Will autonomous vehicles make us sick?

Conference Paper · October 2014

DOI: 10.13140/RG.2.1.1461.0087

Cyriel Diels
Royal College of Art

Diels, C. (2014). Will autonomous vehicles make us sick? In S. Sharples & S. Shorrock (Eds.),
Contemporary Ergonomics and Human Factors (pp. 301-307). Boca Raton, FL: CRC Press.

WILL AUTONOMOUS VEHICLES MAKE US SICK?

Cyriel Diels

Coventry School of Art & Design, Department of Industrial Design, Coventry University, Priory Street
Coventry CV15FB, UK
Cyriel.Diels@coventry.ac.uk

Autonomous vehicles have the potential to radically change the way we use and interact with our cars. Current thinking assumes that drivers will engage in non-driving tasks and, accordingly, future vehicle design may look dramatically different. However, the use cases envisaged are also known to exacerbate the incidence and severity of carsickness. This paper will discuss these scenarios with reference to the aetiology of carsickness and suggest design constraints to facilitate acceptable future autonomous vehicle design.

Introduction

Maturation, integration and affordability of enabling technologies have turned automated driving into a reality. We have seen Google's driverless car clocking up thousands of accident-free miles and now several US states, the UK and Japan have passed laws permitting (human-supervised) autonomous cars on their roads for R&D purposes. Several car manufacturers including GM, Mercedes, and Nissan, also recently announced their intention to offer semi-autonomous vehicles by 2020. These vehicles provide dual-mode operation whereby, on demand, longitudinal and lateral vehicle control can be handed over to the vehicle. The system essentially combines full range adaptive cruise control with automated lane keeping applying steering actions using electrical power steering. On-road trials are currently also underway to evaluate so-called platoon driving, i.e. the grouping of vehicles maintaining a short time headway achieved by using a combination of wireless communications, lateral and longitudinal control units, and sensor technology. Current concepts under consideration assume a system whereby the platoon is led by a trained, professional driver whilst the following vehicles are driven fully automatically by the system (for an overview of vehicle automation see SMART 2011).

By taking the driver out of the loop, automated personal mobility has the potential to be more efficient, safer, and greener (e.g. Robinson et al. 2010). At the same time, it allows drivers to engage in non-driving tasks. With vehicle control in the hands of the automated system, the driver, now passenger, can sit back and relax, have a coffee, check emails, read the morning paper, or swivel his or her chair and have a face to face conversation with other passengers.

Diels, C. (2014). Will autonomous vehicles make us sick? In S. Sharples & S. Shorrock (Eds.), Contemporary Ergonomics and Human Factors (pp. 301-307). Boca Raton, FL: CRC Press.

Vehicle interiors will be designed to become more like social, work, and entertainment spaces.

Besides the critical aspect of liability, there are several human factors issues that require a better understanding to ensure the successful introduction of vehicle automation. Current research activities focus around the topics of transfer of control, situational awareness, HMI design, mixed traffic conditions, system trust, reliability, and user acceptance. There is one aspect, however, that thus far has appeared to have gone unnoticed: *carsickness*.

Susceptibility to carsickness varies widely but it has been found that around 60% of the population has experienced some nausea from car travel, whereas about a third has vomited in cars before the age of 12 (Griffin, 1990). Although the ultimate manifestation of motions sickness is vomiting, it is typically preceded by signs and symptoms such as nausea, headache, fatigue, and drowsiness which may linger on for hours (Griffin, 1990).

Coincidentally, the use cases that are being envisaged for automated driving are also those we know to lead to increased levels of carsickness. First, automation alters the driver’s function from an active to a passive, monitoring one. Secondly, occupants are assumed to engage in non-driving tasks taking the eyes off the road ahead. Finally, flexible seating arrangements may involve rearward facing seats. In the context of carsickness, the common denominator across above scenarios or use cases is the occupants’ inability to sufficiently accurately predict the future path of the vehicle which is known to be a main determinant of sickness (e.g. Golding & Gresty, 2013). Following a brief introduction to the aetiology of carsickness, the different use cases and their exacerbating effect on carsickness will be discussed below.

Aetiology of carsickness

Motion is primarily sensed by the organs of balance located in the inner ear and our eyes. Motion sickness can occur when these motion signals are in conflict with one another or when we are exposed to motion that we are not accustomed to (Reason, 1975; Oman, 1982). It can be caused by a wide variety of motions of the body and the visual scene and is a common problem in travellers by car, train, air, and particularly sea. Seasickness may happen whilst being below deck where a clear view of the visual scene outside the ship is lacking. Under these conditions, motion sickness occurs because the movements of the ship, as perceived by the organs of balance, are in conflict with the motion perceived by the eyes, which indicate a static visual surround.

Sickness can however also occur when we are exposed to motion that, from an evolutionary perspective, we are not used to. Our bodies are not accustomed to low frequency oscillating motion. Sea and airsickness, for example, are mainly caused by slowly oscillating vertical motion. Carsickness, on the other hand, is

Diels, C. (2014). Will autonomous vehicles make us sick? In S. Sharples & S. Shorrock (Eds.), Contemporary Ergonomics and Human Factors (pp. 301-307). Boca Raton, FL: CRC Press.

associated with horizontal accelerations (sway) caused by acceleration, braking, and cornering (Guignard & McCauley, 1990; Turner & Griffin, 1999).

With regard to carsickness, it is linear accelerations (sway) in the low frequency bands (0.1-0.5 Hz) that are most relevant and their effects increase as a function of duration of exposure and the intensity of acceleration (Turner & Griffin, 1999). Apart from the route itself, carsickness heavily depends on the way the car is driven. An aggressive driving style involving plenty of accelerating and braking is therefore more likely to result in carsickness. A study on suburban car journeys reported that the fore-and-aft and lateral acceleration motion patterns were similar over the lower frequency range and were provocative in inducing motion sickness. These low frequency fore-and aft and lateral oscillations are more dependent on the driving behaviour of the driver than the characteristics of the vehicle (Griffin & Newman, 2004).

Characteristics of the vehicle mainly affect higher frequency motion. Similarly, road surface quality also affects the high frequency motion vibrations. From this it follows that road surface quality and suspension affect riding comfort, but do not induce carsickness. Exceptions to this rule are cars with particular soft suspensions. In general, when the suspension frequency is below 1 Hz, the likelihood of carsickness significantly increases (Turner & Griffin, 1999). Cars with stiffer suspensions are therefore less likely to lead to cars sickness. Larger amplitudes of lateral (sway) are particularly provocative. As the amplitude of sway tends to increase towards the rear of vehicles (cars and buses), rear seat passengers are particularly prone to car sickness, especially under conditions where external visual views are limited (Turner & Griffin, 1999).

Carsickness and Autonomous Vehicles

The novel use cases that are being envisaged for autonomous driving are also those we know to significantly increase the incidence and severity of carsickness. First, automation alters the driver’s function from an active to a passive, monitoring one. Secondly, occupants are assumed to engage in non-driving tasks taking the eyes off the road ahead. Finally, flexible seating arrangements may involve rearward facing seats. In the context of carsickness, the common denominator across above scenarios is the occupants’ inability to sufficiently accurate predict the future path of the vehicle which is known to be a main determinant of sickness (e.g. Golding & Gresty, 2013).

Changing roles: From driver to passenger

With longitudinal and lateral vehicle control automated, the driver is no longer required to actively engage in the driving task. In dual-mode systems where the driver has the choice to drive the vehicle manually or hand over control to the automated system, the driver may still be required to monitor vehicle status to allow for manual override in case of emergencies. In effect, however, the driver becomes a passive passenger.

Diels, C. (2014). Will autonomous vehicles make us sick? In S. Sharples & S. Shorrock (Eds.),
Contemporary Ergonomics and Human Factors (pp. 301-307). Boca Raton, FL: CRC Press.

It is commonly reported that drivers of cars, pilots of aircraft, or Virtual Reality users in control of their own movements are usually not susceptible to motion sickness despite the fact that they experience the same motion as their passengers (Geeze & Pierson, 1986; Reason & Brand, 1975; Stanney & Hash, 1998). This moderating effect of control on the generation of motion sickness symptoms has typically been attributed to the presence of muscular activity. When we initiate a movement, a copy of the movement command sent out by our central nervous system (CNS), referred to as an "efference copy", is used to perform a simulation of the expected results (output or "reafference") of the command. The expected reafference is then compared with the actual sensed reafference within an internal model in our CNS. If there is a discrepancy, for example, a movement command normally used to move our finger to our nose does not produce the intended arm movement due to additional exercise weights added to the wrists, the internal model is updated. In this case, the efferent signal is increased to account for the increased resistance. Taking the weights off subsequently results in arm *overshoot* and thus requires a further recalibration of the internal model. The presence of an efference copy to activate an internal model is thought to facilitate this habituation process. With reference to motion sickness, those in control can benefit from this mechanism to a larger extent and are generally found to desensitise or habituate much faster (Oman, 1982; Reason, 1978; Reason & Benson, 1978; Reason & Brand, 1975; Rolnick & Lubow, 1991; Stott, 1990). Oman (1991) argued that motion stimuli are relatively benign when individuals are able to motorically anticipate incoming sensory cues. However, a fundamental question is whether this anticipatory mechanism is only activated when the perturbation is self-produced or whether this mechanism is also set in motion in case the perturbation is made predictable by sensory information.

An anticipatory mechanism has been explicitly incorporated in the Subjective Vertical-conflict model or SV-conflict model developed by Bles and colleagues (Bles et al., 1998). As in the classical sensory conflict theory (Oman, 1982; Reason, 1978), self-initiated movement results in an efference copy of the command signal sent to the internal model which subsequently predicts how the body will react, what the sensor responses will be, and which motion and body attitude is to be expected. In the SV-conflict model, however, an anticipatory mechanism is incorporated so that even during imposed passive motion, the internal model is also activated as long as this motion can be anticipated based on sensory information. Therefore, the SV-conflict model predicts that not only drivers but also passengers sitting next to the driver to be less prone to motion sickness, provided passengers have a clear view and looking at the road ahead (Bles et al., 1998; Bles et al., 2000). Note, however, that this does not preclude particularly sensitive passengers from getting sick.

Engagement in non-driving activities

Automated vehicles allow the driver to engage in non-driving activities. It is highly probable that popular activities may include reading, checking one's emails, or engaging otherwise with nomadic or integrated infotainment systems such as in-vehicle displays, laptops, video games, or tablets. On the basis of the sensory conflict theory of motion sickness, one would expect to see an increase in carsickness under these conditions. Similar to reading a map or book whilst driving, the (static or dynamic) image displayed on displays will not correspond to the motion of the vehicle which ultimately may lead to carsickness. This will be particularly true for downward viewing angles or displays that prevent a clear view from the road ahead or horizon. Note therefore that see-through displays may provide one possible solution to minimise the impact of incongruent motion cues.

Research indicates that in-vehicle entertainment systems indeed increase the likelihood of carsickness. Cowings et al. (1999) reported a negative impact on crew performance and health when subjects attended to visual computer screens while the vehicle was moving. More recently, in a study by Kato and Kitazaki (2008), 20 people were driven around for 30 minutes whilst sitting in the backseat either watching the road ahead, or a rear-seat display showing written text. During each of the two drives, the participants were asked to verbally rate their motion sickness on a motion sickness scale that ranged from 0 ("*No symptoms, I feel fine*") to 6 ("*moderate nausea, I want to stop*"). As expected based on the conflict between the motion sensed by the visual and vestibular system, results confirmed that watching the in-car screen led to significantly higher levels of carsickness.

Flexible seating arrangements

An idea that can be traced back to at least the 50's, autonomous vehicles are considered to provide an opportunity to facilitate social interaction. Numerous concepts for autonomous vehicles suggest flexible interior layouts which frequently involve swivelling chairs allowing the driver and front passenger to turn to the rear passengers. In the light of the previous sections, it becomes apparent that facing rearwards may not only lead to conflicting sensory information provided by the visual and vestibular system, it also reduces the ability to anticipate the future motion path. Consequently, alternative layouts with rearward facing seats will almost certainly lead to increased levels of carsickness.

Surprisingly, there appears to be no published data to support this contention however. This is even more surprising given the fact that rearward facing seats are standard in trains. UK train operators offer customers the option to choose the preferred direction of travel when purchasing pre-booked tickets. This would imply a significant proportion of the customer base to have a preference to travel forward facing. This is in agreement with the anecdotal evidence which suggests that passengers prefer not to face rearwards in order to avoid motion sickness. Facing forwards allows the passenger to anticipate the train's motion to a large extent than facing backwards even though the available visual information in trains will be limited. Unlike drivers, train passenger will not be able to see the Focus Of Expansion (FOE) which refers to the most informative part of the observers' visual field with regard to the direction of travel.

Diels, C. (2014). Will autonomous vehicles make us sick? In S. Sharples & S. Shorrock (Eds.), Contemporary Ergonomics and Human Factors (pp. 301-307). Boca Raton, FL: CRC Press.

Design Implications for Autonomous Vehicles

The above discussion points towards 2 fundamental principles that need to be taken into account to prevent carsickness: (1) avoid sensory conflict where possible, and (2) maximise the ability to anticipate the future motion path. When applied to the design of autonomous vehicles and its anticipated use cases, the following design guidelines are suggested.

Forward and sideway visibility should be maximised. Ideally occupants have a clear view of the road ahead. However, under conditions that this view is compromised, any visual information (i.e. optic flow) that correctly indicates the direction of travel will reduce the amount of sensory conflict and enhance the ability to anticipate the motion path. The design should therefore aim for maximum window surface areas or Day Light Openings (DLO), minimal obstruction by A-, B-, and C-pillars, and low belt lines or seats of sufficient height to ensure passengers ability to look out of the vehicle. New lighting technologies such as OLED (Organic Light Emitting Diodes) may provide the possibility to provide simulated optic flow patterns inside the vehicle. See-through displays, such as head up displays will reduce the impact of incongruent motion cues. Future research may also explore the effectiveness of using visual, auditory, and/or tactile cues to provide an artificial horizon and signal the future motion path. With regards to seasickness and airsickness, artificial spatial or motion cues have already been shown to alleviate sickness (e.g. Rolnick & Bles, 1989; Tal et al. 2012). The extent to which these techniques can be extrapolated to the automotive field has yet to be determined.

Finally, the occurrence of carsickness in autonomous vehicles will be dependent on the driving scenario. Our organs of balance are in essence biological accelerometers and this means that they are sensitive to accelerations only (Howard, 1982). As a corollary, sensory conflict and hence the likelihood carsickness from occurring, is significantly reduced when traveling at constant speed. The organs of balance signal the body to be stationary and therefore any stationary scene as sensed by our eyes will be perceived as congruent. Under conditions of constant motion, i.e. no lateral or longitudinal accelerations, carsickness is less likely to occur. With respect to the implementation of autonomous systems this would suggest that future levels of carsickness may be manageable provided the automation is not applied under traffic conditions that involve high levels of accelerations as typically observed in urban or rush hour motorway traffic.

References

Bles, W., Bos, J. E., de Graaf, B., Groen, E., & Wertheim, A. H. (1998). Motion sickness: only one provocative conflict? *Brain Res Bull, 47*(5), 481-487.

Bles, W., Bos, J. E., & Kruit, H. (2000). Motion sickness. *Current Opinion in Neurology, 13,* 19-25.

Diels, C. (2014). Will autonomous vehicles make us sick? In S. Sharples & S. Shorrock (Eds.),
Contemporary Ergonomics and Human Factors (pp. 301-307). Boca Raton, FL: CRC Press.

Cowings, P.S., Toscano, W.B., DeRoshia, C, & Tauson, R.A. (1999). *The effects of the command and control vehicle (C2V) operational environment on soldier health and performance (ARL-MR-468)*. Aberdeen Proving Ground, MD: U.S. Army Research Laboratory.

Geeze, D. S., & Pierson, W. P. (1986). Airsickness in B-52 crewmembers. *Mil Med, 151*(12), 628-629.

Golding, J. F., & Gresty, A. (2013). Motion Sickness and Disorientation in Vehicles. In A. Bronstein (Ed.), Oxford Textbook of Vertigo and Imbalance. Oxford: Oxford University Press.

Griffin, M. J. (1990). *Handbook of Human Vibration*: London Academic Press.

Griffin, M.J. Newman, M.M. (2004). Visual Field Effects on Motion Sickness in Cars. *Aviation, Space, and Environmental Medicine, 75*(9), 739-748.

Howard, I. P. (1982). *Human visual orientation*. Chichester, Wiley.

Kato, K., Kitazaki, S. (2008). Improvement of Ease of Viewing Images on an In-vehicle Display and Reduction of Carsickness. *Human Factors in Driving, Seating Comfort and Automotive Telematics, 2008 (SP-2210). SAE Technical Paper Series 2008-01-0565*.

Oman, C. M. (1982). A heuristic mathematical model for the dynamics of sensory conflict and motion sickness. Acta Otolaryngol Suppl, 392, 1-44.

Reason, J. T., & Brand, J. J. (1975). *Motion Sickness*. London, New York, San Francisco: Academic Press.

Reason, J. T. (1978). Motion sickness adaptation: a neural mismatch model. *J.R.Soc.Med., 71*(11), 819-829.

Reason, J. T., & Benson, A. J. (1978). Voluntary movement control and adaptation to cross-coupled stimulation. *Aviat.Space Environ.Med., 49*(11), 1275-1280.

Robinson, T., Chan, E. and Coelingh, E. 2010. Operating Platoons On Public Motorways: An Introduction To The SARTRE Platooning Programme., Seventeenth World Congress on Intelligent Transport Systems, 25–29 October 2010, Busan, Korea.

Rolnick A, Bles W. (1989). Performance and well-being under tilting conditions: the effects of visual reference and artificial horizon. *Aviat Space Environ Med. 60*(8), 779-85.

Rolnick, A., & Lubow, R. E. (1991). Why is the driver rarely sick? The role of controllability in motion sickness. *Ergonomics, 34*(7), 867-879.

SMART (2011). Definition of necessary vehicle and infrastructure systems for Automated Driving. Final report SMART 2010/0064, European Commission.

Stanney, K.M., Hash, P. (1998). Locus of User-Initiated Control in Virtual Environments: Influences on Cybersickness. *Presence, 7*(5), 447-459.

Stott, J. R. R. (1990). Adaptation to nauseogenic motion stimuli and its application in the treatment of airsickness. In G. H. Crampton (Ed.), *Motion and Space Sickness* (1 ed., pp. 373-390). Boca Raton, Florida: CRC Press.

Tal, D., Gonen, A., Wiener G., Bar, R., Gil, A., Nachum, Z., Shupak, A. (2012). Artificial horizon effects on motion sickness and performance. *Otol Neurotol.33*(5), 878-85.

Turner, M., & Griffin, M. J. (1999). Motion sickness in public road transport: the relative importance of motion, vision and individual differences. *Br.J.Psychol., 90 (Pt 4)*, 519-530.