Applied Ergonomics 50 (2015) 105–112

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Use of adaptive cruise control functions on motorways and urban roads: Changes over time in an on-road study

Marta Pereira[*], Matthias Beggiato, Tibor Petzoldt

Cognitive and Engineering Psychology, Technische Universität Chemnitz, 09107 Chemnitz, Germany

ARTICLE INFO

Article history:
Received 15 June 2014
Accepted 1 March 2015
Available online 27 March 2015

Keywords:
Changes in behaviour
In-vehicle systems
On-road study

ABSTRACT

The study aimed at investigating how drivers use Adaptive Cruise Control and its functions in distinct road environments and to verify if changes occur over time. Fifteen participants were invited to drive a vehicle equipped with a Stop & Go Adaptive Cruise Control system on nine occasions. The course remained the same for each test run and included roads on urban and motorway environments. Results showed significant effect of experience for ACC usage percentage, and selection of the shortest time headway value in the urban road environment. This indicates that getting to know a system is not a homogenous process, as mastering the use of all the system's functions can take differing lengths of time in distinct road environments. Results can be used not only for the development of the new generation of systems that integrate ACC functionalities but also for determining the length of training required to operate an ACC system.

1. Introduction

Adaptive Cruise Control (ACC) was introduced to the market in the 90s; first in Japan (1995), then in Europe (1998) and North America (2000) as an option for some luxury vehicle models (Bishop, 2005). The system was then made available in a wider range of vehicles over subsequent years (Jagtman and Wiersma, 2003). ACC functions are expected to become increasingly more available to drivers as the costs of production decrease, and their incorporation into the next generation of systems becomes a reality. Some examples of the latter are already present in the literature: 1) Workload-Adaptive Cruise Control (WACC – Hajek et al., 2013); 2) Cooperative ACC (Güvenç et al., 2012); or 3) Eco-ACC (Hülsebusch et al., 2012). ACC was initially designed to operate on motorways. Its utilisation however in other road environments has been reported (Fancher et al., 1998). Changing ACC functions or integrating them with new ones might increase ACC usage on other roads. Knowing if, when, and how ACC is utilised in different contexts is important as the utilisation of the same system in two distinct contexts might lead to different interaction results. The same holds true for experience, as this can change the way drivers use a system. The influence of context and experience thus deserves an in-depth analysis. Consideration of their effect may diversify output with regards to road safety, whilst the varying nature of context and experience indicates that solutions for problems might not be applicable to all contexts and levels of expertise. Given that knowledge on how system functions are utilised in different road environments over time is still sparse, in our paper we aim to address this gap by presenting data on an extended ACC trial.

A considerable number of studies conducted to date are cross-sectional and analyse the interaction between manual driving and ACC (for an overview: Morsink et al., 2007). ACC has been recognized as transforming the driving task and consequently driver behaviour, as its activation no longer requires constant actions (for regulating speed and headway distance), but a large portion of monitoring (Lin et al., 2009). The usage of ACC has already been associated with less safe driving when compared with manual driving. Speed increase, especially when interacting with ACC systems that support the driver at a higher level (Morsink et al., 2007), and shorter minimum time-gap (Rajaonah et al., 2006) have been reported.

Changes in driver behaviour however do not exclusively occur immediately after the introduction of the system in the driving task. As Rudin-Brown and Parker (2004) demonstrated, they can occur after the driver has been interacting with the system for some time, indicating that drivers continue to adapt. Manser et al. (2013) theorize about the temporal factors affecting the behaviour after

* Corresponding author. Tel.: +49 (0)371 531 38669.
E-mail address: marta-sofia.pereira@psychologie.tu-chemnitz.de (M. Pereira).

http://dx.doi.org/10.1016/j.apergo.2015.03.002
0003-6870/

the introduction of a change in the road system (such as the interaction with new in-vehicle equipments). Three stages are mentioned: 1) the immediate phase, which occurs immediately after a driver experiences the change; 2) the short-term phase, occurring hours, days or weeks after the introduction of the change; and 3) the long-term phase, which transpires after months or years.

Analysing how drivers interact with the system over time provides an insight into whether the risks already observed in the immediate phase remain the same or increase. How frequently is the ACC used? Which speed ranges are set by the drivers? Which time headway is preferred? Which strategies are utilised to override the system? These are questions that, apart from typifying the nature of the interaction, can contribute to evaluating the impacts of system usage.

Positive or negative impacts on safety can be over- or underrepresented dependent on how often the drivers use an in-vehicle system. The AVV Transport Research Centre in the Netherlands (as cited in Morsink et al., 2007) stated that if all cars were equipped with ACC, accident numbers could be reduced by approximately 12.9% on motorways, 3.4% on rural provincial roads, and 0.5% on urban provincial roads. In the event however that use of the systems remain discretionary, this scenario will only be realistic with high usage rates. Longitudinal studies have reported ACC usage of about 30% of the total miles travelled (Fancher et al., 1998). Similar values were given by Sanches et al. (2012), who observed that system usage increased over time (19%–25% when comparing the beginning and end of the data collection). Higher utilisation rates were stated to occur on high-speed roads (Fancher et al., 1998; Simon, 2005), whereas for built-up areas low values were presented (Simon, 2005) or associated with higher system disengagement (Larsson, 2012). However, a clearer picture on how ACC is utilised over time in different road environments is still lacking.

Associated with the usage frequency is the overriding frequency, i.e. how frequently do drivers regain full control of the vehicle. For similar systems, like conventional cruise control (CCC), constantly disengaging and resuming the system has been reported to be annoying and tiresome (Youngbin, 1997). Drivers thus might avoid performing these actions and adapt their behaviour accordingly. Additionally, Rajaonah et al. (2006) associated experience in using the system with disengagement frequency, and reported a decrease in the deactivation of the system when comparing performance of the first and second trial in a driving simulator. This aspect was also mentioned by Sanches et al. (2012), however only a tendency was reported – about a 10% decrease in the number of overriding per hour travelled.

ACC can be overridden in several ways: 1) using the switch, 2) pressing the brake pedal or 3) the accelerator pedal. The first two strategies deactivate the system permanently, and their usage was also reported to be linked with experience. Simon (2005) reported a trend towards a greater use of the switch over time and a reduction in deactivation via brake pedal. By using the third strategy (accelerator pedal), the driver makes a temporary deactivation of the system until the pedal is released. Previous settings are then resumed automatically. A similar function exists in certain in-vehicle speed limit systems: after setting a maximum speed, this can be overridden by applying maximum pressure on the accelerator pedal. Reports have indicated a lack of knowledge about, and low usage of this function on these systems (Pereira et al., 2013). Similar behaviour might be expected when using the ACC accelerator pedal overriding strategy. Furthermore, in the study from Fancher and colleagues (1998) drivers almost never overrode with the accelerator pedal. A thorough understanding of the utilisation of each overriding strategy in distinct road environments and the occurrence of changes over time is still non-existent.

The selection of speed and headway can be directly associated with the adoption of riskier or safer behaviours. Due to their importance, they have been used to characterise the differences between manual driving and ACC (e.g. Hoedemaeker and Brookhuis, 1998), and the effect of experience on the selection of these two ACC functions has already been described. Nowakowski et al. (2010) reported a trend on the way drivers used the time gap: during the first commuting trip, the longest time-gap was favoured in 52% of the time. By the third commute however, the shortest time-gap setting was selected more than 50% of the time.

Though the ACC was a system initially conceived to be mainly used on the motorway, its utilisation in other road environments has been reported. The development of the system has brought about new features, which probably encourage its usage in lower speed environments (e.g. Stop & Go – system description and evaluation of in-car display can be found by Stanton et al., 2011). Specific knowledge however on how system functions are utilised in different road environments over time is still sparse. The present study thus aimed at investigating how drivers use ACC functions on distinct roads (urban and motorway), and at verifying if changes occur over time for what Manser and colleagues (2013) described as the short-term phase. By analysing the aggregated data of both road environments, it is hypothesised that there will be (1) higher ACC usage percentage for the motorway. The comparison of time headway selection, overriding frequency and overriding strategy between road environments belong to the exploratory part of the analysis. Regarding the analysis over time (the comparison between the first and following interactions with the system), it is hypothesised that there will be (2) an increase in the usage rate accompanied by a (3) decrease in the overriding frequency, (4) a change in the overriding strategies for the switch (increase) and brake pedal (decrease), (4) an increase in the set speed values and (5) more frequent selection of the shortest headway distance along the trials.

2. Materials and method

2.1. Sample

Fifteen drivers were recruited to take part in the study (eight male, seven female). Their age ranged between 25 and 32 years ($M = 28.2$; $SD = 1.82$). All participants had possessed a driving licence for at least seven years and stated that they had driven an average of approximately 15,000 km ($SD = 8094.68$) in the past 12 months. All 15 subjects reported having never previously used an ACC.

2.2. The ACC system

The experiment was conducted using a BMW 5 Series vehicle equipped with ACC. The system was a full range ACC (with Stop & Go). As with other ACC models, the system automated the rate of engine motion by maintaining a set cruising speed. After turning it on, cruise speed was defined whilst the vehicle was in motion and could be set between 30 and 180 km/h. The driver was able to modify the speed whilst the system was active by pressing two buttons (with + and − signs). Moreover, when approaching a slower car travelling on the same lane, the system reduced the vehicle speed. In that case, the headway distance defined by the driver (or set by default in case the driver did not interact with this function interface) was maintained. Four headway distance possibilities could be chosen: TH1 (the shortest headway); TH2; TH3 (set by default upon activation); and TH4 (the longest headway).

This ACC differed from other models as the Stop & Go function allowed the system to be active when travelling with speeds below