using multimodal displays across various information types among different individual differences (normal-hearing and hearing-impaired). The findings suggest that multimodal (VT) displays provide the driver with effective alerts and a smooth manual-to-autonomous transition during the takeover. This may enhance driver safety and alertness. These findings imply that future designs should consider using multimodal displays as guidelines while designing the takeover request for automated vehicles. Surprisingly, no differences were found between hearing-impaired and normal-hearing participants. One possible explanation is that this study did not recruit actual hearing-impaired participants. To find a better takeover request design for this demographic, actual hearing-impaired participants should be involved in future studies. Additionally, the combination of different locations among tactile and visual displays should be further explored. This could help hearing-impaired people identify the most suitable takeover request system.

The baseline signal as an abstract warning had shorter response times compared to other signals, most likely due to the warning signal taking less time to process. Drivers were able to interpret the takeover situation using baseline signals by looking at the environment, a concept they are often familiar with doing. On the other hand, instructional and informative signals were newly learned signals, making drivers much slower at responding. However, more research should be conducted to see if the findings are consistent in more complex takeover scenarios.

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REFERENCES

[1] H. Yun and J. H. Yang, "Multimodal warning design for take-over request in conditionally automated driving," *Eur. Transp. Res. Rev.*, vol. 12, no. 1, p. 34, May 2020, doi: 10.1186/s12544-020-00427-5.

[2] G. Huang and B. J. Pitts, "Takeover requests for automated driving: The effects of signal direction, lead time, and modality on takeover performance," *Accid. Anal. Prev.*, vol. 165, p. 106534, Feb. 2022, doi: 10.1016/j.aap.2021.106534.

[3] L. Fostick and N. Fink, "Situational Awareness: The Effect of Stimulus Type and Hearing Protection on Sound Localization," *Sensors*, vol. 21, no. 21, p. 7044, Oct. 2021, doi: 10.3390/s21217044.

[4] World Health Organization (2024). *Deafness and hearing loss*. https://www.who.int/news-room/fact-sheets/detail/deafness-and-hearing-loss

[5] P. Bazilinskyy, S. M. Petermeijer, V. Petrovych, D. Dodou, and J. C. F. de Winter, "Take-over requests in highly automated driving: A crowdsourcing survey on auditory, vibrotactile, and visual displays," *Transp. Res. Part F Traffic Psychol. Behav.*, vol. 56, pp. 82–98, Jul. 2018, doi: 10.1016/j.trf.2018.04.001.

[6] D. Choi, T. Sato, T. Ando, T. Abe, M. Akamatsu, and S. Kitazaki, "Effects of cognitive and visual loads on driving performance after take-over request (TOR) in automated driving," *Appl. Ergon.*, vol. 85, p. 103074, May 2020, doi: 10.1016/j.apergo.2020.103074.

[7] B. Thorslund *et al.*, "Hearing loss and a supportive tactile signal in a navigation system: Effects on driving behavior and eye movements," *J. Eye Mov. Res.*, vol. 6, no. 5, Art. no. 5, Dec. 2013, doi: 10.16910/jemr.6.5.1.

[8] J. B. F. Van Erp and H. A. H. C. Van Veen, "Vibrotactile in-vehicle navigation system," *Transp. Res. Part F Traffic Psychol. Behav.*, vol. 7, no. 4, pp. 247–256, Jul. 2004, doi: 10.1016/j.trf.2004.09.003.

[9] A. McKerral, K. Pammer, and C. Gauld, "Supervising the self-driving car: Situation awareness and fatigue during highly automated driving," *Accid. Anal. Prev.*, vol. 187, p. 107068, Jul. 2023, doi: 10.1016/j.aap.2023.107068