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# MITIGATING MOTION SICKNESS IN ELECTRIC VEHICLES THROUGH ACTIVE SOUND DESIGN

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## ABSTRACT

The adoption of electric vehicles (EVs) introduces a unique driving experience; however, it poses challenges to passenger comfort due to distinct vehicle dynamics, such as rapid acceleration and regenerative braking, which may contribute to motion sickness. While prior studies have highlighted the potential of anticipatory audio cues in mitigating motion sickness, their practical implementation remains limited. From an in-vehicle soundscape perspective, the acoustic environment consists of both vehicle-generated sounds and those produced by audio systems. This study investigates the effectiveness of active sound design (ASD) in alleviating motion sickness in EVs. Controlled real-world experiments were conducted with healthy participants who experienced 30 minutes of natural acceleration, deceleration, and stopping on public roads. Motion sickness levels were recorded every three minutes using the misery scale, with participants engaging in a non-driving-related task (video viewing) under two conditions: without ASD and with ASD. The findings indicate that the introduction of ASD, functioning as situational cues for vehicular movements such as acceleration and deceleration, significantly reduces motion sickness. These results suggest that ASD, beyond its conventional role in enhancing auditory enjoyment, can serve as a practical tool to improve passenger comfort by enabling the anticipation of vehicle motion.

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## 1. INTRODUCTION

The automotive industry is presently undergoing a profound transformation, marked by a transition from conventional vehicle manufacturing to the realm of future mobility and the evolution of transportation. This paradigmatic shift is characterized by the development of pioneering powertrain technologies, exemplified by electric vehicles and hydrogen fuel cell vehicles. Concurrently, it is propelled by the proliferation of innovative mobility paradigms, notable progress in autonomous driving technologies, and the establishment of connected vehicle ecosystems. These emerging trends serve as focal points of research and development inquiry within the automotive sector. The emergence of new mobility and autonomous driving technologies presents a myriad of opportunities, offering unique and substantial advantages to passengers. However, within this evolving mobility landscape, a significant challenge emerges in the form of motion sickness [1-3], highlighting the imperative need for comprehensive investigation and mitigation strategies.

Motion sickness is primarily attributed to sensory conflicts between the visual and vestibular systems [4]. It is also influenced by the absence of mental models for the unfamiliar vehicle behaviors [5]. Specifically, in electric vehicles, behaviors such as rapid acceleration and regenerative braking significantly contribute to an increased incidence of motion sickness. Previous studies have attempted to mitigate motion sickness by enabling vehicle occupants to predict the vehicle's behavior and enhance their awareness of the surrounding environment. Kuiper et al. [6] explored the effect of peripheral vision on motion sickness during driving. They evaluated the impact of the display mounting position on motion sickness while participants performed a visual search task using a display for non-driving related tasks (NDRT) at a low speed, such as 25 km/h. They found that NDRT using a display with a higher mounting position was associated with less motion sickness. Miksch et al. [7] investigated the effects of providing current road conditions in real-time on motion sickness. They reported that displaying real-time road conditions behind text during reading tasks associated with NDRT could reduce motion sickness, although this effect was not consistent across all subjects. In addition to visual information, there have been studies that utilize auditory and tactile information to perceive or anticipate driving conditions [8-11]. Kuiper et al. [11] examined the effect of providing information about vehicle motion via auditory cues on motion sickness. Subjects reported less motion sickness with auditory cues when seated in a chair that moved back and forth on rails, compared to conditions without auditory cues.

Although it has been reported that using various modalities such as visual, auditory, and tactile cues to provide passengers with information about the driving situation or to help them anticipate the vehicle's behavior can alleviate motion sickness, research on practical applications is still in its infancy. In this study, we aim to investigate whether artificial engine sounds, a component of the in-vehicle soundscape used in electric vehicles (EVs), can be effective in alleviating motion sickness by making passengers aware of the vehicle's driving situation. In other words, we explore the possibility that Active Sound Design (ASD) can offer a practical solution to alleviate motion sickness in EVs, extending beyond its role as merely an entertainment factor.

## 2. EXPERIMENTAL SETUP

### 2.1 Experimental environment

This study involved an experiment conducted on a public road to assess whether artificial engine sounds in electric vehicles can mitigate the symptoms of motion sickness. We recruited fifteen healthy adult women, ranging in age from 20 to 30 years, as participants. The experiment utilized a 2023 KIA EV6 and included typical driving maneuvers such as acceleration, deceleration, and stops. While seated in the back and watching a video, the participants experienced 30 minutes of driving. The intensity of motion sickness was measured at two-minute intervals using the Misery Scale (MISC). To induce motion sickness, the participants' view outside the vehicle was obstructed by a curtain. Figure 1 depicts the vehicle used in the experiment and the interior cabin where the evaluator was positioned.

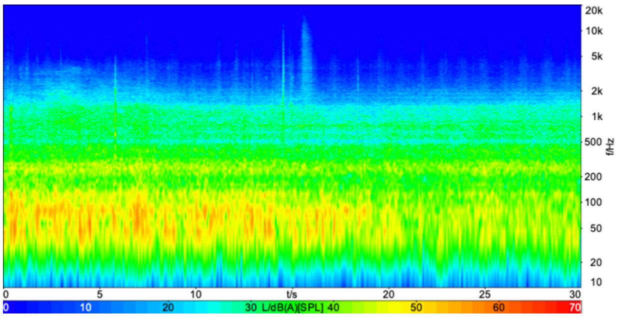
**Figure 1**. The electric vehicle used in the experiment and the interior conditions to which participants were exposed.

### 2.2 Active sound design

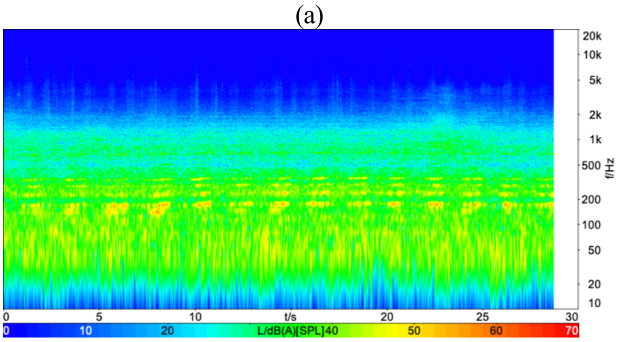
EVs are known for their quiet operation, which, while reducing noise pollution, presents challenges in terms of pedestrian safety and driver feedback. ASD or artificial engine sound is a technology developed to address these challenges by synthesizing sounds that enhance the acoustic presence of EVs. Traditional drivers often rely on engine sounds for sensory feedback about vehicle performance. ASD serves to bridge this sensory gap by artificially generating engine-like sounds or futuristic tones that provide necessary auditory feedback. In this study, an artificial engine sound was developed based on granular synthesis. The pitch and loudness of the artificial engine sound are controlled in response to the accelerator pedal sensitivity, vehicle speed, and engine torque. Moreover, the artificial engine sound was embedded in an external audio amplifier and reproduced in the cabin using the audio speaker.

### 2.3 Experimental condition

Two experiments were considered to evaluate whether providing artificial engine sounds mitigates motion sickness. The first experiment was a baseline driving scenario without artificial engine sounds, while the second experiment included these sounds. Figure 2 depicts the measured interior noise in each experimental condition. The artificial engine sound was designed to be mainly prominent within the 100 to 500 Hz range. As illustrated in Figure 2, during acceleration, a prominent sound in the 200 Hz band provides auditory feedback about the vehicle's motion. The experiments assessed the symptoms of motion sickness both with and without the artificial engine sound while subjects performed NDRT, during which they watched a video in the car.




(a)




(b)

**Figure 2**. Spectrogram of the interior noise measured from the right rear seat position: (a) under the original condition, and (b) with active sound design.

## 3. EXPERIMENTAL RESULTS

In this study, we measured MISC scores every two minutes to evaluate whether artificial engine sound could delay or mitigate the onset of motion sickness symptoms. The MISC includes 11 levels, from 0 to 10. A MISC level of 0 means there are no symptoms of motion sickness; level 2 is associated with vague symptoms such as dizziness, warmth, headache, stomach awareness, and sweating; level 4 represents medium intensity symptoms. Level 6 indicates mild nausea. We then converted the measured MISC levels into a metric known as 'MISC onset time', which determines the duration until levels 2, 4, and 6 are reached, reflecting the escalating severity of motion sickness under each experimental condition.

Figure 3 shows the progression of MISC measurements in the two experimental conditions, such as the baseline and artificial engine sound scenarios. At first glance, it can be seen that the symptoms of motion sickness were mitigated in the condition with artificial engine sounds compared to the baseline condition.

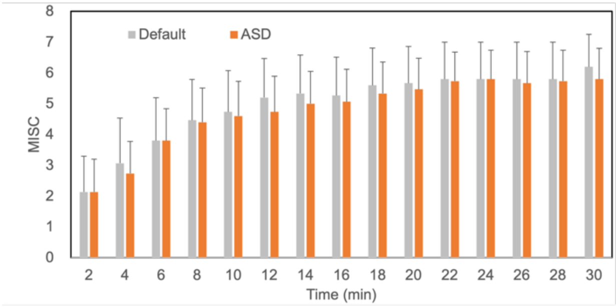



**Figure 3**. Evaluation of MISC measurements under two experimental conditions: with and without ASD.

Figure 4 presents the measurements of MISC onset times for levels 2, 4, and 6, by experimental conditions. In the baseline scenario, it took an average of 4.6 minutes for the MISC to reach level 2. With ASD, this time was extended to 5.8 minutes, resulting in a delay of 1.2 minutes. Furthermore, the time required for the MISC to reach level 4 increased by 3.5 minutes, from 6.7 to 10.2 minutes. Conversely, the time to reach level 6 slightly decreased by 0.1 minute, from 10.5 to 10.4 minutes. The artificial engine sound was found to moderately affect the early stages of motion sickness symptoms, notably at MISC levels 2 and 4. However, it did not prove effective at higher levels where nausea is present.

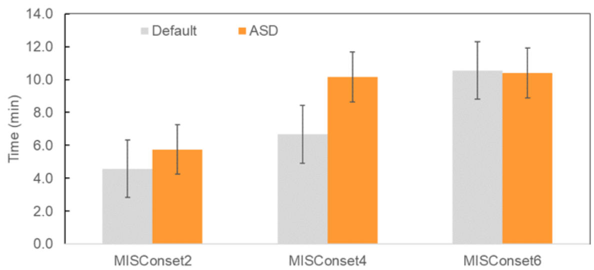



**Figure 4**. Experimental results of MISC onset times for levels 2, 4, and 6 by experimental condition: with and without ASD.

## 4. CONCLUSIONS

This study explored the impact of ASD in mitigating motion sickness within EVs. The experimental results show that artificial engine sounds can effectively delay the onset of early motion sickness symptoms, as evidenced by the increased MISC onset times for levels 2 and 4 in the ASD scenario compared to the baseline. This suggests that ASD can significantly enhance passenger comfort during the initial stages of travel. However, its effectiveness in addressing more severe symptoms was found to be limited. Future studies will focus on various parameters, such as the loudness and pitch of the artificial engine sound. Additionally, we will investigate the effectiveness of ASD in enhancing the anticipation of vehicle behavior, aiming to further understand and improve ASD's role in passenger comfort.

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