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The perceived criticality of different time headways is depending on velocity

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ABSTRACT

Time headway (THW) presumably represents a velocity-independent measure of safe following distances during car-following. However, studies using on-road data show that drivers decrease their THWs as velocity increases (e.g., Brackstone, Waterson, & McDonald, 2009). This contradicts recent findings of simulator-based studies suggesting independence of velocity and chosen THW (Siebert, Oehl, & Pfister, 2014; Siebert, Oehl, Bersch, & Pfister, 2017). This study aimed at investigating the relationship between velocity and subjective risk of different THWs using an experimental setup with a motion-based driving simulator. $N = 29$ participants followed a preceding vehicle with five different velocities ranging from 30 km/h to 140 km/h in urban, rural and highway environments. At each velocity level, drivers were instructed to follow with three different THWs (0.7 s, 1.1 s and 1.5 s). Subjective criticality ratings were analysed for the different combinations of these independent variables (IV1: velocity, IV2: THW). Drivers rated situations with short THWs as more critical when following with slower velocities compared to higher velocities. These results show that the criticality of theoretically velocity-independent THWs is indeed depending on velocity. These findings have both theoretical implications, such as a better understanding of drivers' car following behavior and risk acceptance, and practical implications as they may be used in the design of automated driving functions.

1. Introduction

Car following is one of the most fundamental tasks during driving. Technologies such as Adaptive Cruise Control (ACC) allow drivers to hand off speed and acceleration to driver assistance systems that maintain a comfortable distance to preceding vehicles. One crucial parameter for these systems is an optimal time headway (THW). The THW is defined as the distance to the preceding vehicle divided by the speed of the following vehicle. It thus can be described as the time it takes until the following vehicle will pass the momentary position of the preceding vehicle. When deciding whether the following distance is safe or not, the main advantage of this measure over meter-based distances is its independence of velocity and that it allows for calculations of required decelerations that are not constrained to a specific velocity range (Winner, 2009). Driver trainings in different countries recommend thresholds for highly critical THWs (e.g., Germany: 1.8 s, US: 2.0 s; Michael, Leeming, & Dwyer, 2000; Underwood, 2005, p. 244). Still, drivers often choose THWs below this threshold, possibly rendering their behavior dangerous for themselves and other road users.

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It is thus of great interest to better understand the cognitive processes that cause drivers to adopt possibly dangerous following distances. Different factors that influence preferred THWss have been reported in the literature. This paper aims to highlight especially the role of velocity in the context of preferred THWs and subjective risk. We argue that velocity is a key factor for understanding appraisal process involved in the assessment of criticality of following distances, however, it is precisely in this regard the traffic observations, and experimental findings have provided mixed results. The remainder of the paper is as follows. Known influencing factors on chosen following distances are explained, considerations on the effect of velocity on preferred THWs are summarized, and the results of the study are reported and discussed.

1.1. Preferred time headways – influencing factors

Several influencing factors on preferred THWs have been reported. For example, studies show that drivers choose smaller THWs when they score high on the personality traits aggression (Maag, Benmimoun, & Neunzig, 2004) or sensation seeking (Heino, Van der Molen, & Wilde, 1992). Younger adults choose smaller THWs compared to older adults (Evans & Wasielewski, 1983; Ohta, 1993) and sleepy drivers tend to follow with larger THWs (van der Hulst, Meijman, & Rothengatter, 2001). On the other hand, situational factors also influence the preferred THWs. Drivers tend to increase their THW because of fog (Broughton, Switzer, & Scott, 2007; van der Horst & Hogema, 1993) or rain (Ichikawa, 2003). Interestingly, only older drivers tend to choose larger THWs at night compared to daytime (Kiefer et al., 1999). Traffic states also seem to influence preferred THWs as drivers tend to close gaps between vehicles during congested traffic, resulting in smaller THWs compared to free-flow traffic (Ayres, Li, Schleuning, & Young, 2001). Furthermore, drivers seem to be inconsistent in their day-to-day choosing of THWs (Brackstone, Waterson, & McDonald, 2009). In sum, several influencing factors on preferred THWs have been reported so far. The scope of this study, however, is on the influence of velocity on preferred THWs, as will be explained in the next section.

1.2. The effect of velocity and driving environment on time headways

Using instrumented vehicles, Brackstone et al. (2009) report that chosen THWs can be split by velocity roughly in two ranges. THWs stay approximately constant between 1.0 and 1.5 s above a velocity of 15 m/s (≈50 km/h), whereas THWs increase up to 2.2 s when the velocity is under this threshold. In line with this, several on-road studies investigating different velocity ranges report different preferred THWs. For high velocities, Knospe, Santen, Schadschneider, and Schreckenberg (2002) found a peak in the distribution of THWs at about 0.9 s on German highways. Brackstone, Sultan, and McDonald (2002) showed that 95.8% of all THWs of UK's highways fall under 2 s and 29.2% even under 0.8 s. Accordingly, Brackstone et al. (2009) report a maximum frequency of approximately 1 s on UK's highways. In contrast, in urban areas with lower velocities, larger THWs are found. Here, according to Piao and McDonald (2003), most common THWs range from 1 to 2.5 s with a peak at 1.9 s. Ichikawa (2003) consistently reports mean THWs in urban areas of 2.11 s. Comparing reported on-road THWs from studies conducted on highways versus those measured in urban areas suggests a clear effect of velocity on the drivers' preferred THWs. When driving slowly, drivers prefer larger THWs compared to high velocities even though the THW is commonly seen as a velocity-independent distance measurement. Still, one has to acknowledge a possible influence of the completely different driving environments (urban roads versus highway) on the driver behavior. To the knowledge of the authors, however, no experimental proof of a velocity effect on preferred THWs either in the same or different driving environment has been reported in the literature.

On the contrary, studies in driving simulators suggest a clear absence of a velocity effect on preferred THWs during car following scenarios. Based on a previous study from Lewis-Evans and Rothengatter (2009), Siebert, Oehl, and Pfister (2014) as well as Siebert, Oehl, Bersch, and Pfister (2017; study part one) report no significant effect of velocity on the subjective risk rating of different THWs that ranged between 0.5 s and 4.0 s. Contrary to the on-road studies described above, they did not investigate natural driving behavior and observable preferred THWs but the subjective risk of different following distance while longitudinal vehicle control was an automated system (by ACC). Still, this contradicts a possible mechanism that drivers choose smaller THWs when driving with lower velocities because they perceive the same THW as more critical compared with driving in higher velocities, as would be suggested by the above-cited on-road studies. Additionally, Siebert et al. (2017; study part two) asked participants in a free-driving simulator scenario to follow a preceding car with a risky or not comfortable distance and showed that the chosen THWs were independent of velocity. Older simulator studies similarly suggest that preferred THWs should be independent of velocity (Taieb-Maimon & Shinar, 2001; van Winsum & Heino, 1996). One possible explanation for a missing velocity effect in earlier studies could be the mostly generic driving environment that was independent of velocity in most studies. However, a realistic driving environment might, in fact, be essential for finding a velocity effect on criticality ratings during car following. In line with this, Siebert et al. (2014) presumed, but did not investigate, a possible influence of the driving environment on the subjective risk of each THW. For example, on rural roads with a recommended traveling speed of 100 km/h, the same THWs were rated as more critical for higher or lower velocities (50 km/h and 150 km/h) compared to the same THWs at the recommended velocity of 100 km/h. They argue that the typical traveling speed for a specific road type could be taken as being the safest and that deviations from the recommended speed increase subjective risk. In sum, a velocity effect on preferred THWs or subjective risk for different traveling velocities as suggested by on-road data has not been reported in controlled experimental settings so far.