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Semi-automated versus highly automated driving in critical situations caused by automation failures

Niklas Strand [a,b,*], Josef Nilsson [a,c], I.C. MariAnne Karlsson [a,d], Lena Nilsson [a,b]

[a] *SAFER Vehicle and Traffic Safety Centre at Chalmers, Box 8077, SE-402 78 Göteborg, Sweden*
[b] *VTI Swedish National Road and Transport Research Institute, Box 8072, SE-402 78 Göteborg, Sweden*
[c] *SP Technical Research Institute of Sweden, Box 857, SE-501 15 Borås, Sweden*
[d] *Division Design & Human Factors, Chalmers University of Technology, SE-412 96 Göteborg, Sweden*

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ABSTRACT

The purpose of this study was to examine the effects of vehicle automation and automation failures on driving performance. Previous studies have revealed problems with driving performance in situations with automation failures and attributed this to drivers being out-of-the-loop. It was therefore hypothesized that driving performance is safer with lower than with higher levels of automation. Furthermore, it was hypothesized that driving performance would be affected by the extent of the automation failure. A moving base driving simulator was used. The design contained semi-automated and highly automated driving combined with complete, severe, and moderate deceleration failures. In total the study involved 36 participants. The results indicate that driving performance degrades when the level of automation increases. Furthermore, it is indicated that car drivers are worse at handling complete than partial deceleration failures.

1. Introduction

Vehicle automation has many potential positive effects such as safety, comfort and convenience to mention a few, but there are also potential difficulties, especially in the interaction between humans and automation. In a seminal article by Bainbridge (1983) the consequences, or ironies, of the changed control task associated with automation are discussed. For instance, it is argued that automation does not necessarily remove difficulties, and somewhat paradoxically, that automation can even make it more difficult for the human operator. This occurs when automatic control replaces the operator while at the same time it is still required that the operator monitors that the automated tasks are carried out effectively. In order for the operator to carry out this monitoring task in an effective manner it is necessary that he/she is in control. Furthermore, Bainbridge (1983) debated how operators can observe abnormal behaviour of variables in their control task and how poor they can be in noticing changes in other variables. Sheridan (2002) extensively covered system design and research issues relating to human–automation interaction from a human factors point of view. Issues relating to interaction with automation span everything from those related to human performance, via design, to more technical matters. A recurring notion of Sheridan (2002) – which was also touched upon in Bainbridge (1983) – is that humans are poor monitors of automation.

Even though vehicle automation in terms of advanced driver assistance systems (ADAS) is designed to assist the driver, it also entails those potentially negative effects highlighted by Bainbridge (1983) and Sheridan (2002). ADAS changes the

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* Corresponding author at: VTI Swedish National Road and Transport Research Institute, Box 8072, SE-402 78 Göteborg, Sweden. Tel.: +46 317502600.
E-mail address: niklas.strand@vti.se (N. Strand).

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drivers' control task from manual control to supervisory control and thus increases the demand for monitoring. This change also suggests a shift in driver performance from in-the-loop performance to out-of-the-loop performance. Problems associated with out-of-the-loop performance have, at times, been referred to as out-of-the-loop unfamiliarity by Wickens and Hollands (2000) and as the out-of-the-loop performance problem by Endsley and Kiris (1995).

Out-of-the-loop concerns in human–automation-interaction, for instance operator performance when automation fails, have previously been studied in several domains outside the automotive one. A flight simulator experiment by Molloy and Parasuraman (1996) is a good example from the aviation domain. The Molloy and Parasuraman (1996) experiment studied the monitoring of an automated system for a single automation failure. Their results support the view that there is inefficiency in monitoring automation. Excessive trust in automation and overreliance on automation were recognized as likely explanations for reduced monitoring performance. In the automotive domain, Stanton, Young, and McCaulder (1997) reported results showing that there were drivers who failed to resume manual control when an ACC failed to detect the vehicle ahead in a car-following scenario. Furthermore, a driving simulator study by De Waard, Van Der Hulst, Hoedemaeker, and Brookhuis (1999) points in the same direction. Their study examined automated driving in an emergency situation due to an automation failure. The participants were presented with a situation in which the highly automated vehicle failed to brake when another vehicle entered the same lane. In their study the majority of participants either did not react at all (50%), or had a late response (15%). As discussed in the article, the reason why so many drivers had problems in reclaiming control may have been overreliance on the automation and/or reduced situational awareness (SA). In addition, a study by Vollrath, Schleicher, and Gelau (2011) compared manual driving and driving with Adaptive Cruise Control (ACC). They reported delayed responses when driving with ACC in a situation where the drivers had to reduce their speed.

In a study by Nilsson, Strand, Falcone, and Vinter (2013) regarding automation failures in ACC, subjects were faced with deceleration failure scenarios. In their study deceleration failures were failures in which the ACC failed to brake sufficiently. One notable result concerning driver performance in those scenarios was how the number of collisions differed depending on the extent of the failure. Contrary to what could be expected, the results indicated that a complete lack of deceleration by the ACC led to fewer collisions than did partial lack of deceleration. However, another measure of driving performance, i.e. minimum time-headway, did not indicate that complete lack of deceleration would be less severe than partial lack of deceleration. The explanation for these results may be that partial deceleration failures provide deceleration cues about system functionality which could be interpreted by drivers as though the system is succeeding in its operation. In other words: it is easier for drivers to detect a complete loss of deceleration than it is to assess whether deceleration is sufficient or not. In addition, with a complete deceleration failure, the severity of the scenario propagates more quickly, i.e. the distance between vehicles decreases rapidly, which makes it more obvious for drivers that action needs to be taken. Based on the findings in Nilsson et al. (2013) it could be expected that driving performance follows the same pattern when comparing additional intermediate levels of deceleration failures.

In the context of human monitoring of automation, one widely used term is complacency. An article by Parasuraman and Manzey (2010) thoroughly reviews the literature on automation complacency and the closely connected concept of automation bias (a form of human decision bias). They conclude that automation complacency should be understood in terms of an attention allocation strategy in which automated tasks are neglected to some extent, in favour of manual tasks. Furthermore, Parasuraman and Manzey (2010) summarize three common features of complacency that are derived from literature on the issue. These features are, firstly, that human monitoring is involved; secondly, that the frequency of such monitoring is lower than an optimal value; and thirdly, that there is a consequence on system performance. Typically, complacency has been operationalized as poorer detection of malfunctions under automation than under manual control. However, as Parasuraman and Manzey (2010) point out, this definition falls short since detection misses may occur without complacency. In the previously mentioned study by De Waard et al. (1999) complacency was thought to play a key role as many participants were surprised when the car did not react.

Another term closely connected to monitoring of automation and complacency is situation awareness (SA). One widespread definition of SA is that of Endsley, 1988: "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future". The topic of SA was further covered by Kaber and Endsley (2004) who discussed SA problems, viz., failure to detect and failure to understand problems with automation. Mechanisms behind SA problems, such as vigilance and complacency in monitoring as well as an assumption of a passive (rather than active) role when controlling the system, are dependent on the quality or form of the feedback that operators receive from the system. Although a large proportion of the studies applying SA have been conducted in the aviation domain (as pointed out by Stanton, Chambers, and Piggott (2001)), there are several studies (such as De Waard et al., 1999; Stanton & Young, 2005) which have discussed reduced SA in relation to assisted driving. Stanton and Young (2005) conducted a driving simulator study (fixed-base) in which automation was a within-subjects variable consisting of manual driving and driving with ACC. The study also had two between-subjects variables, namely workload (low, medium, and high traffic intensity) and level of feedback from the ACC (low, medium, and high). Their results concerning automation revealed reduced SA, measured with the SA rating technique (SART), when driving with ACC compared with manual driving. A high level of feedback as well as high traffic intensity led to lesser SA than a low level of feedback and low traffic intensity, respectively. In addition they also highlighted decreased overall subjective workload when driving with ACC, as well as reduced stress in high traffic conditions. Again, this connects to the concept of complacency which has been found to predominantly occur in multitask conditions when workload is high (Parasuraman, Molloy, & Singh, 1993).

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