Analysis of naturalistic driving videos of fleet services drivers to estimate driver error and potentially distracting behaviors as risk factors for rear-end versus angle crashes

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ABSTRACT

Objective: The objective of this study was to estimate the prevalence and odds of fleet driver errors and potentially distracting behaviors just prior to rear-end versus angle crashes.

Methods: Analysis of naturalistic driving videos among fleet services drivers for errors and potentially distracting behaviors occurring in the 6 s before crash impact. Categorical variables were examined using the Pearson’s chi-square test, and continuous variables, such as eyes-off-road time, were compared using the Student’s t-test. Multivariable logistic regression was used to estimate the odds of a driver error or potentially distracting behavior being present in the seconds before rear-end versus angle crashes.

Results: Of the 229 crashes analyzed, 101 (44%) were rear-end and 128 (56%) were angle crashes. Driver age, gender, and presence of passengers did not differ significantly by crash type. Over 95% of rear-end crashes involved inadequate surveillance compared to only 52% of angle crashes (P < .0001). Almost 65% of rear-end crashes involved a potentially distracting driver behavior, whereas less than 40% of angle crashes involved these behaviors (P < .01). On average, drivers spent 4.4 s with their eyes off the road while operating or manipulating their cell phone. Drivers in rear-end crashes were at 3.06 (95% confidence interval [CI], 1.73–5.44) times adjusted higher odds of being potentially distracted than those in angle crashes.

Conclusions: Fleet driver driving errors and potentially distracting behaviors are frequent. This analysis provides data to inform safe driving interventions for fleet services drivers. Further research is needed in effective interventions to reduce the likelihood of drivers’ distracting behaviors and errors that may potentially reducing crashes.

Introduction

Occupationally related motor vehicle crashes account for about 6.5% of all motor vehicle crashes in the United States (U.S. Department of Transportation 2005). These crashes cost employers an average of over $24,500 per crash (U.S. Department of Transportation 2005). The costs of these crashes are greatest among those in the transportation-related industries, with an estimated $4.1 million in employer costs (U.S. Department of Transportation 2005). In 2012, 42% of occupational fatalities were ground transportation related, making it the leading cause of occupational fatalities. Among such fatal crashes, 60% occurred on a roadway, and 1 in 5 (22%) occurred in the truck transport and transit/ground passenger transportation industries (Bureau of Labor Statistics 2012). The highest fatality rate was in the truck transportation industry, with 19.6 fatalities per 100,000 employed workers (Centers for Disease Control and Prevention 2011). Among roadway fatalities, almost half were collisions with another vehicle (Bunn and Struttmann 2003; Centers for Disease Control and Prevention 2011). Males and older occupants were more likely to be victims in these crashes (Bureau of Labor Statistics 2012; Janicak 2003).

Much less is known about nonfatal work-related crashes. An estimated 67,800 emergency room visits associated with such crashes occur every year (Jackson 2001). Approximately 7% of these emergency room visits result in hospitalization (Jackson 2001). Previous studies suggest that excess speed (Boufous and Williamson 2006), fatigue/sleepiness (Boufous and Williamson 2006; Bunn and Struttmann 2003; Robb et al. 2008; Wiegand et al. 2009), and driver distraction (Bunn and Struttmann 2003) contribute to occupation-related crashes. In a study of such crashes in Kentucky, Bunn and Struttmann (2003) found that 1 in 4 crashes was due to driver distraction and inattention, but in almost one third of crashes no driver contributing factor could be determined.

The prevalence of commercial driver distraction in naturalistic driving studies is not well established. In a naturalistic driving study of commercial drivers, Olson et al. (2009) found that over 81% of crashes or near-misses involve a driver performing a potentially distracting behavior. In contrast, Hickman and...
Hanowski (2012) reported that just over 6% of these events involved a driver performing a potentially distracting behavior. However, both studies found that commercial drivers who sent text messages or were seen dialing their cell phone were significantly more likely to crash or have a near miss than those who did not exhibit these behaviors and those who were talking/listening on a hands-free device were less likely to have a crash (Hickman and Hanowski 2012; Olson et al. 2009).

Studying fatigue and driver distraction as a contributing cause can be very difficult due to drivers’ inability to recall incidents or fear of admitting fault. The Federal Motor Carrier Safety Administration (2006) states that “without in-vehicle data recorders or video cameras, driver performance in crash situations must be inferred after the fact from interview data, crash reconstructions, and expert judgment.” This analysis uses naturalistic driving videos to examine the 6 s before vehicle-to-vehicle angle or rear-end crashes involving fleet drivers, allowing for an assessment of driver, passenger, vehicle, and environmental factors that may have contributed to the crash.

Methods
The naturalistic driving videos used for this study were of fleet services drivers enrolled in a safe driving program in 2013. This program offers services aimed at commercial fleet drivers that include installation of in-vehicle event recorders that are then used to instruct a driver toward safer driving. The system collects video, audio, and accelerometer data when a driver triggers the device by hard braking, fast cornering, or an impact that exceeds a certain g-force. Each video is 12 s long and provides information on the 8 s before and 4 s after the trigger. To make the results of this analysis comparable to other naturalistic driving studies, only the 6 s before the crash were coded (Olson et al. 2009). The videos display both the interior and exterior of the vehicle with audio including an approximately 120° field of view out the front of the vehicle at a frame rate of 4 Hz (or 4 frames per second). Only moderate-to-severe crashes were used for this analysis. A moderate-to-severe crash was defined as an impact greater than 1 g. Fleet services vehicles were defined as 2-axle vehicles under 10,000 lb. gross weight. This included mostly sedans, heavy-duty pickups, large capacity vans, and mini-buses and included taxis, shuttles, government vehicles, and private company vehicles. A total of 777 crash videos were reviewed; 4 were identified as not meeting the criteria of a moderate-to-severe crash, 67 crashes were identified as single-vehicle crashes, and 459 had unusable videos, limiting the number of vehicle-to-vehicle crashes to 247 (see Figure 1).

For this analysis, angle (n = 128) and rear-end crashes (vehicle with in-vehicle event recorder striking the rear of a lead vehicle; n = 101) were used.

The video coding method was developed by experts in video coding of naturalistic driving behavior and performance (Carney et al. 2015). Each crash was coded by 2 independent reviewers using coding method described elsewhere (Carney et al. 2015). The data files were then merged and discrepancies identified. If the discrepancy was due to a data entry error, it was corrected. However, if it was due to a disagreement, the event was turned over to a third reviewer for mediation. Eyes-off-road times differing by even as little as one frame (0.25 s) were mediated in an attempt to achieve the highest possible level of accuracy. The driver, crash, and environmental characteristics examined included date and time of the crash, weather (clear, partly cloudy, cloudy, fog/smoke, mist, rain, sleet/hail/freezing rain, snow, severe winds, blowing sand/soil/dirt/snow, other), lighting conditions (daylight, dusk, dawn, dark–roadway lighted, dark–roadway not lighted), road surface conditions (dry, wet, ice, snow, slush, sand/mud/dirt/oil/gravel, water [standing or moving], other), and road type (interstate, arterial, collector, local, and other). The manner of collision (rear-end or angle), critical precipitating event, driver, environment, and roadway contributing circumstances were also examined. The following driver characteristics were collected: age (approximately 16–19, 20–29, 30–64, 65+), gender, potentially distracting behaviors, number of glances off roadway, total time eyes of roadway, seat belt use, and driver errors. Definitions of drivers’ potentially distracting behaviors and errors can be found in Carney et al. (2015). A crash could have more than one potentially distracting behavior or more than one error coded in the 6 s before the crash occurred; therefore, totals for behaviors and errors may exceed 100%.
Analysis

To compare driver characteristics, errors, and behaviors across crash type (rear-end versus angle), Pearson's chi-square test or Fisher's exact test was used for categorical variables. Multivariable logistic regression was used to estimate the odds of a rear-end crash compared to an angle crash after controlling for important covariates. Covariates were included in the model based on a priori knowledge.

Results

Of the crashes coded (n = 247), 52% (n = 128) were angle, 41% (n = 101) were rear-end, 4% (n = 10) were head-on, 2% (n = 5) were sideswipe, and 1% (n = 3) were backing-up crashes (Figure 1). Given the small number of crashes that were not angle or rear-end, the comparison of crash types focuses on rear-end and angle crashes (n = 229). The majority of drivers were estimated to be between the ages of 30 and 64 (72.9%), and 86% (n = 197) were male (Table 1).

Most drivers had their seat belt on at the time of the crash (92.1%, n = 211). Nearly a quarter of the drivers (21.4%, n = 49) were carrying passengers at the time of the crash. Over half of the crashes occurred on arterial roads (51.5%) or interstate (12.2%). Almost three fourths of crashes occurred when there were no adverse weather conditions (see Appendix Table 1, online supplement). Crashes did not seem more likely to occur on any particular day of the week or time of day. Regardless of fault, in 84% of crashes a driver error contributed to the crash in some way and 50% of crashes involved a driver exhibiting a potentially distracting behavior (Table 2).

Characteristics of rear-end and angle crashes

The critical precrash event in 97% of rear-end crashes was another vehicle in the driver’s lane decelerating or stopping in the roadway (Table 1). Among angle crashes, 45% of the participants were crossing the centerline or turning at an intersection; in 51%, another vehicle encroached into the participant’s right-of-way. Driver error was much more likely to occur in a rear-end crash than an angle crash (99.0% vs. 72.7%, P < .0001; Table 2). In addition, 64.4% of rear-end crashes compared to 39.8% of angle crashes showed a driver performing a potentially distracting behavior (P = .0002). Rear-end crashes occurred more frequently on interstates, whereas angle crashes were more likely to occur on collector roads (P < .0001).

Driver errors just prior to impact

Overall, driver errors occurred in 84.3% of crashes (193 of 229 crashes; Table 2). A crash could have more than one driver error coded in the 6 s before the crash. In fact, 394 errors were coded in the 193 crashes with driver errors; 44 crashes involved one error, 102 crashes involved 2 errors, and 47 crashes involved 3 or more errors. Among all crashes, 81.7% involved a recognition error, 40.1% involved a decision error, 3.1% a performance error, and approximately 1% had a nonperformance error (Table 2). The most common errors were inadequate surveillance (71.2%), distraction/inattention (50.2%), following too closely (12.2%), and running a stop sign or signal (11.4%). Rear-end crashes were more likely to involve recognition errors, whereas angle crashes were more likely to be due to decision errors. Rear-end crashes involved recognition errors (97% vs. 70%, P < .0001) significantly more often than angle crashes. Leading up to 95% of rear-end crashes, drivers performed inadequate surveillance, whereas this was true of only about half of angle crashes (52.3%). In addition, over 60% of rear-end crashes involved driver inattentiveness, whereas only 40% of angle crashes had such an error. In contrast, half of all angle crashes involved a decision error, compared to approximately one quarter of rear-end crashes. Drivers more often ran stop signs or traffic signals prior to angle crashes (19.5% vs. 1%) and followed too closely in rear-end collisions (26.7% vs. 0.8%).

Driver behaviors just before impact

Potentially distracting driver behaviors were observed in a little over half of crashes (50.2%, n = 115; Table 2). A crash could involve more than one driver behavior prior to the crash—86 crashes involved one driver behavior, 21 involved 2 driver behaviors, and 9 involved 3 or more driver behaviors. The most frequent behaviors seen were attending to an unknown location outside the vehicle (15.3%) and attending to an unknown location inside the vehicle (13.5%). Overall, in 8.3% of crashes the driver was using a cell phone, with the most prevalent cell phone activity being manipulating or looking at their phone (e.g., texting).

Driver behaviors differed significantly by crash type (Table 2). In rear-end crashes, drivers were more likely to be seen using their cell phones than in angle crashes (13.9 vs. 3.9%, P < .01); specific behaviors included operating or looking at the phone (7.9% vs. 1.6%, P < .05) and attending to an unknown location inside the vehicle (18.8% vs. 9.4%, P < .05).

Additionally, driver behaviors were examined by the number of passengers present in the vehicle (data not shown). Only 49 of the 229 crashes (21.4%) had passengers present: 17 rear-end crashes and 32 angle crashes. Among crashes with passengers present, potentially distracting driver behaviors were present in 55% of crashes with one passenger on board and 41% of crashes with 2 or more passengers. When passengers were present, attending to a passenger was the most frequent driver behavior, occurring in 21% of crashes with a single passenger (7 of 33) and 14% of crashes with 2 or more passengers (3 of 22). Of note, no potentially distracting passenger behaviors (e.g., yelling, talking with other passengers) were associated with crash type. Several behaviors were observed more frequently when the driver was alone. Engaging in cell phone–related tasks was more likely (10.9% vs. 1.8%, P = .04) when the driver was alone. Additional nonsignificant driver errors and potentially distracting behaviors may be found in Appendix Table 2 (see online supplement).

Driver eyes-off-road time

In crashes where no driver behaviors were coded, the driver had their eyes off the road an average of 0.6 s; in crashes where a driver behavior was coded, this time was significantly longer at
Table 1. Driver, crash, and environmental characteristics among fleet services drivers involved in vehicle-to-vehicle rear-end or angle crashes.

|                   | All (N = 229)                  | Rear-end (n = 101)                  | Angle (n = 128)                  | P value<sup>a</sup> |
|-------------------|-------------------------------|-----------------------------------|---------------------------------|---------------------|
| Age               |                               |                                   |                                 |                     |
| 16–19             | 3 (1.3)                       | 1 (1.0)                           | 2 (1.6)                         | .7341               |
| 20–29             | 42 (18.3)                     | 21 (20.8)                         | 21 (16.4)                       |                     |
| 30–64             | 167 (72.9)                    | 73 (72.3)                         | 94 (73.4)                       |                     |
| 65+               | 17 (7.4)                      | 6 (5.9)                           | 11 (8.6)                        |                     |
| Gender            |                               |                                   |                                 |                     |
| Male              | 197 (86.0)                    | 88 (87.1)                         | 109 (85.2)                      | .6691               |
| Female            | 32 (14.0)                     | 13 (12.9)                         | 19 (14.8)                       |                     |
| Driver belted     | 211 (92.1)                    | 92 (91.1)                         | 119 (93.0)                      | .5997               |
| Any passengers    | 49 (21.4)                     | 17 (16.8)                         | 32 (25.0)                       | .1345               |
| Contributing circumstances<sup>b</sup> |                           |                                   |                                 |                     |
| Road conditions   |                               |                                   |                                 |                     |
| Over centerline or in intersection | 58 (25.3) | 0 (0.0) | 58 (45.3) | <.0001 |
| Lost control      | 5 (2.2)                       | 2 (2.0)                           | 3 (2.3)                         |                     |
| Action of another vehicle in lane | 100 (43.7) | 98 (87.0) | 2 (1.6) |                     |
| Another vehicle encroaching on lane | 66 (28.8) | 1 (1.0) | 65 (50.8) |                     |
| Critical event    |                               |                                   |                                 |                     |
| Road type         |                               |                                   |                                 |                     |
| Interstate        | 28 (12.2)                     | 25 (24.8)                         | 3 (2.3)                         | <.0001 |
| Arterial          | 118 (51.5)                    | 52 (51.5)                         | 66 (51.6)                       |                     |
| Collector         | 56 (24.5)                     | 13 (12.9)                         | 43 (33.6)                       |                     |
| Local             | 14 (6.1)                      | 4 (4.0)                           | 10 (7.8)                        |                     |
| Other             | 13 (5.7)                      | 7 (6.9)                           | 6 (4.7)                         |                     |
| Day of week       |                               |                                   |                                 | .0985               |
| Monday            | 35 (15.3)                     | 18 (17.8)                         | 17 (13.3)                       |                     |
| Tuesday           | 29 (12.7)                     | 10 (9.9)                          | 19 (14.8)                       |                     |
| Wednesday         | 50 (21.8)                     | 15 (14.9)                         | 35 (27.3)                       |                     |
| Thursday          | 39 (17.0)                     | 21 (20.8)                         | 18 (14.1)                       |                     |
| Friday            | 36 (16.7)                     | 21 (20.8)                         | 15 (11.7)                       |                     |
| Saturday          | 26 (11.4)                     | 10 (9.9)                          | 16 (12.5)                       |                     |
| Sunday            | 14 (6.1)                      | 6 (5.9)                           | 8 (6.3)                         |                     |

<sup>a</sup>Chi-square test or Fisher's exact test (cell size smaller than 5) was used for comparisons across proportions.
<sup>b</sup>Categories are not mutually exclusive; a crash could have more than one of these contributing circumstances.

Table 2. Type and frequency of driver errors and potentially distracting behaviors made in rear-end and angle fleet services vehicle crashes<sup>a</sup>.

| Driver error                          | Rear-end (n = 101)                  | Angle (n = 128)                  | All crashes (n = 229) n (col%) |
|---------------------------------------|-----------------------------------|---------------------------------|-------------------------------|
| All*                                  | 100 (99.0)                        | 93 (72.7)                       | 193 (84.3)                    |
| Recognition errors                    |                                   |                                 |                               |
| Any recognition errors*               | 98 (97.0)                         | 89 (69.5)                       | 187 (81.7)                    |
| Inadequate surveillance               | 96 (95.1)                         | 67 (52.3)                       | 163 (71.2)                    |
| Inattentive/potentially distracting behaviors** | 65 (64.4) | 50 (39.1) | 115 (50.2) |                     |
| Decision errors                       |                                   |                                 |                               |
| Any decision errors**                 | 28 (27.7)                         | 64 (50.0)                       | 92 (40.1)                     |
| Followed too closely*                 | 27 (26.7)                         | 1 (0.8)                         | 28 (12.2)                     |
| Ran stop sign/traffic signal*         | 1 (1.0)                           | 25 (19.5)                       | 26 (11.4)                     |
| Made improper turn***                 | 0                                 | 6 (4.7)                         | 6 (2.6)                       |
| Performance errors                    |                                   |                                 |                               |
| Any performance errors                | 3 (3.0)                           | 4 (3.1)                         | 7 (3.1)                       |
| Nonperformance errors                 |                                   |                                 |                               |
| Any nonperformance errors***         | 4 (4.0)                           | 0                               | 4 (1.8)                       |
| Fatigued/tired***                     | 4 (4.0)                           | 0                               | 4 (1.8)                       |
| Potentially distracting driver behaviors |                                 |                                 |                               |
| Any behaviors**                       | 65 (64.4)                         | 51 (39.8)                       | 116 (50.7)                    |
| Any cell phone use**                  | 14 (13.9)                         | 5 (3.9)                         | 19 (8.3)                      |
| Cell phone use (manipulating/looking)** | 8 (7.9) | 2 (1.6) | 10 (4.4) |                     |
| Cell phone use (talking/listening)    | 2 (2.0)                           | 4 (3.1)                         | 6 (2.6)                       |
| Cell phone use likely but not visible*** | 5 (5.0) | 0 | 5 (2.2) |                     |
| Attending inside vehicle, unknown***  | 19 (18.8)                         | 12 (9.4)                        | 31 (13.5)                     |
| Attending outside vehicle, unknown**  | 23 (22.8)                         | 12 (9.4)                        | 35 (15.3)                     |
| Attending to passenger(s)             | 3 (3.0)                           | 4 (3.1)                         | 7 (3.1)                       |

<sup>a</sup>Driver errors and behaviors are not mutually exclusive. One crash can have multiple driver errors or behaviors coded.
<sup>*</sup>P < .0001. <sup>**</sup>P < .01. <sup>***</sup>P < .05.
Eyes-off-roadway time differed by driver behavior as well: for drivers attending outside of the vehicle, the average was 3.3 s, inside of the vehicle 3.8 s, and any cell phone use 3.5 s, all significantly longer than in crashes without driver behaviors (P < .0001). Among cell phone behaviors, manipulating or looking at the cell phone resulted in the longest eyes-off-road time at 4.4 s, again significantly longer than in crashes with no driver behaviors (P < .0001). Although a small proportion of crashes involved passengers, when a driver was attending to passengers, their eyes-off-road time was lower when engaged in no behavior at 0.9 s (Table 3).

There was a significant difference in the average eyes-off-road time when examined by crash type (Table 3). Drivers involved in a rear-end crash had their eyes off the forward roadway more than 4 times longer than those involved in an angle crash (3.2 s vs. 0.7 s, P < .0001). Among crashes with no driver behaviors recorded, rear-end crashes had significantly longer eyes-off-road time than angle crashes (1.9 s vs. 0.1 s, P < .0001). Among all different driver behaviors, rear-end crashes had longer eyes-off-road time than did angle crashes, with significant differences found with any cell phone use (4.2 s vs. 1.4 s, P < .01), in particular, manipulating or looking at the phone (4.8 s vs. 2.8 s, P < .01), attending to an unknown location outside the vehicle (3.7 s vs. 2.6 s, P < .05), and reaching for an object (4.4 s vs. 2.7 s, P < .05).

When comparing within crash types to a crash without a driver behavior, significant differences also exist. Compared to rear-end crashes with no driver behaviors, those with any cell phone use (particularly looking and manipulating the cell phone), using other electronic devices, attending to an unknown location outside the vehicle, personal grooming, and reaching for an object had significantly longer eyes-off-road time. Many of the same relationships existed in angle crashes. In contrast to angle crashes with no driver behaviors present, those with cell phone use (in particular, manipulating/looking), using other electronic devices, attending to an unknown location inside the vehicle, personal grooming, and reaching for an object had significantly longer total eyes-off-road time.

### Adjusted odds of a rear-end versus angle crash

After controlling for driver age, gender, and presence of any passengers in the fleet vehicle, crashes with a road condition contributing cause were 5.08 (95% confidence interval [CI], 2.17–11.9) times more likely to be in a rear-end than an angle crash (Table 4). In addition, crashes with any driver distraction had a 3.06 (95% CI, 1.73–5.44) higher odds of being a rear-end crash than an angle crash.

### Discussion

Very few crashes were due to road surface (10%) or environmental conditions. Over half of crashes occurred on arterial roads (51.5%) and interstates (12.2%), which was similar to the results of Bunn and Struttmann (2003), who found that 44% of fatal crashes occurred on 4-lane roads. Although fatal crashes were not studied in this analysis, these combined data suggest that arterial roads and interstates may be where the majority of crashes are likely to occur. Almost three quarters of crashes occurred when there were no adverse weather conditions. Decision errors, such as following too closely (12.2% of crashes),

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**Table 3. Eyes-off-roadway time by crash type and driver behavior.**

| Potentially distracting driver behaviors | Rear-end | Angle | All crashes |
|-----------------------------------------|---------|------|------------|
|                                        | n       | Mean (SD) | n       | Mean (SD) | n       | Mean (SD) |
| All                                     | 101     | 3.2 (2.1) | 128     | 0.7 (1.3)* | 229     | 1.8 (2.1) |
| No behaviors                            | 36      | 1.9 (2.1) | 77      | 0.1 (0.3)* | 113     | 0.6 (1.4) |
| Any behaviors                           | 65      | 3.8 (1.8)* | 51      | 1.9 (1.6)* | 116     | 3.0 (1.9)* |
| Any cell phone use                      | 14      | 4.2 (1.4)** | 5       | 1.4 (1.8)** | 19      | 3.5 (1.9)* |
| Cell phone (manipulating/looking)       | 8       | 4.8 (0.7)** | 2       | 2.8 (1.4)** | 10      | 4.4 (1.2)* |
| Cell use (talking/listening)            | 2       | 2.3 (1.8) | 4       | 0.6 (1.0)  | 6       | 1.3 (1.5)  |
| Cell use likely but not visible         | 5       | 4.0 (1.2)** | 0       | 1.6 (1.8)** | 3       | 1.6 (1.8)  |
| Eating or drinking                      | 0       | 0        | 3       | 2.3 (1.2)** | 7       | 4.6 (2.1)* |
| Using electronic device (mp3, iPod, navigation system) | 5 | 5.5 (0.6)*** | 2 | 2.7 (1.3)* | 31 | 3.8 (1.6)* |
| Attending inside vehicle, unknown       | 19      | 4.4 (1.5)* | 12      | 2.6 (1.1)* | 35      | 3.3 (1.5)* |
| Attending to another vehicle or passenger in vehicle | 1 | 1.8 | 0 | 0 | 1 | 1.8 |
| Attending outside vehicle, unknown      | 23      | 3.7 (1.5)* | 12      | 2.6 (1.1)* | 35      | 3.3 (1.5)* |
| Attending to passenger(s)               | 3       | 1.5 (1.6) | 4       | 0.8 (1.4)  | 7       | 0.9 (1.4)  |
| Personal grooming                       | 8       | 3.8 (1.8)** | 4       | 1.5 (2.1)** | 12      | 3.2 (2.0)* |
| Reaching for object                     | 7       | 4.4 (1.6)** | 9       | 2.7 (1.0)* | 16      | 3.4 (1.5)* |
| Singing/dancing to music                | 1       | 3.8      | 2       | 1.0 (no SD) | 3       | 2.4 (1.9)  |
| Smoking related                         | 1       | 2.0      | 2       | 0         | 3       | 1.0 (1.4)  |
| Talking to self                         | 4       | 2.2 (2.0) | 6       | 0.4 (0.9)  | 10      | 1.2 (1.7)  |
| Operating in-vehicle controls/devices   | 2       | 3.1 (1.4) | 5       | 1.2 (0.9)** | 7       | 1.8 (1.9)  |

*P < .0001; **P < .01; ***P < .05 compared to no behaviors; #P < .0001; ##P < .01; ###P < .05 compared to rear-end crashes.

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**Table 4. Adjusted odds of a rear-end versus angle crash among fleet service drivers.**

| Age | Adjusted odds ratio (95% CI) |
|-----|-----------------------------|
| 16–19 | 0.22 (0.02–3.04) |
| 20–29 | 1.13 (0.54–2.36) |
| 30–64 | 1.00 (ref) |
| 65+   | 0.51 (0.17–1.57) |
| Gender |                               |
| Male | 1.00 (ref) |
| Female | 0.89 (0.39–2.02) |
| Any passengers | 0.62 (0.30–1.26) |
| Contributing circumstances |                               |
| Any road conditions | 5.08 (2.17–11.9) |
| Any driver distraction | 3.06 (1.73–5.44) |

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*aReferent group is angle crashes.*

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running a stop sign or traffic signal (11.4%), and failure to yield the right-of-way (12.7%) were observed more frequently than in previous research (Bunn and Struttman 2003). Although performance errors were rare in our study (3.1% of crashes), the proportion was similar to that in Bunn and Struttman’s (2003) study, which found that 3–7% of driver errors in crashes were performance errors. In this analysis, driving too fast was observed in very few crashes (1.8%); previous studies, however, suggested that 9–15% of crashes were due to speed (Boufous and Williamson 2006). This difference could be due to actual crash causation, recall bias of self-reports in previous research, or the difficulty of verifying speed in the current study’s naturalistic videos.

The most common driver errors seen were inadequate surveillance (71.2%) and driver distraction or inattention (50.2%). The proportion of crashes involving driver distractions was more than twice that reported by Bunn and Struttmann (2003) in Kentucky but less than the 74% inattention found in the naturalistic driving study by Engstrom et al. (2013) or the almost 82% found by Olson et al. (2009). The higher proportion in comparison to Bunn and Struttmann (2003) may be due to our more objective measurement of distractions through reviewing naturalistic driving data, rather than through driver self-report or police crash reports. Interestingly, Bunn and Struttmann (2003) were unable to determine whether or not the driver contributed to the crash in almost one third of crashes; using these videos, a driver contribution was identified in over 80% of crashes. This suggests that naturalistic driving data may offer a more holistic and accurate view of what is occurring inside a vehicle just before a crash. Our study did find a lower proportion of distraction than other naturalistic driving studies of fleet drivers, which is hypothesized to be due to the inclusion of near-crashes and less severe crashes in previous research (Engstrom et al. 2013; Olson et al. 2009).

To the best of our knowledge, this analysis is the largest to examine driver behaviors and errors among a fleet services population by crash type. As hypothesized, rear-end crashes were more likely to involve a driver engaging in a potentially distracting behavior. Rear-end crashes had a higher proportion of the 3 most common behaviors seen than angle crashes. Drivers exhibiting these behaviors had longer eyes-off-road times and less time to react to potential crash situations due to inadequate surveillance and distraction.

This is believed to be the first analysis published on the average time fleet drivers’ eyes are off the road prior to a crash. As expected, videos with no coded driver behaviors had shorter eyes-off-road time than crashes where a potentially distracting driver behavior was seen. The type of driver behavior also affected the amount of eyes-off-road time and the type of vehicle-to-vehicle crash that occurred. This baseline information regarding driver behaviors, their effect on the amount of time drivers’ eyes are off the road, and the crash types that ensue can be used to inform technological interventions.

A small proportion of crashes (1.8%) involved driver fatigue/sleepiness. In previous studies, between 4 and 15% of crashes were attributed to fatigue/sleepiness (Boufous and Williamson 2006; Bunn and Struttmann 2003; Engstrom et al. 2013). This discrepancy may be due to actual crash causation, recall bias of self-reports in previous research, or the difficulty in identifying fatigue/sleepiness (e.g., long eye closures, blanks stares) in our videos because of the relatively low frame rate of 4 frames per second.

Conclusion
Use of in-vehicle event recorders in naturalistic driving allows researchers a unique view into the vehicle and provides invaluable information regarding the behavioral and environmental factors present before a crash. This type of data provides a much more detailed context relative to police reports and other crash databases and allows analyses to be conducted at a more micro level. This study is the largest naturalistic study of moderate-to-severe fleet services crashes, to our knowledge, to provide information regarding the prevalence of driver errors and potentially distracting behaviors among fleet services drivers using naturalistic video while examining these behaviors by crash type and eyes-off-road time. The results of this study indicate that there are different driver behaviors and contributing circumstances present for rear-end versus angle crashes. However, fleet drivers were more likely to be seen engaging in these potentially distracting behaviors when they were alone in the vehicle. Additional research is needed to examine the prevalence of driver errors and potentially distracting behaviors when a crash does not occur.

Strengths and limitations
Naturalistic driving studies allow researchers to examine many aspects of driving and provide invaluable data that would not be available otherwise. Until now, the only way to obtain large amounts of data regarding driver crashes was through NHTSA Fatality Analysis Reporting System and NASS General Estimates System data, obtained from police-reported crashes. Though this information is helpful, it has many limitations. One important limitation of previous research is the lack of information regarding driver distraction, which is limited to what police were able to view or a witness reported. This study allows us to report all driver and passenger behaviors. In addition, the data from this naturalistic study are able to provide a micro level of detail about a crash, such as eyes-off-road time—information unavailable in police-reported data.

A major advantage of this study is that it provides data from 229 moderate-to-severe crashes. Having such a large sample makes our findings more generalizable to the fleet driver population. In addition, we were able to look at different types of crashes within vehicle-to-vehicle crashes (i.e., rear-end vs. angle) by risk factors to provide a more holistic view of these crash subtypes. Understanding the nuances of crash subtypes is vital to the prevention of crashes.

Another major advantage of this particular study, compared to previous naturalistic studies, is the view of the entire cab and the ability to hear what was taking place inside the vehicle. This information provided a fuller context of what was occurring during the 6 s before a crash. It was particularly important when examining driver distraction. Other naturalistic studies have been limited by the partial view and the inability to see what or whom the driver is looking at or to review audio to...
examine conversations between drivers and passengers or other audio present.

In addition, this is the first study to examine risk factors for rear-end or angle crashes among professional drivers. Given that transportation-related death is the leading cause of occupational deaths, this analysis is invaluable in its investigation of driver behaviors among a high-risk group.

As with all naturalistic driving research, there are concerns regarding the representativeness of the drivers involved in the study. Because the drivers in these crashes were not volunteers, they may be slightly more representative than those who might normally sign up for such studies. However, their employers required that they participate in a program that provided an intervention when unsafe driving behaviors were observed. Drivers knew they were part of the program, and one might argue that this would make them less likely to exhibit risky or aggressive driving behaviors or to engage in potentially distracting behaviors. If this is true, the frequency of driver behaviors reported may not be generalizable to all fleet services drivers, and we hypothesize that the proportions reported may underestimate certain behaviors among the general driver population. Nevertheless, more than half of all fleet driver crashes (50.7%) involved a potentially distracting behavior in the 6 s before the crash.

Another concern is that this is event-triggered data, as opposed to data collected continuously. As a result, there is an inability to examine driver or passenger behaviors during non-collision events. Therefore, the true extent to which a driver engages in particular behaviors is unknown. In addition, we cannot provide crash rates by behavior but can only say that when a crash occurred, certain behaviors were most likely to be present. Again, however, it is notable that given the large study sample, we were able to examine how the presence of such behaviors contributed to different crash types, specifically rear-end and angle. Further, prevalence data, such as those examined in this study, are limited in that we are unable to say anything about causation or associated risk.

Finally, there are a few concerns regarding the in-vehicle event recorders used in this study and their ability to detect information that is known to be significant contributors to crashes. Global Positioning System data were not available and therefore we could not assess vehicle speed (available for less than 10% of crashes). In addition, drowsy driving/sleepiness was difficult to determine due to the low frame rate (4 frames per second), and it is likely that 6 s may not provide enough time to determine fatigue. In addition, the quality of nighttime videos made it difficult to see drivers’ eyes, also reducing possible findings of drowsy or fatigued driving.

Acknowledgments

The authors acknowledge the AAA Foundation for Traffic Safety for sponsoring this project—Brian Tefft and Jurek Grabowski in particular. The authors also like thank John Lee and Arthur Goodwin for their comments during the early stages of this project and Teresa Lopes for her assistance in the review and preparation of the manuscript. Thank you to Madonna Weiss and Mireille Raby for their contribution to the original report submitted to the AAA Foundation for Traffic Safety.

Funding

Funding for this study was provided by the AAA Foundation for Traffic Safety (AAAFTS 4035-5121).

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