Journal of Safety Research 73 (2020) 263–269

Contents lists available at ScienceDirect

Journal of Safety Research

journal homepage: www.elsevier.com/locate/jsr

Near crash characteristics among risky drivers using the SHRP2 naturalistic driving study

Thomas Seacrist [a,*], Ethan C. Douglas [a,b], Chloe Hannan [a], Rachel Rogers [a], Aditya Belwadi [a], Helen Loeb [a]

[a] Center for Injury Research and Prevention, The Children's Hospital of Philadelphia, United States
[b] Department of Bioengineering, University of Pennsylvania, United States

ARTICLE INFO

Article history:
Received 1 March 2019
Received in revised form 9 September 2019
Accepted 17 March 2020
Available online 2 April 2020

Keywords:
Naturalistic driving
SHRP2
Risky drivers
Near crashes

ABSTRACT

Problem: Previous research have focused extensively on crashes, however near crashes provide additional data on driver errors leading to critical events as well as evasive maneuvers employed to avoid crashes. The Strategic Highway Research Program 2 (SHRP2) Naturalistic Driving Study contains extensive data on real world driving and offers a reliable methodology to study near crashes. The current study utilized the SHRP2 database to compare the rate and characteristics associated with near crashes among risky drivers. *Methods:* A subset from the SHRP2 database consisting of 4,818 near crashes for teen (16–19 yrs), young adult (20–24 yrs), adult (35–54 yrs), and older (70+ yrs) drivers was used. Near crashes were classified into seven incident types: rear-end, road departure, intersection, head-on, side-swipe, pedestrian/cyclist, and animal. Near crash rates, incident type, secondary tasks, and evasive maneuvers were compared across age groups. For rear-end near crashes, near crash severity, max deceleration, and time-to-collision at braking were compared across age. *Results:* Near crash rates significantly decreased with increasing age ($p < 0.05$). Young drivers exhibited greater rear-end ($p < 0.05$) and road departure ($p < 0.05$) near crashes compared to adult and older drivers. Intersection near crashes were the most common incident type among older drivers. Evasive maneuver type did not significantly vary across age groups. Near crashes exhibited a longer time-to-collision at braking ($p < 0.01$) compared to crashes. *Summary:* These data demonstrate increased total near crash rates among young drivers relative to adult and older drivers. Prevalence of specific near crash types also differed across age groups. Timely execution of evasive maneuvers was a distinguishing factor between crashes or near crashes. *Practical Applications:* These data can be used to develop more targeted driver training programs and help OEMs optimize ADAS to address the most common errors exhibited by risky drivers.

1. Introduction

Motor-vehicle crashes continue to be a significant problem in the United States and worldwide. While the National Center for Statistics and Analysis (NCSA) found a decrease in the number and rate of fatal crashes in 2017 and the first half of 2018 (NCSA, 2018a, 2018b), bringing the United States out of a multi-year increase in fatal crashes, motor-vehicle crashes remain a leading cause of death for those 65 years and younger as well as the second leading cause of unintentional injury-related deaths (Webb, 2018). Globally, road traffic fatalities remain a leading cause of death, particularly among low to middle-income countries (WHO, 2015).

Disproportionately represented among motor-vehicle fatalities are risky drivers, specifically young and older drivers (IIHS, 2018a). Previous research has suggested that *inexperience* and *skill deficits* among young drivers (McKnight & McKnight, 2003; White and Caird, 2010; Curry et al., 2011; McDonald, 2013, McDonald Curry, Kandadai, Sommers, & Winston, 2014; Montgomery, Kusano, & Gabler, 2014; Loeb, Kandadai, McDonald, & Winston, 2015; McGehee et al., 2016) and *degrading health and motor skills* among older drivers (Braitman, Kirley, Chaudhary, & Ferguson, 2007; Callaghan, Holland, & Kessler, 2017; Conlon, Power, Hine, & Rahaley, 2017; Owsley, McGwin, & Ball, 1998; Oxley, Charlton, Koppel, Scully, & Fildes, 2005) contribute to their increased crash rate. However, it is important to recognize that crashes alone do *not* tell the whole story. Near crashes – events where the driver executes an evasive maneuver to avoid a collision or road departure – are also important to fully understand the contributing

* Corresponding author at: Center for Injury Research and Prevention, The Children's Hospital of Philadelphia, 2716 South St, 13th Floor, Philadelphia, PA 19146, United States.

E-mail address: seacrist@email.chop.edu (T. Seacrist).

https://doi.org/10.1016/j.jsr.2020.03.012
0022-4375/

factors and crash avoidance mechanisms that differentiate which driving errors result in crashes or near crashes.

Some previous small-scale naturalistic studies have combined crashes and near crashes into safety critical events (Farmer et al., 2015; Guo et al., 2013; Simons-Morton et al., 2011a, 2011b). While the use of near crashes as a proxy for crashes has been shown to increase the precision of odds ratio estimates and allow for statistically significant estimations that would not be possible with the analysis of crashes alone, significant differences in the number of contributing factors for lead vehicle conflicts have also been found between crashes and near crashes (Guo et al., 2010). Furthermore, the validity of linking safety critical events, such as near crashes, to more severe crashes has been called into question, particularly given that crashes are typically defined by consequences such as fatality, injury, and property damage, whereas near crashes are defined by driver maneuvers (Knipling, 2015). Previous large truck naturalistic driving studies have shown significant differences in evasive maneuver presence and crash type between severe crashes and safety critical events (Hickman et al., 2005). Consequently, there is a need to study near crashes in isolation and compare their characteristics to those of crashes. Additionally, near crashes may differ in frequency, incident type, driver behavior, crash avoidance mechanisms, or vehicle dynamics among risky drivers. Therefore, there is also a need to study the characteristics of near crashes among risky driving groups to inform more targeted, driver-specific interventions.

Given that near crashes are not police-reported nor quantified in archival databases, naturalistic driving studies represent one of the only methods for reliably studying near crashes. Several previous studies have conducted small scale naturalistic evaluations of near crashes. Results from the 100-Car Study reported increased near crash incidence rates among the youngest three age groups compared to older drivers (Dingus, Klauer, & Neale, 2006). Simons-Morton, Ouimet, and Zhang, (2011) compared crashes, near crashes, and risky driving events between 42 adolescent-parent driver dyads over 18-months and found that adolescents exhibited nearly four-times greater crash/near crash incidence rate, and five-times greater incidence rate ratio for risky driving, than their parents. While these studies provide valuable data on the incidence of near crashes, a larger more comprehensive naturalistic driving study, inclusive of both younger teen drivers and older drivers, is needed to ensure these findings are generalizable.

The Strategic Highway Research Program 2 (SHRP2) Naturalistic Driving Study (NDS) contains extensive data on real world driving and offers a reliable methodology to quantify and study near crashes. The current study utilized the SHRP2 database to compare the rate, type, evasive maneuvers, and secondary tasks associated with near crashes among risky drivers. Our previous SHRP2 research studied near crashes among young drivers (Seacrist et al., 2018), illustrating that young drivers exhibited increased incidence of near crashes, but utilized similar crash avoidance mechanisms compared to adult drivers. The current study expands this work to include older drivers as well as an additional 3,000+ events among young and adult drivers released as part of the August 2017 SHRP2 NDS update.

2. Methods

This study protocol was approved by the Institutional Review Board at the Children's Hospital of Philadelphia.

2.1. SHRP2 dataset

A subset of the SHRP2 NDS data set was obtained via a data use license with the Virginia Tech Transportation Institute (VTTI). Scene videos, event narratives, secondary tasks, incident type, evasive maneuvers, and times series data pre- and post-event including vehicle velocity and radar data were obtained for all crash (n = 1,317) and near crash (n = 4,818) events previously identified by VTTI for four groups: teens (16–19 yrs), young adults (20–24 yrs), adults (35–54 yrs), and older adults (70+ yrs). All participants were independent drivers; no learner stage (supervised) drivers were included in the SHRP2 NDS. Time series data ranged from 20 s prior to 10 s post event and were collected at 10 Hz. Trip distance – computed by VTTI by integrating the recorded vehicle speed during each trip – was obtained for all trips for the four age groups.

2.2. Data processing

Near crash events were previously identified by VTTI based on elevated vehicle acceleration and/or yaw rate and verified by 2 video coders (Hankey et al., 2016). In this study, near crashes were defined as events where the instrumented vehicle or other vehicle, pedestrian, cyclist, or animal executed an evasive maneuver to avoid a collision or departing the roadway, where the instrumented vehicle was *at-fault* (Simons-Morton et al., 2011a). *At-fault* was defined as an event where the driver of the subject vehicle committed an obvious error that led to the near crash (e.g., illegal vehicle maneuvers and distracted driving). *Non-fault* was defined as an event where the driver of another vehicle, pedestrian, or cyclist committed an obvious error or the sudden appearance of an animal/object resulted in a near crash (e.g., illegal vehicle maneuvers and the sudden appearance of a deer). *Fault* was determined based on VTTI classifications and confirmed based on scene video and event narrative review.

Near crashes were classified into seven incident types – (1) rear-ends, (2) road departures, (3) intersections, (4) side-swipe, (5) head-on, (6) animal, and (7) pedestrian/cyclist – by two independent coders based on scene video and event narrative review. Discrepancies were reconciled by the study team.

Secondary tasks preceding crashes and near crashes were previously logged by VTTI based on the interior cabin videos; these tasks were grouped into six secondary task categories:

(1) Cell Phone – talking, texting, or using an app
(2) Distraction (internal) – eating/drinking, adjusting radio, tending to objects, hygiene
(3) Distraction (external) – looking at objects outside of the vehicle
(4) None
(5) Passenger interaction – talking or looking at passengers
(6) Singing/talking – soliloquies, singing, dancing

Evasive maneuvers occurring during crash and near crash events were previously logged by VTTI; these maneuvers were grouped into five categories: (1) braked, (2) braked & steered, (3) steered, (4) other, (5) none.

Miles driven was computed by summing the recorded trip distance for all trips within each age group. Near crash rates were computed as the number of *at-fault* near crashes per million miles driven for each age group. *Non-fault* near crashes as well as minor near crashes with small animals, curbs, or traffic cones were excluded. The near crash rate ratio was computed as the ratio of the near crash rate of teen, young adult, and older drivers to adult drivers. Crash rates among young adults were calculated similarly, using previously established methods (Seacrist et al., 2016, 2018).

To compare the total number of *at-fault* critical events across age, crashes and near crashes within each cohort were combined and redefined as critical events. A critical event rate ratio was computed for teens and young adults compared to experienced adults.

To determine whether a particular age group was more effective at avoiding crashes when encountering critical events, a Near Crash-to-Crash rate ratio was compared between the four cohorts. A higher ratio indicated better crash avoidance when encountering a critical event.

Time series data for rear-end near crashes were imported into MATLAB 2017a (Mathworks, Inc.) for further processing. These time series logs were processed to extract relevant data such as max deceleration, braking timestamp, as well as the distance headway, relative velocity, and time-to-collision at the braking timestamp. The braking timestamp was extracted by identifying the time at which the largest difference in peaks occurred in the acceleration data. This method allowed for the extraction of the point at which the brakes were applied before the near crash. This timestamp was then verified for accuracy by video coders. Radar data used to derive distance headway and relative velocity at braking.

Radar data were only available at the braking timestamp for a subset of rear-end near crash events ($n = 1278$). An additional 81 events were removed from the analysis due to inaccurate radar data, yielding a total radar data set of 1,197 rear end near crashes. Relative velocity and distance headway at the braking timestamp were used to calculate time-to-collision at braking. Near crash severity was defined as the constant deceleration necessary to avoid a crash. Near crash severity was derived from basic kinematics and calculated using Eq. (1):

$$Near\ Crash\ Severity = \frac{\Delta V^2}{2 \cdot \Delta X} \tag{1}$$

where ΔV is relative velocity and ΔX is distance headway at the braking timestamp.

2.3. Statistical analysis

The Type I error rate was held at 0.05 for each test. Near crash and critical event rates were compared using Stata 15 statistical software; teen, young adult, and experienced adult rates were compared using the ratio of the Poisson 95% confidence intervals, along with Benjamini & Hochberg's method of controlling the false discovery rate. Statistical analysis on incident type, secondary tasks, evasive maneuvers, and rear-end near crash time series data were conducted in SPSS 25 (IBM Statistics, Inc.). A Pearson's chi-square test was used to compare near crash secondary tasks and evasive maneuvers between the four age groups. Pairwise Proportions tests with a Bonferroni correction were applied for a post-hoc comparison of significant chi-square test results. Given the relatively small number of animal, head-on, and side-swipe events, these were combined into an "Other" category for statistical analysis.

Shapiro–Wilk's tests of normality were conducted on rear-end near crash severity, maximum deceleration, and time-to-collision. These data were not normally distributed; therefore the variables were compared by age groups using Kruskal–Wallis test by ranks. Post-hoc pairwise significance was determined using Bonferroni corrected criteria.

For comparison between crashes and near crashes, secondary tasks and evasive maneuvers were re-categorized into a binary variable (present vs. not present). Crash events were combined among the four cohorts. Similarly, near crash events among the four cohorts were combined. The presence of secondary tasks and evasive maneuvers between crashes and near crashes was compared using Pearson's chi-square tests and logistic regression. Time-to-collision was compared between crashes ($n = 23$) and near crashes ($n = 853$) that had both a secondary task and evasive maneuver as well as reliable radar data. Time-to-collision between crashes and near crashes were compared using a Wilcoxon Rank-Sum test.

3. Results

3.1. Near crash and critical event rates

Filtering near crash events based on driver fault and severity yielded a total of 2,916 near crashes among the four age groups (teens = 779, young adults = 1206, adults = 583, older adults = 348). These events were further classified into the seven aforementioned crash types. Near crash rates per million miles driven for each near crash incident type are listed in Table 1.

Overall near crash rate ($p < 0.01$) as well as rear-end near crash rate ($p < 0.01$) significantly differed across all age groups. Teens ($p < 0.01$) exhibited a significantly greater road departure near crash rate compared to all other age groups. Young adults ($p < 0.05$) also exhibited elevated road departure near crash rate than adult and older adults. Older drivers exhibited an elevated inter-section near crash rate compared to young adults ($p < 0.05$). Young adults exhibited an elevated side-swipe near crash rate compared to teens ($p < 0.05$) and older adults ($p < 0.05$).

Critical event rates, near crash-to-crash ratios, and critical event ratios are listed in Table 2. Teens exhibited a significantly greater critical event rate ($p < 0.01$) compared to all other ages. Similarly, young adults ($p < 0.01$) exhibited a significantly greater critical event rate compared to adults and older drivers. No differences were found in critical event rate between adults and older drivers ($p = 0.15$), however the older driver near crash-to-crash ratio indicated that a substantially greater proportion of these events resulted in crashes. Teens and young adults also exhibited lower near crash-to-crash ratios compared to adults, indicating that a larger proportion of critical events resulted in crashes as opposed to near crashes. Teens and young adults were 2.0 and 1.6 times as likely to encounter a critical event compared to adults, respectively.

3.2. Near crash characteristics

The distribution of secondary tasks performed by drivers during near crashes for the four age groups is shown in Fig. 1. Secondary tasks were performed in 68% of near crashes. The most common secondary task category was "none" followed by "distraction (internal)" for all age groups. Results of the Pearson's chi-square test revealed a significant association between secondary task type and age group ($\chi^2 = 180$, $p < 0.01$). Cell phone use significantly differed across all age groups ($p < 0.05$), with young adults having the highest percentage of near crashes with cell phone use, whereas older adults had the lowest percentage of near crashes with cell phone use. Older adults had a significantly higher percentage of near crashes with external distractions compared to the other three age groups ($p < 0.05$). Older adults had a significantly higher percentage of near crashes with no distraction ($p < 0.05$) compared to the other three age groups. Adults also exhibited a higher percentage of near crashes with no distraction compared to teens ($p < 0.05$) and young adults ($p < 0.05$). Teens exhibited a significantly greater percentage of near crashes involving passenger interaction compared to young adults ($p < 0.05$). Finally, adults and older adults exhibited a significantly lower percentage of near crashes involving singing/talking ($p < 0.05$) compared to teens and young adults.

The distribution of evasive maneuvers performed by drivers during near crashes for the four age groups is shown in Fig. 2. Braking (73%) followed by a combination of braking and steering (23%) were the most common evasive maneuvers used to avoid near

Table 1
At-Fault Near Crash Rates per Million Miles Driven.

Group	Age Range	Miles Driven	Near Crash	Rear End	Road Departure	Inter-section	Side Swipe	Head-On	Animal	Pedestrian/Cyclist
Teen	16–19	4,205,474	185.2^{Y,A,O}	147.4^{Y,A,O}	12.6^{Y,A,O}	11.4	5.7^{Y}	1.7	1.4	2.4
Young Adult	20–24	7,691,129	156.8^{T,A,O}	125.5^{T,A,O}	5.1^{T,A,O}	9.5^{O}	10.0^{T,O}	1.2	0.3	3.5
Adult	35–54	5,651,315	103.2^{T,Y,O}	72.5^{T,Y,O}	2.5^{T,Y}	11.9	8.0	0.5	0.2	5.1
Older Adult	70–99	4,766,699	73.0^{T,Y,A}	42.8^{T,Y,A}	1.9^{T,Y}	14.7^{Y}	5.7^{Y}	0.2	0.2	4.0

T $p < 0.05$, compared to Teens.
Y $p < 0.05$, compared to Young Adults.
A $p < 0.05$, compared to Adults.
O $p < 0.05$, compared to Older Adults.

Table 2
Crash, Near Crash, and Critical Event Rates Per Million Miles Driven.

Group	Age Range (years)	Miles Driven	Crash Rate	Near Crash Rate	Near Crash-to-Crash Ratio	Critical Event Rate	Critical Event Ratio
Teen	16–19	4,205,474	23.5	185.2^{Y,A,O}	7.9	208.8^{Y,A,O}	2.0
Young Adults	20–24	7,691,129	17.9	156.8^{T,A,O}	8.8	174.7^{T,A,O}	1.6
Adult	35–54	5,651,315	3.9	103.2^{T,Y,O}	24.5	107.1^{T,A}	1.0
Older Adult	70–99	4,766,699	23.1	73.0^{T,Y,A}	3.2	96.1^{T,A}	0.9

T $p < 0.05$, compared to Teens.
Y $p < 0.05$, compared to Young Adults.
A $p < 0.05$, compared to Adults.
O $p < 0.05$, compared to Older Adults.

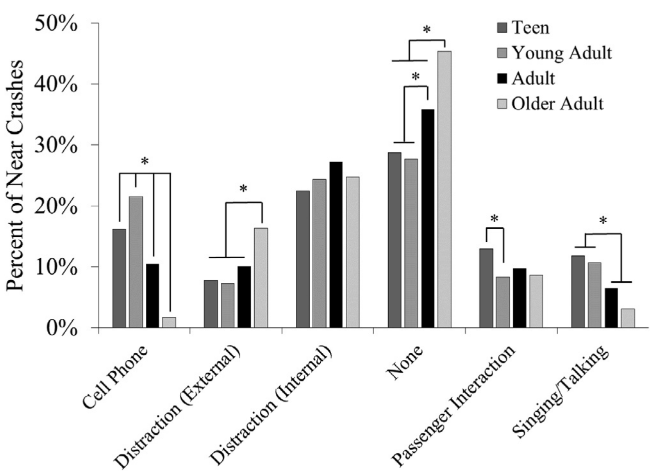

Fig. 1. Secondary tasks performed by drivers prior to near crashes.

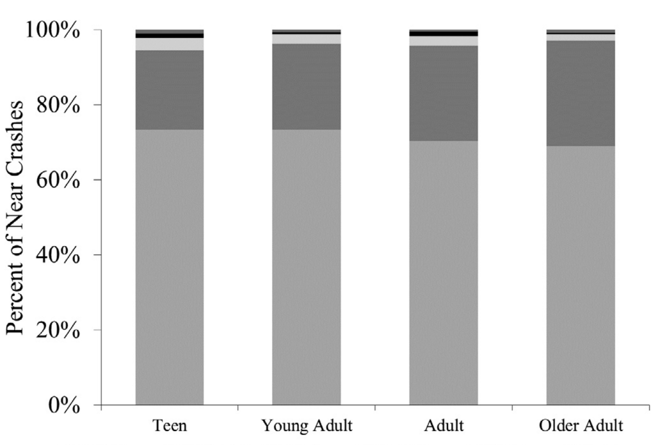

Fig. 2. Distribution of evasive maneuvers by age group.

crashes. Results of the Pearson's chi-square test revealed a significant association between evasive maneuver type and age group ($\chi^2 = 31$, $p < 0.01$). However, post-hoc proportions tests did *not* find significant differences in specific evasive maneuver types across age groups.

Mean ± standard error (SE) for maximum deceleration, near crash severity, and time-to-collision at braking are listed in Table 3. Maximum deceleration ($p < 0.01$), near crash severity ($p < 0.01$), and time-to-collision at braking ($p < 0.01$) significantly differed across age groups. Specifically, older adults had significantly greater maximum deceleration compared to all other age groups ($p < 0.01$). Young adults also exhibited a significantly lower ($p < 0.01$) max deceleration compared to teens. Older adults also had significantly higher near crash severity compared to young adults ($p < 0.01$) and adults ($p < 0.01$). Finally, older drivers exhibited a significantly shorter time-to-collision at braking than young adults ($p < 0.01$).

3.3. Comparison of crashes and near crashes

Secondary Task and Evasive Maneuver prevalence among crashes and near crashes as well as mean ± SE time-to-collision at braking for critical events with secondary tasks and evasive maneuvers are shown in Fig. 3. The prevalence of secondary tasks did not significantly differ between crashes and near crashes ($\chi^2 = 0$, $p = 0.99$). A significant association ($\chi^2 = 774$, $p < 0.01$) was observed between evasive maneuver type and critical event type (crash or near crash). Specifically, the odds of evasive maneuver being present was 61.1 (95% CI: 38.0–98.0) times greater for near crashes compared to crashes ($p < 0.01$). Time-to-collision at braking among crashes and near crashes with both a secondary task and evasive maneuver was significantly greater ($p < 0.01$) for near crashes compared to crashes.

4. Discussion

To our knowledge, this represents the first study to compare near crash characteristics between young and older drivers using the SHRP2 Naturalistic Driving Study. Our findings highlight

Table 3
Rear-End Near Crash Vehicle Time-Series Data.

Group	Age Range (years)	Maximum Deceleration (g)	Near Crash Severity (m/s^2)	Time-to-Collision (sec)
Teen	16–19	0.72 ± 0.01[O,Y]	0.11 ± 0.00	3.7 ± 0.2
Young Adult	20–24	0.69 ± 0.01[O,T]	0.10 ± 0.00[O]	4.2 ± 0.1[O]
Adult	35–54	0.72 ± 0.01[O]	0.10 ± 0.01[O]	4.0 ± 0.2
Older Adult	70–99	0.76 ± 0.01[T,Y,A]	0.15 ± 0.01[Y,A]	3.0 ± 0.2[Y]

[T] $p < 0.05$, compared to Teens.
[Y] $p < 0.05$, compared to Young Adults.
[A] $p < 0.05$, compared to Adults.
[O] $p < 0.05$, compared to Older Adults.

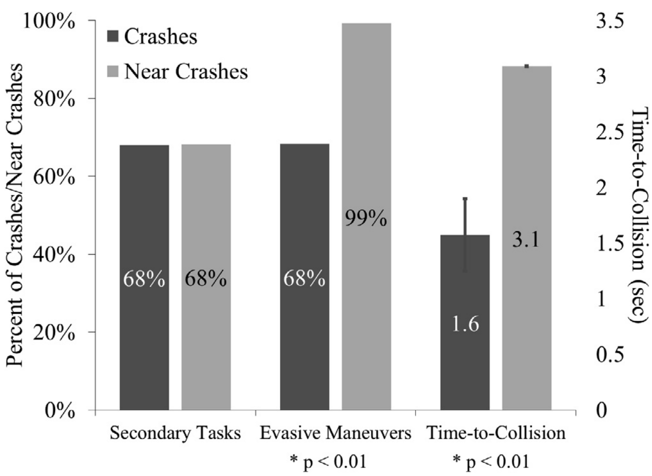

Fig. 3. Comparison of secondary tasks and evasive maneuvers between crashes and near crashes as well as time-to-collision at braking in rear-end striking crashes and near crashes with both an evasive maneuver and secondary task.

increased near crash rates among young drivers compared to adult and older drivers for overall near crashes as well as specific near crashes types: rear-ends and road departures near crashes. These data confirm to the small number of previous studies on near crashes, which showed increased incidence of near crashes among young drivers compared to older drivers (Dingus et al., 2006; Simons-Morton et al., 2011). These data also reflect data from the Fatality Analysis Reporting System and National Automotive Sampling System/General Estimates System databases (Williams, 2003) as well as data from nonfatal police-reported crashes (Tefft, 2017), indicating that young drivers are at elevated crash risk. These data support the validity of using non-severe safety critical events, such as near crashes, as proxies for injurious and fatal crashes when studying elevated crash risk among young drivers.

Contrarily, these near crash rates do *not* reflect the elevated crash risk observed in older adults (Williams, 2003; IIHS, 2018a). Previous research has suggested that the increase in fatal crashes among older drivers is due to age-based increases in injury risk rather than an increased number of crashes (Li, Braver, & Chen, 2003). Our findings support this study, showing that older drivers exhibit a lower near crash rate and critical event rate compared to other age groups. Consequently, the validity of linking non-severe safety critical events and injurious crashes for older drivers may not be supported.

Consistent with previous crash literature (Mayhew, Simpson, & Ferguson, 2006; Braitman et al., 2007; Sifrit, Stutts, Martell, & Staplin, 2011; Lombardi, Horrey, & Courtney, 2017; IIHS, 2018b), older drivers exhibited *reduced* rear-end and road departure near crash rates as well as *elevated* intersection near crash rates compared to other age groups. These findings support the argument that older drivers require more-targeted assistance at intersections (Dotzauer, Caljouw, de Waard Dick, & Brouwer, 2013).

Previous research has shown that cell phone use while driving contributes to crash risk (Asbridge, Brubacher, & Chan, 2013; Caird et al., 2014; Klauer et al., 2014; Carney, Mcgehee, Harland, Weiss, & Raby, 2015) and accounts for nearly one-quarter of distraction-based fatal crashes among adolescents (NHTSA, 2017). Interestingly, cell phone use accounted for the greatest variation in secondary tasks across age group (Fig. 1), with young drivers – specifically young adults – exhibiting the greatest prevalence of near crashes with cell phone use. One potential explanation is related to graduate drivers licensing (GDL) laws. Thirty eight states incorporate cell phone restriction into their GDL laws and all but two states ban texting for novice drivers (IIHS, 2018b). However, young adults (20–24 yrs) have likely phased out of these GDL restrictions and, consequently, may exhibit increased cell phone use compared to adult and older drivers. Older drivers exhibited the lowest proportion of near crashes involving cell phone use. This is in line with data from the National Survey on Distracted Driving Attitudes and Behaviors (Schroeder, Wilbur, & Peña, 2018), which indicate that older drivers (65+) were the least likely to use a cell phone while driving for calls, texting, navigation, and smartphone app use. These data suggest that cell-phone-use and texting-while-driving laws as well as apps that restrict cell phone use while driving will have greater influence on young adult near crashes than adult or older drivers, given their increased propensity for cell-phone use during these near crashes.

Previous research has established that passenger interaction among young drivers increases crash risk (Chen, Baker, Braver, & Li, 2000; Lam, Norton, & Woodward, 2003; Ouimet, Simons-Morton, & Zador, 2010; Williams, Ferguson, & McCartt, 2007) as well as other crash-associated factors such as aggressive driving and illegal maneuvers (Curry, Mirman, Kallan, Winston, & Durbin, 2012). In this study, teens exhibited a greater percentage of near crashes with passenger interaction (Fig. 2). These data suggest that passenger interaction among teens may also be a contributing factor to increased young driver near crash rates (Table 1). However, a comparison of passenger interaction during baseline driving among these SHRP2 drivers is needed to establish the association of passenger interaction with near crash risk.

Interestingly, older drivers exhibited the greatest proportion of near crashes with no secondary task (Fig. 1). This relative lack of secondary tasks compared to other age groups, suggests that the reason for older driver near crashes may be the result of declining motor function and skill degradation (Owsley et al., 1998; Oxley et al., 2005; Cicchino and McCartt, 2015; Conlon et al., 2017), rather than distraction and inexperience found in younger drivers (McKnight & McKnight, 2003; Curry et al., 2011; White and Caird, 2010; McDonald, 2013; Montgomery et al., 2014; McDonald et al., 2015). This is supported by the near crash radar data (Table 3), which showed that older drivers braked later than the younger age groups – possibly the result of slower reaction times or decreasing visual acuity. Congruently, older drivers exhibited elevated near crash severity, requiring a greater maximum deceleration to avoid the crash compared to the younger age groups (Table 3).

Surprisingly, the prevalence of secondary tasks did not differ between near crashes and crashes (Fig. 3). These data suggest that secondary task involvement may not be associated with the outcome of the safety critical event (crash vs. near crash), at least among those SHRP2 events included in this analysis. Rather, the safety critical event outcome seems to be associated with the driver's reaction to the critical event, specifically the timely execution of an evasive maneuver. This is evident from the significantly greater time-to-collision at braking among near crashes compared to crashes (Fig. 3). Interestingly, the mean time-to-collision at braking for near crashes is greater than the 2.7 second alert threshold used by some forward collision warning systems; conversely, the time-to-collision at braking is below this threshold. This suggests that advanced driver assistance systems (ADAS) that elicit driver reactions earlier in the critical event can shift the safety critical event outcome from crashes to near crashes.

Several limitations warrant discussion. First, given the relatively small number of studies on near crashes among teens (Dingus et al., 2006; Simons-Morton et al., 2011a), data available for comparison are limited. Consequently, the discussion compared some of our findings to crash literature with different outcomes than near crashes (e.g., fatal and police-reported crashes). While crashes differ with respect to near crashes, as illustrated by the data presented herein, these data help place the elevated young driver near crash risk in context with the well-known elevated fatal and police-reported crash risk as well as driving skill differences exhibited by teens that can help explain the elevated incidence of near crashes. Additionally, the identification of near crashes by subject vehicle dynamics necessitates that nearly all near crashes included in the SHRP2 NDS and this analysis included a driver-initiated evasive maneuver. There are likely additional near crashes in the SHRP2 NDS where the subject driver did *not* execute an evasive maneuver; these were not included in the current analysis. Therefore, the results presented herein may not be generalizable to all near crashes. Specifically, the significant difference in the prevalence of evasive maneuvers between crashes and near crashes (Fig. 3) may solely be due to the criterion used to detect near crashes. However, the absence of these crashes should not have a substantial effect on the time-to-collision at braking results (Fig. 3) since crashes and near crashes were matched based on the presence of a driver-initiated evasive maneuver. This study also presents data on secondary tasks conducted by drivers during SHRP2 near crashes. While specific secondary tasks such as cell phone use, passenger interaction, and distraction have been previously associated with increased crash risk, a comparison to baseline driving among these SHRP2 drivers is needed to truly establish whether these secondary tasks contributed to increased near crash risk. Furthermore, reliable radar data were only available for 55% of rear-end near crashes; this possibly introduced selection bias because this subset may not be representative of all rear-end near crash events. Finally, as with any naturalistic study, participant selection can introduce bias into the sample. The current study did not account for sociodemographic factors or driver-specific variables such as length of licensure or pre-existing medical conditions that were permissible inclusion criteria in SHRP2. These factors are a planned area of future work to determine how near crashes vary with behavioral, experiential, and environmental factors.

Nevertheless, this study utilizes one of the largest and most reliable datasets, to date, capable of analyzing near crashes. These data provide valuable information on the frequency, type, and characteristics of near crashes among risky driving groups, which can be used to develop more targeted driver training programs. Furthermore, these data can help inform the development of driver-specific ADAS. Specifically, driver monitoring systems may help reduce secondary task involvement, leading to reductions in the incidence of critical events, as well as forward collision warning to stimulate quicker driver reactions leading to a shift in the severity of rear-end critical events from crashes to near crashes.

Acknowledgements

The authors would like to acknowledge Walter Faig from the Children's Hospital of Philadelphia for his assistance with the statistical analysis. The authors would like to acknowledge the National Science Foundation (NSF) Center for Child Injury Prevention Studies (CChIPS), United States IU/CRC at the Children's Hospital of Philadelphia (CHOP) and The Ohio State University (OSU) for sponsoring this study and its Industry Advisory Board (IAB) members for their support, valuable input, and advice. This material is also based upon work supported by the National Science Foundation under Grant Number EEC-1460927. The views presented here are solely those of the authors and not necessarily the views of CHOP, CIRP, OSU, the NSF, or the IAB members.

References

Asbridge, M., Brubacher, J. R., & Chan, H. (2013). Cell phone use and traffic crash risk: A culpability analysis. *International Journal of Epidemiology, 42*(1), 259–267.

Braitman, K. A., Kirley, B. B., Chaudhary, N. K., & Ferguson, S. A. (2007). Factors leading to older driver' intersection crashes. *Traffic Injury Prevention*.

Caird, J. K., Johnston, K. A., Willness, C. R., Asbridge, M., & Steel, P. (2014). A meta-analysis of the effects of texting on driving. *Accident Analysis & Prevention, 71*, 311–318.

Callaghan, E., Holland, C., & Kessler, K. (2017). Age-related changes in the ability to switch between temporal and spatial attention. *Frontiers in Aging Neuroscience, 9*, 28.

Carney, C., Mcgehee, D. V., Harland, K., Weiss, M., & Raby, M. (2015). Using naturalistic driving data to assess the prevalence of environmental factors and driver behaviors in teen driver crashes.

Chen, L. H., Baker, S. P., Braver, E. R., & Li, G. (2000). Carrying passengers as a risk factor for crashes fatal to 16–17 year old drivers. *JAMA, 283*, 1578–1582.

Cicchino, J. B., & McCartt, A. T. (2015). Experiences of model year 2011 Dodge and Jeepowners with collision avoidance and related technologies. *Traffic Injury Prevention, 16*, 298–303.

Conlon, E. G., Power, Garry F., Hine, Trevor J., & Rahaley, Nicole (2017). The impact of older age and sex on motion discrimination. *Experimental Aging Research, 43*(1), 55–79.

Curry, A. E., Mirman, J., Kallan, M. J., Winston, F. K., & Durbin, D. R. (2011). Prevalence of teen driver errors leading to serious motor vehicle crashes. *Journal of Adolescent Health, 50*, 588–594.

Dingus, T. A., Klauer, S. G., Neale, V. L., et al. (2006). *The 100-Car naturalistic driving study, Phase II—Results of the 100-car field experiment.*. Washington, DC: National Highway Traffic Safety Administration. DOT HS 810 593.

Dotzauer, M., Caljouw, S. R., de Waard Dick & Brouwer, W. H. (2013). Intersection assistance: A safe solution for older drivers? *Accident Analysis & Prevention, 59*, 522–528.

Farmer, C. M., Klauer, S. G., McClafferty, J. A., & Guo, F. (2015). Relationship of near crash/crash risk to time spent on a cell phone while driving. *Traffic Inj Prev., 16*, 792–800.

Guo, F., Klauer, S. G., Hankey, J. M., & Dingus, T. A. (2010). Near crashes as crash surrogates for naturalistic driving studies. *Transp. Res Rec., 2147*, 66–74.

Guo, F., Simons-Morton, B. G., Klauer, S. E., Ouimet, M. C., Dingus, T. A., & Lee, S. E. (2013). Variability in crash and near crash risk among novice teenage drivers: a naturalistic study. *J Pediatr., 163*, 1670–1676.

Hankey JM, Perez MA, McClafferty JA. Description of the SHRP2 Naturalistic Database and the Crash, Near-Crash, and Baseline Data Sets. Task Report. Blacksburg, VA: Virginia Tech Transportation Institute; 2016.

Hickman, J. S., Knipling, R. R., Olson, R. L., Fumero, M., Hanowski, R. J., & Blanco, M. (2005) Phase 1 - preliminary analysis of data collected in the drowsy driver warning system field operational test: task 5, phase i data analysis, NHTSA Contract DTNH22-00-C-07007, TO #21. Wash., DC: DoT.

Insurance Institute for Highway Safety (IIHS). Older Drivers – Fatality facts. December 2018. https://www.iihs.org/iihs/topics/t/older-drivers/fatalityfacts/older-people/2017. Accessed 29 Jan 2019.

Insurance Institute for Highway Safety (IIHS). Teenagers – Graduate drivers licensing. May 2018. https://www.iihs.org/iihs/topics/t/teenagers/qanda#teenagers–graduated-driver-licensing. Accessed 28 Jan 2019.

Klauer, S. G., Guo, F., Simons-Morton, B. G., Ouimet, M. C., Lee, S. E., & Dingus, T. A. (2014). Distracted driving and risk of road crashes among novice and experienced drivers. *New England Journal of Medicine, 370*(1), 54–59.

Knipling RR. 2015. Naturalistic driving events: No harm, no foul, no validity. Driving Assessment 2015: International Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design.Public Policy Center, University of Iowa Iowa City, 196–20.

Lam, L. T., Norton, R., Woodward, M., et al. (2003). Passenger carriage and car crash injury: A comparison between younger and older drivers. *Accident Analysis and Prevention, 35*, 861–867.

Li, G., Braver, E. R., & Chen, L. H. (2003). Fragility versus excessive crash involvement as determinants of high death rates per vehicle-mile of travel among older drivers. *Accident Analysis & Prevention, 35*(2), 227–235.

Loeb, H. S., Kandadai, V., McDonald, C. C., & Winston, F. K. (2015). Emergency braking in adults versus novice teen drivers: Response to simulated sudden driving events. *Journal of Transportation Research Board, 2516*, 8–14.

Lombardi, D. A., Horrey, W. J., & Courtney, T. K. (2017). Age-related differences in intersection crashes in the United States. *Accident Analysis & Prevention, 99*, 20–29.

Mayhew, D. R., Simpson, H. M., & Ferguson, S. A. (2006). Collisions involving senior drivers: High-risk conditions and locations. *Traffic Injury Prevention, 7*(2), 117–124.

McDonald, C. C. et al. (2013). Headway time and crashes among novice teens and experienced adult drivers in a simulated lead truck braking scenario. *Proceedings of the international driving symposium on human factors in driver assessment, training, and vehicle design. Vol. 2013*. NIH Public Access.

McDonald Curry, A. E., Kandadai, V., Sommers, M. S., & Winston, F. K. (2014). Comparison of teen and adult driver crash scenarios in a nationally representative sample of serious crashes. *Accident Analysis and Prevention, 74*, 302–308.

McDonald, C. C., Kandadai, V., Loeb, H., et al. (2015). Evaluation of a risk awareness perception training program on novice teen driver behavior at left-turn intersections. *Transp. Res. Rec., 2516*, 15–21.

McGehee, D. V., Roe, C. A., Boyle, L. N., Wu, Y., Ebe, K., Foley, J., et al. (2016). The wagging foot of uncertainty: Data collection and reduction methods for examining foot pedal behavior in naturalistic driving. No. 2016–01-1526. *SAE Technical Paper*.

McKnight, A. J., & McKnight, A. S. (2003). Young novice drivers: Careless or clueless? *Accident Analysis and Prevention, 35*, 921–925.

Montgomery, J., Kusano, K. D., & Gabler, H. C. (2014). Age and gender differences in time to collision at braking from the 100-car naturalistic driving study. *Traffic Injury Prevention, 15*, S15–S20.

National Center for Statistics and Analysis (2018a). *2017 fatal motor vehicle crashes: Overview. (Traffic Safety Facts Research Note. Report No. DOT HS 812 603)*. Washington, DC: National Highway Traffic Safety Administration.

National Center for Statistics and Analysis (2018b). *Early estimate of motor vehicle traffic fatalities for the first half (Jan–Jun) of 2018 (Crash•Stats Brief Statistical Summary. Report No. DOT HS 812 629)*. Washington, DC: National Highway Traffic Safety Administration.

National Highway Traffic Safety Administration (NHTSA). (2017). Distracted Driving 2015. Washington, DC.

Ouimet, M. C., Simons-Morton, B. G., Zador, P. L., et al. (2010). Using the U.S. National Household Travel Survey to estimate the impact of passenger characteristics on young drivers' relative risk of fatal crash involvement. *Accident Analysis and Prevention, 42*, 689–694.

Owsley, C., McGwin, G., & Ball, K. (1998). Vision impairment, eye disease, and injurious motor vehicle crashes in the elderly. *Ophthalmis Epidemiology, 5*(2), 101–113.

Oxley, J. A., Charlton, J. L., Koppel, S. J., Scully, J., & Fildes, B. N. (2005). Crash risk of older female drivers – contributing factors. *Annals of Advances in Automotive Medicine*.

Schroeder, P., Wilbur, M., & Peña, R. (2018). *National survey on distracted driving attitudes and behaviors – 2015 (Report No. DOT HS 812 461)*. Washington, DC: National Highway Traffic Safety Administration.

Seacrist T, Belwadi A, Prabahar A, Chamberlain S, Megariotis J, Loeb H. (2016) Comparison of crash rates and rear-end striking crashes among novice teens and experienced adults using the SHRP2 Naturalistic Driving Study. Traffic Inj Prev. 17(Suppl 1):48–52.

Seacrist, T., Douglas, E. C., Huang, E., Megariotis, J., Prabahar, A., Kashem, A., et al. (2018). Analysis of near crashes among teen, young adult, and experienced adult drivers using the SHRP2 naturalistic driving study. *Traffic Injury Prevention, 19*, 89–96.

Sifrit, K. J., Stutts, J., Martell, C., & Staplin, L. (2011). *Intersection crashes among drivers in their 60s, 70s, and 80s. Report No. DOT HS 811 495*. Washington, DC: National Highway Traffic Safety Administration.

Simons-Morton, B. G., Ouimet, M. C., Zhang, Z., et al. (2011b). The effect of passengers and risk-taking friends on risky driving and crashes/near crashes among novice teenagers. *J. Adolesc. Health., 49*, 587–593.

Simons-Morton, B. G., Ouimet, M. C., Zhang, Z., et al. (2011a). Crash and risky driving involvement among novice adolescent drivers and their parents. *American Journal of Public Health, 101*, 2362–2367.

Tefft B. Rates of Motor Vehicle Crashes, Injuries and Deaths in Relation to Driver Age, United States, 2014–2015. Available online: https://aaafoundation.org/rates-motor-vehicle-crashes-injuries-deathsrelation-driver-age-united-states-2014-2015/.

Webb, C. N. (2018). *Motor vehicle traffic crashes as a leading cause of death in the United States, 2015 (Traffic Safety Facts Crash•Stats. Report No. DOT HS 812 499)*. Washington, DC: National Highway Traffic Safety Administration.

White, C. B., & Caird, J. K. (2010). The blind date: the effects of change blindness, passenger conversation and gender on looked-but-failed-to-see (LBFTS) errors. *Accident Analysis and Prevention, 42*, 1822–1830.

Williams, A. F. (2003). Teen drivers: patterns of risk. *Journal of Safety Research, 34*, 5–15.

Williams, A. F., Ferguson, S. A., & McCartt, A. T. (2007). Passenger effects on teenage driving and opportunities for reducing the risks of such travel. *Journal of Safety Research, 38*, 381–390.

Thomas Seacrist is a Project Manager for Engineering Research in the Center for Injury Research (CIRP) and Prevention at the Children's Hospital of Philadelphia (CHOP). Mr. Seacrist joined CIRP in 2007 and has conducted research on pediatric occupant kinematics, ATD biofidelity, teen driving, naturalistic driving data, ADAS optimization, and autonomous vehicles. He holds a Master's degree in biomedical engineering from the Catholic University of America in Washington, DC.

Ethan Douglas is a research assistant for Engineering Research in the Center for Injury Research and Prevention (CIRP) at the Children's Hospital of Philadelphia (CHOP). Since joining CIRP in 2016 Williams, Mr. Douglas has been focused on establishing determinants of increased injury risk in children and young adults. He holds a Bachelor's degree in kinesiology from the University of Arkansas and is currently pursuing a Master's degree in bioengineering from the University of Pennsylvania.

Chloe Hannan is a Master's student in epidemiology at Drexel University and a Research Assistant at the Center for Injury Research and Prevention (CIRP) at the Children's Hospital of Philadelphia (CHOP). Ms. Hannan joined CIRP in 2017 and has worked on research projects including teen driving, ADAS optimization, and data archiving. She holds a Bachelor's degree in public health from West Chester University of Pennsylvania.

Rachel Rogers is a senior biostatistician at the CHOP-Westat Biostatics & Data Management Core (BDMC). Her responsibilities include developing project specific designs and analysis plans and analyzing data using statistical approaches. She hold a Master's degree in Biostatistics from the University of Pennsylvania.

Aditya Belwadi is a Research Scientist II for biomechanics research at the Center for Injury Research and Prevention at Children's Hospital of Philadelphia. An internationally recognized expert on injury biomechanics, injury causation and the effectiveness of safety products for children, Dr. Belwadi's research efforts have been funded by the National Science Foundation, the National Highway Traffic Safety Administration, and several corporate entities in the field of automotive safety. His work focuses on the biomechanics of pediatric injury for the development of new safety designs and biofidelic child anthropomorphic dummies, quantifying the mechanical response of the pediatric thorax during cardiopulmonary resuscitation in MRI systems, and evaluating positive reinforcement feedback for teenage drivers using simulated driving assessments.

Helen Loeb is a Principal Investigator in the Center for Injury Research (CIRP) and Prevention at the Children's Hospital of Philadelphia (CHOP). She received a Master in Aerospace Engineering at ISEA, and a PhD in Robotics from the University of Bordeaux I, France. Her interests include naturalistic driving, driving simulation, and virtual reality. She is leading a line of Research in Human Factors and self-driving through a National Science Foundation grant in collaboration with the University of Pennsylvania and Drexel University.