# *PILOT RESULTS ON FORWARD COLLISION WARNING SYSTEM EFFECTIVENESS IN OLDER DRIVERS*

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**Summary:** Advanced Driver Assistance Systems (ADAS) have largely been developed with a "one-size-fits-all" approach. This approach neglects the large inter-individual variability in perceptual and cognitive abilities that affect aging ADAS users. We investigated the effectiveness of a forward collision warning (FCW) with fixed response parameters in young and older drivers with differing levels of cognitive functioning. Drivers responded to a pedestrian stepping into the driver's path on a simulated urban road. Behavioral metrics included response times (RT) for pedal controls and two indices of risk penetration (e.g., maximum deceleration and minimum time-to-collision (TTC)). Older drivers showed significantly slower responses at several time points compared to younger drivers. The FCW facilitated response times (RTs) for older and younger drivers. However, older drivers still showed smaller safety gains compared to younger drivers at accelerator pedal release and initial brake application when the FCW was active. No significant differences in risk metrics were observed within the condition studied. The results demonstrate older drivers likely differ from younger drivers using a FCW with a fixed parameter set. Finally, we briefly discuss how future research should examine predictive relationships between domains of cognitive functioning and ADAS responses to develop parameter sets to fit the individual.

## INTRODUCTION

The number of drivers 65 and older in the United States is rapidly increasing and will continue to rise in coming decades. From 1999-2009, the number of licensed drivers 65 and older increased by 23%, with 33 million licensed older drivers on the road in 2009 (FHA, 2009). Older drivers are at an increased risk for automobile accidents and on-road fatalities (NHTSA, 2009). In the 1990's, automobile industries introduced Advanced Driver Assistance Systems (ADAS) to enhance driver awareness, in an effort to improve safety. However, current in-vehicle technologies are developed and tested with healthy young adults in mind. As the age demographic shifts in the U.S., a "one-size-fits-all" approach to ADAS and vehicle safety may be suboptimal. Furthermore, concrete data on ADAS and aging is strongly lacking. For example, it is largely unknown how cognitive status and physical limitations interact with system design parameters (Davidse, 2006; Jamson et al., 2008).

This pilot study examines potential age-related differences in responses to a forward collision warning (FCW) component of a larger on-going simulator study of ADAS effectiveness. In the current study, the FCW system detects any forward obstacle, including an automobile or a pedestrian. Our analyses focus on a specific incursion where drivers encounter a pedestrian unexpectedly entering the roadway in an urban driving environment (see description below). We hypothesize that: 1) older drivers should show cognitive impairments in several neuropsychological domains, 2) older drivers should show deteriorated responses during the pedestrian incursion compared to younger drivers, 3) FCW should improve responses of both younger and older drivers, but the magnitude of improvements will be smaller for older drivers, 4) older drivers should show greater risk penetration during the pedestrian scenario even with a FCW.

## METHODS

### Participants

Table 1 shows the number of drives analyzed as a function of age group and FCW status. Drives were analyzed based on the currently available dataset. Younger adults had a mean age of 39.4 (*SD* = 9.1) and older adults' mean age was 77.6 (*SD* = 7.5). All participants were neurologically normal and passed several prescreening measures of visual and cognitive processing. Previous studies have demonstrated that cognitive functioning is a mediator of driving safety over and above age and basic visual functioning (Anstey et al., 2005). This study also conducted detailed assessments of cognitive functioning in several domains, including processing speed, visuospatial construction, memory, and executive function (see Anderson et al., 2012 for detailed discussion).

### Apparatus & Procedures

Experimental drives were conducted in a DriveSafety DS-600 fixed-base simulator with five LCD monitors creating a 180° forward field of view. A rear-view and two side-view LCD screens provided a rear-facing traffic perspective. All driving scenarios were created using HyperDrive (v 1.9.39) software.

**Table 1. Analyzed drives by FCW status and age group**

| FCW status | Age group | # of drives |
|---|---|---|
| Off | Older | 4 |
| | Younger | 4 |
| On | Older | 3 |
| | Younger | 2 |

*Pedestrian incursion*. A pedestrian incursion was used as the critical event of interest. The pedestrian incursion was identical in the timing of critical events and road culture. It differed only in FCW status across two drives. Specifically, the pedestrian incursion was encountered when the FCW system was active (FCW On) and again with no warning (FCW Off), in a counterbalanced order. The scenario used in this study was a part of longer scenario with multiple events; therefore, subjects' anticipation for the same event was minimal. The FCW off drive served as a baseline measurement of driver response behavior. The pedestrian incursion consisted of the driver traveling in the rightmost lane of a four-lane urban environment, with a posted speed limit of 45 miles per hour. Drivers approached a large bus parked at a bus stop, to the right of the subject vehicle's lane. A pedestrian unexpectedly appeared from behind the parked bus. The pedestrian moved at a velocity of ~5 M.P.H., the pedestrian's direction of travel was roughly perpendicular to the subject vehicle's direction of travel. The pedestrian incursion was initiated using a timed trigger, where the pedestrian began moving once the subject vehicle reached a TTC value of 2.8 seconds from the pedestrian's starting position.

*FCW parameters.* The FCW system consisted of visual and auditory components. The visual component consisted of a red (RGB: 255, 0, 0) horizontal bar (4.97 x 1.27° of visual angle) that appeared on the center screen (33.4 x 20.8°) of the driving simulator. The icon appeared in the lower third of the screen, just below the driver's line-of-sight. A sustained auditory tone (~80 dB) activated along with the visual icon. The auditory tone was easily detected against background drive noise without startling drivers.

*Drive metrics.* To quantify ADAS effectiveness across age groups, the following metrics were computed in both FCW on and off drives. RTs included: 1) time to release the accelerator pedal after the pedestrian appeared, 2) time to initial brake depression (10% of maximum) after the pedestrian appeared, 3) brake application time (time to maximum brake depression from initial depression). Also, maximum deceleration of the subject's vehicle and minimum TTC values were computed as metrics of risk penetration. No collisions with the pedestrian were observed in either age group; as a result, collision rate is not analyzed further. Two-sided t-tests were used in all analyses to compare if the effects of FCW status and age group significantly differed between the variables of interest during the pedestrian incursion.

## RESULTS

### Cognitive function

Two-sided t-tests compared cognitive functioning in four domains between younger and older drivers. Degrees of freedom were corrected for violations of equality of variance, when appropriate. The neuropsychological battery (see Anderson et al., 2012) revealed that the scores of the older age group were significantly lower in processing speed ($t(7.3) = 5.5$, $p < .001$), visuospatial construction abilities ($t(10) = 2.6$, $p = .026$), overall memory ($t(10) = 2.1$, $p = .056$), and executive function ($t(7.3) = 2.7$, $p = .030$).

### RTs in pedestrian incursion (Figure 1)

*Effect of FCW.* Effects of FCW were investigated by comparing RTs with and without FCW across all subjects. The effect of FCW was marginally significant for initial accelerator pedal release ($t(9.76) = 1.88$, $p = .09$). Time to initial brake depression did significantly differ with and without FCW ($t(9.91) = 1.88$, $p = .04$), while brake application time was not significantly influenced by FCW ($t(11) = 0.47$, $p = .64$). These results demonstrate the presence of the FCW decreased RTs for accelerator release and initial brake depression across all subjects. Preliminary trends suggest that FCW increased brake application time, however the trends were not statistically significant.

*Effect of driver age*. Influences of driver age were investigated by comparing RTs of two age groups across both FCW drives. The influence of driver age significantly affected RTs for accelerator pedal release ($t(7.47) = 3.13$, $p = .01$) and initial brake depression ($t(11) = 2.48$, $p = .03$) times. These results demonstrate that aging adults showed longer RTs at accelerator release and initial brake depression points. While brake application time did not significantly differ between age groups ($t(11) = -0.50$, $p = .62$). However, preliminary trends suggest older drivers appeared to show faster, less controlled, brake application times compared to younger drivers.

*Age differences in each FCW status*. Differences in RTs were examined across age group, at each time point during FCW off drives (Figure 1). At accelerator pedal release, a significant difference in RTs was observed ($t(6) = -4.08$, $p = .007$) demonstrating older drivers were significantly slower than younger drivers. A significant difference was observed in initial brake depression RTs ($t(6) = -3.41$, $p = .014$), with older drivers slower to depress the brake pedal. No significant differences were observed for brake application time in the FCW off drive ($t(6) = .15$, $p = .887$). Next, statistical comparisons tested if age-related differences in RTs persisted in the presence of the FCW. RTs were compared at the same three time points for FCW on drives. Marginally significant differences in RTs were observed between age groups at accelerator pedal release ($t(3) = -2.04$, $p = .10$) and initial brake depression ($t(3) = -2.45$, $p = .09$), with older drivers still showing slower RTs when FCW was present. Again, no significant differences in brake application time were observed in the FCW on drive ($t(3) = .60$, $p = .59$), although brake application time appeared to remain smaller for older drivers.

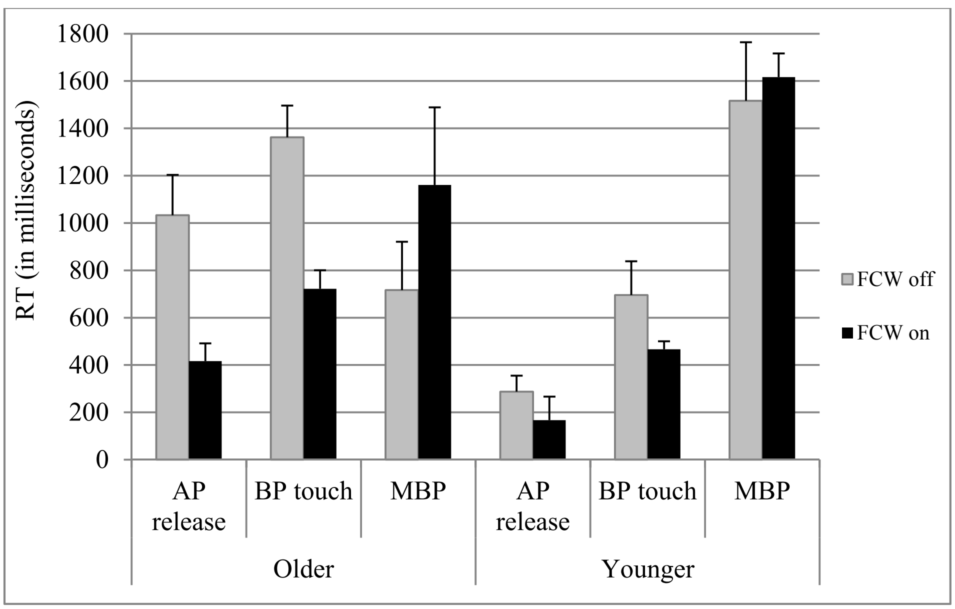


**Figure 1. Reaction times (RTs) in the pedestrian incursion as function of age group and FCW status. RTs were calculated for initial accelerator pedal release (AP release), initial brake depression (BP touch), and brake application time (MBP). Error bars represent standard error estimates**

## Maximum deceleration & minimum TTC (Figure 2)

Risk penetration was quantified using maximum deceleration and minimum TTC. Both FCW status ($t(7.81) = -0.66$, $p = .52$) and driver age ($t(11) = -0.35$, $p = .73$) did not significantly influence maximum deceleration values. FCW status did not significantly influence minimum

TTC ($t(8.97) = -1.20$, $p = .26$). Also, the effect of age group did not significantly influence minimum TTC ($t(11) = -1.69$, $p = .12$).
Maximum deceleration was compared across age groups for FCW off and FCW on drives (Figure 2). No significant effects of age were observed for FCW off ($t(6) = 1.95$, $p = .81$) and FCW on drives ($t(6) = .889$, $p = .44$). For minimum TTC, a marginally significant effect of age was observed in FCW off drives ($t(6) = -1.95$, $p = .09$). Minimum TTC was not significantly different between older and younger drivers in FCW on drives ($t(6) = .43$, $p = .70$). Maximum deceleration and minimum TTC analyses suggest FCW status and age did not significantly influence risk penetration in the pedestrian incursion. These findings are discussed further below.

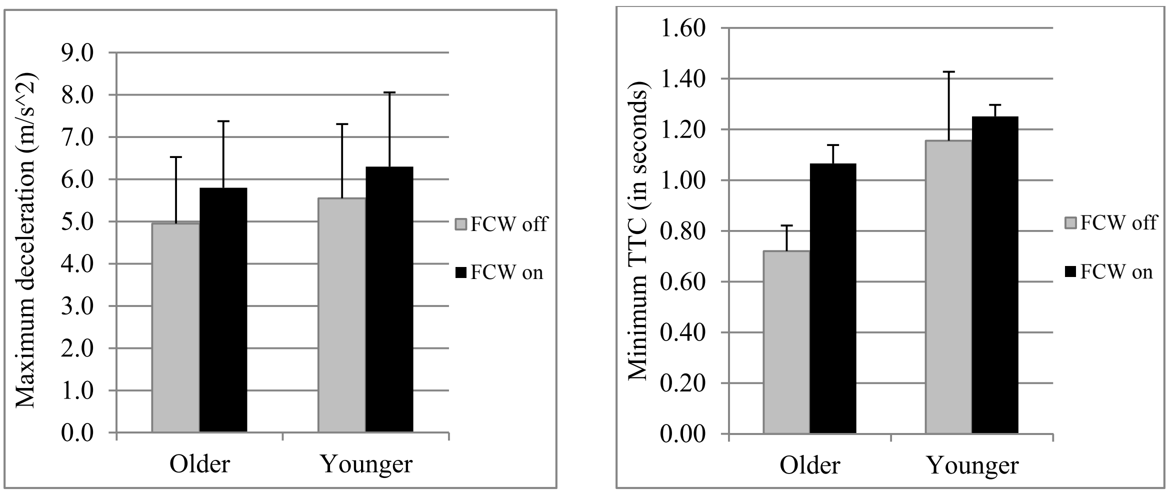


**Figure 2. Maximum deceleration and minimum TTC as function of age group and FCW status. Error bars represent standard error estimates**

## DISCUSSION

We examined older and younger driver responses to an unexpected pedestrian incursion, using a fixed parameter FCW system. We hypothesized that: 1) older drivers should show cognitive impairments in several neuropsychological domains, 2) older drivers should show deteriorated responses during the pedestrian incursion compared to younger drivers, 3) FCW should improve responses of both younger and older drivers, but the magnitude of improvements will be smaller for older drivers, 4) older drivers should show greater risk penetration during the pedestrian scenario even with an active FCW.

Significantly impaired functions of older drivers were observed in processing speed, visuospatial construction abilities, overall memory, and executive functions (*Hypothesis #1*). Cognitive process for successful collision avoidance include perception of hazard / warning, understanding the situation, planning and prioritizing actions, making a decision, and executing an action. Effective collision avoidance requires coordination of multiple levels of cognition, and declines at individual processing levels are likely correlated with deteriorated driving behaviors. However, direct comparisons to driving performance and ADAS responses were not examined given the pilot nature of the current experiment. Future analyses will examine how these domains might predict ADAS responses and safety gains in older drivers.

Preliminary analyses demonstrate older drivers' behavioral responses to a FCW, and the accompanying safety gains, differ from young drivers in several ways (Figure 1). Older drivers did show significantly deteriorated response times during the pedestrian incursion without the FCW (*Hypothesis #2*). Overall, older drivers showed larger RTs regardless of FCW status. Importantly, the FCW system did confer safety gains for both age groups. However, marginally significant differences in safety gains persisted in FCW on drives, at accelerator pedal release and initial brake depression time points, demonstrating older drivers still had greater RTs when the FCW was on. Finally, FCW status and age did not significantly influence brake application times. However, the results suggest that FCW may increase brake application times, potentially resulting in more controlled braking (see Lee et al., 2002). We note that the low criticality of the current scenario study may explain the insignificant effects in brake application time if the subjects did not have to use the additional time generated by FCW for more control of the brake. Also, we observed reduced safety gains in this sample of older drivers. (*Hypothesis #3*). Further study with an increased sample size is underway.

In contrast to our predictions, no significant differences in maximum deceleration or minimum TTC were observed for age group or FCW status (*Hypothesis #4*). Again, these non-significant differences are likely due to the relatively low criticality of the pedestrian scenario. Driving speed was not experimentally controlled; as a result, drivers could have controlled the vehicle using small changes in acceleration to minimize crash risk and avoid a collision. This result is further supported by the finding that no drivers collided with the pedestrian. Future scenarios will focus on high criticality scenarios such as car following with abrupt lead vehicle braking (Lee et al., 2002; McGehee et al., 2002).

## CONCLUSIONS

These results demonstrate older adults can benefit from a FCW system. However, safety benefits were smaller in older drivers when FCW is active, suggesting ADAS parameter settings can interact with age status. However, we note that the current investigation is preliminary and requires continued analyses. Furthermore, additional participants are required to investigate potential relationships between ADAS safety gains and component cognitive functions. Preliminary neuropsychological assessments demonstrated aging adults showed decreased functioning in processing speed, visuospatial abilities, memory, and executive function domains (Anderson et al., 2012). These reductions in brain functioning likely mediate behavioral responses to ADAS and subsequent safety gains (Uc & Rizzo, 2008; Rizzo, 2011). While it is beyond the aim of this paper to identify predictive relationships between laboratory measurements of behavior and FCW safety gains, we believe this is a critical avenue for future research. It is possible that adjusting system parameters (i.e., "tailor-made" systems) may compensate for age-related declines in driving, thereby closing the safety gap, and further boosting ADAS benefits in the aging population.

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