Safety potential of crash avoidance features, improved headlights, and V2V-enhanced technologies for older drivers

May 2022

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Contents

ABSTRACT

Introduction: Age-related changes and frailty are among the reasons that older drivers are overrepresented in certain crash types. Vehicle safety features that address these crash types may therefore deliver greater safety benefits for older drivers than for other age groups even though they are designed for the general population.

Methods: U.S. crash data from 2016–2019 were used to estimate the proportion of crash involvements and fatal and nonfatal driver injuries for older (70 years old and above) and middle-aged (35–54 years old) drivers from crash scenarios to which current crash avoidance features, improved headlights, and forthcoming vehicle-to-vehicle (V2V)-connected intersection-assistance features could be relevant. Risk ratios were then calculated to determine the relative benefits of each technology for older drivers compared with middle-aged drivers.

Results: Combined, these technologies were potentially relevant to 65% of older driver and 72% of middle-aged driver fatalities during the study period. Intersection assistance features showed the most promise for older drivers. Such features were potentially relevant to 32% of older driver crash involvements, 38% of older driver injuries, and 31% of older driver fatalities. Intersection assistance features were significantly more likely to be relevant to older driver deaths than middle-aged driver fatalities (RR, 3.52; 95% CI, 3.33–3.71).

Conclusions: Vehicle technologies have the potential to substantially reduce or mitigate crashes and the injuries that they cause for everyone, but the potential safety impact of each technology varies by driver age because different age groups are over- or underrepresented in specific crash scenarios.

Practical applications: With the older driver population growing, these findings underscore the need to bring intersection assistance technologies to the consumer market. At the same time, everyone stands to benefit from currently available crash avoidance features and improved headlights, so their use should be promoted among all drivers.

Keywords: older drivers; ADAS; safety benefits; intersections; vehicle technology; middle-aged drivers

INTRODUCTION

The number of drivers aged 70 years and older is growing (U.S. Census Bureau, 2017; Federal Highway Administration [FHWA], 1999, 2020) because life expectancy is increasing (National Center for Health Statistics, 1999, 2019) and drivers are retaining their licenses longer (Insurance Institute for Highway Safety [IIHS], 2021). That raises safety concerns because older drivers are at a greater risk than younger drivers for certain types of crashes and related injuries. Although police-reported crash involvement rates per mile traveled are no longer higher for drivers in their 70s than for middle-aged drivers in the United States, crash rates remain higher for drivers 80 years and older than for either of those groups (Cox & Cicchino, 2021a). Furthermore, drivers 70 years and older are involved in substantially more fatal crashes per vehicle miles traveled than middle-aged drivers (Cox & Cicchino, 2021a). Frailty increases the injury severity risk for older drivers, and therefore crash involvements tend to have more severe consequences for older drivers than for younger drivers (Sifrit et al., 2010). Fortunately, vehicle design improvements and the implementation and improvement of passive and active safety systems over the years have reduced both crashes and resulting injuries for drivers in general (Highway Loss Data Institute [HLDI], 2020a, 2020b) and for older drivers (Fausto & Tefft, 2018). While designed for the general population, some driver assistance features may have greater safety benefits for older drivers because they are designed to address the types of crashes for which older drivers are especially at risk.

Age-related cognitive, perceptual, and motor declines lead to degradations in driving performance that predispose older drivers to be involved in certain types of crashes more often than middle-aged drivers (Lombardi et al., 2017). For example, older drivers tend to have trouble navigating driving conditions that require divided attention (Dotzauer et al., 2013). They are thus more likely than middle-aged drivers to be involved in intersection-related crashes (Alam & Spainhour, 2008; Cicchino & McCartt, 2015; Clarke et al., 2010; Dotzauer et al., 2013). The problem is particularly acute with regard to left turns at signalized intersections (Mayhew et al., 2006; Stamatiadis et al., 1991; Stutts et al., 2009), which older drivers often don’t realize they have difficulty performing (Bellet et al., 2018). In addition, older drivers are more likely to be operating the struck vehicle than the striking vehicle in nonsignalized, or uncontrolled, intersection crashes (Stutts et al., 2009). Factors that contribute to these elevated crash risks at signalized and nonsignalized intersections among older drivers include failing to recognize appropriate gaps in traffic, failing to yield, misjudging the speeds of other vehicles, and failing to detect other vehicles, (Alam & Spainhour, 2008; Cicchino & McCartt, 2015; Clarke et al., 2010; Rakotonirainy et al., 2012).

For nonintersection crashes, other contributing factors are more common for older drivers than other age groups. These include incapacitation and medical events leading to driver error (Cicchino & McCartt, 2015), sudden loss of control, driver confusion, inappropriate action, and illegal maneuvers (Alam & Spainhour, 2008). In addition, age-related motor and cognitive declines make older drivers slower to react (Lester et al., 2015). Visual impairment, which is associated with nighttime driving performance degradation (Kimlin et al. 2020; Owsley et al., 1991), is also an issue. Though older drivers are less likely to be involved in crashes at night than younger drivers (Stutts et al., 2009), that is most likely because many adjust their driving patterns to avoid driving in the dark (Braitman & McCartt, 2008; Naumann et al., 2011).

Given the risk factors that older drivers face and the types of crashes they tend to be involved in, certain vehicle technologies may offer greater potential safety benefits for them than for other age groups. For example, headlights that do a better job illuminating the roadway, including those that are curve-adaptive or equipped with high beam assist, are important to nighttime driving safety (Brumbelow, 2021; HLDI, 2020c; Leslie et al., 2021; Reagan et al., 2015). Crash avoidance features are also gaining traction in the new vehicle market (HLDI, 2020b), and their efficacy has been demonstrated with significant reductions in relevant police-reported crashes (Cicchino, 2017a, 2018a, 2018b) and insurance claims (HLDI, 2020c). Front crash prevention is designed to prevent rear-end crashes by warning the driver or automatically applying the brakes when the system detects that a collision with a vehicle in front is imminent. Crashes resulting from inadvertent lane drifts are addressed by lane departure prevention, which gives an alert or automatically guides the vehicle back into the lane temporarily when it is at risk of crossing the lane line. Blind spot detection helps to prevent crashes in which one vehicle strikes another while changing lanes by alerting the driver there is a vehicle in their blind spot. Left turn assist addresses left-turn crashes by alerting the driver or automatically applying the brakes to avoid a collision if the system detects that the turn will result in a crash with an oncoming vehicle. All these features are available on various models from most automakers at the time of this publication.

Cutting-edge technology in the form of vehicle-to-vehicle (V2V) connectivity is also on the horizon. V2V communication allows connected vehicles to send and receive information about their position, speed, and travel path so that onboard computers can identify and predict traffic patterns and potential points of conflict (Office of the Federal Register, 2017). At present, too few vehicles on U.S. roads are equipped with the technology for it to be effective, but potential safety benefits are anticipated for drivers in general and older drivers specifically once it is widespread (Bareiss et al., 2019; Marshall et al., 2010; Office of the Federal Register, 2017; Stevens et al., 2020). Among the more promising possibilities are two V2V-connected intersection-assistance features: V2V-enhanced left turn assist and intersection movement assist.

By allowing the two vehicles to communicate, V2V-enhanced left turn assist could alert the oncoming driver as well as the driver who is turning left about a potential crash, rather than only the turning driver. Vehicle connectivity would also facilitate better predictions of possible points of conflict based on the current headings of nearby vehicles (Harding et al., 2014).

Similarly, intersection movement assist is designed to use V2V's information about the speed and trajectory of other connected vehicles to address additional intersection crash scenarios. This feature would alert the driver and possibly automatically engage the brakes if the system detected that it was unsafe to enter an intersection because of another vehicle approaching laterally. This could address crashes that result when another vehicle runs a red light or when the driver's view of the intersection is occluded by another vehicle or object.

Despite their usefulness, commercially available crash avoidance features are still relatively uncommon in the registered vehicle fleet (HLDI, 2020b). Older drivers are also less likely than other age groups to have vehicles equipped with these features because they tend to drive older vehicles than the general population (Cox & Cicchino, 2021b). The goal of this study was to understand how many crash involvements, driver injuries, and driver fatalities could be mitigated by these vehicle technologies for older drivers if all drivers used them and these technologies were completely effective. To understand whether and how these technologies may benefit older drivers in particular, crash outcomes for older drivers were compared with those for middle-aged drivers. This is a relevant comparison because both groups tend to be experienced drivers, but middle-aged drivers do not exhibit the age-related changes in driving performance that affect drivers 70 years and older.

METHOD

Data

Two national crash data sets from the National Highway Traffic Safety Administration (NHTSA), the Fatality Analysis Reporting System (FARS) and the Crash Report Sampling System (CRSS), were used to calculate average annual counts and percentages of crash involvements, injuries, and fatalities of middle-aged drivers (ages 35 to 54 years old) and older drivers (ages 70 years old and above). The analysis included crashes from 2016 to 2019 involving passenger vehicle (body types 1 to 49) drivers in the middle-aged and older age groups.

CRSS is a nationally representative sample of U.S. police-reported crashes of all severities. Sampling weights in the CRSS data were used to generate national estimates, and those weighted estimates were used to calculate the number of crash involvements and the number of nonfatally injured drivers in each age group. A nonfatal injury was identified when a driver sustained suspected incapacitating/serious (A) or evident/minor (B) injuries. When available, statistically imputed values in the CRSS data set were used to address missing data for certain variables.

FARS is an annual census of all vehicle occupant or other U.S. public road user deaths due to and occurring within 30 days of a motor vehicle crash. It includes information on all people and vehicles involved in these crashes. The FARS data were used to count driver deaths.

Crash types

We categorized crashes based on the potential relevance of several technologies hypothesized to provide particular benefits for older drivers. These include some technologies that are currently available and some that are not yet for sale to consumers. Those that are already available include improved headlights, three crash avoidance technologies (front crash prevention, lane departure prevention, and blind spot detection), and one intersection assistance feature (left turn assist). Those that are not yet available commercially include vehicle-to-vehicle (V2V)-enhanced left turn assist and intersection movement assist. For each age group, counts and percentages were estimated for crash involvements and driver injuries and calculated for driver deaths for the crash scenarios to which each technology and each technology category (i.e., conventional crash avoidance features, headlights, and intersection assistance features) could be relevant. The total counts and percentages for all technologies combined were also estimated or calculated. Crash outcomes were not double counted within any of the technology categories or in any of the combined totals. For example, a crash that occurred under dark ambient light conditions to which either V2V technologies or crash avoidance technologies could be relevant was counted as one crash when calculating the total for all technologies combined. This enabled us to estimate the maximum safety potential of these technologies for each age group if all vehicles were equipped with these technologies, all drivers used them, and they always worked optimally.

This study employed the same method used in Mueller and Cicchino (2022) to define the crash scenarios and identify database variables relevant to front crash prevention, lane departure prevention, and blind spot detection and expanded on it to include improved headlight systems and intersection assistance features. Definitions of crash scenarios that could be addressed by V2V-enhanced technologies were based on descriptions in NHTSA's Proposed Rule on V2V Communications (Office of the Federal Register, 2017).

It is difficult to establish sequences of events in crashes with three or more vehicles, so crash scenarios for crash avoidance and intersection assistance features were restricted to single- and two-vehicle crashes. Crashes caused by vehicle failures, such as blowouts, stalled engines, disabling vehicle failures, and nondisabling vehicle problems, were excluded from the analysis (critical precrash events 1 to 4), as most drivers would struggle to prevent a crash in those situations, even with the assistance of the technologies we examined.

As described in Mueller and Cicchino (2022), the crash-type variable acc_type was the primary one used to identify scenarios to which the vehicle technologies could be relevant. Acc_type contains information describing the movement of the crash-involved vehicles in the lead up to the crash. Other variables were also used to identify relevant crash scenarios, including initial point of impact, vehicle movement (i.e., path) prior to the critical event of the crash, relation to junction, critical precrash event, and light condition. Crash configurations to which crash avoidance features and headlights could be relevant were only considered if the older or middle-aged driver would benefit from the technology if their vehicle were equipped regardless of what technology was installed on a crash partner vehicle. Because V2V-enhanced technologies permit communication between vehicles through 360-degree monitoring of equipped vehicles (Office of the Federal Register, 2017), V2V scenarios assumed that both crash-involved vehicles were equipped with that technology.

Vehicle technologies

Front crash prevention. This class of technologies includes forward collision warning and automatic emergency braking. Front crash prevention is also known as forward collision avoidance or autobrake. It either alerts the driver or intervenes on the driver's behalf by applying the brakes when it detects that a collision is imminent with another vehicle in front. The feature is designed to address rear-end crashes with other vehicles. Some front crash prevention features are also designed to address single-vehicle pedestrian crashes with point of impact at the front of the vehicle. Because pedestrian crash prevention is predominantly designed to protect pedestrians, as opposed to the driver, the analysis only investigated the potential of pedestrian crash prevention to avert crashes involving pedestrians and not its possible effect on driver injuries and fatalities.

Lane departure prevention. Using cameras to detect the lane lines and the vehicle's position within them, this feature is designed to prevent the vehicle from inadvertently drifting from the lane. It goes beyond lane departure warning and actively intervenes on behalf of the driver by steering or braking to stop the vehicle from departing the lane or to return it back to the lane. It is relevant to road departure, sideswipe, and head-on collisions that result from the vehicle inadvertently drifting out of the lane. Crash scenarios where the driver passed or overtook another vehicle, changed lanes, merged, or avoided another critical event prior to the crash were excluded, as lane departure prevention is not designed to address those circumstances. Furthermore, crashes on roads with speed limits below 35 mph were excluded from the analysis because most lane departure prevention systems can only be used at higher speeds and on roads with painted lane lines.

Blind spot detection. This feature alerts the driver when another vehicle is present in the adjacent lane in the driver's blind spot. It is designed to address sideswipe crashes that result from intentionally changing lanes, passing, or merging.

Improved headlights. IIHS introduced a headlight evaluation and rating system in 2016 that has demonstrated that headlights vary greatly in how well they illuminate the roadway. Several relatively new technologies improve performance. For example, high-intensity discharge (HID) bulbs and light-emitting diodes (LED) offer greater light output than halogen bulbs, curve-adaptive headlights turn with the driver's steering input to better illuminate curved roadways, and high beam assist automatically switches between the low and high beam settings based on the presence of other vehicles (Reagan et al., 2015; Van Derlofske et al., 2001). HID headlights, high beam assist, and good IIHS headlight ratings are associated with reductions in nighttime crash risk (Brumbelow, 2021; Leslie et al., 2021). Improved headlights are therefore relevant to crash scenarios with low light conditions.

Left turn assist. This crash avoidance feature is designed to address left-turn crashes, including those at intersections, in which one vehicle makes a left turn across the path of another vehicle traveling straight from the opposite direction. This study explored the potential benefit of two left turn assist technologies. The first version, which is currently available on select vehicle models, uses the same sensors as front crash prevention. When the driver of the turning vehicle activates the turn signal (and possibly based on other criteria like speed, acceleration, and steering angle), the system determines if there is a risk of a collision with an oncoming vehicle and either warns the driver or applies the brakes. Current left turn assist relies on line-of-sight, and its performance may be affected by factors such as the speed of the left-turning vehicle, the speed of the oncoming vehicle, the presence of multiple oncoming vehicles, whether the oncoming vehicle's headlights are on, and inclement weather.

The second version of left turn assist is enhanced by V2V connectivity, which is not yet commercially available. With this system, the turning vehicle and the oncoming vehicle inform each other of their presence, speed, relative distance, and intended path. This communication potentially allows the oncoming vehicle to decelerate to avoid colliding with the turning vehicle. The 360-degree monitoring and data sharing facilitated by V2V could provide superior safety benefits to those offered by forward facing sensors alone. The crash configurations to which V2V-enhanced left turn assist could be relevant are the same as those that conventional left turn assist might address, but the V2V-enhanced version applies to both the turning vehicle and the oncoming vehicle.

Intersection movement assist. This technology is also made possible through V2V connectivity. It alerts multiple drivers approaching an intersection of a potential collision. Although not currently available in the North American market, the feature will address common intersection-related crash scenarios related to a vehicle approaching another from the lateral direction, including crashes in which vehicles are crossing paths while both are traveling straight and crashes in which one vehicle is turning into the path of another from the same or opposite direction. Because older drivers are overrepresented in left-turn crashes, we present estimates for relevant crashes where the driver's vehicle was turning left into the path of a laterally approaching vehicle separately from other turn-into-path crashes. Table 1 defines the crash scenario types, scenario definitions, and CRSS/FARS coding for all six types of vehicle technologies.

Analysis

Risk ratios were calculated to compare the magnitude of the maximum estimated potential safety benefits of each technology for each crash outcome (i.e., crash involvements, driver injuries, and driver deaths) among older drivers compared with middle-aged drivers. The risk ratio was calculated as the proportion of the crash outcome among older drivers divided by the proportion of the crash outcome among middle-aged drivers. SAS 9.4 was used to compute 95% confidence intervals (CI) for the risk ratios (RR). Risk ratios were considered statistically significant when the confidence intervals did not include 1.

RESULTS

From 2016 to 2019, the CRSS sampling weighting represented 2,734,451 older driver crash involvements (annual average n = 683,613) with 197,223 injured drivers (annual average n = 49,306). Over the same period, the sampling weighting represented 12,038,740 middle-aged driver crash involvements (annual average n = 3,009,685) with 762,780 injured drivers (annual average n = 190,695). There were 10,988 older driver fatalities (annual average n = 2,747) and 18,590 middle-aged driver fatalities (annual average n = 4,648).

Table 2 shows the annual number and percent of older and middle-aged driver involvements in crashes to which each vehicle safety feature might have been able to prevent or mitigate. Overall, about 60% of crash involvements for each age group were of types that at least one of the safety features of interest might have addressed. One in five of all older driver crash involvements occurred in scenarios to which conventional crash avoidance features might have applied. Fewer older driver crash involvements than middle-aged driver crash involvements occurred in scenarios in which front crash prevention was potentially relevant. However, a larger percentage of older driver crashes (12%) were of types that front crash prevention might have addressed than of types potentially addressed by blind spot detection (4%) or lane departure prevention (3%). Headlight improvements were 38% less likely to be potentially relevant to crashes involving older drivers than those involving middle-aged drivers (14% vs. 23%), and this difference was significant. Intersection assistance features might have been relevant to the largest proportion of older driver crashes (32%), compared with only 22% of crashes involving middle-aged drivers. Within that category, nearly a quarter of older driver crash involvements were types to which intersection movement assist, in particular, might have been able to address. Up to 6% and 8% of older driver crash involvements were types that left turn assist and V2V-enhanced left turn assist might have addressed, respectfully. Despite those differences, when all the features were considered on a combined basis, the proportion of crashes they might have addressed did not differ significantly for the two age groups.

Table 3 shows the annual average number and percent of minor and serious injuries sustained by older and middle-aged drivers in crashes to which each vehicle technology might have been relevant. Overall, the proportion of injured drivers in crashes to which all safety features were potentially relevant was similar for the two age groups, but the distribution by age group varied by technology type. Compared with their middle-aged counterparts, older drivers were 34% more likely to be injured in a crash that front crash prevention might have addressed and 15% less likely to be injured in a crash that lane departure prevention might have addressed. Front crash prevention and lane departure warning were each relevant to 9% of all older driver injury crashes. There was not a significant difference between the results for the two age groups for either blind spot detection or the combined conventional crash avoidance features. Among older drivers, the portion of injury crashes that occurred in low lighting conditions to which improved headlights were potentially relevant (14%) was about half what it was for middle-aged drivers (28%), and this difference was significant. Among the different technology categories, the combined intersection assistance features were potentially relevant to the largest portion of older driver injury crashes (38%), and intersection movement assist specifically might have been relevant to the most injury crashes among intersection assistance features (24%). Older drivers were more than twice as likely to sustain injuries in intersection-related crashes when turning left compared with middle-aged drivers. On the other hand, older drivers were 24% less likely to be injured in those crash scenarios when traveling straight through the intersection compared with middle-aged drivers. Overall, older drivers were 40% more likely than middle-aged drivers to be injured in crashes to which V2V-enhanced left turn assist might have been relevant.

Table 4 displays the average number and percent of all older and middle-aged driver fatalities per year associated with crash scenarios to which each vehicle safety feature might have been relevant. It also shows the relative crash fatality risk for older drivers versus their middle-aged counterparts. A quarter of older driver fatalities resulted from crashes to which conventional crash avoidance features were potentially relevant. Crashes to which lane departure prevention might have been relevant accounted for a greater proportion of older driver fatalities (22%) than the other conventional crash avoidance features; however, a significantly larger proportion of middle-aged drivers (34%) were killed in crash scenarios that lane departure prevention might have addressed. About the same proportion of older and middle-aged driver deaths resulted from crashes to which front crash prevention and blind spot detection might have been relevant. Improved headlights were potentially relevant to significantly fewer crashes with older driver deaths (17%) than middle-aged driver deaths (48%).

Roughly one third of all older driver fatalities resulted from crashes that all the intersection assistance features combined might have addressed. Crashes in which an older driver died were nearly 5 times as likely as those in which a middle-aged driver was killed to involve a scenario that V2V-left-turn assist might have addressed. Fatal older driver crashes were also more than 3 times as likely as fatal crashes involving middle-aged drivers to have occurred in scenarios to which intersection movement assist might have been relevant. Both were significant. The fatal crash types showing the largest differences between older and middle-aged drivers were left-turn crashes to which left turn assist and intersection movement assist were potentially relevant. Left-turn fatal crashes that left turn assist might have addressed were nearly 7 times as likely for older drivers as for middle-aged drivers, and left-turn fatalities that intersection movement assist might have addressed were more than 5 times as likely for older drivers as for their middle-aged counterparts.

DISCUSSION

This study estimated the percent of older and middle-aged driver crash involvements and injuries and calculated the percent of older and middle-aged driver fatalities sustained from crashes to which vehicle safety features were potentially relevant. We then interpreted those percentages to represent maximum estimates of the potential impact that these technologies could have if they were installed on all vehicles driven by older and middle-aged drivers and all those drivers used them all the time. Those maximum potential estimates allowed us to compare the relative benefits of each technology and technology type for the two age groups and identify any particular benefits for older drivers. Our results indicate that these technologies have the potential to offer resounding benefits for all drivers; however, certain technologies may offer greater advantages for older drivers because they are overrepresented in crash scenarios that these features are designed to mitigate.

Despite a substantial reduction in older drivers' crashes per vehicle miles traveled since the mid-1990s, crashes continue to be more likely to be fatal for older drivers than for middle-aged drivers (Cox & Cicchino, 2021a). This study shows that intersection assistance features may offer more promise for older drivers than several other technologies because older drivers are more often involved and injured in turning-related intersection crashes than middle-aged drivers. Intersection assistance also appears to have potential to prevent or mitigate some of the crash scenarios that tend to be most severe for older drivers. Older drivers are especially likely to be involved in intersection crashes, especially those in which the older driver is turning left (Alam & Spainhour, 2008; Cicchino & McCartt, 2015; Clarke et al., 2010; Dotzauer et al., 2013). That suggests the current version of left turn assist—which only benefits the driver who is turning left—may offer more protection for these drivers than for those of other age groups. Our results also indicate that the added intersection-specific crash avoidance capabilities enabled by V2V-connectivity could also have greater benefits for older drivers than for middle-aged drivers. Combined, intersection movement assist and V2V-enhanced left turn assist could potentially address around a third of the intersection crashes that result in older driver injuries and fatalities. Nevertheless, because these technologies are either not yet widely available or not available at all, it will take many years before these benefits come to fruition. An important first step is to quickly increase the proportion of new vehicles that are equipped with the existing left turn assist technology.

When we estimated the maximum potential benefit that might result if every driver used all these vehicle safety features simultaneously, we found that the impact would likely be similar for older and middle-aged drivers with respect to minimizing crash involvements and mitigating driver injuries. However, with regard to preventing driver fatalities, the potential benefits for middle-aged drivers appear to be greater.

Similarly, while conventional crash avoidance features are important for all drivers, our findings suggest that on a combined basis they may not reduce crash involvements and fatalities as much for older drivers as for their middle-aged counterparts. This is because older drivers were underrepresented in the types of crash scenarios to which those technologies are relevant compared with middle-aged drivers—specifically, crash scenarios of all severities to which front crash prevention was potentially relevant and scenarios with driver deaths to which front crash prevention and lane departure prevention were potentially relevant.

Still, the disparities between these two age groups should not be interpreted to mean that these technologies do not have substantial value for the underrepresented age group. The proportion of crash involvements that lane departure prevention might address did not vary significantly between the age groups. However, middle-aged drivers were much more likely than older drivers to be injured or killed in such crashes. That discrepancy likely exists because the most severe of these crashes, particularly single-vehicle road departures, often stem from risky driving behaviors more prevalent among middle-aged drivers than older ones (Guo et al., 2017; Rakotonirainy et al., 2012; Schroeder et al., 2013) such as alcohol use, speeding, and inattention (Liu & Subramanian, 2009). Front crash prevention systems have the potential to address fewer crash involvements and fatalities but more driver injuries for older drivers than for middle-aged drivers, which means front crash prevention offers potential benefits for both age groups. Blind spot detection, too, targets a crash scenario that disproportionately affects older drivers, likely due in part to reduced mobility that makes it difficult for them to turn their heads to see out the side windows (Eby

& Molnar, 2014), though it is possible this technology is relevant to few crashes and resulting injuries and fatalities overall.

Our results also show that improved vehicle headlights may benefit middle-aged drivers more than older drivers, but here the crash numbers may not tell the entire story. It is possible that older drivers have fewer nighttime crashes than their middle-aged counterparts because older drivers do not drive as frequently at night (Braitman & McCartt, 2008; Naumann et al., 2011). The aging process causes a reduction in the size of the pupil and a yellowing of the eye lens that means objects must be illuminated far more brightly for an older adult to see them than is necessary for a younger person (Mortimer & Fell, 1989). The improvements made to headlights in recent years have resulted in clear benefits for all road users, and because of these age-related declines in their vision, the older drivers who do drive at night may benefit.

This study shows what the *maximum* potential safety benefits could be for these vehicle technologies based on the number of crashes, driver injuries, and driver fatalities that occurred in scenarios to which the technologies would potentially be relevant over a 4-year span; however, these numbers are not the same as actual effect estimates. The actual effects would be lower because these systems have inherent functional limitations and cannot prevent every crash that occurs in the scenarios they were designed to address. For example, inclement weather limits the effectiveness of automatic emergency braking (Cicchino & Zuby, 2019; Spicer et al., 2021).

Previous studies have calculated actual effect estimates for the general population for front crash prevention, lane departure warning, and blind spot detection, but not for intersection assistance features. Specifically, automatic emergency braking has been shown to reduce rear-end crash rates by 50% (Cicchino, 2017a), lane departure warning has been shown to reduce relevant crash rates by 11% (Cicchino, 2018b), and blind spot detection has been shown to reduce lane change crash rates by 14% (Cicchino, 2018a). Applying those effect estimates to the numbers of crashes that the current study estimated that the technologies could potentially address demonstrates that they would also have considerable safety benefits for older drivers in actual terms. We anticipate that among older drivers, front crash prevention would prevent nearly 40,000 rear-end crashes per year, lane departure warning would prevent approximately 2,500 crashes per year, and blind spot detection would prevent over 4,000 crashes per year.

Caution is warranted when it comes to interpreting these maximum potential safety benefit estimates. Spicer et al. (2021) and HLDI (2019, 2021a, 2021b) have shown that the benefits of conventional crash avoidance technologies are generally smaller for older drivers than the rest of the population. Nevertheless, the conclusion remains the same: The benefits of these features could be substantial for drivers of all ages if every driver had access to them and used them consistently. This is exemplified in a study by Lester et al. (2015) that found that both older and younger drivers show improved braking reaction time when assisted by forward collision warning, even though the feature has a smaller benefit for older drivers in part due to age-related perceptual and cognitive decline.

Additional barriers could prevent the maximum potential safety benefits estimated in this paper from coming to fruition. Although more new vehicles are being offered with these technologies every year as standard or optional features, they are still not widespread in the registered vehicle fleet (HLDI, 2020b). Compounding this hurdle, Oxley et al. (2019) surveyed Australian older drivers ages 65 years and older and found they were generally unaware of many advanced driver assistance technologies, and Cox and Cicchino (2021b) found that within the United States drivers 70 years and older were less likely than middle-aged drivers to have required blind spot detection and front crash prevention when purchasing their personal vehicles. Cutting-edge features like left turn assist typically become available first as expensive options on luxury vehicles or on top trim levels, then slowly trickle down to mass market models as dictated by consumer demand or government mandates. This means that some, if not all, of these vehicle technologies may remain out of reach for many older drivers who have limited disposable income (Cox & Cicchino, 2021b; Willstrand et al., 2015) for many years. Complicating this adoption barrier further, older drivers retain their vehicles longer than middle-aged drivers, so it takes longer for seniors to gain access to new technologies than younger drivers (Cox & Cicchino, 2021b; Metzger et al., 2020). More encouragingly, though older adults are less likely to be aware of these technologies or drive vehicles equipped with them, they report a high acceptance of (Stevens, 2012) and willingness to use (Souders & Charness, 2016; Souders et al., 2017) these features when they are introduced to them.

Despite the importance of increasing access to and usage of these technologies, there could be unintended consequences, particularly among older drivers with sensory and cognitive impairments (Stevens et al., 2020). For drivers with attention-related impairments, the way some of these technologies communicate to the driver or intervene to avoid a crash could lead to adverse outcomes (e.g., Ziefle et al., 2008). Many crash avoidance features alert the driver but do not act on behalf of the driver—requiring the driver to brake to avoid a hazard or to avoid steering into the adjacent lane when an alert indicates it is occupied. But if the alerts or interventions are startling or distracting, some drivers might not react to the hazards appropriately. Drivers who trust the technologies without understanding their limitations may also rely on the alerts rather than paying attention to the road. In a naturalistic observation study, Stevens (2012) observed that this overreliance was more common among older drivers than younger drivers. Older drivers might also rely on driver assistance technologies to make up for their impairments instead of avoiding challenging driving conditions (e.g., nighttime or highway driving)—increasing their personal mobility with potentially adverse consequences for traffic safety. To minimize these unintended consequences, more research is needed on the requirements of older drivers and the constraints they face according to their various forms and degrees of impairment so that we may better understand whether and how they may benefit from these features. In turn, that additional research may lead to more user-friendly designs that encourage proper system use.

A limitation of this study is that it does not represent an exhaustive list of vehicle technologies relevant to older drivers. The crash data used in this study likely underreports driver distraction at the time of the crash (e.g., McCartt et al., 2014), which prevented an analysis of the possible benefits of driver monitoring and management technologies. Although rearview camera and parking assistance features have been identified as important technologies for older drivers (Cicchino, 2017b), the FARS and CRSS databases only include crashes that occurred on public roads. As a result, the most common types of backing crashes to which rearview camera and parking assistance features could be relevant, such as those that typically occur on a private driveway or parking lot, are not captured in these databases and therefore could not be included in the current study. Our analysis focused on technology installed on the older or middle-aged driver's vehicle, and thus did not consider crashes that could be prevented by conventional crash avoidance features or improved headlights installed on the crash partner vehicle. Considering potential technology on crash partners would have increased the estimated benefits of these technologies in multivehicle crashes.

CONCLUSIONS

In summary, this study has shown that all drivers could benefit from crash avoidance features and improved headlights. Some drivers may benefit more from some features than others, partly because certain age groups are overrepresented in crash types that specific crash avoidance features are designed to address. Specifically, this study demonstrated that crash avoidance features designed to mitigate intersection crash scenarios (i.e., currently existing left turn assist and its future cousin, V2V-enhanced left turn assist), may potentially benefit older drivers more than middle-aged drivers, whereas improved headlight systems may benefit middle-aged drivers more than older drivers. These vehicle technologies can benefit drivers of all ages, however. More research is needed to better understand how age-related driver characteristics influence the efficacy of different vehicle safety features, but the evidence is already clear that these technologies have the potential to address thousands of crashes, driver injuries, and driver deaths every year.

PRACTICAL APPLICATIONS

Widely available crash avoidance technologies should be promoted for and adopted by all drivers. Manufacturers should be encouraged to pursue equipping intersection-specific crash avoidance technologies on all new vehicles.

ACKNOWLEDGEMENTS

This study was supported by the Insurance Institute of Highway Safety

TABLES

Table 1. Crash scenario definitions relevant to each crash avoidance feature.

System	Crash scenario	Scenario definition	CRSS/FARS code [a]
Front crash prevention	Rear end	Two-vehicle rear-end crash in which the driver's vehicle was the striking vehicle.	ve_forms=2 and ((acc_type in (20,24,28)) or (acc_type in (32,33)) and impact1 in (11,12,1) and impact1_p in (5,6,7))
	Pedestrian	Single-vehicle crash involving a pedestrian with frontal point of impact on the vehicle.	ve_forms=1 and per_typ_c=5 and acc_type=13 and impact1 in (11,12,1)
Lane departure prevention	Single-vehicle road departure	Single-vehicle drive-off-road crash; critical precrash event of traveling over the lane line or road edge; not passing, overtaking another vehicle, changing lanes, merging, or executing a successful avoidance maneuver to a previous critical event prior to crash; speed limit ≥ 35 mph.	ve_forms=1 and acc_type in (1,6) and p_crash2 in (10,11,12,13) and p_crash1 not in (6,15,16,17) and 35<=vspd_lim<98
	Same direction sideswipe	Two-vehicle sideswipe crash in which neither vehicle intended to change lanes; critical precrash event of traveling over the lane line; not passing, overtaking another vehicle, changing lanes, merging, or executing a successful avoidance maneuver to a previous critical event prior to crash; speed limit ≥ 35 mph.	ve_forms=2 and acc_type in (44,45) and acc_type_p in (44,45) and p_crash2 in (10,11) and p_crash1 not in (6,15,16,17) and 35<=vspd_lim<98
	Head-on and opposite direction sideswipe	Two-vehicle head-on crash in which the driver's vehicle departed the lane; not passing, overtaking another vehicle, changing lanes, merging, or executing a successful avoidance maneuver to a previous critical event prior to crash; speed limit ≥ 35 mph.	ve_forms=2 and acc_type in (50, 64) and p_crash1 not in (6,15,16,17) and 35<=vspd_lim<98
Blind spot detection	Lane change	Two-vehicle sideswipe crash in which the driver's vehicle was passing, overtaking another vehicle, changing lanes, or merging prior to crash.	ve_forms=2 and acc_type in (46,47) and p_crash1 in (6,15,16)
Improved headlights	Dark ambient lighting	Any crash occurring in low ambient light conditions, including dark and unlighted, dark and lighted by overhead artificial light, and dark with unknown lighting.	lgt_cond in (2,3,6)

System	Crash scenario	Scenario definition	CRSS/FARS code [a]
Left turn assist and V2V-enhanced left turn assist	Left turn across path—opposite direction	Two-vehicle crash at an intersection in which the driver's vehicle was making a left turn and collided with another vehicle traveling straight from the opposite (i.e., oncoming) direction.	ve_forms=2 and reljct2 in (2,3,4,8) and acc_type=68
V2V-enhanced left turn assist (only)	Moving straight into path of another vehicle turning left	Two-vehicle crash at an intersection in which the driver's vehicle was traveling straight through the intersection across the path of another vehicle making a left turn from the opposite (i.e., oncoming) direction.	ve_forms=2 and reljct2 in (2,3,4,8) and acc_type=69
Intersection movement assist	Straight, crossing path	Two-vehicle crash at an intersection in which a vehicle traveling straight through the intersection crossed the path of an oncoming vehicle approaching from the left or right. Includes the striking and struck vehicles.	ve_forms=2 and reljct2 in (2,3,4,8) and 86≤acc_type≤91
	Turn into path, same or opposite directions	Two-vehicle crash at an intersection in which one vehicle turned into the path of another vehicle approaching from the side (right or left), from the same or opposite direction. Includes the striking and struck vehicles.	ve_forms=2 and reljct2 in (2,3,4,8) and acc_type in (76,77,78,79,80,81,83,84, 85)
	Turn into path, opposite direction (turning left only)	Subset of turn-into-path crash type in which the driver's vehicle made a left turn into the path of another vehicle coming from the left side	ve_forms=2 and reljct2 in (2,3,4,8) and acc_type=82

Note: Crash scenario identification, scenario definition, and CRSS/FARS coding for front crash prevention, lane departure prevention, and blind spot detection were first described in Mueller and Cicchino (2022). See the *2019 FARS/CRSS Coding and Validation Manual* (National Center for Statistics and Analysis, 2020) for information on crash type configuration for the acc_type variable.

[a] Coded in terms of driver or vehicle unless otherwise noted. "_p" signifies partner vehicle in crash; "_c" signifies a person of this type was involved in the crash.

Table 2. Average annual number and percent of older and middle-aged driver crash involvements relevant to vehicle technologies, 2016–2019.

Technology	Crash scenario	Older driver crash involvements, *N* per year, (%)	Middle-aged driver crash involvements, *N* per year, (%)	Older drivers' representation in relevant crash scenarios relative to middle-aged drivers (95% confidence limits)
Conventional crash avoidance features				
Front crash prevention	Rear end	78,066 (11%)	465,226 (15%)	0.74 (0.70, 0.78)
	Pedestrian	4,670 (1%)	17,123 (1%)	1.20 (1.08, 1.33)
	Total front crash prevention	82,736 (12%)	482,348 (16%)	0.76 (0.72, 0.79)
Lane departure prevention	Single-vehicle road departure	15,787 (2%)	77,106 (3%)	0.90 (0.81, 1.01)
	Same direction sideswipe	3,280 (0.5%)	11,837 (0.4%)	1.22 (0.96, 1.55)
	Head-on/opposite direction sideswipe	3,430 (1%)	15,737 (1%)	0.96 (0.76, 1.21)
	Total potentially prevented by lane departure prevention	22,497 (3%)	104,680 (3%)	0.95 (0.86, 1.04)
Blind spot detection	Lane change	29,991 (4%)	97,096 (3%)	1.36 (1.24, 1.49)
Total conventional crash avoidance features		135,224 (20%)	684,124 (23%)	0.87 (0.84, 0.90)
Headlights	Dark ambient lighting	99,054 (14%)	702,063 (23%)	0.62 (0.60, 0.65)
Intersection assistance features				
Left turn assist [a]	Left turn across path – opposite direction	38,642 (6%)	96,788 (3%)	1.76 (1.62, 1.91)
	Moving straight into path of another vehicle turning left (with V2V only)	20,156 (3%)	119,671 (4%)	0.74 (0.68, 0.80)
	All V2V left turn assist scenarios	56,230 (8%)	183,721 (6%)	1.35 (1.28, 1.42)
Intersection movement assist [a]	Straight, crossing path	62,992 (9%)	198,815 (7%)	1.39 (1.32, 1.47)
	Turn into path, same or opposite directions	75,295 (11%)	234,608 (8%)	1.41 (1.35, 1.48)
	Turn into path, opposite direction (turning left only)	25,744 (4%)	67,066 (2%)	1.69 (1.53, 1.87)
	All intersection movement assist scenarios	162,114 (24%)	478,986 (16%)	1.49 (1.44, 1.54)
Total intersection assistance features		218,343 (32%)	662,708 (22%)	1.45 (1.41, 1.49)
All technologies combined		407,037 (60%)	1,766,466 (59%)	1.01 (1.00, 1.03)

Note: Total values for each technology category are subject to rounding errors. [a] Individual left turn assist and intersection movement assist crash involvement counts do not add up to the total for those scenarios because crashes in which both drivers involved were of the same age group weren't double counted.

Table 3. Average annual number and percent of older and middle-aged drivers with serious or minor injury (A or B) crash outcomes to which various vehicle technologies could have been relevant, 2016–2019.

Technology	Crash scenario	Injured older drivers, *N* per year, (%)	Injured middle-aged drivers, *N* per year, (%)	Older drivers' representation in relevant crash scenarios relative to middle-aged drivers (95% confidence limits)
Conventional crash avoidance features				
Front crash prevention	Rear end	4,333 (9%)	12,512 (7%)	1.34 (1.09, 1.65)
Lane departure prevention	Single-vehicle road departure	3,661 (7%)	15,896 (8%)	0.89 (0.76, 1.04)
	Same direction sideswipe	63 (0.1%)	414 (0.2%)	0.59 (0.14, 2.54)
	Head-on/opposite direction sideswipe	539 (1%)	3,022 (2%)	0.69 (0.46, 1.04)
	Total potentially prevented by lane departure prevention	4,263 (9%)	19,332 (10%)	0.85 (0.74, 0.99)
Blind spot detection	Lane change	462 (1%)	1,705 (1%)	1.05 (0.61, 1.80)
Total conventional crash avoidance features		9,057 (18%)	33,548 (18%)	1.04 (0.94, 1.16)
Headlights	Dark ambient lighting	6,877 (14%)	52,686 (28%)	0.50 (0.45, 0.57)
Intersection assistance features				
Left turn assist	Left turn across path—opposite direction	4,505 (9%)	7,102 (4%)	2.45 (2.05, 2.94)
	Moving straight into path of another vehicle turning left (with V2V only)	2,301 (5%)	11,763 (6%)	0.76 (0.62, 0.93)
	All V2V left turn assist scenarios	6,806 (14%)	18,865 (10%)	1.40 (1.22, 1.60)
Intersection movement assist	Straight, crossing path	6,005 (12%)	20,868 (11%)	1.11 (0.94, 1.32)
	Turn into path, same or opposite directions	3,608 (7%)	11,325 (6%)	1.23 (0.99, 1.53)
	Turn into path, opposite direction (turning left only)	2,265 (5%)	4,347 (2%)	2.02 (1.52, 2.68)
	All intersection movement assist scenarios	11,878 (24%)	36,539 (19%)	1.26 (1.11, 1.42)
Total intersection assistance features		18,684 (38%)	55,404 (29%)	1.30 (1.20, 1.41)
All technologies combined		31,161 (63%)	118,670 (62%)	1.02 (0.98, 1.06)

Note: Total values for each technology category are subject to rounding errors.

Table 4. Average annual number and percent of older and middle-aged driver fatal injury outcomes to which various vehicle technologies were potentially relevant, 2016–2019.

Technology	Crash scenario	Older driver fatalities, *N* per year, (%)	Middle-aged driver fatalities, *N* per year, (%)	Older drivers' representation in relevant crash scenarios relative to middle-aged drivers (95% confidence limits)
Conventional crash avoidance features				
Front crash prevention	Rear end	73 (3%)	153 (3%)	0.81 (0.70, 0.92)
Lane departure prevention	Single-vehicle road departure	435 (16%)	1,079 (23%)	0.68 (0.65, 0.72)
	Same direction sideswipe	3 (0.1%)	6 (0.1%)	1.00 (0.50, 1.98)
	Head-on/opposite direction sideswipe	177 (6%)	479 (10%)	0.62 (0.57, 0.68)
	Total potentially prevented by lane departure prevention	615 (22%)	1,564 (34%)	0.67 (0.64, 0.69)
Blind spot detection	Lane change	11 (0.4%)	14 (0.3%)	1.34 (0.90, 1.97)
Total conventional crash avoidance features		699 (25%)	1,731 (37%)	0.68 (0.66, 0.71)
Headlights	Dark ambient lighting	464 (17%)	2,213 (48%)	0.35 (0.34, 0.37)
Intersection assistance features				
Left turn assist	Left turn across path—opposite direction	178 (6%)	44 (1%)	6.89 (5.85, 8.12)
	Moving straight into path of another vehicle turning left (with V2V only)	32 (1%)	29 (0.6%)	1.87 (1.45, 2.39)
	All V2V left turn assist scenarios	210 (8%)	73 (2%)	4.88 (4.28, 5.56)
Intersection movement assist	Straight, crossing path	381 (14%)	244 (5%)	2.64 (2.44, 2.85)
	Turn into path, same or opposite directions	73 (3%)	35 (1%)	3.57 (2.92, 4.36)
	Turn into path, opposite direction (turning left only)	190 (7%)	59 (1%)	5.43 (4.70, 6.27)
	All intersection movement assist scenarios	644 (23%)	338 (7%)	3.22 (3.03, 3.43)
Total intersection assistance features		854 (31%)	411 (9%)	3.52 (3.33, 3.71)
All technologies combined		1,796 (65%)	3,360 (72%)	0.90 (0.89, 0.92)

Note: Total values for each technology category are subject to rounding errors.

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