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Distraction or cognitive overload? Using modulations of the autonomic nervous system to discriminate the possible negative effects of advanced assistance system

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ABSTRACT

The interaction with Advanced Driver Assistance Systems has several positive implications for road safety, but also some potential downsides such as mental workload and automation complacency. Malleable attentional resources allocation theory describes two possible processes that can generate workload in interaction with advanced assisting devices. The purpose of the present study is to determine if specific analysis of the different modalities of autonomic control of nervous system can be used to discriminate different potential workload processes generated during assisted-driving tasks and automation complacency situations. Thirty-five drivers were tested in a virtual scenario while using head-up advanced warning assistance system. Repeated MANOVA were used to examine changes in autonomic activity across a combination of different user interactions generated by the advanced assistance system: (1) expected take-over request without anticipatory warning; (2) expected take-over request with two-second anticipatory warning; (3) unexpected take-over request with misleading warning; (4) unexpected take-over request without warning. Results shows that analysis of autonomic modulations can discriminate two different resources allocation processes, related to different behavioral performances. The user's interaction that required divided attention under expected situations produced performance enhancement and reciprocally-coupled parasympathetic inhibition with sympathetic activity. At the same time, supervising interactions that generated automation complacency were described specifically by uncoupled sympathetic activation. Safety implications for automated assistance systems developments are considered.

1. Introduction

Advanced Driver Assistance Systems (ADAS) are making road transportation safer by supporting drivers in specific driving tasks. The introduction of collision-avoidance warning system can mitigate the effect of driver's distraction to avoid rear-end collisions (Lee et al., 2002). However, the introduction of ADAS also has some potential downsides (Kramer et al., 2007; Radlmayr et al., 2014) that may undermine their acceptability (Biassoni et al., 2016). The use of an ADAS can induce distraction, potential overload and fatigue (Brookhuis et al., 2001). For instance, false alarms and unnecessary alarms may limit collision warning system effectiveness (Lees and Lee, 2007), increasing the number of elements that the driver have to pay attention to while driving (Hancock and Parasuraman, 1993). Even the use of highly reliable collision-avoidance warning system generated potentially negative effects on safety performance, in condition of driver's workload (Maltz and Shinar, 2007). Even in the prospective of fully automated driving, a particular risk related to reliance and complacency can still occur when human-operator monitoring of assistance system are involved (Parasuraman and Manzey, 2010). Automation complacency can be defined as a psychological state that result in non-vigilance based on unjustified reliance on automation (Billings et al., 1976). It occurs under conditions of multiple-task load when manual and automated tasks compete for the same attentional resources (Singh et al., 2009). This phenomena has been introduced by the National Aeronautics and Space Administration Aviation Safety Reporting System since 1976, to code the incidents caused by a pilot's failure to detect a warning stimuli anticipated by aids from an advanced safety device (Kennedy et al., 2014). It results in directly observable negative effect on a system performance compared to a standard or optimal

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value (Moray and Inagaki, 2000). In automotive research, this effect has been reported in the autonomous driving situations, where the drivers' take-over responses were influenced by the presence of automated assisting device (Zeeb et al., 2015), making difficult even to estimate a safe time-interval in which present the take-over requests (Gold et al., 2013). Whether providing reliable or misleading anticipatory information, or autonomously taking over control on some specific driving tasks, the presence of assisting device is able to modify driver's expectations, trust and reliance in the device itself. Modifications of these psychological factors could generate potential human-related error, but it is not always clear how to establish whether a given advanced driver assistance systems could generate potential positive or negative effects on the driver. The dual-task interaction with the assisting device could optimize the attentional resource allocations and improve driver's ability to respond to potential dangers, but at the same time it could generate over-reliance on automation process that produce underload and relaxed vigilance effects (Lee and Moray, 1992). Understanding the nature of workload and attention in relation with automation complacency mistakes could improve the operational design of assisting device, improving human-centered transport strategies and making less probable the repetitions of dysfunctional human-machine interactions.

1.1. Malleable attentional resources allocation theory and workload

To understand the nature of interaction process elicited during assisted driving, defining workload in a precise manner is required. Workload represents the costs associated with the limited-capacity of information-processing resources available for the human operator to keep a task performance (Gaillard and Kramer, 2000). According to multiple resources theory, dual-task performance generates workload when attentional source compete for concurrent resources (Wickens, 1993, 2002). For instance, a collision warning system, could generate workload when misleading visual warning are provided to the driver that is already using a consisting amount of visual attention resources, while auditory feedbacks should not create workload in relation to warning reliability. Malleable attentional resources theory (Young and Stanton, 2002) expands the workload construct, including the consideration that attentional capacity accommodates in case of low or high demanding tasks. This could be the case of take-over request in automated driving, where passive supervision tasks reduce driver's attentional resources, generating performance detriment in case of sudden request of higher attentional levels. Malleable attentional resources theory provides also a link between workload and physiological activation. In fact, the autonomic nervous system modulates the parasympathetic and the sympathetic nervous system activity (Kemp and Quintana, 2013) in response to workload (Hoover et al., 2012). The parasympathetic nervous system inhibits cardiac muscle via vagal efferents, slowing heart rate in response to increased attentional workload demands that activate the prefrontal and cingulate cortex during the visual-elaboration related executive functions (Thayer et al., 2010). The sympathetic nervous system, on the other hand, excites cardiac muscle through the norepinephrine neurotransmitter that increases heart rate in response to immediate autonomic response (Braithwaite et al., 2013), which could produce emotional arousal and interference with central processing (Beauchaine, 2001). However, the safety implications that derive from an analytic discrimination of the processes that generate workload during assisted driving, have not always clearly been considered in the transportation research.

1.2. Modulation of autonomic nervous system to measure ADAS effects

Measuring physiological process can provide useful description of the way driver perceive, pay attention, and elaborate external information. Previous research has found several set of behavioral and psychophysiological measures correlated with driver's workload. Self-reported measures (Maltz and Shinar, 2007), mean and maximum heart rate (Johnson et al., 2011; Reimer et al., 2011), power of heart rate variability in mid-frequency band (Dijksterhuis et al., 2011) were all effectively used to assess the potential consequence of the interaction with different ADAS in driving simulations. But none of these measures alone were able to quantify or discriminate in a precise manner the typology of workload process that were activated during automation complacency events. Heart rate variability limited diagnosticity is due to the fact that temporal changes in heart rate variability reflects the simultaneous combined action of parasympathetic and sympathetic nervous system (Thayer et al., 2010). This means that a given heart rate increase could be attributed to an unknown combination of sympathetic activity, or to a decrease in parasympathetic inhibition, or a proportionally equal combination of activity from both systems (Berntson et al., 2008). Thus, simple values of heart rate can suppose very different underlying psychological processes activated by the interaction with an assisting device. To achieve a better discrimination of the processes that generate human-factor mistakes in automation complacency, patterns of autonomy activity should be considered (Backs, 1995). Analysis of the autonomic nervous system modulations emerged relevant to discriminate attentional resources allocation for divided attention and central processing while driving (Backs et al., 2003). Still, additional research on the autonomic modes of control during assisted driving is required to understand the different process involved during information processing and supervising dual-task situations.

1.3. The present research

To test the effect of assisted driving on workload, an assisted detection task (Hoffman et al., 1983) was manipulated, to generate different possible performance detriment. In a previous study, Ruscio et al. (2015) measured how the interaction of a collision warning system generated different reaction time as function of driver's expectations. Participants in real-life driving were required to stop the car at the appearance of a take-over signal. To manipulate divided attention and test the driver's supervision process, the experimental condition included a random repetition of take-over requests in expected/unexpected condition, with and without anticipatory information that could result to be reliable or misleading. This experimental paradigm involves observable performance index (reaction times), a manipulation of cognitive processing (vigilance, information selection and supervisions), active perceptual-motor processing (simple and complex brake-reaction tasks) and response inhibition requests (Berntson et al., 1997; Kelsey et al., 2007). We hypothesize that measuring parasympathetic and sympathetic modulations during these assisted-driving conditions would provide a measure of the process underlying the ADAS' interaction. In particular we expect that: (H1) Changes in autonomic nervous system compared to baseline should be statistically significant in the differently assisted detection tasks; (H2) different modes of autonomic modulation are expected to be measured in the switch from single-task driving to the assisted interaction with the safety device: one for the conditions that require divided information processing and one for the conditions that require only supervision task; (H3) differences in the autonomic regulation should be correlated to brake reaction times; (H4) mean heart rate and power of heart rate indexes would be less discriminative than combined analysis of autonomic nervous system modulations.

2. Method

2.1. Measuring autonomic nervous system

To measure the autonomic nervous modulations, two representative indexes were considered in the study: respiratory sinus arrhythmia and electrodermal activity. Respiratory sinus arrhythmia (RSA) represent a good estimation of parasympathetic activity on vagal efferents, as it