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The influence of Cruise Control and Adaptive Cruise Control on driving behaviour – A driving simulator study

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ABSTRACT

Although Cruise Control (CC) is available for most cars, no studies have been found which examine how this automation system influences driving behaviour. However, a relatively large number of studies have examined Adaptive Cruise Control (ACC) which compared to CC includes also a distance control. Besides positive effects with regard to a better compliance to speed limits, there are also indications of smaller distances to lead vehicles and slower responses in situations that require immediate braking. Similar effects can be expected for CC as this system takes over longitudinal control as well. To test this hypothesis, a simulator study was conducted at the German Aerospace Center (DLR). Twenty-two participants drove different routes (highway and motorway) under three different conditions (assisted by ACC, CC and manual driving without any system). Different driving scenarios were examined including a secondary task condition. On the one hand, both systems lead to lower maximum velocities and less speed limit violations. There was no indication that drivers shift more of their attention towards secondary tasks when driving with CC or ACC. However, there were delayed driver reactions in critical situations, e.g., in a narrow curve or a fog bank. These results give rise to some caution regarding the safety effects of these systems, especially if in the future their range of functionality (e.g., ACC Stop-and-Go) is further increased.

1. Introduction

During the last years an increasing number of Advanced Driver Assistance Systems (ADAS) has been developed to support the driver. A very prominent example is Adaptive Cruise Control (ACC) which is a longitudinal support system that can not only maintain a chosen velocity (like Cruise Control, CC) but also keep a safe distance to a lead vehicle. ACC is commercially available since 1998. Using this system on a highway the driver only has to steer while the system manages vehicle speed and distance. This system was introduced in order to support the driver by making it easier to comply with speed limits and to keep safe distances especially on long trips on the highways. However, from a theoretical point of view, this support may not only be beneficial but also lead to new problems while driving. Young and Stanton (2002) describe some of these in their malleable attentional resources theory. They suggest that as the mental workload while driving decreases, because automation systems take over some part of the driving task, the attentional resources available to the driver are also reduced. Thus, there is less capacity to observe relevant cues in the environment which might be detrimental to driving.

Similar concern arises from the compensatory control model of Hockey (1997) but from somewhat different reasons. According to this model, humans monitor their level of performance in any giving task including car driving using two different loops. The first loop is concerned with keeping one's performance at a level conforming to one's goals. The second loop monitors the workload involved in achieving this level of performance. If the workload exceeds a certain level, goals will be adapted, e.g., accepting a lower level of performance. However, this second loop reacts also, if workload undergoes a certain minimum level. In this case, people will try to increase their workload in order to achieve some optimum medium level. Thus, if drivers' workload decreases too much because ACC takes over the speed and distance control, drivers may try to increase their workload again. To this aim they could engage in other, secondary tasks. But they could also achieve this by making driving more difficult which could be done by driving at higher speeds and selecting small distances towards preceding cars.

Thus, both theories predict negative effects of an automation system which reduces the workload of the driver. In fact, both positive and negative ACC effects have been shown in several stud-

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ies. For example, Abendroth (2001) found in a field study that when driving on highways with ACC drivers chose a mean speed of 119 km/h as compared to 129 km/h when driving without the system. Additionally, speed limits were less frequently violated by more than 20 km/h when using ACC. Similar effects were found in field operational tests (Sayer et al., 2005; NHTSA, 2005) and driving simulator studies (e.g., Törnros et al., 2002).

Besides these positive effects, several studies have also found contradictory or negative effects of ACC. For example, Hoedemaeker et al. (1998) reported a driving simulator study with 38 drivers who drove on a motorway with and without ACC. All of them chose smaller headways with ACC than in manual driving and all drivers went faster with ACC (Hoedemaeker and Brookhuis, 1998). In the study of Törnros et al. (2002), subjects drove longer in the left lane with ACC and the minimum time-to-collision with ACC was reduced. Buld and Krüger (2002) found that when a lead car went through a narrow curve much too fast drivers following that car with ACC used the same inadequate speed. Furthermore, drivers' lane keeping performance deteriorated with ACC. Stanton and Young (Stanton et al., 1997; Stanton and Young, 2000, 2005; Young and Stanton, 2002a,b, 2004) found in a series of simulator studies a reduction of workload when driving with ACC which at first glance might be described as a positive effect. However, situation awareness when driving with ACC was also reduced. Situation awareness is a concept widely used in human factors research. It was introduced by Endsley who defined it as "…the perception of the elements in the environment within a span of time and space, the comprehension of their meaning and the projection of their status in the near future" (Endsley, 1995, p. 36). As drivers rely on the ACC system they do not monitor the surrounding as carefully and might thus lose some of their situation awareness. Additionally, the reduced situation awareness could also be due to reduced attentional resources as Young and Stanton (2002b) describe in their theory of malleable attentional resources (see above).

Rudin-Brown and Parker (2004) found that while driving with ACC drivers performed better in a secondary task, but the response time to break increased when a safety hazard was introduced. Cho et al. (2006) also found that drivers tended to shift their attention away from driving when they used ACC. Finally, when ACC fails and does not adapt speed correctly, drivers have significantly longer reactions times than in similar situations when driving without ACC (Young and Stanton, 2007).

In summary, although ACC was shown in field tests to lead to increased distances towards leading cars and to following speed limits better, there is also strong evidence that drivers have difficulties to keep an adequate level of situation awareness which leads to prolonged response times in some situations. They may also shift their attention away from driving and engage in secondary tasks. Furthermore, their attentional resources may be diminished by the reduced workload caused by ACC.

It is interesting to note that these kinds of studies are missing for Cruise Control (CC). CC is already on the market since the 1960s. When there is hardly any other traffic and driving at a constant speed is possible, the support of CC is quite similar to that of ACC. In this situation, one would expect similar effects of CC, namely that the drivers tend to shift their attention away from driving, that they might focus on secondary tasks, and that they take more time to react in situations that cannot be controlled by CC. However, we are not aware of any research dealing with this issue.

In order to close this gap, a simulator experiment with CC was conducted. In this study, ACC was also included in order to be able to compare the effects of CC and ACC. Both systems were compared to manual driving. Highway driving and driving on a motorway (a German Autobahn) was used in this study, as this is the typical situation where ACC and CC is engaged. In order to provide drivers the opportunity to use CC, there was hardly any traffic in some situations. As it should also be examined whether drivers really tend to direct their attention away from driving, scenarios were implemented which required the drivers to manually adapt speed (e.g., because the speed limit changed or because fog came up). Additionally, driving scenarios were used where the drivers were instructed to engage in secondary tasks.

2. Materials and methods

The study was done in the driving simulator of the German Aerospace Center (DLR, DeutschesZentrum für Luft- und Raumfahrt e.V.). The simulator is a motion based system that provides a realistic driving feeling due to the efficient motion system, a high quality projection system with visualisation and the integration of a complete vehicle. Environment and surrounding traffic are visualised by the projection system and a frontal and lateral field of view ($270^\circ \times 40^\circ$) with a high resolution of 9200×1280 pixel to allow a detailed image. Driving data are transferred to the simulation computer via CAN-bus. Vehicle and environmental sound are rendered by integrated loudspeakers.

The experiment was conducted as a within-subjects design, where each driver drove once with CC, with ACC and manually without any system. The order of the conditions was balanced over the subjects. Twenty-two test subjects participated in the study. Eleven of them were experienced CC drivers which were included to examine whether long-term use of CC changed their driving behaviour in the simulator. However, as this was not the case, the analyses were conducted for the whole group. The sample consisted of 10 women and 12 men with a mean age of 38 years (sd = 10.5). Nine participants drove less than 12,000 km per year, the others drove more than that.

As CC is used mainly on motorways and highways, the test route was constructed to include these road types (see Table 1 for an overview). It was divided into three parts and took an overall of about 3 h to complete. The first and third parts were a motorway route (German Autobahn) consisting of different segments with varying speed limits (100 km/h, 120 km/h, no speed limit) of different length. Overall, the length of each of the two parts was about 90 km. One of the segments was a two-lane road. The others consisted of three lanes. Furthermore, the traffic density was varied between a moderate and low level. A high traffic density level was not included in order to ensure that both systems could be used over longer time periods. A critical situation was introduced at the end of the first motorway segment where a traffic jam occurred. The last motorway part was comparable to the first part with respect to speed limits, duration, number of lanes and traffic density. There was no critical event in this part, but instead it included two secondary task sections of about 10 min duration, one with low and one with medium traffic density. These were included to examine if the drivers would engage more in secondary tasks when they were

Table 1
Different driving situations in the three parts of the test route.

Part	Situation
Motorway 1	120 km/h
	Free driving/no speed limit
	100 km/h
	Traffic jam
Highway	100 km/h
	Narrow curve (70 km/h)
	Narrow curve (80 km/h)
	Overtaking
	Car following
	Fog bank
Motorway 2	120 km/h
	100 km/h
	Free driving/no speed limit