Accident Analysis and Prevention 109 (2017) 18–28

Contents lists available at ScienceDirect

Accident Analysis and Prevention

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

Full length article

Driver compliance to take-over requests with different auditory outputs in conditional automation

Yannick Forster[a,*], Frederik Naujoks[b], Alexandra Neukum[c], Lynn Huestegge[d]

[a] Wuerzburg Institute for Traffic Sciences (WIVW GmbH), Robert-Bosch-Str. 4, Veitshoechheim, 97209, Germany
[b] Interdisciplinary Center for Traffic Sciences (IZVW), University of Wuerzburg, Wuerzburg, 97070, Germany
[c] Interdisciplinary Center for Traffic Sciences (IZVW), University of Wuerzburg, Wuerzburg, 97070, Germany
[d] Institute of Psychology, University of Wuerzburg, Wuerzburg, 97070, Germany

ARTICLE INFO

Keywords:
Highly automated driving
Conditional automation
Human machine interface
Human-machine interaction

ABSTRACT

Conditionally automated driving (CAD) systems are expected to improve traffic safety. Whenever the CAD system exceeds its limit of operation, designers of the system need to ensure a safe and timely enough transition from automated to manual mode. An existing visual Human-Machine Interface (HMI) was supplemented by different auditory outputs. The present work compares the effects of different auditory outputs in form of (1) a generic warning tone and (2) additional semantic speech output on driver behavior for the announcement of an upcoming take-over request (TOR). We expect the information carried by means of speech output to lead to faster reactions and better subjective evaluations by the drivers compared to generic auditory output. To test this assumption, N = 17 drivers completed two simulator drives, once with a generic warning tone ('Generic') and once with additional speech output ('Speech + generic'), while they were working on a non-driving related task (NDRT; i.e., reading a magazine). Each drive incorporated one transition from automated to manual mode when yellow secondary lanes emerged. Different reaction time measures, relevant for the take-over process, were assessed. Furthermore, drivers evaluated the complete HMI regarding usefulness, ease of use and perceived visual workload just after experiencing the take-over. They gave comparative ratings on usability and acceptance at the end of the experiment. Results revealed that reaction times, reflecting information processing time (i.e., hands on the steering wheel, termination of NDRT), were shorter for 'Speech + generic' compared to 'Generic' while reaction time, reflecting allocation of attention (i.e., first glance ahead), did not show this difference. Subjective ratings were in favor of the system with additional speech output.

1. Introduction

Automated driving systems are on the doorstep of the consumer market (Neville A Stanton et al., 2015). Conditionally Automated Driving (CAD) will soon follow already commercially available Partially Automated Driving systems. CAD characterizes systems are designed to assume vehicle control without the need for the human driver to continuously monitor the system. The driver is thus free to engage in non-driving related tasks (NDRT) such as writing emails or reading a newspaper. However, the driver is still required to be available in case the system exceeds its operational limits. According to SAE (2016), such a CAD system can be classified as a level 3 system.

Taking over vehicle control in such situations can be a demanding task for the human driver as automation removes drivers from both the physical and cognitive control loops, and he/she has to switch from executing an NDRT to manual driving within a relatively short time-frame. These so-called control transitions have thus attracted considerable research interest recently, focusing mostly on imminent situations in which manual vehicle control has to be regained within a few seconds (Flemisch et al., 2012; Gasser and Westhoff, 2012; Gold et al., 2013; Merat et al., 2014; Naujoks et al., 2014) but also on non-critical transitions of control with a large time budget up to 30 s for the drivers to take over vehicle control (Eriksson and Stanton, 2016; Payre et al., 2016). Examples for system limits are for example a broken vehicle on the lane ahead (Gold et al., 2013; Radlmayr et al., 2014), missing lane markings, emerging secondary lanes or a construction site with offset of lane markings (Forster et al., 2016). This paper seeks to extend existing findings by investigating how the safety of control transitions from automated to manual driving can be enhanced by the implementation of a visual auditory HMI that integrates data from car-

* corresponding author.
E-mail addresses: forster@wivw.de (Y. Forster), naujoks@psychologie.uni-wuerzburg.de (F. Naujoks), neukum@psychologie.uni-wuerzburg.de (A. Neukum), lynn.huestegge@uni-wuerzburg.de (L. Huestegge).

http://dx.doi.org/10.1016/j.aap.2017.09.019
Received 18 February 2017; Received in revised form 26 August 2017; Accepted 22 September 2017

to-car or car-to-X communication with vehicle localized environmental perception (Naujoks et al., 2015a; Rauch et al., 2012).

With such enhanced environmental perception, information about possible system limits (e.g., work zones, missing line markings, etc.) is – in principle – available early and information about upcoming mandatory transitions can be presented to the driver well in advance. However, there is a dearth research about how a suitable human-machine interface (HMI) for this purpose should be designed. We propose an HMI that integrates relevant information for a successful transition of control (Naujoks et al., 2016a) provided by cooperative perception technology into a visual interface and investigate how additional speech output can enhance the effectiveness of the proposed HMI using a motion-based simulator.

1.1. Background: supporting drivers through effective HMI communication

The transition from automated mode where the driver may be engaged in an NDRT to manual mode where she/he has to engage in safety relevant driving behavior can be characterized as a switch from a task A (i.e., NDRT) to another task B (i.e., full manual vehicle control). Research in the field of cognitive psychology has shown that any task switch (when compared with task repetitions) is accompanied by performance costs such as increased response times and error rates. These performance costs are either due to a time-consuming reconfiguration of mental task representations (e.g., assembling new stimulus-response rules) or due to conflict based on persisting activation of a previous task set after switching to a new task (Allport et al., 1994; Rogers and Monsell, 1995). Applying these cognitive psychological research findings to the area of CAD yields the prediction that by switching into a manual driving mode, drivers may also be prone to performance decrements. Any opportunity to prepare for this switch (e.g., by providing timely and maximally specific information regarding an upcoming switch) should be expected to counteract such performance costs (e.g., see Kiesel et al. (2010), for beneficial effects of advance preparation on task switching performance). The role of task switching in the context of driving automation has been discussed by Lorenz et al. (2015). The authors propose a three-staged process for the driver to get back in the loop. At first the driver has to allocate his/her attention away from the NDRT towards the relevant stimulus (e.g., head-up display or vehicle surroundings). Acquiring situation awareness and decision making, form the second step. Eventually the driver has to execute the maneuver that has the highest probability of success in the particular situation.

Thus, to ensure safety of control transitions during automated driving, there is a pressing need of investigation of HMI solutions for automated driving, that prepare the human driver as good as possible for regaining manual vehicle control. Consequently, besides information about the current status of the CAD system, drivers should be provided with sufficient information about upcoming events and actions by the system. Early information about upcoming conflict situations, so called *advisory warnings* (Lenné and Triggs, 2009) can be presented well in advance (Seeliger et al., 2014) without a need for the human driver to immediately react to the warning but rather to be ready to respond (Naujoks et al., 2015a). Wiedemann et al. (2015) have found evidence, that early announcements of the outline of interaction scenarios are beneficial for driver performance.

Relevant information can be carried not only through the visual channel alone but can further be supported through the auditory channel. Auditory interfaces provide advantages such as (1) omnidirectionality, (2) the possibility to be perceived at almost all times, (3) transient sound and (4) the possibility for humans to selectively focus on the content (Bazilinskyy and de Winter, 2015). In manual driving, speech based systems in particular can be beneficial for driver performance resulting in lower lane variation and steadier speed (Barón and Green, 2006; Neville Anthony Stanton and Edworthy, 1999). To date there has been little research on the implementation and design of semantic auditory interfaces for the transition of control in automated driving. Additional speech output could be very beneficial when a larger window of time is left to react to the particular system limit – which is precisely the benefit of cooperative perception technology – for several reasons.

- First, the CAD system could communicate its intention and status more explicitly and clearly so that drivers attain higher mode awareness and thus react appropriately (Naujoks et al., 2016b).
- Second, speech output could reduce visual workload during driver-automation interaction (Bazilinskyy and de Winter, 2015). For example, speech based auditory interfaces reduce the necessity to look away from the road to find out about information content of a system communicated through its HMI (Alvarez et al., 2011). A lot of information that needs to be decoded from the visual part of the automated driving HMI could be delivered quickly through a speech based system alone and therefore reduce visual workload and support driver comfort (Bazilinskyy and de Winter, 2015). Furthermore, Naujoks et al. (2017) have found first evidence that drivers tend to look less towards a visual HMI and the vehicle surroundings during the independent execution of a maneuver by the CAD function when additional speech output is presented.

Third, additional speech output could possibly speed up responses to TORs and enhance the safety of control transitions. Results by Politis et al., 2015 support the assumption that semantic speech output could be important for take over quality (i.e., lane keeping behavior). However, the authors could provide no definite guideline. They conclude that an advantage for superiority of language-based cues compared to abstract ones seemed to be present.

Naujoks et al. (2016b) have examined the effects of a visual HMI supplemented by speech output for the independent execution of a maneuver by the automated system. The study's results support the assumed superiority of semantic auditory output over generic information/warning tones to communicate upcoming automated maneuvers. The results, however, only apply to scenarios where the CAD system can handle the upcoming event by itself. Thus, effects on drivers' compliance to early system indications and their subjective evaluations during a transition from automated to manual are investigated in the present study.

Besides the benefits of auditory and especially speech based interfaces, it is also important to mention the potential downsides of these. There is the nuisance factor that could arise under frequent presentation of speech output or the erroneous perception of an indication as a warning which in turn results in mode confusion (Bliss and Acton, 2003; Cotté et al., 2001). For example, it has been shown that false alarms reduce compliance with urgent visual-auditory car-to-X-warnings, but that this compliance decrement can be prevented by using less urgent visual car-to-X-warnings (Naujoks et al., 2016c).

1.2. Research question

There are many challenges, which remain to be overcome before CAD can be commercially accessible without doubt about driver and passenger safety. All the factors mentioned above explicitly point towards the importance of take-over scenarios. The study was designed to advance knowledge about TORs in two aspects that have not been studied extensively yet.

First, it was of interest to develop an HMI containing useful information about upcoming transitions to manual driving that can be provided by cooperative perception technology. We thus followed the concept of so-called *situation announcements* that was put forward by Wiedemann et al. (2015). To date, research has widely ignored long take-over times of up to 20 s, which might be possible through cooperative perception. There is first evidence, that drivers take longer to resume control in non-critical scenarios when there is no time pressure at the onset of the TOR (Eriksson and Stanton, 2016). An exploratory