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Motion Sickness Mitigation in Road Vehicles with a Triad of Focus on Safety and Sustainability

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Abstract - *Although commonly experienced, the issue of car sickness is still poorly understood. Research towards its alleviation only gained interest in recent years, coinciding with the electric, digital and autonomous transformation of road vehicles. Within these vehicles, a heightened risk of car sickness poses a potential obstacle to their successful integration on public roads. Identifying effective mitigation means for car sickness may not only ensure the acceptability of new transportations means but also have broader benefits in terms of safety, and sustainability. Among others, a solution for car sickness would improve the quality of life for most susceptible individuals, enhance accessibility for people with disabilities, and reduce inequalities to mobility. Addressing car sickness additionally also contribute to vehicle safety by preventing driver distraction and support sustainability by encouraging the use of shared transportation. Such improvements could already be beneficial for current road transportation.*

Keywords: *motion sickness, car sickness, autonomous vehicles, connected cars, future transportation.*

I. INTRODUCTION

Motion sickness refers to a state of illness induced by a prolonged exposition to a physical or visual motion stimulus [1]. The occurrence and severity of this phenomenon increase with time of exposition and magnitude of motion. This condition can persist from few minutes to days depending on individual susceptibility and exposure history.

The onset of motion sickness is due to the uncommon nature of motion environments where the body is unable to adapt [2]. When exposed to a given motion stimulus, the body usually adapts so that the symptoms no longer appear [1], [3]. Such an ability explains why motion sickness occurs when employing new forms of transportations, and may have been discovered along with the adoption of other traveling means than walking [4]. There are different forms of motion sickness, each corresponding to the physical and visual characterization of a provocative motion environment. Most notable forms are

seasickness, airsickness, space-sickness and carsickness, which are respectively induced by particular types of physical motion stimuli. Other forms of motion sickness exist under the notion of visually induced motion sickness [5], [6]. The symptomatology of motion sickness is generally misunderstood: people usually attribute it to moderate to severe symptoms such as hypothermia, nausea and vomiting whereas it also encompasses lighter manifestations such as dizziness, pallor, drowsiness or lethargy [4]. There is a wide variety in autonomic responses and sensitivity to specific motion stimuli between individuals [7], [8], [9], [10], [11].

This paper specifically focuses on car sickness, which is experienced while traveling in road vehicles and characterized by an exposition to unpredictable and low frequency horizontal motion with moderate to high magnitudes [12], [13], [14]. These specific motion stimuli are induced by the vehicle's behaviour on the road, that mainly generates fore-aft and cornering maneuvers. Slight tilts of the car's body also occur due to the combination of accelerations and the vehicle's kinematics [13]. Car sickness is the second most experienced form of motion sickness, with two thirds of the people traveling by car having suffered it once on their life [1], [15], [16].

Although the research community focused on the topic of motion sickness for military purposes in the second half of the 20th century, it is still unclear and discussed through theories. Car manufacturers did poorly consider car sickness occurrence in the design process of automotive vehicles until recently [17], [18]. Yet, motion sickness evolves into a hygiene issue [19], whose addressing is a requirement for the successful introduction of highly automated vehicles (HAVs). This problem motivated further research and development of systems to alleviate car sickness [20], [21].

The next sections aim to help understanding the causes and challenges behind the issue of car sickness. The potential impact of an effective alleviation solution is then discussed in terms of accessibility, safety and sustainability.

II. AETIOLOGY OF CAR SICKNESS

The most accepted hypothesis on the mechanism of motion sickness suggests a sensory discrepancy between expected and real motion forces the body undergoes in a stimulating environment [1]. The body can adapt to provocative motion stimuli by keeping trace of adaptation methods to similar motion patterns that were previously experienced, but in the presence of novel provoking stimuli, the body uses impaired strategies to compensate for the sensory discrepancy, which leads to motion sickness. Another considered hypothesis proposes a relation between motion sickness and postural instability [22]. In a moving car, the postural sway of passengers may be a preceding although not sufficient factor of motion sickness [23], [24].

It has been often noted that susceptible subjects were less sickness-sensitive when driving the vehicle [1], [25]. The reason is that drivers have accurate perception of the vehicle's motion through their steering, clutch and brake inputs. Controllability and predictability are two dimensions that stem from the driving task and are crucial in the mitigation of motion sickness [25], [26], [27]. Such a contrast between drivers and passengers can be observed in their different body reactions to the gravito-inertial forces elicited by the car's motion [28], [29]. This figure supports both the sensory conflict theory and the postural instability theory, as passengers have a reduced perception of motion that results in their use of impaired strategies to stabilize their body.

The low probability of becoming sick as a driver made the issue of car sickness not to be considered in the development of passenger vehicles [30]. However, with the expected widespread of HAVs, this issue may affect passengers' trust and feeling of safety [31], [32]. Such dimensions are crucial for the acceptance of HAVs, and their decline may jeopardize the successful introduction of such vehicles on public roads [17], [33], [34], [35].

III. CAR SICKNESS AND FUTURE TRANSPORTATION

A. Causes of widespread

In the upcoming years, car transportation will undergo technological upheavals such as autonomous, digital, and electric transformations that are likely to increase car sickness prevalence to the point of doubling it [20], [21], [36].

In HAVs, the automation system takes over the driving task, and drivers will evolve into passengers along with a decline of controllability and anticipation, being, as a result, "out-of-the-loop" [37]. The forced reduction of such abilities may increase the likeliness of experiencing motion sickness: the vehicle's driving style may not fit user expectations and the induced motion may feel as unpredictable [38], [39]. Since exposure

history play a role in the development of symptoms [3], [40], [41], some regular drivers may discover themselves as particularly sensitive, and most susceptible individuals might reject this transportation mean [17]. This increase in car sickness prevalence has already been observed with the introduction of vehicles with partial automation and may accentuate with higher levels [21]. By 2050, it is expected that HAVs will constitute a majority of the vehicles on the road [42], which highlights the necessity of dealing with the issue of car sickness.

As previously mentioned, HAVs offer their users the possibility to devote travel time to productive, relaxing, or playful NDRAs. To propose an atmosphere that suits the users' needs, future vehicle cockpits may feature numerous screens and interfaces. Their omnipresence may overload the users with incongruent visual stimuli, restrict outside visibility and affect psychology with sensations of overwhelming. As a result, focusing on NDRA visual content may limit the cognitive resource for perceiving the vehicle motion [43] and lead to incongruent visual inputs with the physical motion [44], [45]. Reading and watching screens while traveling proved to increase the occurrence and severity of sickness symptoms [21], [45], [46]. In the context of HAVs, this issue may lead passengers not to be aware of the vehicle's driving. It is expected that 6-10% of adult American passengers of fully automated cars might almost systematically feel carsick [21]. This incidence might be even higher for other populations like Caucasian passengers [47].

Vehicle electrification may also present a higher risk of experiencing car sickness than in combustion engine vehicles: the suppressing of engine sounds (e.g. revving) may decrease audible information on vehicle longitudinal acceleration, which can be an auditory cues on combustion engine cars [48], [49, p. 170]. The high-frequency vibrations of a combustion engine are also suppressed with such motors. Bos (2015) argued that such vibrations could be perceived as soothing and help decrease sickness symptoms [50]. The high torque and reactivity of an electric motor may generate strong and unexpected accelerations. Same applies to the use of regenerative braking, a feature specific to electrified vehicles that has been lamented for its nauseogenic potential.

B. Challenges in solving car sickness

Even if the main motivation for identifying congruent mitigation means is to ensure the acceptability of HAVs, the impact of these findings could go beyond the strategic interests of car manufacturers. Benefits in terms of accessibility, safety and sustainability could be already observed through applications on the currently available vehicles.

1) Accessibility

A minor part of the population (around 10 %) is known to be very sensitive to motion sickness [40]. Some of these individuals have a restrained mobility, as they are so susceptible that they tend to avoid provocative travel means [9]. For such people, alleviating motion sickness symptoms could be perceived as a relief.

An effective solution for car sickness may not only be of public interest in road vehicles but for other passenger transportation means as well: car motion forces can be considered as a “worst case” of motion environment for ground transportation in the way it is characterized by repetitions of multidirectional and low predictable accelerations of high amplitudes. Hence, an efficient countermeasure to this provocative motion may be of great interest for less provocative transportation means like coaches and trains, which could become accessible to most unfortunate subjects.

In the context of future transportation, the identification of such a solution would mainly contribute to increase the acceptance of HAVs. Such vehicles are emphasized to facilitate access to mobility and improve the quality of life for people with disability or a medical condition [51], [52], [53], [54]. In France, a 2019 study showed that 8.4 % of a population aged 16 to 64 surveyed was in a “situation of disability”. These individuals cited more difficult access to mobility with a lack of vehicle equipment as one of the reasons for this disparity [55].

Solving car sickness may help in reducing inequalities to passenger transportation while helping susceptible people in better adapting [7].

2) Safety

In conventional cars as well, car sickness may be a safety issue if one passenger complains about the rise of symptoms or feels the urge to vomit. The driver’s cognitive resources may be altered and represent a potential safety risk if the driving situation is delicate to handle. In cases of incoming emesis for a passenger and the urge to stop the car, the type of driven road or traffic situation may be a dangerous situation for stopping the vehicle. The emergency to stop may also make the driver panic and create a crash while losing concentration when trying to stop the car.

Safety is also an underlying aspect of car sickness when considering HAVs. When considering level 3 and 4, there may be some situations where the vehicle automation surpasses its operational domain and requests the designated driver to regain awareness of the surroundings and take over control within 30 seconds. However, the onset of sickness symptoms, even

unnoticeable, may hinder the designated driver’s capacity to take over these responsibilities [30]. Several studies have reported degraded levels of physical, cognitive and visual performance when under motion sickness symptoms [56], [57], [58], [59], [49, p. 127].

3) Sustainability

As earlier reported, some people tend to reject passenger travel due to their likeliness of becoming sick. Such people may have no other choice than using the car to commute, a case of use that is known harmful for environment and health [60]. With a successful solution, they would hence be able to use shared transportation means. With regards to this hypothesis, the individual carbon footprint could be reduced for such subjects [61]. Considering that, in France, more than 70 % of commuters use individual vehicles, including 9 out of 10 alone in the car [62], solving the issue of carsickness may encourage the use of shared transportation and decrease this proportion.

C. Mitigation approaches and research perspectives

Medication is usually suggested as a reliable countermeasure of motion sickness. However, the efficacy of anti-motion sickness drugs may be counterbalanced by undesirable side effects such as drowsiness [8]. Some of these treatments may even report no improvements in comparison to placebos. Such methods are not compatible with the use of a car, as they could compromise safety and performance. Therefore, the challenge is to identify a universal, non-intrusive and sufficiently effective mitigation technique. Addressing this issue first requires sufficient knowledge on the causes of motion sickness in a car [63]. With the variety of factors to influence car sickness [12], [15], [16], [64], different types of corresponding solution have been elaborated. Recent work proposed clustering these solutions into three respective categories [65].

The first category “Vehicle-Centric Adaptation” clusters solutions to minimize and limit the vehicle dynamics. They involve choosing the most compliant itinerary to follow depending on user requirements (Route Planning) [66], [67], operating a feasible and comfortable trajectory (Motion Planning) [68], [69], [70], [71], and attenuating the motion forces that are generated (Vehicle Dynamic Optimization) [72], [73], [74], [75], [76], [77].

The second category “Cabin Layout” includes design guidelines for vehicle architecture. They mainly propose to maximize outside visibility while considering the position and size of windows (Daylight Opening), seats, and displays [44], [49, Ch. 12], [78], [79].

The third category “Sensory Cueing” involves delivering sensory stimuli to enhance the passenger’s individual perception of the vehicle’s motion or helping in its anticipation. Given that human motion perception is made of sensory integration of visual, vestibular and haptic information mainly, the majority of tested solutions replicated to increase visual [46], [49], [80], [81], [82], vestibular [46], [50], [83] and haptic [84], [85], [86] perception respectively.

Since psychology has a strong influence on the prevalence and development of motion sickness, the present paper proposes including a fourth category “In-Vehicle Atmosphere”, where sensory stimuli with no influence on motion perception are delivered to the user to increase feelings of comfort, wellbeing, promote relaxation and relieve negative feelings. This category includes methods such as olfactory stimuli [87], [88], acupressure [89], [90], [91], pleasant music [92], [93], temperature regulation [94], distraction effects [50] or even the incitation to controlled breathing [93]. Some of these solutions may include placebos, but should be considered given the influence they can have on motion sickness [95].

An overview of these categories can be seen in Figure 1. It is worth noting that each category of solutions addresses a specific cause of motion sickness. Since each category targets to reduce a specific cause of motion sickness, combining solutions from different categories should be considered to yield maximal alleviation effects [96].

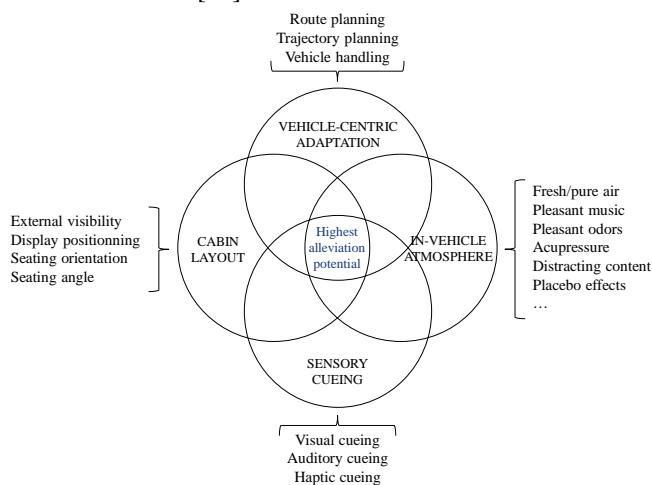


Figure 1. Overview of the different categories of an in-vehicle integrated car sickness mitigation solution.

IV. DISCUSSION

A. A further step towards sustainability... really?

The sustainable aspect of autonomous transportation is to nuance with regards to consumption trends. Identifying a

solution against car sickness may also present a rebound effect: carbon emissions may increase due to a more frequent use of HAVs. A wider adoption of such vehicles may be expected at the expense of “cleaner” mobility systems such as walking or riding a bike, which would be considered as less safe, less comfortable and slower. Some researchers anticipate that the widespread of autonomous transportation may increase the number of individual vehicles on the roads, even crossing the two billion threshold by 2030, even though the one billion mark was crossed in the early 2010s [97]. The use of traveling time as dedication to NDRAs would also increase the average traveled distance of individual vehicles [98], [99, p. 203]. Regarding those predictions, HAVs cannot be considered as sustainable unless promoting softer mobility and using more neutral energies [100].

B. How effective could be motion sickness alleviated in cars?

Motion sickness is a natural phenomenon that developed over millions of years as an adaptive defense mechanism of the body to a provoking motion environment [9], [101]. Yet, it is still poorly understood due to its intricate aetiology and the difference in body reactions from one individual to another [102], [103]. There are several worsening factors of motion sickness as well that may influence the development of symptom when traveling in a car, and designing sufficiently effective countermeasure would first imply identifying all these causes and how to prevent them.

There is a wide inter-individual range in motion sickness susceptibility. The challenge of finding a universal solution is tough, but not impossible if attention is first given to better understand human perception, psychology, sensitivity, and their respective influence [7]. Nevertheless, combining different mitigation systems has been suggested as a promising alternative [63], [65]. While simultaneously considering sensory cueing, dynamic optimization, cockpit design requirements and a wellbeing atmosphere, such a solution would help in limiting the causes, minimizing the severity, and facilitating recovery simultaneously.

V. CONCLUSION AND PERSPECTIVES

Addressing car sickness gained interests within recent years with the purpose of ensuring a good user experience on board future road vehicles that will be electrified, automated, and digitalized. The paper proposed an extended approach to such benefits and discussed further outcomes of safety, accessibility and sustainability. The identification of a universal and effective solution could be already applied in current road vehicles to reduce inequalities to mobility and help in adopting passenger

transportation. In this optic, a sharpened understanding of perception as well as the implication of individual psychology and sensitivity would make it possible to design compelling mitigation means.

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