Accident Analysis and Prevention 55 (2013) 116–123

Contents lists available at SciVerse ScienceDirect

Accident Analysis and Prevention

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

Factors associated with civilian drivers involved in crashes with emergency vehicles

Christopher Drucker[a,*], Susan G. Gerberich[a], Michael P. Manser[b], Bruce H. Alexander[a], Timothy R. Church[a], Andrew D. Ryan[a], Ensar Becic[b]

[a] *Midwest Center for Occupational Health and Safety Education and Research Center, Division of Environmental Health Sciences, School of Public Health, University of Minnesota, 420 Delaware Street SE, Minneapolis, MN 55455, USA*

[b] *Department of Mechanical Engineering, College of Science and Engineering, University of Minnesota, 111 Church Street SE, Minneapolis, MN 55455, USA*

ARTICLE INFO

Article history:
Received 4 December 2012
Received in revised form 4 February 2013
Accepted 17 February 2013

Keywords:
Motor vehicle crash
Risk factors
Emergency vehicle
Civilian driver

ABSTRACT

Motor vehicle crashes involving civilian and emergency vehicles (EVs) have been a known problem that contributes to fatal and nonfatal injuries; however, characteristics associated with civilian drivers have not been examined adequately. This study used data from The National Highway Traffic Safety Administration's Fatality Analysis Reporting System and the National Automotive Sampling System General Estimates System to identify driver, roadway, environmental, and crash factors, and consequences for civilian drivers involved in fatal and nonfatal crashes with in-use and in-transport EVs. In general, drivers involved in emergency–civilian crashes (ECCs) were more often driving: straight through intersections (vs. same direction) of four-points or more (vs. not at intersection); where traffic signals were present (vs. no traffic control device); and at night (vs. midday). For nonfatal ECCs, drivers were more often driving: distracted (vs. not distracted); with vision obstructed by external objects (vs. no obstruction); on dark but lighted roads (vs. daylight); and in opposite directions (vs. same directions) of the EVs. Consequences included increased risk of injury (vs. no injury) and receiving traffic violations (vs. no violation). Fatal ECCs were associated with driving on urban roads (vs. rural), although these types of crashes were less likely to occur on dark roads (vs. daylight). The findings of this study suggest drivers may have difficulties in visually detecting EVs in different environments.

1. Introduction

Motor vehicle crashes between civilian and emergency vehicles (EVs), such as police, fire trucks, and ambulances, are a known concern due to high risk of fatal and nonfatal roadway injuries (Custalow and Gravitz, 2004). The National Highway Traffic Safety Administration (NHTSA, 2001–2010) reported that 368,946 EVs were involved in crashes from 2001 to 2010. This number represents an increase of over 20%, compared to the previous decade, during which 302,969 crashes were reported (Ray and Kupas, 2005). According to the National Emergency Medical Services Advisory Council (2009), identifying the rate of EV crashes is difficult because of the inadequacies of data collections systems to acquire common denominator data, such as vehicle miles traveled.

Research pertaining to emergency–civilian crashes (ECCs, crashes involving civilian and EVs) have predominantly focused on factors associated with EV drivers (Kahn et al., 2001), the environment (Kahn et al., 2001; Ray and Kupas, 2007), and health-related outcomes (Becker et al., 2003), in part, due to the high transportation fatality rate among emergency medical service personnel (Maguire et al., 2002; Slattery and Silver, 2009). Ambulance drivers have received particular attention (Studnek and Fernandez, 2008; Weiss et al., 2001) since they are at a higher risk for crashes compared to law enforcement officers and fire fighters (Sanddal et al., 2008). Other crash characteristics, such as the use of lights and sirens, have received dual consideration, examining their impact on emergency response time (Ho and Lindquist, 2001; Petzäll et al., 2011) as well as a connection with crash frequency (Custalow and Gravitz, 2004; Pirrallo and Swor, 1994).

It is important to note that an ECC combines various factors, including those that relate to the civilian driver (Custalow and Gravitz, 2004); however, such factors for civilian drivers have not been examined adequately. Identifying these factors is essential since occupants of non-EVs are more likely to be fatally wounded as a consequence of these crashes (Sanddal et al., 2010).

In light of the paucity of research examining ECCs, the purpose of this study was to identify driver, roadway, environmental, and crash factors, and consequences for civilian drivers involved in fatal and nonfatal motor vehicle crashes with in-use and in-transport EVs.

---

* Corresponding author at: Division of Environmental Health Sciences, School of Public Health, University of Minnesota, MMC 807, 420 Delaware Street SE, Minneapolis, MN 55455, USA. Tel.: +1 612 626 0900; fax: +1 612 626 4837.
E-mail address: druck029@umn.edu (C. Drucker).

0001-4575/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.aap.2013.02.035

2. Methods

2.1. Study design

To identify the characteristics of civilian crashes involving EVs, we compared ECCs to non-ECCs (civilian crashes not involving EVs) for both fatal and nonfatal crashes. This analysis is similar to proportionate morbidity or mortality analyses in which the characteristics of ill or deceased people are compared. While this study design cannot identify causal factors, because of being unable to characterize all motor vehicles at risk of being involved in a crash with an EV, it is useful for generating hypotheses about causal factors that contribute to these types of crashes.

Publicly available data from the NHTSA's Fatality Analysis Reporting System (FARS) and National Automotive Sampling System General Estimates System (NASS-GES), from 2002 through 2010, were used. The FARS data are a census of all fatal motor vehicle crashes that occurred within the United States and Puerto Rico. For a crash to be eligible within the FARS dataset, the death of a motorist or a non-motorist must have occurred within 30 days from the time of the crash. The NASS-GES data are a nationally-representative probability sample of all police-reported motor vehicle crashes. General eligibility requirements for the FARS and NASS-GES datasets can be found in the Analytical Users' Manuals (US Department of Transportation, 2010, 2011). Both datasets contain information regarding the special use of vehicles (e.g., taxi, police, military) and whether the vehicles were listed as in-use for emergencies. In-use and in-transport EVs were defined as EVs on emergency calls and in motion at the time of the crash. All fatal observations within the NASS-GES dataset were removed to form a nonfatal-only dataset.

The ECC and non-ECC type datasets contained observations only for in-transport civilian drivers who were involved in fatal or nonfatal crashes with another in-transport motor vehicle, that is, an EV or non-EV. Crashes involving EVs exclusively, and single vehicle crashes, were removed from the datasets. One nonfatal crash observation was removed due to the vehicle being listed as in-use for an emergency but listed as a non-EV.

2.2. Statistical analysis

Descriptive statistics were used to report frequencies of driver, roadway, environmental, and crash factors, and consequences between the two crash types. Multivariate logistic regression models for fatal and nonfatal crashes were used to identify potential factors associated with ECCs compared to non-ECCs (expressed as estimated odds ratios [OR] and 95% confidence intervals [CI]) while holding a priori selected covariates constant based on directed acyclic graphs (Hernán et al., 2002). The directed acyclic graphs enable identification of parsimonious models and exclude covariates that should not be entered into the regression lest they introduce bias. The resulting models estimate the odds that an individual in a crash will be more, or less likely to have a specific characteristic (e.g. age or distraction) if they are involved in an ECC rather than a non-ECC. The analyses for this study were generated using SAS® software, Version 9.2 (SAS Institute Inc, 2010).

3. Results

3.1. Vehicle crash characteristics

Examination of the two datasets revealed that ECCs represented a small proportion of all of fatal and nonfatal civilian crashes, 0.20% and 0.17%, respectively (Table 1). Sex and age distributions of ECCs and non-ECCs were similar within fatal and nonfatal crashes (Table 1). Among nonfatal crashes, higher proportions of ECCs, compared with non-ECCs involved: distracted drivers; obscured vision; traffic controlling devices; and crashes at angles. The two most reported sources of distractions for drivers were "inattentive or lost in thought" and "looked but did not see", which accounted for 37% and 17%, respectively (results not shown in table). Nonfatal ECCs also occurred at intersections, at night on dark but lighted roads, and resulted in some level of bodily injury, vehicle damage, and drivers receiving traffic violations.

Among fatal crashes, ECCs compared to non-ECCs, more frequently: indicated no source of distraction; occurred on urban roads, at intersections and at night on dark but lighted roads; involved traffic controlling devices and crashes at angles. Civilian drivers were more likely to be fatally wounded when involved in a fatal crash with an EV compared to a fatal crash with a non-EV.

3.2. Multivariate analyses

Table 2 presents results of multivariate modeling of driver, roadway, environmental, and crash factors, and consequences for civilian drivers involved in fatal and nonfatal crashes with in-use and in-transport EVs. Factors of interest were adjusted for potential confounders (see footnote in Table 2) based on directed acyclic graphs.

3.2.1. Nonfatal crashes

Driver factor analyses indicated differences between crash types for age and distraction (Table 2). Teenaged drivers in crashes were less likely to be involved in ECCs (OR = 0.7), compared to young drivers aged 20–29. Overall, drivers were more likely to be distracted (OR = 1.9). Gender was not shown to be a differentiating factor.

Analyses of roadway factors showed that physical objects obstructing drivers' vision, location within a road, and presence of traffic control devices were associated with crash types (Table 2). Emergency–civilian crashes were more likely to have driver's vision obstructed by objects on the road: buildings, billboards, and other structures (OR = 36.4); parked vehicles (OR = 3.4); trees, crops and vegetation (OR = 4.5); and other in-transport motor vehicles (OR = 2.2). Emergency–civilian crashes occurred more frequently at intersections, specifically intersections that contained four-points or more (OR = 2.1), compared to not being located at intersections. The presence of automatic traffic lights (OR = 2.4) and traffic controlling persons (OR = 6.7), compared to no controlling devices were associated with ECCs. However, the association between automatic traffic lights and ECCs may be confounded by the location within the roadway, i.e., intersection or non-intersection, given the limited data available for this variable.

Environmental factors identified for ECCs included time of day and lighting characteristics at the time of the crash (Table 2). Driving at night (9 pm to 5 am), compared to driving during midday (11 am to 4 pm), was three times more likely in ECCs (OR = 2.8). Similarly, ECCs were more likely to occur when driving on dark but lighted roads (OR = 1.6), compared to driving in daylight.

Emergency-civilian crashes were associated with: angles (OR = 4.3); head-on collisions (OR = 1.9); or sideswipes in opposite (OR = 3.0) and same (OR = 2.5) directions, compared to rear-end collisions (Table 2). Similarly, ECCs were more likely to occur when civilian and EV drivers were heading in opposite directions (OR = 4.8) and when they were crossing straight through intersections (OR = 3.1), compared to crashes in the same direction.

Consequences for drivers included increased risks for bodily injury, receiving traffic violations, and incurring disabling damage to their vehicles, as a result of ECCs versus non-ECCs (Table 2). Risks were increased for all injury outcomes (excluding fatal) when crashes involved an EV. Similarly, civilian vehicles were more likely

Table 1
Driver, roadway, environmental, and crash-level characteristics, and consequences among civilian drivers involved in nonfatal and fatal emergency–civilian crashes (ECCs).

Variables	Nonfatal crashes[a]				Fatal crashes[b]			
	ECC		Non-ECC		ECC		Non-ECC	
	N = 1025[c]	%[d]	N = 602,889[c]	%[d]	N = 527[c]	%[d]	N = 266,662[c]	%[d]
Driver-level								
Gender								
Female	394	38.4	248,239	41.2	171	32.4	75,344	28.3
Male	623	60.8	351,757	58.3	356	67.6	190,667	71.5
Missing	8	0.8	2,893	0.5	0	0.0	651	0.2
Age								
14–19	81	7.9	64,246	10.7	43	8.2	22,941	8.6
20–29	275	26.8	145,565	24.1	117	22.2	57,987	21.7
30–39	197	19.2	117,923	19.6	94	17.8	48,251	18.1
40–49	209	20.4	113,163	18.8	86	16.3	49,403	18.5
50–59	134	13.1	81,077	13.4	77	14.6	38,479	14.4
60–69	57	5.6	40,998	6.8	43	8.2	22,216	8.3
70+	57	5.6	32,460	5.4	67	12.7	27,385	10.3
Missing	15	1.5	7,457	1.2	0	0.0	0	0.0
Distracted[e]								
No	519	50.6	357,107	59.2	45	88.2	20,180	81.4
Yes	199	19.4	74,600	12.4	1	2.0	1,664	6.7
Missing	307	30.0	171,182	28.4	5	9.8	2,958	11.9
Roadway-level								
Vision obscured by[f]								
No obstruction	753	73.5	461,709	76.6	84	15.9	46,600	96.0
Building, billboard or other structure	10	1.0	184	0.0	0	0.0	0	0.0
Parked vehicle	22	2.1	4,798	0.8	0	0.0	44	0.1
Trees, crops, and vegetation	4	0.4	683	0.1	0	0.0	102	0.2
In-transport motor vehicle	19	1.9	4,745	0.8	1	0.2	226	0.5
Other	17	1.7	8,099	1.3	31	5.9	1,147	2.4
Missing	200	19.5	122,671	20.3	411	78.0	422	0.9
Location								
Rural	121	11.8	102,242	17.0	169	32.1	146,422	54.9
Urban	477	46.5	281,044	46.6	357	67.7	119,055	44.6
Other	316	30.8	164,798	27.3				
Missing	111	10.8	54,805	9.1	1	0.2	1,185	0.4
Intersection type[g]								
Not an intersection	32	35.2	25,992	45.8	12	23.5	14,877	60.2
Y-intersection	1	1.1	256	0.5	0	0.0	218	0.9
T-intersection	3	3.3	6,395	11.3	12	23.5	2,849	11.5
Four-points or more	42	46.2	17,073	30.1	27	52.9	6,716	27.2
Roundabout	0	0.0	81	0.1	0	0.0	4	0.0
Missing	13	14.3	6,972	12.3	0	0.0	58	0.2
Traffic control devices								
No controls	337	32.9	330,465	54.8	261	49.5	169,789	63.7
Yield sign	3	0.3	7,351	1.2	3	0.6	1,596	0.6
Warning sign	10	1.0	7,765	1.3	2	0.4	3,875	1.5
Traffic signal (lights)	490	47.8	174,693	29.0	167	31.7	35,020	13.1
Stop sign	56	5.5	46,689	7.7	74	14.0	44,860	16.8
Person	10	1.0	1278	0.2	1	0.2	423	0.2
Other	104	10.1	13,155	2.2	15	2.8	10,321	3.9
Missing	15	1.5	21,493	3.6	4	0.8	778	0.3
Environmental-level								
Time of day								
11 am to 4 pm (midday)	365	35.6	267,786	44.4	165	31.3	99,014	37.1
5 pm to 8 pm (evening)	213	20.8	132,814	22.0	117	22.2	56,835	21.3
9 pm to 5 am (night)	232	22.6	62,461	10.4	147	27.9	57,770	21.7
6 am to 10 am (morning)	213	20.8	137,820	22.9	97	18.4	52,758	19.8
Missing	2	0.2	2,008	0.3	1	0.2	285	0.1
Light condition								
Daylight	662	64.6	463,712	76.9	316	60.0	171,241	63.5
Dark	45	4.4	30,228	5.0	79	15.0	49,055	18.2
Dark but lighted	284	27.7	87,029	14.4	117	22.2	34,397	12.8
Dawn	7	0.7	6,764	1.1	1	0.2	5,055	1.9
Dusk	20	2.0	12,791	2.1	14	2.7	9,278	3.4
Missing	7	0.7	2,365	0.4	0	0.0	630	0.2
Crash-level								
Manner of collision								
Rear-end	164	16.0	256,858	42.6	88	16.7	43,606	16.4
Angle	740	72.2	258,373	42.9	360	68.3	135,623	50.9
Head-on	35	3.4	29,382	4.9	48	9.1	67,067	25.1
Sideswipe opposite direction	11	1.1	8,054	1.3	9	1.7	8,688	3.3
Sideswipe same direction	74	7.2	49,983	8.3	18	3.4	9,311	3.5
Other	1	0.1	239	0.0	2	0.4	1,570	0.6
Missing	0	0.0	0	0.0	2	0.4	802	0.3

Table 1 (*Continued*)

Variables	Nonfatal crashes[a]				Fatal crashes[b]			
	ECC		Non-ECC		ECC		Non-ECC	
	N = 1025[c]	%[d]	*N* = 602,889[c]	%[d]	*N* = 527[c]	%[d]	*N* = 266,662[c]	%[d]
Crash type[h]								
Same direction	214	20.9	268,694	44.6	5	9.8	4,618	18.7
Opposite direction	36	3.5	23,178	3.8	6	11.8	8,339	33.7
Vehicle turning	276	26.9	161,333	26.8	11	21.6	4,687	19.0
Intersection – straight path	309	30.1	71,439	11.8	17	33.3	4,328	17.5
Other	0	0.0	0	0.0	12	23.5	2,681	10.8
Missing	190	18.5	78,245	13.0	0	0.0	69	0.3
Consequences								
Injury								
No injury	348	34.0	277,260	46.0	101	19.2	63,807	24.9
Possible	245	23.9	129,027	21.4	46	8.7	27,826	10.8
Non-incapacitating	232	22.6	109,547	18.2	58	11.0	28,196	11.0
Incapacitating	197	19.2	82,070	13.6	55	10.4	33,639	13.1
Fatal	–	–	–	–	265	50.3	101,694	39.6
Missing	3	0.3	4,985	0.8	2	0.4	1,500	0.6
Moving violation								
None	624	60.9	406,054	67.4	468	88.8	232,767	87.3
Failed traffic signal	9	0.9	13,621	2.3	7	1.3	2,842	1.1
Failed to yield the right-of-way	156	15.2	34,543	5.7	11	2.1	3,721	1.4
Reckless driving	11	1.1	6,741	1.1	18	3.4	10,777	4.0
Speed-related	11	1.1	18,031	3.0	1	0.2	1,501	0.6
Other	214	20.9	123,899	20.6	12	2.3	10,202	3.8
Missing	0	0.0	0	0.0	10	1.9	4,852	1.8
Vehicle damage								
None	13	1.3	11,269	1.9	1	0.2	1,877	0.7
Minor	123	12.0	122,332	20.3	31	5.9	16,333	6.1
Functional	153	14.9	102,186	16.9	56	10.6	36,588	13.7
Disabling	437	42.6	190,736	31.6	436	82.7	208,710	78.3
Missing	299	29.2	176,366	29.3	3	0.6	3154	1.2

[a] Data from the National Automotive Sampling System General Estimates System (2002–2010).
[b] Data from the Fatality Analysis Reporting System (2002–2010).
[c] Total may differ by factor depending on data collection for each year.
[d] Percentages may not add up to 100 due to rounding.
[e] FARS data only available for 2010 (*N* = 24,853).
[f] FARS data only available for 2009 and 2010 (*N* = 48,677).
[g] GES and FARS data only available for 2010, *N* = 57,372 and *N* = 24,773, respectively.
[h] FARS data only available for 2010 (*N* = 24,773).

to become disabled (OR = 2.7), compared to no vehicle damage, and drivers were more likely to receive a “failed to yield the right-of-way” violation (OR = 3.0), compared to receiving no violations, when an EV was involved in the crash. However, drivers were less likely to receive a speed-related violation (OR = 0.4) when involved in a nonfatal ECC.

3.2.2. *Fatal crashes*

Analyzing driver factors for fatal crashes were limited due to high proportions of fatalities among civilian drivers (Table 1). However, roadway factors were associated with differences between the two crash types (Table 2). Fatal ECCs were more than two times greater on urban compared to rural roads, and more likely to occur at T-intersections (OR = 5.6) and intersections of four-points or more (OR = 4.9), compared to crashes not occurring at intersections. Similar to nonfatal ECCs, the presence of automatic traffic lights was associated with fatal ECCs (OR = 2.6).

Environmental factors were similar between crash types. Fatal and nonfatal ECCs were more likely at night (OR = 2.8 and 1.6, respectively), versus the afternoon. However, driving on dark roads at the time of the crash was less likely than driving in daylight (OR = 0.6) for fatal ECCs, and driving on dark but lighted roads, versus in daylight, was associated with nonfatal ECCs only.

Crash factors indicated head-on versus rear-end collisions were less likely for fatal ECCs (OR = 0.4). Similar to nonfatal ECCs, fatal ECCs were associated with crashes that occurred as civilian drivers drove straight through intersections (OR = 3.4).

Consequences identified increased risk of fatal injury (OR = 2.1) among civilian drivers who were involved in crashes with EVs, compared to those involved in crashes with non-EVs. Other crash consequences (moving violations and vehicle damaged) indicated no significant differences.

4. Discussion

This study of two national datasets identified several driver, roadway, environmental, and crash-level factors, and consequences for civilian drivers involved in fatal and nonfatal crashes with in-use and in-transport EVs. Identifying the factors more common in ECCs, compared to other crashes, can help focus research and prevention efforts for civilian crashes with EVs.

4.1. *Driver factors*

Civilian drivers’ failure to notice EVs has been previously identified as a primary factor associated with ECCs (Clarke et al., 2009); however, this is a rather broad explanatory factor. The current study enabled investigation of factors that contribute to this broad concept of failing to notice EVs. For example, older adults experience numerous perceptual and cognitive declines (Salthouse et al., 1996), including those in visual acuity (Klein et al., 1991) and inattentional blindness (Graham and Burke, 2011); yet, no difference was identified for older (60+) or middle aged (30–59), compared to young (20–29) drivers involved in ECCs. In fact, teenage (14–19), compared to young drivers, were less likely to be involved in a

Table 2
Multivariate logistic regression analyses of driver, roadway, environmental, and crash-level characteristics, and consequences among civilian drivers involved in nonfatal and fatal emergency–civilian crashes (ECCs).

Variables	Nonfatal ECC[a] Adjusted		Fatal ECC[b] Adjusted	
	OR	95% CI	OR	95% CI
Driver-level				
Gender				
Female	1.0	–	1.0	–
Male	1.1	1.0–1.3	0.8	0.7–1.0
Age				
14–19	0.7	0.5–0.9	0.9	0.7–1.3
20–29	1.0	–	1.0	–
30–39	0.9	0.7–1.1	1.0	0.7–1.3
40–49	1.0	0.8–1.2	0.9	0.7–1.1
50–59	0.9	0.7–1.1	1.0	0.7–1.3
60–69	0.7	0.6–1.0	1.0	0.7–1.4
70+	0.9	0.7–1.2	1.2	0.9–1.6
Distracted[c]				
No	1.0	–	1.0	–
Yes	1.9	1.6–2.3	0.8	0.1–5.9
Roadway-level				
Vision obscured by[d]				
No obstruction	1.0	–	1.0	–
Building, billboard or other structure	36.4	18.4–71.9	–	–
Parked vehicle	3.4	2.2–5.2	–	–
Trees, crops, and vegetation	4.5	1.7–12.0	–	–
In-transport motor vehicle	2.2	1.3–3.9	2.7	0.4–19.8
Location[e]				
Rural	1.0	–	1.0	–
Urban	1.3	1.0–1.6	2.2	1.8–2.7
Intersection type[f]				
Not an intersection	1.0	–	1.0	–
Y-intersection	3.0	0.4–22.2	–	–
T-intersection	0.4	0.1–1.3	5.6	2.4–12.7
Four-points or more	2.1	1.3–3.4	4.9	2.4–10.0
Traffic control devices[g]				
No controls	1.0	–	1.0	–
Yield sign	0.6	0.2–2.1	1.2	0.4–3.9
Warning sign	1.2	0.7–2.3	0.4	0.1–1.5
Traffic signal (lights)	2.5	2.1–2.9	2.6	2.1–3.2
Stop sign	1.2	0.9–1.7	1.1	0.8–1.4
Officer, guard, etc.	6.7	3.1–14.2	1.6	0.2–11.8
Other	5.8	4.4–7.5	1.0	0.6–1.8
Environmental-level				
Time of day[h]				
11 am to 4 pm (midday)	1.0	–	1.0	–
5 pm to 8 pm (evening)	1.2	1.0–1.4	1.3	1.0–1.6
9 pm to 5 am (night)	2.8	2.3–3.3	1.6	1.3–2.1
6 am to 10 am (morning)	1.2	1.0–1.4	1.1	0.9–1.4
Light condition[i]				
Daylight	1.0	–	1.0	–
Dark	0.7	0.5–1.1	0.6	0.4–0.9
Dark but lighted	1.6	1.1–2.1	0.9	0.6–1.2
Dawn	0.3	0.1–1.0	–	–
Dusk	1.3	0.8–2.3	1.0	0.6–1.7
Crash-level				
Manner of collision[j]				
Rear-end	1.0	–	1.0	–
Angle	4.3	3.4–5.5	1.2	0.9–1.6
Head-on	1.9	1.1–3.2	0.4	0.3–0.6
Sideswipe opposite direction	3.0	1.4–6.6	0.5	0.3–1.1
Sideswipe same direction	2.5	1.7–3.7	1.1	0.6–1.8
Crash type[k]				
Same direction	1.0	–	1.0	–
Opposite direction	4.8	1.5–14.6	0.8	0.2–2.5
Vehicle turning	0.8	0.3–2.1	2.1	0.7–6.2
Intersection – straight path	3.1	1.3–7.0	3.4	1.2–9.4
Consequences				
Injury[l]				
No injury	1.0	–	1.0	–
Possible	2.3	1.6–3.2	1.3	0.8–2.0
Non-incapacitating	1.8	1.3–2.5	1.3	0.9–1.9
Incapacitating	2.1	1.4–2.9	1.2	0.8–1.8
Fatal	–	–	2.1	1.5–2.9

Table 2 (*Continued*)

Variables	Nonfatal ECC[a] Adjusted		Fatal ECC[b] Adjusted	
	OR	95% CI	OR	95% CI
Moving violation[m]				
None	1.0	–	1.0	–
Failed traffic signal	0.4	0.2–0.8	1.4	0.7–3.1
Failed to yield the right-of-way	3.0	2.5–3.6	1.7	0.9–3.1
Reckless driving	0.8	0.4–1.6	1.0	0.6–1.6
Speed-related	0.4	0.2–0.7	0.4	0.1–2.9
Other	1.0	0.8–1.2	0.7	0.4–1.3
Vehicle damage[n]				
Minor	1.0	–	1.0	–
Functional	1.2	0.8–1.8	1.2	0.6–2.2
Disabling	2.7	1.9–3.8	1.4	0.8–2.4

[a] Data from the National Automotive Sampling System General Estimates System (2002–2010).
[b] Data from the Fatality Analysis Reporting System (2002–2010).
[c] Adjusted for age, location, reported alcohol, reported drugs, roadway surface condition, sex (fatal crash data only for 2010).
[d] Adjusted for age, body type, location, roadway surface condition, sex, time of day (fatal crash data only for 2010).
[e] Adjusted for age, light condition, number of lanes, region, sex.
[f] Adjusted for age, location, region, sex; data only available for 2010.
[g] Adjusted for age, day of week, number of lanes, region, sex, traffic flow, weather.
[h] Adjusted for age, location, season, sex.
[i] Adjusted for age, location, number of lanes, time of day, season, sex, weather.
[j] Adjusted for age, distracted (only for injury), roadway alignment, roadway surface condition, sex, vision obscured (only for injury).
[k] Adjusted for age, location, number of lanes, roadway surface condition, sex (Fatal crash data only for 2010).
[l] Adjusted for age, body type, crash avoidance maneuver, location, sex.
[m] Adjusted for age, injury severity, time of day, sex.
[n] Adjusted for age, body type, crash avoidance maneuver, roadway surface condition, sex.

nonfatal ECC, a finding that may be associated with drivers' license restrictions. Younger drivers may be required to drive only during daylight hours; therefore, not being exposed to nighttime driving, which was shown to be associated with ECCs.

Internal distractions among drivers are well known risks for motor vehicle crashes with potential serious costs (Strayer et al., 2006). In this study, drivers who indicated a source of distraction were more likely to be involved in nonfatal ECCs. Cognitive distractions, such as being inattentive or lost in thought, which was the highest reported type of distraction, has been shown to negatively affect visual detection for changes in traffic scenes (McCarley et al., 2004). Drivers that are taxed with a secondary cognitive task spend more time looking forward of their vehicle and are less likely to detect a target in the periphery of their vision (Harbluk et al., 2007). This may provide insight into nonfatal ECCs that occurred at angles and civilian drivers driving straight through intersections as visual scanning in the periphery declines.

4.2. Roadway factors

In this study, it was identified that general age-related changes may not contribute to drivers' failure to notice EVs but, rather, how roadway characteristics, such as visual obstructions due to external objects may contribute. The analyses showed that buildings, billboards, parked vehicles, trees, crops, vegetation, and other in-transport motor vehicles were more likely involved in nonfatal ECCs. The purpose of lights on an EV is to provide a visual stimulus to alert motorists of an approaching EV; however, if a driver's vision is obstructed, an EV that is not following standard roadway rules (e.g., driving through red lights at intersections) may go undetected.

Intersections in general, more specifically T- and four-points or more intersections, may be a contributing factor to drivers failing to notice. When drivers approach an intersection, they typically scan for relevant objects (e.g., traffic signals) in an attempt to decipher how these objects impact their ability to cross a junction safely. However, as the number of distractors (e.g., pedestrians, traffic routes) increase, visually searching for a specific target among the clutter becomes more difficult (Verghese and McKee, 2004). When the target is dissimilar to the distractors, the "pop-out effect" may be responsible for immediate detection of the target (Becker, 2010). For example, an EV's warning lights acts as a pop-out when the vehicle is traveling down a street full of parked cars; however, when the EV is at a busy urban intersection, the EV's warning lights would not act like a pop-out. This example can be illustrated by the second most frequent type of distraction that may have influenced driver performance, looked but did not see, suggesting that drivers might have attempted to identify the target but failed to identify or discriminate it from other vehicles on the road. Visual perception of relevant information may be disrupted among these types of looked but did not see crashes (Koustanai et al., 2008).

The FARS data analyzed within this study showed that majority of fatal non-ECCs (55%) occurred on rural roads; however, among fatal ECCs, the majority occurred on urban roads (68%). Urban roads present more visual clutter (e.g., pedal cyclist, pedestrians, traffic congestion) compared to rural roads, which can mask impending critical events (Underwood, 2007). Consequently, visually detecting an EV may become more difficult on urban roads.

4.3. Environmental factors

The ability of a driver to visually detect objects in the environment is affected by the amount of light present; a driver's visual performance declines in reduced lighting conditions (Plainis et al., 2005). As a result, driving in such conditions decreases the visibility of objects in the environment and may contribute to fatal and nonfatal ECCs at night. Surprisingly, fatal ECCs were less likely to occur on dark roads while driving on dark but lighted roads was more likely for nonfatal ECCs. Since emergency lights have greater contrast in darker environments, it is possible that the civilian drivers' ability to detect an approaching EV increases (Hsieh et al., 2011). When dark environments become lighted, objects become more visible and the EV's warning lights lose contrast; therefore, becoming less effective in orienting a driver's attention. This concept may explain the association between nonfatal ECCs and driving on roads in environments that are dark but lighted. The implication of this finding is contrary to the recommendation of increased roadway lighting as a method to reduce motor vehicle crashes. Although roadway lighting is associated with decreases in pedestrian-motor vehicle crashes (Retting et al., 2003; Sullivan and Flannagan, 2002), at rural stop-controlled intersections (Donnell et al., 2010), and in other possible crash scenarios, roadway lighting may be detrimental to the safe interaction between civilian drivers and EVs. In addition, roadways that are lighted have been shown to be associated with faster driving speeds (Assum et al., 1999), which may also contribute to the underlying factors associated with these types of crashes; however, limitations within the datasets did not allow for analyses to include such factors.

4.4. Crash factors

Describing harmful events between civilian and EVs provided an understanding into the sequence of events which led to the ECCs. Such analyses have been conducted previously by recreating crash events and identifying which mechanisms failed along the function event sequence (Malaterre, 1990). By including such sequences, it allows for identification of potential failures which may have likely contributed to issues related to visibility.

The manner of collision represents the nature of impact between civilian and EVs while crash type takes into account the crash category (e.g., vehicle turning) for the first harmful event specific to the civilian driver. The first harmful events suggest visual detection of the EVs may not have been completed or drivers may not have had enough time to detect and react to the situation as EVs were more likely approaching in different directions (e.g., opposite, perpendicular) of the civilian drivers. The available time to detect an EV decreases when the vehicles are moving toward each other compared to moving in the same direction.

4.5. Consequences

Post-crash factors can provide important information to help understand the consequences of ECCs. Failing to yield the right-of-way, found to be the most common violation among civilian drivers involved in EV crashes in this study, suggests that drivers are unable to visually detect oncoming EVs and, as a result, execute inappropriate driving maneuvers that contribute to the crashes.

The current study allowed us to better understand how civilian driver, roadway, environmental, and crash factors, and consequences are associated with fatal and nonfatal ECCs. As a result, we were able to expound on a widely accepted concept – civilian drivers failing to notice EVs – and ascertain how specific endogenous (e.g., internal distractions) and exogenous (e.g., roadway locations) factors contribute to this overarching failure in recognition.

These results, although not causal, can identify potential avenues for future research and prevention efforts. Recommendations for changes to roadway infrastructures, such as improved roadway lighting, can decrease the risk for certain types of motor vehicle crashes (Donnell et al., 2010; Retting et al., 2003) but may also increase the risk for ECCs. Traffic safety engineers could utilize the data to design and integrate infrastructure-based solutions (e.g., emergency vehicle preemption systems) in high risk areas, such as urban intersections.

Advancements in technologies have made in-vehicle devices commonplace for providing information to drivers of potential critical situations and assisting in navigation of difficult driving environments (Becic et al., 2013). The use of collision warning systems to alert drivers to a myriad of potential collision events, including approaching in-use and in-transport EVs (Lenné et al., 2008), have shown promising results. The integration of technology within and between vehicles on the road is the future of driving. Connected-vehicle safety systems (i.e., vehicle-to-vehicle and vehicle-to-infrastructure) communicate relevant information that may create the necessary components for a collision event (e.g., roadway conditions, obstacles, approaching EVs). We believe this study can open pathways to scientific questions and research aimed at reengineering roadways and integrating in-vehicle technologies to further improve roadway safety for civilian and EV drivers.

4.6. Limitations

The present study is not without limitations. Emergency vehicles' operating lights and sirens have been associated with increased risk for crashes (Custalow and Gravitz, 2004); however, the FARS and NASS-GES datasets only indicate if the EV was in-use, that is, on an emergency call. It is not known whether or not all EVs' lights and sirens were activated at the time of the crashes. For study purposes, we made the assumption that an EV on an emergency call consisted of using lights and sirens.

The FARS dataset is inherently limited in its ability to identify driver factors if the person fatally injured was the driver. The inability to collect driver data among the deceased can introduce subjectivity by the crash scene investigator into the crash reports and, subsequently, bias the results. In addition, drivers not fatally injured at the time of data acquisition may provide inappropriate information to law enforcement and crash scene investigators, particularly in the context of distracted driving, in order to avoid potential fault or penalty. As a result, some driver information within the NASS-GES and FARS dataset may be misleading.

Factors observed within the NASS-GES and FARS dataset may have been limited by the amount of data that was collected and as a result, the observed outcome may have been affected. Finally, as described previously, the analyzed data only included crash events; therefore it is not possible to directly estimate risk of an ECC for any given factor. However, by comparing to other crashes, we have identified potential patterns of risk associated with ECCs.

5. Conclusion

Results of this study suggest that drivers may have difficulties in visually detecting EVs that are approaching in different driving conditions. An EV warning system may not be as effective in conditions where: a driver's vision is obstructed (e.g., buildings, parked vehicles) or limited (e.g., nighttime); drivers are distracted; and within roadway locations that may be cluttered (e.g., intersections, urban environments). One method to augment drivers' abilities in detecting approaching in-use EVs is the use of technology in the forms of roadway-based preemption systems and in-vehicle driver support systems. These systems have shown to benefit civilian drivers in detecting EVs and reducing the incidence of ECCs. Future research should continue to evaluate these types of systems under situations in which drivers' visibility is impacted.

References

Assum, T., Bjørnskau, T., Fosser, S., Sagberg, F., 1999. Risk compensation – the case of road lighting. Accident Analysis and Prevention 31, 545–553.

Becic, E., Manser, M., Drucker, C., Donath, M., 2013. Aging and the impact of distraction on an intersection crossing assist system. Accident Analysis and Prevention 50, 968–974.

Becker, L.R., Zaloshnja, E., Levick, N., Guohua, L., Miller, T.R., 2003. Relative risk of injury and death in ambulance and other emergency vehicles. Accident Analysis and Prevention 35, 941–948.

Becker, S.I., 2010. The role of target–distractor relationships in guiding attention and the eyes in visual search. Journal of Experimental Psychology: General 139 (2), 247–265.

Clarke, D.D., Ward, P., Bartle, C., Truman, W., 2009. Work-related road traffic collisions in the UK. Accident Analysis and Prevention 41, 345–351.

Custalow, C.B., Gravitz, C.S., 2004. Emergency medical vehicle collisions and potential for preventive intervention. Prehospital Emergency Care 8 (2), 175–184.

Donnell, E.T., Porter, R.J., Shankar, V.N., 2010. A framework for estimating the safety effects of roadway lighting at intersections. Safety Science 48 (10), 1436–1444.

Graham, E.R., Burke, D.M., 2011. Aging increases inattentional blindness to the gorilla in our midst. Psychology and Aging 26 (1), 162–166.

Harbluk, J.L., Noy, Y.I., Trbovich, P.L., Eizenman, M., 2007. An on-road assessment of cognitive distraction: impacts on drivers' visual behavior and braking performance. Accident Analysis and Prevention 39 (2), 372–379.

Hernán, M.A., Hernández-Diaz, S., Werler, M.M., Mitchell, A.A., 2002. Causal knowledge as a prerequisite for confounding evaluation: an application to birth defects epidemiology. American Journal of Epidemiology 155 (2), 176–184.

Ho, J., Lindquist, M., 2001. Time saved with the use of emergency warning lights and siren while responding to requests for emergency medical aid in a rural environment. Prehospital Emergency Care 5 (2), 159–162.

Hsieh, P.-J., Colas, J.T., Kanwisher, N., 2011. Pop-out without awareness: unseen feature singletons capture attention only when top-down attention is available. Psychological Science 22 (9), 1220–1226.

Kahn, C.A., Pirrallo, R.G., Kuhn, E.M., 2001. Characteristics of fatal ambulance crashes in the United States: an 11-year retrospective analysis. Prehospital Emergency Care 5 (3), 261–269.

Klein, R., Klein, B.E., Linton, K.L., De Mets, D.L., 1991. The Beaver Dam Eye Study: visual acuity. Ophthalmology 98 (8), 1310–1315.

Koustanai, A., Boloix, E., Elslande, P.V., Bastien, C., 2008. Statistical analysis of "looked-but-failed-to-see" accidents: highlighting the involvement of two distinct mechanisms. Accident Analysis and Prevention 40 (2), 461–469.

Lenné, M.G., Triggs, T.J., Mulvihill, C.M., Regan, M.A., Corben, B.F., 2008. Detection of emergency vehicles: driver responses to advance warning in a driving simulator. Human Factors 50 (1), 135–144.

Maguire, B.J., Hunting, K.L., Smith, G.S., Levick, N., 2002. Occupational fatalities in emergency medical services: a hidden crisis. Annals of Emergency Medicine 40 (6), 625–632.

Malaterre, G., 1990. Error analysis and in-depth accident studies. Ergonomics 33 (10–11), 1403–1421.

McCarley, J.S., Vais, M.J., Pringle, H., Kramer, A.F., Irwin, D.E., Strayer, D.L., 2004. Conversation disrupts change detection in complex traffic scenes. Human Factors 46 (3), 424–436.

National EMS Advisory Council, 2009. Meeting Minutes from the US DOT National EMS Advisory Council. Retrieved from http://www.ems.gov/pdf/nemsac/june09/NEMSAC_Minutes_jun09.pdf (2–3.06.09).

National Highway Traffic Safety Administration (2001–2010). Estimate of crashes involving emergency vehicles by year, emergency vehicle and emergency use. Fatal crashes involving emergency vehicles by year and emergency use. General Estimates System (GES). Fatality Analysis Reporting System (FARS).

Petzäll, K., Petzäll, J., Jansson, J., Nordström, G., 2011. Time saved with high speed driving of ambulances. Accident Analysis and Prevention 43, 818–822.

Pirrallo, R.G., Swor, R.A., 1994. Characteristics of fatal ambulance crashes during emergency and non-emergency operation. Prehospital and Disaster Medicine 9 (2), 125–132.

Plainis, S., Murray, I.J., Charman, W.N., 2005. The role of retinal adaptation in night driving. Optometry and Vision Science 82 (8), 682–688.

Ray, A.M., Kupas, D.F., 2005. Comparison of crashes involving ambulances with those of similar-sized vehicles. Prehospital Emergency Care 9, 412–415.

Ray, A.M., Kupas, D.F., 2007. Comparison of rural and urban ambulance crashes in Pennsylvania. Prehospital Emergency Care 11, 416–420.

Retting, R.A., Ferguson, S.A., McCartt, A.T., 2003. A review of evidence-based traffic engineering measures designed to reduce pedestrian–motor vehicle crashes. American Journal of Public Health 93 (9), 1456–1463.

Salthouse, T.A., Hancock, H.E., Meinz, E.J., Hambrick, D.Z., 1996. Interrelations of age, visual acuity, and cognitive functioning. Journal of Gerontology: Psychological Sciences 51B (6), 317–330.

Sanddal, N.D., Albert, S., Hansen, J.D., Kupas, D.F., 2008. Contributing factors and issues associated with rural ambulance crashes: literature review and annotated bibliography. Prehospital Emergency Care 12, 257–267.

Sanddal, T.L., Sanddal, N.D., Ward, N., Stanley, L., 2010. Ambulance crash characteristics in the US defined by the popular press: a retrospective analysis. Emergency Medical International.

SAS Institute Inc., 2010. The SAS System for Windows, Release 9.2. SAS Institute Inc., Cary, NC.

Slattery, D.E., Silver, A., 2009. The hazards of providing care in emergency vehicles: an opportunity for reform. Prehospital Emergency Care 13, 388–397.

Strayer, D.L., Drews, F.A., Crouch, D.J., 2006. A comparison of the cell phone driver and the drunk driver. Human Factors 48 (2), 381–391.

Studnek, J.R., Fernandez, A.R., 2008. Characteristics of emergency medical technicians involved in ambulance crashes. Prehospital and Disaster Medicine 23 (5), 432–437.

Sullivan, J.M., Flannagan, M.J., 2002. The role of ambient light level in fatal crashes: inferences from daylight saving time transitions. Accident Analysis & Prevention 34 (4), 487–498.

Underwood, G., 2007. Visual attention and the transition from novice to advanced driver. Ergonomics 50 (8), 1235–1249.

US Department of Transportation, 2010. FARS Analytic Reference Guide 1975 to 2009.

US Department of Transportation, 2011. National Automotive Sampling System (NASS) General Estimates System (GES) Analytical Users Manual 1988–2010.

Verghese, P., McKee, S.P., 2004. Visual search in clutter. Vision Research 44 (12), 1217–1225.

Weiss, S.J., Ellis, R., Ernst, A.A., Land, R.F., Garza, A., 2001. A comparison of rural and urban ambulance crashes. The American Journal of Emergency Medicine 19 (1), 52–56.