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The exact determination of subjective risk and comfort thresholds in car following

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ABSTRACT

In this study the location of vehicle to vehicle distance thresholds for self-reported subjective risk and comfort was researched. Participants were presented with ascending and descending time headway sequences in a driving simulator. This so called method of limits of ascending and descending stimuli (Gouy, Diels, Reed, Stevens, & Burnett, 2012) was refined to efficiently determine individual thresholds for stable time headways with a granularity of 0.1 s. Time headway thresholds were researched for 50, 100, and 150 km/h in a city, rural, and highway setting. Furthermore, thresholds for self-driving (level 0 automation: NHTSA, 2013) were compared with thresholds for the experience of subjective risk and comfort in assisted driving, similar to adaptive cruise control (level 1 automation). Results show that preferred individual time headways vary between subjects. Within subjects however, time headway thresholds do not significantly differ for different speeds. Furthermore we found that there was no significant difference between time headways of self-driving and distance-assisted driving. The relevance of these findings for the development of adaptive cruise control systems, autonomous driving and driver behavior modelling is discussed.

1. Introduction

Recent studies suggest that the relation between time headway in car following and the subjective experience of a driver is subject to a threshold effect (Lewis-Evans, De Waard, & Brookhuis, 2010; Siebert, Oehl, & Pfister, 2014). This means that drivers do not experience subjective risk for time headways higher than a specific threshold, while the subjective risk increases significantly for time headways lower than the specific subjective threshold. Studies have also found a consistency of time headway thresholds over different speeds (Siebert et al., 2014). These findings of a threshold effect for time headway and its consistency over different speeds are relevant for the advancement of theoretical issues in traffic psychology, i.e., driver behavior modelling, as well as applied issues such as adaptive cruise control and autonomous driving.

In driver behavior modelling there is a theoretical dispute that can be best observed between so called "zero risk" models (Näätänen & Summala, 1974; Summala, 1988) and "target risk"/"target task difficulty" models (Fuller, 2005; Taylor, 1964). In zero risk models it is generally assumed that drivers choose their path and speed in a way that minimizes their experience of

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risk. In these models drivers will change the path or speed of their vehicle as soon as any feeling of risk arises no matter how small. Following the "target risk" or "target task difficulty" models however, drivers do not choose their path and speed to completely avoid a feeling of risk or task difficulty. In these "target" models, drivers aim for a target level of risk or task difficulty that is higher than zero. If the driving situation leads to a subjective risk level or a task difficulty that is below the target level, a driver will change the speed and/or path of his vehicle to increase his subjective feeling of risk or perceived task difficulty until the target risk/task difficulty level is reached and vice versa. For the "target" models to be applicable to driving there has to be a level of variance in drivers' subjective experience of risk or task difficulty in normal driving situations. Target models do not imply that drivers actively drive in a reckless way where they expect an accident, i.e. that the accident risk is higher than zero, but that their experienced level of general risk/task difficulty is higher than zero. Following the "zero risk" models there should be very little variance in the subjective feeling of risk, because following this theory, drivers will avoid risky situations thereby maintaining a constantly low level of subjective risk.

The findings of a threshold effect for the influence of time headway on the subjective experience of risk (Lewis-Evans et al., 2010; Siebert et al., 2014) give credence to zero risk models. If a driver does not experience subjective risk up until an individual threshold, there is no variance in subjective risk experience before the threshold. Therefore, a driver cannot use subjective risk to select a time headway respectively distance to another vehicle that he likes to keep. The threshold effect further presumes a significant increase in subjective risk for time headways lower than the individual threshold. In theory, the target level of risk could be located in this area. This, however, is unlikely for two reasons; the sharp increase in the subjective risk experience would either lead to a very large target level of risk, or would require very frequent and precise control of time headway. Furthermore it was shown by Siebert et al. (2014) that drivers experience time headways lower than the threshold as unpleasant, making it unlikely that drivers would choose a time headway that is lower than the subjective threshold.

Consequentially the existence of a threshold effect and the resulting assumption of the validity of the zero risk models can lead to the dichotomization of the subjective risk experience of drivers. A researcher therefore does not need to ask "how much risk is experienced?" but is allowed to ask "is risk experienced or not?".

Apart from a general threshold effect, there is evidence for a consistency of individual time headways over different speed conditions (Ayres, Li, Schleuning, & Young, 2001; Siebert et al., 2014; Taieb-Maimon & Shinar, 2001; Winsum & Heino, 1996). This study aims to replicate these findings of constant individual time headways over different driving speeds for a broader speed range with an efficient and precise method that can alleviate some confounding interference of existing study designs.

Besides theoretical issues, the existence of a threshold effect of time headway on the subjective experience of a driver is meaningful to applied issues as well. As discussed earlier, drivers will change their path or speed once they experience subjective risk when they drive themselves. With the adoption of advanced driver assistance systems, such as adaptive cruise control (level 1 automation), and the emergence of level 3 automation in vehicles (NHTSA, 2013) the task of changing the vehicle's speed and its resulting distance to other road users is carried out by the vehicle itself. In level 1 automation, drivers might decide not to use a system that does not adhere to subjective time headway thresholds. In level 3 automation systems the problem of not-individually adjusted time headway can be much more dangerous. Level 3 automation allows the driver to be distracted from the driving task and just requires occasional control. This might lead to situations in which a driver refocuses on the driving task after being distracted, perceiving the car to car distance as risky, and taking over control of the car in a hasty and dangerous way. Furthermore, perceiving a level 3 automation system as risky, can lead to a decline in trust in the system and general disuse of the system (Parasuraman & Riley, 1997). Taking into account the subjective experience of the driver will therefore be a prerequisite for the adoption and frequent usage of automation systems of different levels. This will be especially important in the initial usage phase, where users have not adjusted the system for their subjective preference.

Accurately identifying the location of the time headway threshold for an experience of subjective risk could therefore help to design the automation to stay above said threshold. This higher than personal threshold headway can help to build trust and prevent a feeling of subjective risk in the driver, thereby increasing the use of such systems (Muir, 1994; Pereira, Beggiato, & Petzoldt, 2015), preventing dangerous takeover situations by the driver, and lowering the number of traffic accidents.

In the location of the time headway threshold rests another important research question for the application of advanced driver assistant systems. What is the relation between time headways of drivers when they have full control of the car (level 0 automation), compared to time headway thresholds in automated driving (level 1 automation and higher)? An earlier study by Lewis-Evans et al. (2010) suggests that time headways of self-driving are congruent with time headway thresholds of subjective risk experience in driving with adaptive cruise control (level 1 automation). This study aims to replicate these findings of a high correlation of time headways in self-driving and driving with an adaptive cruise control.

Apart from subjective risk, which helps to locate the absolute boundaries of what is an acceptable distance in car following, it is also import to locate the range of distances that drivers feel comfortable to keep (Marsden, McDonald, & Brackstone, 2001; Stanton & Young, 2005), as comfortable time headways might differ from non-risky thresholds. In earlier studies, subjective risk and comfort experience were investigated together in a within subject design and risk and comfort ratings showed a significant and high correlation (Lewis-Evans et al., 2010; Siebert et al., 2014). While Lewis-Evans et al. (2010) argue that the correlation of different subjective variables might be a sign for an underlying construct that is rated, they also support an effort to try and separate subjective variables. We therefore used a between-subject design for the two subjective