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# A comparison of car following behaviors: Effectiveness of applying statistical quality control charts to design in-vehicle forward collision warning systems

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## ABSTRACT

This study aims to evaluate the usability of the forward collision warning (FCW) system as adopted by the statistical quality control (SQC) chart design concepts on drivers' car following behaviors and task performance. A total of 48 highly aggressive and 48 less aggressive drivers participated in a two (aggressive driving: high vs. low; between-subjects) by two (driving workload: high vs. low; within-subjects) by three (the FCW system: five-stages vs. X-bar vs. X-bar plus exponentially weighted moving-average (EWMA) control charts; between-subjects) mixed-factorial simulation experiment. The drivers' behaviors, response time to divided attention (DA) tasks, as well as subjective workload and trust ratings were collected. Findings showed that drivers with the FCW's assistance improved their car-following behaviors and that the FCWs with the SQC chart design concepts showed better results than the five-stage system. Drivers who used both SQC FCWs performed correspondingly in their car-following behaviors. However, the X-bar FCW aided drivers in responding to DA tasks much faster, and drivers felt less stressed and had more trust in using the X-bar FCW system than those who used the X-bar + EWMA FCW system.

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## 1. Introduction

Previous research found that between a quarter to a third of all road accidents can be attributed to rear-end collisions (National Highway Traffic Safety Administration (NHTSA), 2012; Wierwille, Lee, DeHart, & Perel, 2006). It was shown that rear-end collisions are currently the most common type of vehicle-related accidents that constitute a major traffic and even social problem, requiring urgent worldwide attention.

Failure by drivers to maintain a safe time headway is a result of aggressive driving, negative driving conditions (e.g., fatigue and drunk driving), distractions, or inattention. It is therefore a probability that unsafe time headway is playing a factor in traffic collisions (Deffenbacher, Lynch, Filetti, Dahlen, & Oetting, 2003; Ellison-Potter, Bell, & Deffenbacher, 2001). Furthermore, aggressive driving is considered an emotion composed of anger-related feelings and thoughts provoked by various traffic situations. Numerous studies show driving anger to be associated with aggressive driving behaviors that can possibly lead to reckless driving actions, such as speeding, excessive lane changing, tailgating, and improper passing (Deffenbacher et al., 2003; Ellison-Potter et al., 2001; Fernandes, Hatfield, & Soames Job, 2010; Iversen & Rundmo, 2002; Lajunen,

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Parker, & Summala, 1999; Mesken, Hagenzieker, Rothengatter, & Dewaard, 2007; Moore & Dahlen, 2008; Ulleberg, 2002). Such driving behavior can consequently result in a high risk of traffic accidents or injuries. Previous studies did confirm the link between aggressive driving behavior and traffic accidents (Heino, van der Molen, & Wilde, 1996; Iversen & Rundmo, 2002; Ranney, 1999).

Information technologies have led to different vehicle manufacturers taking an interest in the development of forward collision warning (FCW) systems. Dingus et al. (1997) used three on-road experiments to determine how headway maintenance and FCW displays influence driver behavior. The authors also indicated that when drivers were provided with salient visual warnings presented by well-designed FCW displays, they effectively increased their time headway between their vehicle and the lead vehicle. In addition, auditory warnings were less effective than visual warnings for maintaining a safe headway, but they were nevertheless helpful for decreasing reaction time for deceleration. Maltz and Shinar (2007) argued that distracted drivers increased their temporal headway with the lead vehicle by using a less reliable collision avoidance warning system and that such drivers, by contrast, maintained shorter headways with warning systems having higher reliability levels.

Ben-Yaaco, Maltz, and Shinar (2002) used auditory warnings to alert drivers that the temporal headway between the host vehicle and lead vehicle was too short. They reported that drivers often overestimated their temporal headways to lead vehicles, a behavior resulting in dangerous traffic conditions. In-vehicle collision avoidance warning systems have been proven to effectively aid at maintaining an appropriate headway, as well as at reducing the risk of rear-end crashes. A majority of studies have shown the benefits of FCW systems in reducing the number and severity of rear-end collisions (Lee, McGehee, Brown, & Reyes, 2002; Lee, Ries, McGehee, Brown, & Perel, 2000; Mohebbi, Gray, & Tan, 2009; Scott & Gray, 2008).

However, previous studies rarely considered individual differences in car-following behaviors. Since the safety distance of headway for each driver's perception varies, Jamson, Lai, and Carsten (2008) proposed an adaptive FCW system that adjusted the timing of warnings according to each driver's reaction time. Although this did not have significant implications for the adaptive and non-adaptive systems for non-aggressive drivers, the benefits of the adaptive system for aggressive drivers were clearly demonstrated. Aggressive drivers reported a preference for the adaptive system: they rated it as less "stress-inducing" and more "safety-enhancing" compared to the non-adaptive system. We therefore intend to likewise develop an adaptive FCW system by using the statistical quality control chart concept, with the additional aim to determine the benefits of such system. Individual differences and "monitoring in time" are features of control charts that are consequently well suited to evaluate drivers' behaviors in following cars while using the FCW systems.

Traditionally, statistical quality control charts were developed to determine process capabilities and to evaluate process performance in industries. They have developed into useful SQC techniques for monitoring the stability of manufacturing processes and the quality of products. In addition, applications of control chart concepts in other domains have accurately detected departures from the average in practice cases (Maguad, 2005). Some of these domains included human performance and designing warning systems (i.e., the X-bar control charts) to diagnose work-related asthma (Hayati, Maghsoodloo, Devivo, & Carnahan, 2006), to monitor several channels of electroencephalogram (EEG) and electrooculogram (EOG) signals (Cannon, Krokhmal, Chen, & Murphey, 2012).

The concept of control charts has been applied to warning systems. Hwang et al. (2008) used X-bar control charts to design a pre-alarm system for a nuclear power plant control room, and then compared the performances of three types of systems: text, graphic pre-alarm, and the original. The results showed that participants had lower mental workloads and higher secondary-task performances when monitoring either type of pre-alarm system along with an X-bar control chart. Moreover, the pre-alarm systems with X-bar control charts effectively provided warnings to operators' monitoring tasks.

For human performances, Ong, Harvey, Shehab, Dechert, and Darisipudi (2004) used three tasks (i.e., identification of out-of-control points, estimates of process means, and identification of process patterns) to investigate the effectiveness of three control charts: the X-bar, EWMA, and cumulative sum (CUSUM) charts. Their research results showed that each chart performed well in the identification of out-of-control points. For the mean estimation task, both the X-bar and EWMA charts yielded similar accuracy, and participants produced the fastest reactions by using the X-bar charts. In addition, participants reported higher subjective preferences for X-bar chart in all tasks compared to the other respective charts. The advantages of the X-bar charts make it widely used in industries, and findings implied that X-bar charts were a very appropriate technique to monitor or evaluate human performances in identification of out-of-control points, estimates of process means.

Shehab and Schlegel (2000) also adopted X-bar, EWMA, and CUSUM charts to monitor and classify the cognitive and physical performance. The three control charts were tested in 174 trials involving 10 participants and 23 cognitive performance assessment measures. Results indicated that continuous performance measures, such as reaction time, were best examined with EWMA charts. However, X-bar control charts were only moderately effective for these data, with CUSUM charts proving to be relatively ineffective. In addition, X-bar control charts most effectively detected a single time outlier caused by a sudden event. The EWMA chart was more effective in detecting accumulative performance shift produced by continuing small effects, such as fatigue or sleep deprivation.

In light of the aforementioned research findings, the aims of this study are to evaluate the effects of adopting FCW systems on two levels of angry drivers' car-following behaviors, and to examine the differences among drivers' on-road performances and subjective workloads using different FCW systems.

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