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Driving next to automated vehicle platoons: How do short time headways influence non-platoon drivers' longitudinal control?

Magali Gouy [a], Katharina Wiedemann [b], Alan Stevens [a], Gary Brunett [c], Nick Reed [a,*]

[a] *TRL (Transport Research Laboratory), UK*
[b] *University of Würzburg, Germany*
[c] *Nottingham University, UK*

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ABSTRACT

Advanced driver assistance systems (ADAS) are taking over an increasing part of the driving task and are supporting the introduction of semi- and fully automated vehicles. As a consequence, a mixed traffic situation is developing where vehicles equipped with automated systems taking over the lateral and longitudinal control of the vehicle will interact with unequipped vehicles (UV) that are not fitted with such automated systems. Different forms of automation are emerging and it appears that regardless of which form is going to become popular on our roads, there is a consensus developing that it will be accompanied by a reduction in time headway (THW). The present simulator study examined whether a 'contagion' effect from the short THW held in platoons on the UV drivers would occur. Thirty participants were asked to follow a lead vehicle (LV) on a simulated motorway in three different traffic conditions: surrounding traffic including (1) platoons with short following distance (THW = 0.3 s), (2) large following distance (THW = 1.4 s) or (3) no platoons at all. Participants adapted their driving behaviour by displaying a significant shorter average and minimum THW while driving next to a platoon holding short THWs as when THW was large. They also spent more time keeping a THW below a safety threshold of 1 s. There was no carryover effect from one platoon condition to the other, which can be interpreted as an effect that is not lasting in time. The results of this study point out the importance of examining possibly negative behavioural effects of mixed traffic on UV drivers.

1. Introduction

Significant technical progress over the last thirty years has increased the capability for a vehicle to collect information about the driving environment, to support the driver in the execution of manoeuvres and to communicate with other road users or infrastructure. Several recent milestones have demonstrated that the grouping of all these capabilities makes fully automated driving a possibility. In 2005, the DARPA Grand Challenge attracted a variety of research and commercial organisations each of which had developed autonomous vehicles that were required to complete an off-road route (Buehler, Iagnemma, & Singh, 2007). In 2007, the DARPA Urban Challenge required autonomous vehicles to manage behaviour among other vehicles and obey traffic rules (Buehler, Iagnemma, & Singh, 2009) . Subsequently, the 2010 VisLab Intercontinental

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[*] Corresponding author. Address: TRL (Transport Research Laboratory), Crowthorne House, Nine Mile Ride, Wokingham, Berkshire RG40 3GA, UK. Tel.: +44 (0) 1344 770457.

E-mail address: nreed@trl.co.uk (N. Reed).

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Autonomous Challenge (Broggi et al., 2012) exposed supervised fully autonomous vehicles to general traffic, requiring the vehicles to drive 13,000 km from Parma, Italy to the World Expo in Shanghai, without human intervention. In 2012, Google announced that their fleet of Toyota Prius hybrids and Lexus RX hybrids had driven more than 500,000 km on public roads with only a few human interventions ("Look, no hands," 2012).

Regardless of which scenario will succeed in introducing automated driving, automated vehicles will all be accompanied by the same common feature: gaps or time headway (THW) between automated vehicles will be reduced by automating longitudinal control of vehicles and making use of vehicle-to-vehicle communication (V2V), resulting in an increasing traffic capacity of the existing road infrastructure. Besides saving space and increasing the traffic flow (Van Arem, Van Driel, & Visser, 2006), tightly spaced vehicles have a positive effect on energy consumption induced by the slipstream effect (Zabat, Stabile, Farascaroli, & Browand, 1995). The form of automation currently in development were all announced with a planned reduction in vehicles' THW: platoon (Dávila & Nombela, 2010; Lank, Haberstroh, & Wille, 2011), CACC (cooperative adaptive cruise control) (Van Arem et al., 2006), AHS (Automated Highway System) (Horowitz & Varaiya, 2002) and 'self-driving' cars ("Look, no hands," 2012).

Despite the encouraging technical results, autonomous vehicles raise a range of human factors issues. These include over-reliance on automation, possible loss of situation awareness and loss of the skills needed to perform the automated functions manually (Parasuraman, Sheridan, & Wickens, 2000). These issues are especially critical in case of a system failure (De Waard, van der Hulst, Hoedemaeker, & Brookhuis, 1999). In addition, another issue related to the introduction of on-board technologies has been identified. The issue resides in the fact that drivers can react in unexpected ways to the introduction of new systems, a phenomenon labelled "behavioural adaptation" (OECD, 1990). The literature is full of examples showing behavioural adaptation, but these examples also show a high diversity in terms of the underlying factors and effect, which makes behavioural adaptation a complex phenomenon that is hard to predict. Further work is needed to better understand the complexity of behavioural adaptation (Stevens, Brusque, & Krems, 2013). In addition, research on behavioural adaptation has tended thus far to focus on equipped vehicle (EV) drivers and neglected the unequipped vehicle (UV) drivers. This approach is justified whilst the number of equipped vehicles remains negligible. However, in the expectation of mixed traffic and a possible behaviour change of EV drivers by automated systems (i.e. reduction of distance between vehicles), behavioural adaptation for UV drivers is conceivable.

The EC co-funded SARTRE project on vehicle platooning identified a range of critical scenarios that could arise in a mixed traffic situation and stressed that some of them are challenging (Robinson, Chan, & Coelingh, 2010). Simulator studies analysed subjective data from participants in the role of UV drivers that interacted with a platoon to investigate the acceptance of the platoon (Lank et al., 2011) and to determine platooning requirements such as platoon length (Larburu, Sanchez, & Rodriguez, 2010, October) and THW in platoons (De Waard et al., 1999). A field study investigating changes in behaviour of UV drivers analysed the speed and overtaking time of UV drivers (Lank et al., 2011). Results showed no differences in behaviour while overtaking between platoon vehicles maintaining short distances of 10 m at 80 kph (THW = 0.45 s) and a reference case of adaptive-cruise-controlled trucks at the same speed maintaining the mandatory distances of 50 m (THW = 2.25 s) required by German's road traffic regulation (StVO § 4, Abs. 3) (Bouska & Leue, 2009). Nevertheless, work conducted so far has not considered the entire complexity of behavioural adaptation of the UV drivers and more research is required in this field.

There is evidence in the literature showing that driving in a platoon alters perception of a safe driving headway to the car in front. Skottke (2007) conducted a range of studies at RWTH Aachen in the framework of the KONVOI project on truck-platooning and found that drivers, who were engaged in platoons holding short THWs, adapt their behaviour in keeping short THWs in a subsequent manual drive. It appeared that behavioural adaptation of platoon drivers to short THWs was here the result of perceptual mechanisms: after a platoon drive with very short THWs, 'normal' THWs appears very large leading drivers to reduce the THW they would normally keep. Literature shows that a range of norms influence drivers' behaviour (De Pelsmacker & Janssens, 2007). Both the market penetration and the functionality of ADAS are increasing; it is therefore conceivable that, as a results of social mechanisms, the perception of a safe THW could be altered by the UV driver that is not directly engaged in a platoon but driving in its vicinity. Hence as a result of perceptual and social mechanisms, UV drivers may reduce their own THW though it is unclear yet whether the two mechanisms (perceptual vs social) will predominantly lead to a behavioural adaptation of the UV drivers or if one mechanism will prevail over the other.

To investigate BA of UV drivers to short time headway of platoons in the vicinity, a simulator study was conducted where participants were confronted to a car following task in the vicinity of platoons. The THW between the vehicles in platoons was either large or short. Mean THW in stable car-following situation (LV has a constant speed) is assumed to be an indicator for tactical adaptations of driving behaviour to situational factors (Vogel, 2003) and minimum THW was computed as an indicator for criticality. Also, as the influence of the lead vehicle (LV) increases with a decreasing distance to the LV (Vogel, 2002) as smaller THW requires a faster braking response, keeping a shorter THW supposedly intensifies alertness to anticipate any change in the LV's behaviour. There is evidence in the literature for an increase in effort and alertness leading to a reduction in drivers' standard deviation of the lateral position (SDLP) (Brookhuis, de Vries, & de Waard, 1991). Finally, a carry-over effect between the two conditions was expected. In the same way as drivers who keep a steady speed for a certain period of time on a motorway maintain their speed on connecting roads (Casey & Lund, 1992) participants were expected to carry over the THW they were driving in the first condition to the following.

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