

Forward Collision Warning: Clues to Optimal Timing of Advisory Warnings

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ABSTRACT

We examined the effectiveness of a heads-up Forward Collision Warning (FCW) system in 39 younger to middle aged drivers (25-50, mean = 35 years) and 37 older drivers (66-87, mean = 77 years). The warnings were implemented in a fixed based, immersive, 180 degree forward field of view simulator. The FCW included a visual advisory component consisting of a red horizontal bar which flashed in the center screen of the simulator that was triggered at time-to-collision (TTC) 4 seconds. The bar roughly overlapped the rear bumper of the lead vehicle, just below the driver's line-of-sight. A sustained auditory tone (~80 dB) was activated at TTC=2 to alert the driver to an imminent collision. Hence, the warning system differed from the industry standard in significant ways. 95% Confidence intervals for the safety gains ranged from -.03 to .19 seconds in terms of average correction time across several activations. Older and younger adults did not differ in terms of safety gains. Closer inspection of data revealed that younger to middle aged drivers were already braking (42%) on a larger proportion of FCW activations than older drivers (26%), $p < .001$. Conversely, older drivers were still accelerating (38%) on a larger proportion of FCW activations than younger to middle aged drivers (23%) at the time FCW was activated, $p < .009$. There were no differences in the proportion of activations when drivers were coasting at the time FCW was activated, $p = .240$. Furthermore, large individual differences in basic visual, motor, and cognitive function predicted the tendency to brake prior to FCW activation. Those who tended to be better functioning in each of these domains were more likely to be already braking prior to FCW activation at the fixed threshold of $TTC=4$. These findings suggest optimal timing for advisory alerts for forward events may need to be larger than $TTC=4$.

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INTRODUCTION

Extending the mobility of a growing aging population safely has relevance to public health and injury prevention. Aging drivers are at increased risk for crashes [1] and emerging technologies that incorporate Advanced Driver Assist systems (ADAS) hold a particular promise in compensating for declining capacities of elderly to extend safe mobility in later years. Rear-end collisions are among the most common crashes in the US [2] and forward collision warning (FCW) systems are designed to reduce incidence of these types of crashes.

Relatively recent Insurance Institute for Highway Safety (IIHS) data suggest that vehicle models equipped with autonomous braking are associated with reduction in insurance claims. Data on similar vehicle models without autonomous braking feature suggest benefits of FCW maybe more limited [3]. One of the challenges in designing a FCW without the added benefits of autonomous braking is to determine the

timing of the initial alert. Ideally, the timing of the alert would adjust for or factor in both the risk tolerance preferences and the capabilities of the driver in responding to a forward event. For example, aging drivers would be expected to react more slowly than younger to middle aged drivers owing to declines in visual, motor, and cognitive function typical of aging [4], hence alerts that would be effective for older drivers would have to be presented earlier.

Our goal in this study was to evaluate the effectiveness of an idealized FCW that differed from industry standards in significant ways especially with respect to its visual components, examine individual differences in profiles of pedal behavior at the time of FCW activation, and ask whether basic visual, motor, and cognitive functioning predicted pedal behavior and effectiveness as measured by reaction time to turn FCW off. [Figure 1](#) illustrates the FCW we implemented in a fixed-based simulator.

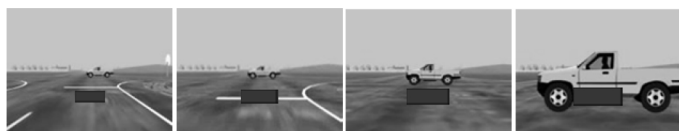


Figure 1. Illustration of the FCW visuals. As the participant nears a vehicle ahead (depicted left to right), the size of the ‘red’ visual rectangle increases as a function of the increase in time-to-collision (TTC) value. When $TTC \leq 2.0$ seconds, the visual is at its largest and is accompanied by a beeping tone to alert the driver to imminent danger. FCW system was only active at speeds above 5 mph to avoid over-alerting when approaching other vehicles at an intersection or in low speed traffic.

The *advisory* component of the FCW consisted of a red horizontal bar appearing in the center channel. The spatial position of the bar roughly overlapped the rear bumper of the lead vehicle, allowing the observer’s attention to be rapidly drawn to the area of the environment where corrective action is needed. We elected to manipulate length and width of the visual icon because it creates a powerful sense of looming. This form of motion has been demonstrated to be a powerful attractor of attention in the literature [5]. A combination of driver manual recommendations and prior research [6,7,8] suggested a TTC of 4 seconds may be large enough to accommodate the declining reaction time of older drivers to forward-critical events. Hence the visual warning appeared when TTC reached 4 seconds. When TTC was reduced to 2 seconds or less, a sustained auditory tone was added to indicate an *imminent* crash.

To address the question of safety gains, younger to middle aged drivers and older drivers completed two versions of the same drive once with warnings turned on and once with warnings turned off. We included measures of both average reaction time (RT) to increase distance to greater than $TTC = 4$ and turn off FCW, total time drivers were exposed to FCW, and number of times they activated FCW. In addition, for each activation of FCW we tracked pedal behavior of the drivers as being in one of the three states: already braking, already costing, or still accelerating. These measures were tracked identically whether the participants actually saw the FCW or not. To gauge the appropriateness of $TTC=4$ threshold and functional significance of pedal behavior at the time of FCW activation, we examined these driving measures in relation to extensive assessments of basic visual, motor, and cognitive functioning.

METHODS

Sample

The sample consisted of 39 younger to middle-aged and 37 older drivers. The younger to middle aged drivers were 25 to 50 years old (mean = 35 years), and consisted of 18 males and 21 females. The older drivers were 66 to 87 years old (mean = 77 years), and consisted of 23 males and 14 females. Inclusion criteria included: a) valid driver’s license, b) minimum 10 years of driving experience, c) driving at least 1 hour or 50 miles per week, d) negative screen for dementia (MoCA > 18) [9], and e) corrected visual acuity better than 20/50. 35% of the sample scored in the Mild Cognitive Impairment range and the remaining scored normal on MoCA. 86% of the sample was white. Educational achievement was distributed as follows: 7% had high school or less, 45% had less than college degree, 45% had a college degree or more, others did not indicate education level.

Procedure and Design

Following basic visual function and dementia screening, participants took a simulator drive (fixed base, full cabin with 180° FOV, DriveSafety RS600) to assess motion sickness. Of those tested in the simulator, 28 got motion sick and were not part of the 76 whose data were analyzed here. The remainder participated in detailed assessments of their cognitive function including processing speed, memory, and visuospatial construction during a second visit (see Figure 2). In four additional visits scheduled 2 weeks apart, participants took eight simulated drives that took 15-18 minutes to complete designed to examine long-term adaptation to warning systems that included in addition to FCW, also a lane deviation warning and lane change/merge warning. The data from the other warning systems were not examined in this report. This report also did not address long-term adaptation to FCW. In each of the four visits, participants were exposed to the warnings-on version and warnings-off version of the same drive (i.e. same layout, with same hazards differing only in whether the warnings were turned off (not visible to driver) or on (visible to driver). The order of presentation was randomized and counterbalanced both with respect to: a) whether they experienced the no-warn or the warn version of the drive first in each of four visits b) which of the four distinct drive layouts they first experienced. The drive layouts were similar in terms of tile composition with respect to road culture, total time (15-18 minutes each), and number of hazards encountered.

Measures and Statistical Analyses

Assessments of Functioning

A battery of standardized tests measuring basic visual function [10,11], motor function[12,13,14], and extensive assessment of cognitive functioning were administered [15, 16]. The assessments took approximately 2.5 to 3 hours. Figure 2 illustrates some of the tests in the cognitive battery.

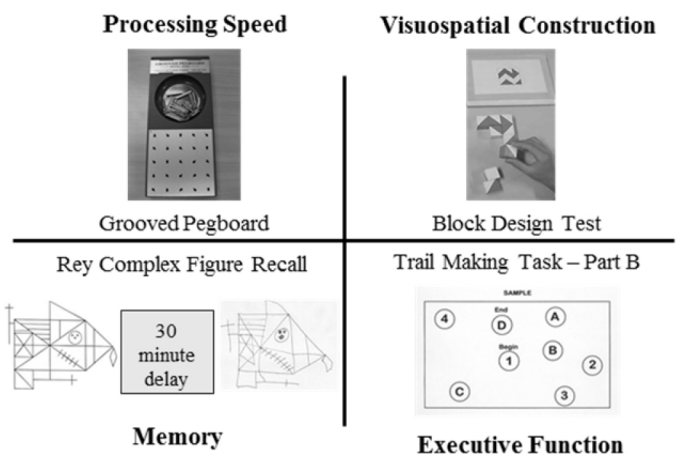


Figure 2. Examples of tasks used to measure each of the cognitive function domains; processing speed, visuospatial construction, memory, and executive function.

Table 1 lists the specific tests included in the basic visual and motor function domains. Table 2 lists the specific tests that were included in each of the four cognitive functioning domains: processing speed, visuospatial construction, memory, and executive functioning. The assignment of the tasks to these four cognitive domains was guided