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Comfort in automated driving: An analysis of preferences for different automated driving styles and their dependence on personality traits

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ABSTRACT

As technical realization of highly and fully automated vehicles draws closer, attention is being shifted from sheer feasibility to the question of how an acceptable driving style and thus comfort can be implemented. It is increasingly important to determine, how highly automated vehicles should drive to ensure driving comfort for the now passive drivers. Thus far, only little research has been conducted to examine this issue. In order to lay a basis on how automated vehicles should drive to ensure passenger comfort, different variations of three central maneuvers were rated and analyzed. A simulator study (N = 72) was conducted in order to identify comfortable driving strategies. Three variations of lane changes, accelerations and decelerations were configured by manipulating acceleration and jerk, and thus the course of each maneuver. Furthermore, the influence of personality traits and self-reported driving style on preferences of differently executed automated maneuvers was analyzed. Results suggest keeping acceleration and jerk as small as possible for acceleration maneuvers. For lane changes, both small accelerations as well as an early motion feedback are advisable. Interestingly, decelerating as a manual driver would is rejected compared to two artificial alternatives. Moreover, no influence of personality traits on maneuver preference was found. Only self-reported driving style had a marginal effect on participants' preferences. In conclusion, a recommendation for an automated driving style can be given, which was perceived as comfortable by participants regardless of their personality.

1. Introduction

Automated driving is currently one of the main trends in the automotive industry. As technical realization of highly automated driving or automation on SAE level 3 (SAE International, 2014) draws closer, attention is now being shifted from the sheer feasibility to the question of how an acceptable driving style and thus comfort can be implemented.

So far, no widely shared and agreed-upon definition of comfort has been established in the scientific community. For one, it is still debated whether comfort and discomfort should be seen as opposite poles of one construct or whether they can coexist (see Vergara & Page, 2000; Zhang, Helander, & Drury, 1996; for a review on comfort in driving assistance see

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Engeln & Vratil, 2008). Comfort is commonly associated with a feeling of well-being and an attribution of positive valence towards the eliciting entity and, depending on the view on comfort, associated with the absence of discomfort and uneasiness. Summala (2007) also points out that comfort is pleasant and is not experienced in the face of high arousal. Even though no definition of comfort is agreed upon, de Looze, Kuijt-Evers, and van Dieën (2003) identified commonly shared aspects of the majority of definitions of comfort: (1) comfort is subjective, (2) comfort is influenced by internal and external factors, and (3) comfort is experienced as a reaction to something. Regarding highly automated driving, the relationship between expected and actual driving, as well as experiencing loss of control, provide further promising influencing factors on comfort (Elbanhawi, Simic, & Jazar, 2015; Krist, 1994; Krüger, Neukum, & Schuller, 1999). Furthermore relevant to highly automated driving, a close relationship is seen between comfort and trust, as well as acceptance of automated vehicles (Siebert, Oehl, Höger, & Pfister, 2013). Both trust and acceptance are vital to the usage of a system (Muir, 1987; Parasuraman & Riley, 1997), thus comfort may be seen as a barrier to technology adoption. This makes an evaluation of driving style preferences in automated driving important.

Apart from the question of how comfort can be defined, driving comfort has – so far – been mainly investigated in the context of manual driving. Only little research exists on passenger comfort (see Ellinghaus & Schlag, 2001). Key results found by Ellinghaus and Schlag (2001), which may be transferred to being driven in an automated vehicle, address the feeling of control, possible reasons for motion sickness and factors influencing experiencing comfort. Concerning the latter, Ellinghaus and Schlag (2001) found that a passenger's experienced comfort relies strongly on the driver's driving style and, among others, on factors such as the vehicle's safety equipment, safety systems and seats. Evaluating the comfort of passengers in automated vehicles, however, is yet a novel field. Out of the mentioned options, manipulating driving style seems to be the most promising option for substantially influencing experienced driver comfort in highly or fully automated vehicles. Both the passive safety systems of the vehicles and the seats are not very likely to change substantially due to a higher automation level.

Manual driving styles are described by a person's habitual way of driving (Elander, West, & French, 1993). Among others, this includes the preference for speed, acceleration profiles, individual conditions for overtaking, preferred headway distance, and abiding traffic laws. In the past years, driving styles have received scientific attention (for an overview see Sagberg, Selpi, Bianchi Piccinini, & Engström, 2015). This research has however, been largely focused on manual driving and crash risk (see e.g. Elander et al., 1993) or topics such as fuel efficiency (see e.g. Murphey, Milton, & Kiliaris, 2009). Based on these findings and on findings by Ellinghaus and Schlag (2001), it seems important to take a closer look at the relationship between driving style and experiencing comfort in a context of automated vehicles. Due to the existing relationship between user, comfort, acceptance, trust, and likeliness of usage (Jamson, 2006; Siebert et al., 2013; Winner, Hakuli, & Wolf, 2012), it is important to identify a most comfortable driving style. The many anticipated advantages of SAE level 3+ driving automation, such as fewer traffic accidents and less traffic congestion, depend on the extent of system usage. Thus, the success of automated driving also depends on the systems' automated driving style.

From a technology-driven perspective, an endless number of automated driving styles present themselves. For example, it is possible to mimic an average human driving style, to match the automated driving style to the passive driver's own driving style, or to implement an artificially constructed driving style. Out of the plethora of possibilities, it is important to identify the underlying factors determining a comfortable automated driving style. For this purpose, a simulator study was conducted. The aim was to evaluate differently implemented automated maneuvers regarding experienced comfort. To ensure findings result in a comfortable experience for as many people as possible, it was also analyzed whether the found preferences are personality dependent.

As highly and fully automated driving will first be possible on highways, focus lay on the most frequent maneuvers on highways. The most common lateral maneuver is the lane change. In addition, this maneuver is still rather novel in automation context. Concerning longitudinal maneuvers, focus lay on acceleration as well as on deceleration. Here, deceleration is performed in relation to another vehicle driving ahead. This was done, not only because of the maneuvers commonness, but also because it takes the restraints arising from surrounding traffic into account.

In this study, three variations of each of the three maneuvers are compared. On the basis that familiar circumstances elicit less distress and may make a person feel more comfortable (see Elbanhawi et al., 2015), we have chosen to base the variations in this study on recorded data of manual driving (Bellem, Schönenberg, Krems, & Schrauf, 2016). Because jerk has been shown to elicit a stronger influence on experiencing comfort than acceleration itself (Gianna, Heimbrand, & Gresty, 1996) and further based on findings in previous studies (Bellem et al., 2016, 2017), our focus lay on the manipulation of lateral or longitudinal jerk. The maneuvers and their variations will be described more thoroughly in Section 2.3 Maneuvers.

As stated above, it is also a goal of this paper to assess whether preferences for automated driving styles depend on the driver's personality. In manual driving, it is assumed that as a person's own driving style is internalized and not only influenced by experience but also by the driver's personality (Lajunen, Corry, Summala, & Hartley, 1998). This has been suspected for automated driving as well (see Stanton & Young, 2000). This assumption has, however, not been investigated. These results can provide implications for the design of highly automated driving systems.

Alongside self-reported driving style, trust in automation, locus of control, sensation seeking, and willingness to take risks were used to investigate personality dependency of comfort. Trust in automated systems presents itself as a potential influence, because control is handed over to the vehicle completely in highly automated driving. In general, trust is seen as a very important factor for reliance on automated systems as well as their dis- or misuse and use (Lee & Moray, 1992; Lee & See, 2004; Muir, 1994). Likewise, locus of control – an important driver characteristic (Beggiato & Krems, 2013; Holland,