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Self-driving carsickness

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ABSTRACT

This paper discusses the predicted increase in the occurrence and severity of motion sickness in self-driving cars. Self-driving cars have the potential to lead to significant benefits. From the driver's perspective, the direct benefits of this technology are considered increased comfort and productivity. However, we here show that the envisaged scenarios all lead to an increased risk of motion sickness. As such, the benefits this technology is assumed to bring may not be capitalised on, in particular by those already susceptible to motion sickness. This can negatively affect user acceptance and uptake and, in turn, limit the potential socioeconomic benefits that this emerging technology may provide. Following a discussion on the causes of motion sickness in the context of self-driving cars, we present guidelines to steer the design and development of automated vehicle technologies. The aim is to limit or avoid the impact of motion sickness and ultimately promote the uptake of self-driving cars. Attention is also given to less well known consequences of motion sickness, in particular negative aftereffects such as postural instability, and detrimental effects on task performance and how this may impact the use and design of self-driving cars. We conclude that basic perceptual mechanisms need to be considered in the design process whereby self-driving cars cannot simply be thought of as living rooms, offices, or entertainment venues on wheels.

1. Introduction

Maturation, integration and affordability of enabling technologies have turned self-driving cars from science fiction into reality. Whereas automation of the driving task as such is not new, e.g. cruise control was introduced in the late fifties (Akamatsu et al., 2013), the crucial difference is that today's automated vehicle technologies not only control the vehicle, but also monitor, interpret, and act in response to the driving environment without any driver engagement. Google's self-driving car famously has been clocking up thousands of accident-free miles and several countries are now preparing themselves to adapt laws permitting self-driving cars on public roads (BBC news, 2013). At the same time, the car industry seems to have entered a "first to market" race with some manufacturers announcing their intention to introduce self-driving vehicles as early as 2017 (e.g. NBC news, 2014).

Automation is widely regarded as the most significant development within the automotive industry (e.g. Wallace and Sillberg, 2012). This not only relates to the transformation of the concept of the "driving experience", but, more importantly, to its potential societal, environmental, and economic impact (for an overview see Begg, 2014). Given that the vast majority of accidents can be attributed to human error, taking the driver out of the loop may reduce or even eliminate driver error which, in turn, may lead to safer roads. It will also allow for more effective road use with vehicles able to safely drive close together thereby using less road space, reducing congestion and journey times. The optimisation of acceleration profiles enabled by automation will allow energy usage to be optimised leading to reduced pollution and associated emissions. Further reductions in energy consumption may be achieved by reducing the weight of automated vehicles. In the light of the reduced likelihood and severity of collisions, heavy protective structures may be replaced by structures made out of lighter materials. In particular given our ageing societies, automated vehicles could also improve mobility for those unable or unwilling to take the wheel. Finally, automation may make travelling by car more productive and comfortable. The driver, now passenger, is able to engage in non-driving activities, sit back and relax, have a coffee, check emails, read the morning paper, or swivel the front seat and have a face-to-face conversation with rear passengers.

Yet, if, and to what extent, these potential benefits will materialise, is as yet unclear. In the short term, questions with regard to system reliability, cybersecurity, ethics, and liability will need to be addressed. However, automation raises more fundamental questions, in particular with respect to the interaction between driver and vehicle. To appreciate the nature of this interaction, it is instructive to briefly review the different levels of vehicle automation under consideration.

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Fig. 1. Illustration of the three main scenarios for automated vehicles: From active driver to passive supervisor/passenger (left); Engagement in non-driving tasks (middle); Rearward facing seating arrangements (right).

Automated vehicle technologies have a range of capabilities, from anti-lock brakes and forward collision warning, to adaptive cruise control and lane keeping, to fully automated driving. Following the Society for Automotive Engineers taxonomy (SAE, 2014), we here define 5 levels of vehicle automation. Level 0 indicates the absence of automation, i.e. manual driving. Automation level 1 (*Driver assistance*) refers to the situation where the vehicle technology takes over either longitudinal or lateral control. These automation features have been available within the premium segment for some time in the form of Adaptive Cruise Control and Lane Keeping Assist systems, respectively. Level 2 (*Partial automation*) refers to automation of multiple and integrated control functions, such as adaptive cruise control combined with lane centring. The driver is responsible for monitoring the roadway and expected to be available for control at all times, but under certain conditions can be disengaged from vehicle operation. From level 3 upwards, the driver is no longer required to monitor the environment and is thus able to engage in non-driving tasks under certain conditions. Unlike level 4 and 5, level 3 (*Conditional automation*) would still require the driver to regain manual control if required within a certain time buffer, e.g. within 30 s following a warning signal. Level 4 (*High automation*) no longer requires the driver to intervene, but the autonomous mode may not be available on all types of roads. Finally, at level 5 (*Full automation*), the vehicle can perform all driving functions and monitor roadway conditions for an entire trip, and so may operate with occupants who cannot drive, or without human occupants.

From the above taxonomy and definitions, it can be seen that the driver's role changes depending on the level of automation. Starting from an active driver, automation gradually transforms the driver into a system supervisor and ultimately a passenger at automation levels 4 and 5. Not surprisingly, the introduction of automation has raised several classic human factors issues (for a review see Trimble et al., 2014). Of particular immediate concern are the questions that arise at automation level 3, which is widely anticipated to be introduced towards the end of this decade (NBC news, 2014). At this level, the driver is expected to resume vehicle control with a sufficiently comfortable transition time in case the system reaches its performance limits, or because the driver desires to return to manual drive. The safe and comfortable transitioning between in-the-loop and out-of-the-loop behaviours raises several questions. The current human factors research agenda focusses on questions related to control authority, human machine interface design, transition periods and strategies, driver performance over time, safety impact of secondary tasks, situation awareness, driver acceptance and trust, driver training, and system evaluation tools (e.g. NHTSA, 2013; Trimble et al., 2014).

However, there is one human factors issue that appeared to have gone unnoticed and which we would like to draw attention to in this paper, namely motion sickness. As will be argued here, vehicle automation can be predicted to increase the likelihood and severity of motion sickness, or what we refer to as *Self-Driving Carsickness*. The reason for this is that the scenarios envisaged for self-driving cars create conditions that are known to promote the incidence and severity of motion sickness. Furthermore, the issue of motion sickness will be of concern across *all* automation levels.

1.1. Scenarios for self-driving cars

Automation creates a new set of design opportunities where the vehicle can be increasingly thought of as a space for living, working and socialising. Recently, several concepts and technology demonstrators have been presented to explore the possibilities that automated driving may offer. The envisaged scenarios can be summarised into three main categories and are illustrated in Fig. 1.

- *Transition from an active driver to a passive supervisor or passenger*

Automation level 2 as already provided by some premium car manufacturers (Forbes, 2013), allows the driver to disengage from the driving task and sit in comfort without the need to control pedals and steering wheel. The transfer of vehicle control and the subsequent lack of vehicle control on behalf of the driver will be a fundamental condition across all automation levels.

- *Engagement of the driver in non-driving tasks*

Automation levels 3 and higher open up more opportunities and enable the driver, now passenger, not only to relax but also to engage in non-driving activities. Concept vehicles such as Rinspeed's *XchangeE* (Forbes, 2014), *ZOOX* (Digital Trends, 2013), Akka's *Link & Go* (Akka, 2015), and Mercedes-Benz's *Future Truck 2025* and *F015* (Mercedes, 2015) point towards future vehicle designs that may include steering wheels that are stowed away or can slide into the centre of the car, allow the driver's seat to swivel away from the steering wheel, read a book or watch media content on in-vehicle displays, simply relax, or have a face to face conversation with the other passengers.

- *Rearward facing seating arrangements*

A frequently suggested scenario for self-driving cars is the idea that drivers and front seat passengers are able to swivel their seats. This concept seems to be based around the idea of the vehicle becoming a social space with occupants being able to face each other, e.g. Rinspeed's *XchangeE* (Forbes, 2014), and secondly, to create sufficient space for the driver behind the steering wheel to engage in certain non-driving activities such as the use of nomadic devices such laptops or tablets (e.g. Mercedes-Benz's *Future Truck 2025*).

The argument we put forward in this paper is that these scenarios can be expected to significantly increase the likelihood of motion sickness in self-driving cars, or self-driving carsickness. Here, motion sickness refers to a condition in which people get sick due